Matthew J. Martin
Alec C. Beekley
Matthew J. Eckert *Editors*

# Front Line Surgery

## A Practical Approach

Second Edition

Springer

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*Editors*
Matthew J. Martin
Trauma Medical Director
Professor of Surgery
Uniformed Services University
Madigan Army Medical Center
Department of Surgery
Tacoma, WA, USA

Alec C. Beekley
Thomas Jefferson University Hospitals
Paoli Hospital
The Lankenau Hospital
Division of Acute Care Surgery
Division of Bariatric Surgery
Philadelphia, PA, USA

Matthew J. Eckert
Associate Trauma Medical Director
Assistant Professor of Surgery
Uniformed Services University
Madigan Army Medical Center
Department of Surgery
Tacoma, WA, USA

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*We dedicate this book first to the military service members, those "rough" men and women who always stand ready to put life and limb at risk to protect and defend their families, friends, and homeland. We dedicate it to the countless soldiers and civilians who have made it their life's mission to provide comfort and care during times of war, and who have trained others to carry on this sacred mission.*

*We dedicate it to the most important assets of the soldier at war – the spouses, children, parents, family, and friends who give us the will to carry on and a reason to come home. This book would not have been possible without the three most important people in our Chain of Command: our wives – Becky, Melodie, and Carly. In the "fog of war" they serve as a constant reminder that strength, grace, and beauty still exist.*

*Finally, we dedicate this book on combat surgery to our surgical comrades who have made the ultimate sacrifice in the conflicts in Iraq and Afghanistan: to Lieutenant Colonel Mark Taylor, MD, killed in action in Fallujah, Iraq, in 2004; to Colonel Brian Allgood, MD, killed in action in Baghdad, Iraq, in 2007; and to Major John Pryor, MD, killed in action in Mosul, Iraq, in 2008. A common uniting factor among these heroes was their dedication as both surgeons and teachers. We pray that their spirit is reflected in this effort to pass on lessons learned from the recent front line combat experiences. These lessons have come at too high a price to ever allow them to fade or be forgotten.*

*"Who kept the faith and fought the fight;*
*The glory theirs, the duty ours."*
*Wallace Bruce*

# Foreword[1]

> The current war will be the first in history from which detailed concurrent analyses of the epidemiology, nature, and severity of injuries, care provided, and patient outcomes can be used to guide research, training, and resource allocation for improved combat casualty care [1].

As the US military enters a tenuous interwar period, the second edition of *Front Line Surgery* and the considerable experience at its foundation embody the quote from Holcomb published during the height of the wars in Afghanistan and Iraq. As the editors of this text have stated, regardless of where, when, or in what proportion or operational stance US service members deploy, a surgeon will be with them. To best prepare those surgeons, and all members of the combat casualty care team, *Front Line Surgery* (2nd ed.) builds on the success of its 2011 edition, to provide an easily accessible repository of trauma management, trauma systems, and trauma readiness information. Arranged by an accomplished group of authors, this edition summarizes the pearls and best-practice standards for all facets of trauma and injury care today and promises to inform "research, training and resource allocation to improve combat casualty care" in years to come[2].

Equal to its relevance to military providers, *Front Line Surgery* contains a wealth of useful information for those tackling trauma and injury care in austere, nonmilitary settings. As highlighted in a 2016 National Academy of Medicine report, rates of trauma and injury from accidents, intentional acts of violence, and natural disasters are increasing at home and abroad [2]. Increasingly, the shared ethos touted by Knudson and colleagues between military and civilian surgeons is seen to be vital to optimizing trauma care [3]. Both in its range of military and civilian authors and in its breadth of content, this edition of *Front Line Surgery* epitomizes the beneficial synergy between military and civilian surgery. As aptly pointed out by Dr. Donald Berwick, lead author of the National Academies' report, "when it comes to success in optimizing injury care, the civilian and military communities will either

[1] *Disclaimer*: The views herein are those of the author and do not reflect the official position or policy of the US Air Force, US Army, or the Department of Defense.

[2] See footnote 1.

succeed together or will fail together" [2]. The second edition of this textbook offers a prime example of shared success!

The breadth of topics addressed in the second edition is impressive and includes all phases of trauma and injury care – point of injury, en route, and facility-based – as well as new focus areas related to trauma systems development, resident readiness and training and response to mass shooting events. The book has an exciting table of contents that will be interesting and useful to those with all levels of experience – students, trainees, and experienced providers. Additionally, the range of topics goes beyond the limits of "surgery," allowing the text to be an informative resource for all members of the trauma care team, including prehospital and emergency medical systems specialists, emergency medicine physicians, and critical and intensive care providers.


Surgery team (left to right: Joe DuBose, surgeon; Elaine Spotts, OR technician; Todd Rasmussen, surgeon; and Danny Kim, surgeon) after a long day sewing in circles at Craig Joint Theater Hospital (U.S. Role III facility), Bagram, Afghanistan (circa February 2012)

Making use of the familiar Bottom Line Up Front, or BLUF, approach, each chapter provides key "take home points" and follows these summary sections with a more thorough, evidence-based discussion of the various management strategies. Many of the chapters also provide a summary of ongoing research and development efforts in the different areas of resuscitation and injury care (i.e., discuss new and emerging approaches to challenging problems). By doing this, the text emphasizes the importance of research and new innovation in this topic area and provides a glimpse of what front line trauma care and surgery may look like a decade from now.

In a similar vein as the quote from Holcomb et al., the 2016 National Academies' report stated that "those who serve in the military need and deserve a promise that, should they sustain a traumatic injury, the best care known will come to their assistance to offer them the best chance possible for survival and recovery and, further, that over time, learning and innovation will steadily increase that chance" [1]. In its second edition, *Front Line Surgery* has taken this important step over time and now instructs us as we look back at the wars in Afghanistan and Iraq. It's our job to consider the experience in the pages of this edition and to read and study its content. Done with diligence, the use of this resource will improve efforts to increase that chance of survival and recovery for those injured in military and civilian settings in years to come. Now get to work!

Todd E. Rasmussen
Program Director
Combat Casualty Care Research Program
U.S. Army Medical Research and Materiel Command
Fort Detrick, MD, USA

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# Foreword


**Kenneth L. Mattox, MD, FACS**

It is a unique honor to be asked to write a foreword for this book on combat casualty care, entitled *Front Line Surgery: A Practical Approach*. A foreword provides the opportunity to set the tone and "prepare the brain" for what the textbook is about. More than anywhere else in the broad field of medicine and health care delivery, the surgeon providing front line actions must be poised, ready, and accurate, without hesitation. The editors wrote the first edition of this book to codify the critical information that is passed on from surgeon to surgeon in the military war zone and, secondly, for all to benefit from lessons learned in the military theaters. The reader is alerted as to what the hands and brain must do when faced with a front line surgical judgment situation, be it technical/procedural or decision making. And, of course, the response is the culmination of training, reflex, experience, and insight.

I was told by one of the editors that *Front Line Surgery* was somewhat inspired by a little book that Asher Hirshberg and I had written, entitled *Top Knife*. We are both humbled and honored that *Top Knife* could contribute, in this way, to this project. The fact that the military editors of this book are now producing a second edition reflects the continuing advances and innovations of our surgical and medical crafts, as well as the thirst (and need) for such knowledge in both the military and the civilian sectors. The addition of civilian contributors demonstrates the ever-broadening implications of the lessons learned and the fact that the pendulum swings between the civilian and military partnership environments, benefiting both. We have learned, do learn, and will continue to learn from each other.

As one reads previous handbooks of front line trauma response, misconceptions and shallow assumptions of the past, often occurring because of overstatement of tradition and bias, stand out – overhydration, use of solutions containing hepatitis virus, and the rise and fall of various drugs, devices, gauzes, and theories, to name just a few, among many other ever-changing approaches. We learn from each other's successes, failures, and evidence-based data.

Many of the chapters in this textbook are especially germane to military medicine and the type of injuries seen in the combat zone, and most information translates well to the civilian sector. Of note:

- Chapter 4. Damage Control Resuscitation
- Chapter 5. To Operate or Image? (Pulling the Trigger)
- Chapter 9. Pancreatic and Duodenal Injuries (Don't Mess with the…)
- Chapter 12. To Close or Not to Close: Managing the Open Abdomen
- Chapter 21. Traumatic Amputations

Each chapter in the book begins with documentation of the military experience and credibility of the author, followed by a BLUF (Bottom Line Up Front) box listing that quickly and succinctly provides the reader the operational points of the chapter. Immediately under each BLUF box is a short phrase in the form of a pertinent quote to evoke a philosophical chuckle from the past. For this new edition, civilian surgeons were involved, and selected chapters have a "civilian translation" commentary that discusses key military lessons learned that have been incorporated into the civilian arena, as well as key differences between the civilian approach to trauma and combat trauma.

Although a book of more than 500 pages, it is an easy read because of its orientation and format. Many of the chapters are anatomically focused. Some of the more militarily unique chapters include:

- Chapter 6. Ultrasound in Combat Trauma
- Chapter 38. Patient Transfer, En route Care, and Critical Care Air Transport Team (CCATT)
- Chapter 42. Humanitarian and Local National Care
- Chapter 43. Expectant and End of Life Care in the Combat Zone

In this era of new and competing textbooks in the areas of trauma, resuscitation, acute care surgery, and critical care surgery, this book stands out as a unique approach to some of the most complex problems in surgery.

Kenneth L. Mattox
Distinguished Service Professor
Division of Cardiothoracic Surgery
Baylor College of Medicine
Houston, TX, USA

Chief of Staff and Surgeon-in-Chief
Ben Taub Hospital
Houston, TX, USA

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No editor or author of this work received or will receive any royalties, reimbursements, or payments in any form. All proceeds from the sale of this work that would normally go to the editors will be donated to the Center for the Intrepid and the Intrepid Fallen Heroes Fund.

# Preface

As you step off the plane you are struck by an oppressive heat, but this is not what catches your attention. It is the foreignness of this place – the unfamiliar terrain, the noise, the oddly clustered tents and buildings, the serious and determined looks of people involved in a war. I had completed a trauma fellowship at one of the busiest penetrating trauma centers in the USA and thought I was ready for anything – mistake number one. Fortunately, you have at least several days of overlap with the outgoing group of surgeons that you are replacing.

I first met the surgeon I was replacing in a dusty tent in Tikrit, Iraq. Luckily for me it was Marty Schreiber, one of the best trauma surgeons I know. His last and most important task at the end of his combat tour was to pass on everything a new and inexperienced combat surgeon needed to know to survive and thrive in this environment. Over the next 72 hours I received a mini-fellowship in forward medicine and combat trauma surgery. After that, the first month was an eye-opening crash course in how to manage a constant stream of the most severely injured patients you will ever see. I had plenty of tough cases, difficult decisions, and rookie mistakes. I distinctly remember thinking that if it was this tough for someone coming right out of a two-year trauma and critical care fellowship, how much harder would it be for a newly graduated resident or even an experienced surgeon who had not done any trauma for years? This was the initial seed of inspiration for creating *Front Line Surgery*.

My goal was to create the book that I wish someone had handed to me before I was deployed. To formalize and expand upon the informal "pass-on" sessions that occur every time a new group of surgeons arrives. No basic science, no extensive reference lists; just practical information, techniques, and lessons learned. I believe that the first edition of *Front Line Surgery* achieved that goal, and the most personally and professionally rewarding feedback I ever received was from a surgeon telling me that this book helped them in some way when they were deployed to a combat zone. The first edition was written for a very "niche" audience, and thus we were somewhat surprised by the sales numbers and how widely the book was distributed and utilized. In the second edition, we have purposefully not changed the things that we believe made the original so successful — namely, the "been there and done that"-type chapters written by experts with combat trauma experience, and geared toward easily digested and practical advice. However, we have also recognized the unprecedented level of cooperation and collaboration between military and civilian physicians and surgeons over the past decade-plus of combat operations, and the urgent need to share concepts and key lessons between these two groups. Thus, we have added a number of our civilian colleagues to add their perspective to many of the chapters and to highlight key areas of commonality and difference in that area of care. As with the first edition, I could not have hoped for a better group of authors and colleagues, and have learned a great deal more about combat trauma just from reviewing their chapters. I hope you enjoy it, find it useful, and continue the tradition of passing on these lessons learned to those who follow.

Tacoma, WA, USA Matthew J. Martin

# Preface

Of the first five casualties I treated in Iraq in 2004 after joining my forward surgical team, two died and one lost his leg. Four of these casualties arrived at the same time. Their wounds were appalling. One casualty had been blown out of the HUMMV turret, ruptured every solid organ in his body, and broke both his legs. Another had a head injury, impending airway loss, flail chest, ruptured thoracic aortic arch, ruptured spleen, and open femur and tib-fib fractures. We had a total of only 20 units of blood. For a two-surgeon forward surgical team, it was a humbling and overwhelming experience.

The next day I met John Holcomb for the first time as he visited all the surgical units in theater as Trauma Consultant to the Surgeon General. After I discussed the mass casualty from the day before – and it *was* a MASCAL for our unit – he encouraged us to continue to collect our experiences, write them up, and pass them on. He reminded me that not so long ago another army major had written up his life-changing experiences treating casualties in Somalia.

With the first edition of *Front Line Surgery*, we set out to create a book that would provide any deployed surgeon with a well-organized, easy-to-read reference to get or keep them out of trouble. One of the most heart-warming experiences I have had since the first edition's publication, however, was to see copies of it, spine bent and worn, on some of my junior (and senior) civilian trauma colleagues' desks. I realized, as my coeditors did, that the first edition was successful precisely because it provided no-nonsense, prescriptive guidance relevant to *any* clinician caring for trauma patients.

With the second edition, we sought to update and refine that guidance while preserving the overall readability and practical tone of the first book. Several brand-new and relevant chapters have been added. In addition, we have been fortunate to be able to assemble an extraordinary set of authors to provide expert civilian perspective on lessons hard-learned in war time and how they may be applied in any trauma setting, civilian or military. I hope you enjoy reading and learning from the new edition as much as I have.


Philadelphia, PA, USA Alec C. Beekley

# Preface

As one of the younger generation of current military surgeons during this stretch of recent conflicts, I finished training in trauma and critical care in 2012, and was promptly deployed to the NATO Role III hospital in Helmand, Afghanistan. While coalition casualties were declining, a steady flow of Afghan military, police, and civilian patients arrived daily. My partner, Col. Tom Wertin, and a host of experienced UK surgeons showed me the difference between civilian and combat trauma. Day after day we saw fresh casualties, took back others for washouts and debridements, and slowly closed the physical wounds inflicted by a war waged with improvised explosive devices. This was the world of the dismounted complex blast injury, a visually and professionally shocking pattern of injury that has become a hallmark of all recent conflicts.

My first deployment was the last of the "busy" combat medical tours and in a way I was lucky to have that experience. Many of the old guards and mentors like Drs. Holcomb, Jenkins, Eastridge, Sebesta, Brown, and Beekley have since moved on to civilian careers. A newer generation of surgeons without the deep experience from the height of the wars in Iraq or Afghanistan is now faced with the endless rotations in Afghanistan and the re-entry of Iraq and Syria. While institutional memory always fades with time, the hard lessons learned are recorded in numerous reports, the guidelines of the Joint Trauma System, and the pages of *Front Line Surgery*. My copy of the first edition, dog-eared and coffee-stained, has accompanied me now six times overseas, and this updated edition will help the next generation of military surgeons who face the challenges of providing extraordinary care in the worst of places.


Tacoma, WA, USA Matthew J. Eckert

# Top Ten Combat Trauma Lessons[1]

1. Patients die in the ER, and
2. Patients die in the CT scanner;
3. Therefore, a hypotensive trauma patient belongs in the operating room ASAP.
4. Most blown-up or shot patients need blood products, not crystalloid. Avoid trying "hypotensive resuscitation" – it's for civilian trauma.
5. For mangled extremities and amputations, one code red (4 PRBC +2 FFP) per extremity, started as soon as they arrive.
6. Patients in extremis will code during rapid sequence intubation; be prepared, and intubate these patients in the OR (not in the ER) whenever possible.
7. This hospital can go from empty to full in a matter of hours; don't be lulled by the slow periods.
8. The name of the game here is not continuity of care; it is throughput. If the ICU or wards are full, you are mission incapable.
9. MASCALs live or die by proper triage and prioritization – starting at the door and including which x-rays to get, labs, and disposition.
10. No personal projects! They clog the system, waste resources, and anger others. See point 8

[1] Reprinted from "The Volume of Experience" (January 2008 edition), a document written and continuously updated by US Army trauma surgeons working at the Ibn Sina Hospital, Baghdad, Iraq.


Baghdad ER

# Contents

# Contributors

**Hasan B. Alam, MD, FACS** University of Michigan, Department of Surgery, Ann Arbor, MI, USA

**Jared L. Antevil, MD** Walter Reed National Military Medical Center, Navy Specialty Leader for Cardiothoracic Surgery, Department of Surgery, Division of Cardiothoracic Surgery, Bethesda, MD, USA

**Jayson D. Aydelotte, MD** University of Texas Dell Medical School, Department of Surgery, Austin, TX, USA

**Kenneth S. Azarow, MD, FACS, FAAP** Doernbecher Children's Hospital, Division of Pediatric Surgery, Portland, OR, USA

**Jeffrey A. Bailey, MD** Uniformed Services University, Walter Reed National Military Medical Center, Bethesda, MD, USA

**Hans Bakken, MD, FAANS** Brooke Army Medical Center, Department of Radiology, San Antonio, TX, USA

**Alec C. Beekley, MD** Thomas Jefferson University Hospitals, Paoli Hospital, The Lankenau Hospital, Division of Acute Care Surgery, Division of Bariatric Surgery, Philadelphia, PA, USA

**Andrew C. Bernard, MD** University of Kentucky Hospital, Department of Surgery, Lexington, KY, USA

**Lorne H. Blackbourne, MD** Department of Surgery, Joint Base San Antonio, Brooke Army Medical Center, San Antonio, TX, USA

**Raquel C. Bono, MD, MBA, FACS** Defense Health Agency, Defense Health Headquarters, Falls Church, VA, USA

**Jason D. Bothwell, MD** Madigan Army Medical Center, Department of Emergency Medicine, Tacoma, WA, USA

**Nici Eddy Bothwell, MD** Ear, Nose, Throat and Allergy Associates, a Division of Proliance, Puyallup, WA, USA

**Mark W. Bowyer, MD, MBA, FACS** Uniformed Services University and Walter Reed National Military Medical Center, Department of Surgery, Bethesda, MD, USA

**Carlos V.R. Brown, MD** Division of Acute Care Surgery, Department of Surgery and Perioperative Care, Dell Medical School, University of Texas at Austin, Austin, TX, USA

**Frank K. Butler Jr, MD** Committee on Tactical Combat Casualty Care, Joint Trauma System, Joint Base San Antonio – Fort Sam Houston, San Antonio, TX, USA

**Daniel G. Cuadrado, MD** General and Thoracic Surgery, Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA

**Kevin K. Chung, MD** Brooke Army Medical Center, Department of Medicine, Fort Sam Houston, San Antonio, TX, USA

Uniformed Services University of the Health Sciences, Bethesda, MD, USA

**Christine S. Cocanour, MD, FACS, FCCM** University of California David Medical Center, Department of Surgery, Sacramento, CA, USA

**James W. Davis, MD** University of California, San Francisco, CA, USA

Surgery UCSF/Fresno, Community Regional Medical Center, Department of Surgery, Fresno, CA, USA

**Demetrios Demetriades, MD, PhD, FACS** Acute Care Surgery, LAC+USC Medical Center, Department of Surgery, Trauma Division, Los Angeles, CA, USA

**John G. DeVine, MD** Medical College of Georgia at Augusta University, Department of Orthopedic Surgery, Augusta, GA, USA

**Warren C. Dorlac, MD, FACS** Medical Center of the Rockies, University of Colorado Health, Department of Surgery, Loveland, CO, USA

**Joseph J. DuBose, MD, Lt Col USAF, MC** Uniformed Services University of the Health Sciences, Davis, CA, USA

**James R. Dunne, MD, FACS** Memorial University Medical Center, Trauma Services, Savannah, GA, USA

**Alexander L. Eastman, MD, MPH, FACS** The Rees-Jones Trauma Center at Parkland/Department of Surgery, UT Southwestern Medical Center and The Dallas Police Department, Dallas, TX, USA

**Brian Eastridge, MD** University of Texas Health Science Center at San Antonio, Department of Surgery, San Antonio, TX, USA

**Matthew J. Eckert, MD, FACS** Uniformed Services University, Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA

**Eric Elster, MD** Department of Surgery at Uniformed Services University of the Health Sciences and the Walter Reed National Military Medical Center, Bethesda, MD, USA

**Raymond Fang, MD** Air Force Center for Sustainment of Trauma and Readiness Skills, University of Maryland Medical Center, R Adams Cowley Shock Trauma Center, Baltimore, MD, USA

**David V. Feliciano, MD** IUH Methodist Hospital, Department of Surgery, Indiana University, Indianapolis, IN, USA

**Charles J. Fox, MD** Vascular Surgery Denver Health, Denver Health and the University of Colorado Hospitals, Department of Surgery, Denver, CO, USA

**Joseph M. Galante** Division of Trauma, Acute Care Surgery and Surgical Critical Care, UC Davis Medical Center, Sacramento, CA, USA

**Ryan Gocke, MD** Naval Medical Center Portsmouth, Department of Orthopedic Surgery, Portsmouth, VA, USA

**Eduardo Gonzalez, MD** University of Colorado Denver, Department of Surgery, Denver, CO, USA

**Daniel Grabo, MD** Navy Trauma Training Center, LAC+USC Medical Center, Keck School of Medicine of USC, Department of Surgery, Los Angeles, CA, USA

**Kirby R. Gross, MD** Army Trauma Training Department, Jackson Memorial Hospital, Department of Trauma, Miami, FL, USA

**Jennifer M. Gurney, MD** United States Army Institute of Surgical Research, San Antonio Military Medical Center, Department of Surgery, San Antonio, TX, USA

**Benjamin Harrison, MD, FAAEM** St. Anthony's Hospital, Department of Emergency Medicine, Gig Harbor, WA, USA

**John B. Holcomb, MD** Department of Surgery, Center for Translational Injury Research, Memorial Hermann Hospital, Houston, TX, USA

**Brandon R. Horne, MD** Wright-Patterson Medical Center, Department of Orthopaedics, Wright-Patterson AFB, Dayton, OH, USA

**Matthew T. Hueman, MD, FACS** Walter Reed National Military Medical Center, USU Walter Reed Department of Surgery, Bethesda, MD, USA

**Kenji Inaba, MD, FACS, FRCSC** Anesthesia and Emergency Medicine, LAC+USC Medical Center, Department of Surgery, Los Angeles, CA, USA

**Mubeen A. Jafri, MD** Doernbecher Children's Hospital, Division of Pediatric Surgery, Portland, OR, USA

**Donald H. Jenkins, MD, FACS** Military Health Institute The University of Texas Health Science Center at San Antonio, San Antonio, TX, USA

**Jay A. Johannigman, MD, FACS** Surgical Critical Care and Acute Care Surgery, University Hospital, Cincinnati, OH, USA

Department of Surgery, Cincinnati, OH, USA

**Eric Keith Johnson, MD** Uniformed Services University of the Health Sciences, Tacoma General Hospital, Department of Surgery, Fox Island, WA, USA

**Bellal Joseph, MD** The University of Arizona Banner Medical Center, Department of Surgery, Tucson, AZ, USA

**Riyad Karmy-Jones, MD** Legacy Emanuel Hospital, Trauma Department, Portland, OR, USA

**Paul B. Kettle** Madigan Army Medical Center - Pulmonary Critical Care Service, Department of Medicine, Tacoma, WA, USA

**David R. King, MD, FACS** Massachusetts General Hospital, Division of Trauma, Acute Care Surgery, and Surgical Critical Care, Boston, MA, USA

**M. Margaret Knudson, MD** American College of Surgeons, University of California San Francisco, Department of Surgery, San Francisco, CA, USA

**Joseph G. Kotora Jr, DO, MPH, FACEP** Navy Region Southeast, Naval Hospital Camp Lejeune, Emergency Department, Camp Lejeune, NC, USA

**Russ S. Kotwal, MD, MPH** Joint Trauma System, U.S. Army Institute of Surgical Research, Joint Base San Antonio, Fort Sam Houston, San Antonio, TX, USA

**James C. Krieg, MD** Thomas Jefferson University, Rothman Institute of Orthopaedic Surgery, Philadelphia, PA, USA

**John J. Lammie, MD, COL** Womack Army Medical Center, Fort Bragg, NC, USA

**Robert B. Lim, MD** Tripler Army Medical Center, Department of Surgery, Honolulu, HI, USA

**William B. Long, MD** Legacy Emanuel Hospital, Trauma Department, Portland, OR, USA

**Katherine M. McBride, MD** Memorial University Medical Center, Department of Surgery, Savannah, GA, USA

**Matthew J. Martin, MD** Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA

**Robert A. Mazzoli, MD FACS** Education, Training, Simulation, and Readiness, DoD-VA Vision Center of Excellence, Bethesda, MD, USA

Surgery (Ophthalmology), Uniformed Services University of the Health Sciences, Bethesda, MD, USA

Ophthalmic Plastic, Reconstructive and Orbital Surgery, Madigan Army Medical Center, Tacoma, WA, USA

Madigan Army Medical Center, Department of Ophthalmology, Tacoma, WA, USA

**Michael S. Meyer, MD** Surgery Uniformed Services University of the Health Sciences, Pulse Heart Institute, Multicare Cardiothoracic Surgeons, Multicare Tacoma General Hospital, Tacoma, WA, USA

**Ernest E. Moore, MD** Denver Health Hospital, Department of Surgery, Denver, CO, USA

**Hunter B. Moore, MD** University of Colorado Denver, Department of Surgery, Denver, CO, USA

**Philip S. Mullenix, MD, FACS, FCCP, LTC, MC, USA** Cardiothoracic Surgery, Walter Reed National Military Medical Center, Department of Surgery, Bethesda, MD, USA

**Clinton K. Murray, MD** San Antonio Military Medical Center, Department of Medicine, Fort Sam Houston, TX, USA

**Richard Nahouraii, MD** Duke-Lifepoint Conemaugh Memorial Medical Center, Department of Surgery, Johnstown, PA, USA

**Lucas P. Neff, MD** David Grant Medical Center, Department of Surgery, Travis AFB, CA, USA

**Daniel W. Nelson, DO** Brian Allgood Army Community Hospital, Department of General Surgery, Seoul, South Korea

**Vahagn C. Nikolian, MD** University of Michigan Health System, Department of General Surgery, Ann Arbor, MI, USA

**Alexander S. Niven, MD** Madigan Army Medical Center - Pulmonary Critical Care Service, Department of Medicine, Tacoma, WA, USA

**Timothy C. Nunez, MD, MMHC** Vanderbilt University Medical Center, Trauma, Surgical Critical Care and Emergency Surgery, Nashville, TN, USA

**Morohunranti O. Oguntoye, MD** Kimbrough Ambulatory Care Center, Department of Vision and Hearing, Fort Meade, WA, USA

**John S. Oh, MD** Division of Trauma, Acute Care, and Critical Care Surgery, Penn State Hershey Medical Center, Hershey, PA, USA

**Stephen A. Parada, MD** Orthopedic Residency, Dwight D. Eisenhower Army Medical Center, Department of Orthopedic Surgery, Fort Gordon, GA, USA

**Jeremy G. Perkins** Walter Reed National Military Medical Center, Department of Medicine, Bethesda, MD, USA

**Michael D. Perreault, MD** Madigan Army Medical Center, Department of Emergency Medicine, Tacoma, WA, USA

**Robert Jason Thomas Perry, MD** Vascular Surgery, Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA

**Jacob R. Peschman, MD** Mayo Clinic, Department of Surgery, Division of Trauma, Critical Care, and General Surgery, Rochester, MN, USA

**Andrew C. Peterson, MD** Duke University, Department of Urology, Durham, NC, USA

**Travis M. Polk, MD** Naval Medical Center Portsmouth, Department of General Surgery, Portsmouth, VA, USA

**Timothy A. Pritts, MD, PhD** University of Cincinnati Medical Center, Department of Surgery, Cincinnati, OH, USA

**Eric G. Puttler, MD** Good Samaritan Hospital, Department of Surgery, Puyallup, WA, USA

**Todd E. Rasmussen, MD** DoD Combat Casualty Care Research Program, Fort Detrick, MD, USA

**Jamie C. Riesberg, MD** Womack Army Medical Center, Special Warfare Medical Group (Airborne), Ft. Bragg, NC, USA

**Kyle N. Remick, MD FACS** Department of Surgery at Uniformed Services University of the Health Sciences and the Walter Reed National Military Medical Center, Bethesda, MD, USA

**Peter Rhee, MD, MPH, FACS, FCCM** Grady Health System, Department of Trauma, Atlanta, GA, USA

**R. Judd Robins, MD** Uniformed Services University of the Health Sciences, United States Air Force Academy Ambulatory Surgical Center, Department of Orthopaedic Surgery, Sports Medicine Service, USAF Academy, Colorado Springs, CO, USA

**Carlos J. Rodriguez, DO, MBA** Walter Reed National Military Medical Center, Department of Surgery, Bethesda, MD, USA

**Robert M. Rush, MD** Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA

**Ali Salim, MD** Trauma, Burns and Surgical Critical Care, Brigham and Women's Hospital, Department of Surgery, Boston, MA, USA

**Babak Sarani, MD** Department of Surgery, George Washington University, Washington, DC, USA

**Steven A. Satterly, MD, BS, ERST** Madigan Army Medical Center, Department of General Surgery, Tacoma, WA, USA

**Thomas M. Scalea, MD** University of Maryland School of Medicine, R. Adams Cowley Shock Trauma Center, Baltimore, MD, USA

**Martin Schreiber, MD** Oregon Health and Science University, Department of Surgery, Division of Trauma, Critical Care and Acute Care Surgery, Portland, OR, USA

**C. William Schwab, MD, FACS** University of Pennsylvania Perelman School of Medicine, Penn Presbyterian Medical Center, Department of Surgery, Philadelphia, PA, USA

**James Sebesta, COL (ret), MD, FACS** Bariatric Surgery, MultiCare Health System, Tacoma, WA, USA

**Stacy Shackelford, MD** Joint Trauma System, Defense Center of Excellence, Fort Sam Houston, TX, USA

**Anita A. Shah, DO, FCCP** Madigan Army Medical Center - Pulmonary Critical Care Service, Department of Medicine, Tacoma, WA, USA

**Geoff Shapiro, EMT-P** Emergency Medical Services and Operational Medicine Training Programs, George Washington University, Emergency Medical Services, Washington, DC, USA

**Craig D. Shriver, MD** Murtha Cancer Center, Walter Reed National Military Medical Center, Bethesda, MD, USA

**Niten Singh, MD** Harborview Medical Center, University of Washington, Department of Surgery, Seattle, WA, USA

**E. Reed Smith, MD** Department of Emergency Medicine, George Washington University, Washington, DC, USA

**Philip C. Spinella, MD, FCCM** Department of Pediatrics, Washington University in St. Louis, St. Louis Children's Hospital, Department of Pediatrics, St. Louis, MO, USA

**Benjamin Starnes, MD** University of Washington, Department of Surgery, Seattle, WA, USA

**Scott R. Steele, MD** University Hospitals Case Medical Center, Department of Surgery, Cleveland, OH, USA

**Matthew D. Tadlock, MD** Department of Surgery, Naval Hospital Camp Pendleton, Camp Pendleton, CA, USA

**Alex B. Valadka, MD** Virginia Commonwealth University, Department of Neurosurgery, Richmond, VA, USA

**Jonathan R. Van Horn, MPAS, PA-C** Oregon Army National Guard, Legacy Emanuel and Randall Children's Hospital, Department of Trauma, Portland, OR, USA

**Gary Vercruysse, MD** University of Arizona School of Medicine, Tucson, Arizona, USA

**George Velmahos, MD, PhD, MSEd** Emergency Surgery and Surgical Critical Care, Massachusetts General Hospital, Department of Surgery, Boston, MA, USA

**Amy Vertrees, MD** Walter Reed National Military Medical Center, Department of Surgery, Bethesda, MD, USA

**Jack R. Walter, MD** Urology, Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA

**Timothy K. Williams, MD** David Grant Medical Center, Heart, Lung and Vascular Center, Travis AFB, CA, USA

**Sherry M. Wren, MD, FACS, FCS(ECSA)** Palo Alto VA Medical Center, Stanford University, Department of Surgery, Palo Alto, CA, USA

**Zaradhe M.S. Yach, MSN, FNP-BC** Mercy Medical Group, Department of Family Medicine/Internal Medicine, Roseville, CA, USA

**Heather C. Yun, MD** San Antonio Military Medical Center, Department of Medicine, Fort Sam Houston, TX, USA

# Part I

# Before the Operating Room

# Tactical Combat Casualty Care

# 1

Frank K. Butler Jr. and Russ S. Kotwal

**Deployment Experience**

| | |
|---|---|
| *Frank K. Butler, Jr.* | Assistant Platoon Commander, Underwater Demolition Team Twelve, Western Pacific, 1973 |
| | Surgeon, Joint Special Operations Task Force, Afghanistan, 2003 |
| *Russ S. Kotwal* | Regimental Surgeon, 75th Ranger Regiment: Afghanistan 2010, 2009, 2008, 2007, 2006, 2005; Iraq 2008, 2007, 2006 |
| | Battalion Surgeon, 3d Battalion, 75th Ranger Regiment: Iraq 2003; Afghanistan 2002, 2001 |

*The fate of the wounded lays with those who apply the first dressing.*

COL Nicholas Senn

F.K. Butler Jr. (✉)
Committee on Tactical Combat Casualty Care, Joint Trauma System, Joint Base San Antonio – Fort Sam Houston, San Antonio, TX, USA
e-mail: fkb064@yahoo.com

R.S. Kotwal
Joint Trauma System, U.S. Army Institute of Surgical Research, Joint Base San Antonio – Fort Sam Houston, San Antonio, TX, USA


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**BLUF Box (Bottom Line Up Front)**

1. Good medicine can be bad tactics. And bad tactics can get everyone on the mission killed.
2. After tactical considerations, control of hemorrhage is the #1 *clinical* combat casualty care priority.
3. Use CoTCCC-recommended tourniquets aggressively to obtain initial control of life-threatening extremity hemorrhage.
4. Use Combat Gauze and other CoTCCC-recommended hemostatic dressings to control external hemorrhage from sites not amenable to extremity tourniquet use.
5. Junctional tourniquets such as the Combat Ready Clamp (CRoC), the SAM Junctional Tourniquet, and the Junctional Emergency Treatment Tool (JETT) can be used to help control external hemorrhage from the axilla and groin.
6. Use the sit-up and lean-forward casualty positioning to manage the traumatized airway when the casualty is conscious and able to assume this position. This allows blood and tissue to be expelled from the airway by gravity and the casualty's own protective cough reflex.
7. Use a 14 gauge, 3.25 inch needle to decompress suspected tension pneumothorax. Two inch needles do not reliably reach the pleural space and should not be used.
8. In the prehospital phase, intravenous access is not obtained on casualties unless they are in shock and require fluid resuscitation or they need IV medications. Starting IVs takes time and may result in unnecessary tactical delays.
9. If intravascular access is needed, but difficulty is encountered with establishing peripheral IVs, use intraosseous access. These devices allow vascular access directly into the tibia, the humerus, or the sternum.
10. Tranexamic acid (TXA) given within 3 h of injury has been shown to reduce blood loss and to decrease mortality in casualties who are in or at risk of hemorrhagic shock. When indicated, TXA should be used as soon as possible after wounding.
11. The CoTCCC continues to investigate and push both proven and novel interventions (e.g., tourniquets, hemostatic dressings, 1:1 damage control resuscitation, and fresh whole blood) on the battlefield.

## A Preventable Death in Afghanistan

A Special Forces sergeant in Afghanistan was wounded in the right arm and the right leg by an explosion from a rocket-propelled grenade. There was significant external hemorrhage from the injury to his leg. The year was 2003 and the US military had not yet begun to field modern, commercially manufactured tourniquets. The unit's medic was killed early in the attack. Three improvised tourniquets applied by his other teammates failed to stop the hemorrhage, and the wounded Special Forces warrior exsanguinated from his leg wound. A well-designed commercial tourniquet would have saved his life, but neither he nor anyone in his unit had one.

## Introduction

Multiple studies have shown that the very large majority of those killed in combat die in the prehospital phase of care (killed in action, or KIA, just as the casualty described above did). Most of these KIA deaths result from overwhelming injuries and could not have been prevented by improvements in medical care – so-called "non-preventable" deaths. Some deaths, however, result from injuries that were potentially survivable had optimal care been rendered and the casualty transported rapidly to a medical treatment facility with a surgical capability. It is the prehospital phase of care that offers the greatest opportunity to reduce combat fatalities, since the overwhelming majority (97%) of casualties who arrive at a medical treatment facility alive go on to survive their injuries.

In contrast to the medicine practiced in hospitals, which is overseen by hospital commanders, it is the combat line commanders who are responsible for all aspects of what their units do on the battlefield, including the care of wounded unit members. Training and equipping for Tactical Combat Casualty Care and executing these concepts on the battlefield may not be well executed if medical personnel have not emphasized the importance of this critical aspect of combat operations to their commander. If the commanders, in turn, have not made Tactical Combat Casualty Care training and equipment a point of command emphasis, unit members with potentially survivable injuries may be needlessly lost.

Tactical Combat Casualty Care (TCCC) has transformed battlefield trauma care in the US military over the 20-year period from 1996 to 2016. TCCC is a set of evidence-based, best-practice prehospital trauma care guidelines that are customized for use on the battlefield. Its concepts are built around the absolute necessity to combine good medicine with good small unit tactics when caring for casualties at the point of injury. In that setting, there is not just one but rather three goals to consider while rendering care: (1) save the casualty, (2) prevent additional casualties, and (3) complete the mission.

Tactical Combat Casualty Care is the prehospital component of the Joint Trauma System (JTS). The JTS was created by the US military during the Afghanistan and Iraq conflicts to oversee the care provided to our casualties, to document that care, to look for opportunities to improve the delivery of trauma care, and to advise the US Central Command surgeon about how to optimize the delivery of combat casualty care from a systems level.

## Tourniquets Reconsidered: The Impetus for TCCC

At the end of the Vietnam War, Navy Captain J. S. Maughon observed that very little had changed in the prehospital phase of combat casualty care in the last 100 years. Twenty-two years later, in 1992, that statement was still true. Advances in battlefield trauma care are challenging to accomplish because there is very little high-level evidence regarding the interventions used on the battlefield and the benefits associated with their use. Also, combat medics are typically not experts in the academic aspects of trauma medicine; trauma surgeons and emergency medicine physicians, in contrast, are typically not expert in providing trauma care in the midst of the lethal chaos of the battlefield. The line commanders who are the ultimate authority for battlefield medicine are experts at neither. This set of circumstances provides an optimal setting for clinical stagnation, which was exactly where the US military (as well as other militaries) were in 1992.

Since there was no single group in the US military with a mission to develop evidence-based, best practice trauma care guidelines for prehospital combat casualty care, training in this area was based largely on civilian trauma courses. Examples of the principles of battlefield trauma care as practiced in the military in 1992 included the following:

- Tourniquet use was largely discouraged, and no effective tourniquets were being issued to either combat medical providers or nonmedical combatants.
- Hemostatic dressings were not being fielded.
- The recommended resuscitation for casualties in hemorrhagic shock was two liters of crystalloid fluid (normal saline or Ringers lactate) administered as rapidly as possible.
- Combat medical providers were taught to establish two large gauge intravenous lines on *all* casualties with significant trauma.
- Battlefield analgesia was based on Civil War-vintage technology (IM morphine).
- There was no prehospital focus on the prevention of trauma-related coagulopathy.
- There was no consideration of the tactical context with respect to the elements of care rendered. Thus, when corpsmen, medics, and PJs were taught to do a secondary survey of their casualty, there was no caveat that that aspect of care should be deferred until the tactical situation made it feasible.
- Special Operations medics were instructed to do venous cutdowns on the battlefield if they experienced difficulty with obtaining vascular access when that was needed.
- There was a strong emphasis on endotracheal intubation as the option of choice for managing the airway in combat casualties, despite a complete an absence of evidence that combat medical providers could accomplish that intervention reliably in the presence of a traumatized airway.

The initial impetus for TCCC was the observation that the recommendation to avoid tourniquet use, as taught in the Advanced Trauma Life Support (ATLS) course and virtually all other course and other trauma courses at the time, was not well supported by the available evidence. Tourniquet use was strongly discouraged in both military and civilian prehospital trauma care despite the following: (1) exsanguination from extremity hemorrhage had been well described as a leading cause of preventable death in combat casualties; (2) tourniquets can definitively stop extremity hemorrhage; and (3) tourniquets were – and are – routinely used for short periods of time in orthopedic surgery procedures without causing loss of limb from tourniquet ischemia. So, if it is appropriate to use a tourniquet in the operating room to help do extremity surgery in a bloodless field, why was it not appropriate for combat medics, corpsmen, and PJs to use them to save lives on the battlefield?

This realization caused the Naval Special Warfare Biomedical Research Program to launch a complete review of battlefield trauma recommendations in the US military in 1992. This project was a collaborative effort between Special Operations medical personnel and the Uniformed Services University of the Health Sciences as well as and a large group of volunteer civilian consultants. For 3 years, every aspect of prehospital combat casualty care was reviewed in light of current evidence, battlefield conditions, and the unique prism of the combat medic. Combat medics, corpsmen, and PJs played a major role in developing these guidelines through a series of workshops dedicated to obtaining their input for this project.

Also, the interventions proposed by TCCC were sharply focused on the causes of preventable death on the battlefield as described by COL Ron Bellamy, CAPT Maughon, and other military authors from the Vietnam era: hemorrhage, airway obstruction, and tension pneumothorax. Additionally, the rule of evidence was applied to all existing recommendations in prehospital trauma care – as opposed to requiring definitive evidence for only proposed new interventions. Many aspects of prehospital care at the time, not just tourniquets, were not well supported by the available evidence.

This project resulted in the original TCCC paper, which was published as a special supplement in the journal *Military Medicine* in 1996. It included a number of recommendations that were novel and controversial at the time, including the aggressive use of tourniquets for initial control of life-threatening extremity hemorrhage, the use of a hetastarch solution rather than crystalloids for resuscitation of casualties in shock from controlled hemorrhage, no prehospital fluids for casualties in shock as a result of non-compressible hemorrhage, and the use of IV rather than IM morphine for battlefield analgesia, to list a few.

## TCCC 1996–2001

TCCC was well publicized within the Department of Defense but was not widely used in the US military during the interval from the publication of the original TCCC paper in 1996 to the start of the war in Afghanistan in 2001. The novel recommendations in TCCC gave military medical decision makers a pause. Briefings to senior military medical and line leaders did not produce any widespread changes in battlefield trauma care concepts in the DoD.

In 1997 and 1998, TCCC was first made operational by a series of briefings to the medical personnel and the line commanders in a few Special Operations units – the Navy SEAL community, the 75th Ranger Regiment, and the Army Special Missions Unit. TCCC was also well received by the Air Force Special Operations community and incorporated into the *Pararescue (PJ) Handbook*. Only these units and a few other innovative units in the US military had adopted TCCC prior to the onset of hostilities in Afghanistan.

## TCCC in the Early War Years (2001–2005)

After al-Qaeda attacked the twin towers in New York City in September of 2001, the US military went to war in Afghanistan and began to sustain casualties. In the first few years of the war, however, there was no military trauma system and there was no organized performance improvement effort to improve the care afforded to American casualties.

In 2004, the US Special Operations Command requested that the US Army Institute of Surgical Research (USAISR) undertake an analysis of all 82 Special Operations fatalities sustained in the war up to that point in time and what might have been done to prevent these deaths. The study found that most of the Special Operations Forces (SOF) deaths resulted from overwhelming injuries and were non-preventable. Some deaths, however, could have been prevented by simple TCCC interventions, such as tourniquets.

Shortly thereafter, the USSOCOM TCCC initiative was launched. Again USSOCOM partnered with USAISR. Deployment of SOF units were identified and contacted; TCCC equipment deficiencies were determined; and the units were offered the opportunity to be provided with TCCC equipment and training before they left for combat operations. Participating units were contacted by USAISR when they returned from their deployment and provided feedback to the project leaders about how TCCC equipment and techniques worked in combat.

## TCCC During the Mid-War Years (2005–2010)

As the wars in Afghanistan and Iraq progressed, reports of success using TCCC in combat begin to accumulate from both those Special Operations units who had been using TCCC prior to 2001 and units that had been equipped and trained with TCCC equipment as part of the TCCC Transition Initiative. In contrast, reports of preventable death, notably from extremity hemorrhage, were seen in combat units that had not been equipped with tourniquets and other TCCC equipment items. During these 5 years, there was a steady progression of increasing TCCC use in the US military. The most notable reports of success with tourniquet use were the papers written by Colonel John Kragh from the US Army Institute of Surgical Research. His extensive research into this area finally provided definitive evidence that extremity tourniquets were major lifesavers on the battlefield and did not result in loss of limbs to tourniquet ischemia.

## TCCC Becomes Accepted as the Standard for Battlefield Trauma Care

By the conclusion of the conflicts in Afghanistan and Iraq, TCCC had been accepted as the standard of care for managing combat casualties in the prehospital phase of care throughout the US military and in most of our coalition partner nations. This was due in large part to an overwhelming consensus from combat medical providers that the recommendations contained in the TCCC Guidelines gave them the tools that they needed to provide optimal care for their wounded unit members.

This consensus opinion was supported by published papers from combat casualty care researchers. The 75th Ranger Regiment, which had been training every member of the Regiment – not just medics – to perform lifesaving TCCC interventions for their fellow Rangers documented in 2011 (COL Russ Kotwal et al.) that the Regiment had achieved the lowest incidence of prehospital preventable deaths ever reported by a major unit in modern combat - zero. This singular achievement was due to the unit's unique Ranger First Responder program, which not only emphasized TCCC principles of care but taught combat leaders to incorporate these principles into the tactical flow of a combat casualty scenario. While previous studies from Vietnam and from early in the conflicts in Iraq and Afghanistan had documented an incidence of almost 8% preventable deaths due to extremity hemorrhage in combat fatalities, the 75th Ranger Regiment did not lose a single man to extremity hemorrhage on the battlefield throughout the Regiment's combat service in Iraq and Afghanistan. Similarly, the Canadian military initiated its TCCC program in 1999 and, like the 75th Ranger Regiment, trained both medical personnel and nonmedical combatants in TCCC. In 2011, Savage and her colleagues reported that Canadian Forces had experienced the highest casualty survival rate in their history. They attributed this in the largest part to a "comprehensive, multileveled TCCC training package to both soldiers and medics".

In 2012, a remarkable paper was published by Col Brian Eastridge and his coauthors, examining all 4596 US military combat fatalities from Iraq and Afghanistan during the 10-year period from 2001 to 2011. One of the most important findings in that paper was that 87% of those who died from wounds sustained in combat did so in the prehospital phase of care – before they ever reached the hands of a combat surgeon. Additionally, 24% of these prehospital fatalities succumbed to wounds that were potentially survivable. This finding dramatically underscores the importance of the care provided by combat medics, corpsmen, and PJs. Eastridge's findings with respect to the lives saved by tourniquet use are striking in contrast to the findings in the study by Kelly et al., published in 2008, that had found that approximately 8 out of every 100 US combat fatalities in a study cohort that extended up to 2006 had resulted from extremity bleeding. The incidence of death from extremity hemorrhage in the Kelly paper is remarkably similar to that reported by Maughon in Vietnam. With increasing tourniquet use among US combat forces after 2005, however, deaths from extremity bleeding decreased markedly. By the end of Eastridge's study period (2011), deaths from extremity hemorrhage had dropped to 2.6% of total fatalities, a 67% decrease.

## Elements of Battlefield Trauma Care in TCCC, 2016

What is TCCC? Some examples of the recommendations found in the TCCC Guidelines in 2016 include the following:

- Structuring battlefield trauma care such that it takes the evolving, often complex, tactical situation into account when caring for casualties on the battlefield. Good medicine can be bad tactics. And bad tactics can get everyone on the mission killed.
- CoTCCC–recommended tourniquets are used aggressively to obtain initial control of life-threatening extremity hemorrhage.
- Combat Gauze and other CoTCCC-recommended hemostatic dressings are used to control external hemorrhage from sites not amenable to extremity tourniquet use.
- Junctional tourniquets such as the Combat Ready Clamp (CRoC), the SAM Junctional Tourniquet, and the Junctional Emergency Treatment Tool (JETT) are recommended to help control external hemorrhage from the axilla and groin.
- Another recommended hemostatic adjunct for external hemorrhage is XStat. In this device, compressed mini-sponges coated with chitosan (a hemostatic substance) and introduced into a wound cavity through the use of a syringe applicator.

When the sponges come into contact with liquid (blood), they expand and exert pressure on the internal aspect of the wound and the bleeding site(s).

- Sit-up and lean-forward casualty positioning is used to manage the traumatized airway when the casualty is conscious and able to assume this position. This allows blood and tissue to be expelled from the airway by gravity and the casualty's own protective cough reflex.
- When the above technique does not suffice to provide an adequate airway and a more definitive measure is needed, a surgical airway using the CricKey device is preferred over having a provider inexperienced at endotracheal intubation try to intubate a casualty with direct trauma to the airway structures.
- Suspected tension pneumothoraces are decompressed with a 14 gauge, 3.25 inch needle. The previously used 2 inch needles do not reliably reach the pleural space and should not be used.
- Intravenous access is not obtained on casualties unless they are in shock and require fluid resuscitation or they need IV medications. Starting IVs takes time and may result in unnecessary tactical delays.
- If intravascular access is needed, but difficulty is encountered with establishing peripheral IVs, intraosseous access is used. These devices allow vascular access directly into the tibia, the humerus, or the sternum.
- Tranexamic acid (TXA) given shortly after wounding (within 1 h from the time of injury or preoperatively in elective surgery) has been shown to reduce blood loss in elective surgery and to decrease mortality in trauma patients who are in or at risk of hemorrhagic shock. When indicated, TXA should be used as soon as possible after wounding.
- Whole blood or RBCs and plasma in a 1:1 ratio should be used as soon as logistically feasible for casualties in hemorrhagic shock.
- For many combat medics, any blood products that require refrigeration are simply not feasible. For these individuals, dried plasma is the option of choice. At the time of this writing, however, the United States continues to be one of the few first-world nations whose combat medical providers do not have access to an approved dried plasma product.
- When whole blood, RBCs, or plasma are not available, permissive hypotension featuring limited fluid resuscitation should be carried out with Hextend, because of its longer intravascular dwell time as compared to crystalloids. If Hextend is also not available, the crystalloid solutions of choice are lactated Ringers or PlasmaLyte-A.
- Care should be taken not to over-resuscitate the casualty and potentially exacerbate hemorrhage from non-compressible bleeding sites.
- The TCCC "triple-option analgesia" approach should be used to obtain rapid, effective, and safe battlefield analgesia. IM morphine is slower-acting and may cause hemodynamics and pulmonary depression. The delayed analgesic effect may result in multiple re-dosing and deaths from morphine overdose. The triple-option plan, in contrast, calls for the use of oral analgesics, transmucosal fentanyl citrate (OTFC) lozenges, or ketamine depending on the casualty's specific condition. Severe pain is much more quickly relieved by OTFC and ketamine than by IM morphine. Ondansetron is recommended for the nausea and vomiting that may result either from opioid administration or from the combat wounds themselves.

- Hypothermia is common in combat casualties and may worsen the coagulopathy of trauma, thereby increasing the risk of death from hemorrhage. TCCC recommends the use of a hypothermia prevention protocol that includes the use of both active and passive warming measures.
- Open combat wounds require antibiotics and they should be started as soon as possible after wounding. Moxifloxacin is the prehospital antibiotic of choice when the casualty is able to take oral medications. IM or IV ertapenem is used when the casualty is not able to take oral medications. Both antibiotics were selected because of their excellent spectrum of activity and their relative lack of serious adverse effects. Additionally, moxifloxacin has excellent bioavailability when taken orally.
- Eye injuries are commonly encountered on the battlefield despite an increased emphasis on protective eyewear use. The key elements of first-responder management of these injuries are to document vision as feasible, to cover the injured eye(s) with a rigid eye shield, and to immediately administer TCCC-recommended antibiotics.
- Coagulopathy is endemic on the battlefield and contributes significantly to the most common cause of preventable death in combat casualties – hemorrhagic shock. Platelet-impairing medications such as ASA and ibuprofen must be avoided in combat theaters. Pain should be managed with analgesics that do not impair platelet function, such as acetaminophen and meloxicam. This is true for both noncombat conditions and for combat casualties with minor wounds who can continue to be an effective combatant – if they are not given analgesic medications that alter their sensorium.
- The Department of Defense 1380 (TCCC casualty card – June 2014) and the electronic TCCC Medical After-Action Reports should be completed for every combat casualty. Documentation of prehospital care is critical both to help guide the subsequent care of the casualty and to contribute to Joint Trauma System combat casualty care performance improvement efforts.
- The TCCC Guidelines provide the corpsman, medic, or PJ with a comprehensive set of evidence-based, best-practice trauma care recommendations customized for use on the battlefield. Every tactical casualty scenario, however, will have its own unique considerations, and the principles of TCCC must be modified as necessary to fit each particular combat casualty situation. Tactical combat scenarios, both historical and hypothetical, are therefore emphasized in TCCC training to help combat medics, corpsmen, and PJs gain experience tailoring the TCCC Guidelines to ensure that the care provided is consistent with both good small-unit tactics and the particulars of each combat casualty scenario.

## The Committee on TCCC, the TCCC Working Group, and Strategic Messaging

All evidence-based best practice guidelines, including TCCC, must be frequently updated as new evidence and increased experience become available. The TCCC Guidelines are updated as needed by the Committee on TCCC (CoTCCC). The CoTCCC is comprised of trauma care subject matter experts from all branches of the armed services. It includes trauma surgeons, emergency medicine physicians, intensivists, operational physicians, physician assistants, medical educators, and – very importantly – combat medics, corpsmen, and PJs. It is the combat medical providers who will be using TCCC to save lives on the battlefield, and their experience and tactical wisdom have been essential to the success of TCCC. The CoTCCC works closely with a panel of designated TCCC subject matter experts and liaison members from other government agencies and allied partner nations. Together, this collection of battlefield trauma care experts meets regularly as the TCCC Working Group to help define optimal care for our nations' combat wounded.

TCCC in 2016 uses a variety of strategic messaging tactics. The TCCC Guidelines are crafted by the CoTCCC and contain the essential elements of TCCC. TCCC change papers are now published in the *Journal of Special Operations Medicine* whenever the TCCC Guidelines are updated. These papers contain a detailed review of the evidence that supports the new change to the TCCC Guidelines and become a permanent part of the published medical literature, thus providing a definitive record of the evolution of TCCC. The TCCC Curriculum is maintained by the CoTCCC Developmental Editor and is a compilation of educational materials designed to train TCCC to combat medics, corpsman, and PJs. At the request of these user groups, the TCCC curriculum does not contain the evidence base that supports TCCC recommendations. The TCCC chapters in the *Prehospital Trauma Life Support* textbook, in contrast, present the TCCC recommendations along with a succinct review of the pertinent literature. The TCCC chapters in the PHTLS textbook are much less detailed than the TCCC change papers, but are valuable as a means for providing physicians, PAs, and senior medical NCOs with an overview of the evidence base for the recommendations in TCCC. Finally, TCCC Mobile is an emerging method of presenting TCCC recommendations that are designed specifically for use on the personal electronic devices that the vast majority of combat medical providers use as a primary source of medical informatics for CoTCCC knowledge products. The combat medical providers who oversee this messaging tool tailor it to the requested level of detail as provided by the majority of enlisted TCCC stakeholders.

## Battlefield Trauma Care Lessons Still Unlearned in 2016

TCCC has been very successful in some aspects of its functioning. Its ongoing critical review of the battlefield trauma care literature and experience has transformed how prehospital trauma care is performed in the US military and, increasingly, in the militaries of our Allied nations and the civilian sector in the United States and abroad. As visionary thinkers such as COL Bob Mabry point out, however, divided responsibilities and distributed authorities for combat casualty care have presented challenges to effecting needed change. The experience gained through 14 continuous years of conflict in Afghanistan and Iraq has identified a number of opportunities to improve that, at this point in time, have not been effectively addressed. These include:

1. The need to develop a TCCC Equipment Rapid Fielding Initiative that expedites the fielding of newly recommended battlefield trauma care equipment to deploying combat units, trains them in its use, and gathers feedback about the newly fielded equipment from those units when they return from deployment.

2. In 2016 “TCCC Training” in the DoD can mean anything from an hour of Powerpoint slide training to 10 days of completely inappropriate battlefield trauma care training – or anything in between. The Joint Trauma System has a TCCC Curriculum that is updated every year. This material should be taught under the auspices of the Military Training Network and/or the National Association of Emergency Medical Technicians to assure the quality of both the material presented and the TCCC instructors.
3. There is a need to train physicians, nurses, and physician assistants in TCCC so that they will be aware of what their corpsmen, medics, and PJs will be doing to care for combat casualties on the battlefield.
4. The DoD and the FDA should mutually establish a military use panel for the purpose of granting approval for medications and blood products of special interest for use in combat casualty care – as supported by the available evidence and the military’s battlefield experience.
5. The Joint Trauma System, in conjunction with the Armed Forces Medical Examiner System, should conduct an analysis of all combat fatalities to determine which deaths might have been potentially preventable through improvements in care or faster transport to a surgical facility.
6. Documentation of prehospital trauma care for combat casualties needs to be more reliably accomplished through the uniform use of the DD 1380 and the TCCC electronic after-action form.

## Translation of TCCC Concepts to the Civilian Sector

The epidemiology of death from trauma in the civilian sector varies significantly from that seen on the battlefield. In the civilian setting, there is more death from blunt trauma sustained in motor vehicle crashes, while in combat, explosions are a leading cause of death. Both sectors experience injuries and death from gunshot wounds. One aspect of care remains the same, however, and that is the critical importance of controlling life-threatening external hemorrhage with tourniquets and hemostatic dressings. One can bleed to death just as easily in Atlanta as Afghanistan.

Thanks in large part to the leadership of Dr. Norman McSwain, a strong partnership developed, beginning in 1999, between the CoTCCC, the American College of Surgeons (ACS) Committee on Trauma, and the Prehospital Trauma Life Support committee. The latter group has been a long-standing part of the National Association of Emergency Medical Technicians and was recently re-designated as the Prehospital Trauma Committee, but retains its long-standing mission. The robust working relationship between the CoTCCC, the ACS CoT, NAEMT, and PHTLS has greatly facilitated the ongoing translation of prehospital trauma care interventions advocated for by TCCC in the military to civilian trauma care systems. Examples of these advances include tourniquets, hemostatic dressings, intraosseous device use, hypotensive resuscitation, and modified spinal protection techniques for penetrating injury to the head and neck.

In recent years, the increasing prevalence of civilian bombings and active shooter incidents has caused the American College of Surgeons (ACS) and the Hartford Consensus Working Group to assume leadership roles in promoting the TCCC concepts of tactical awareness and the use of first responder tourniquets and hemostatic dressings in mass casualty incidents that occur in the civilian settings. Dr. Lenworth Jacobs, who is a trauma surgeon and the Director of the Trauma Institute at the Hartford Hospital in Connecticut, is also a member of the ACS Board of Regents. Through Dr. Jacobs' leadership, a series of meetings that has become known as the Hartford Consensus was conducted from 2013 to 2016. Participants included representatives from the White House, the ACS, the DoD Committee on TCCC, the Department of Homeland Security, as well as fire and law enforcement agencies. The military evidence base from the conflicts in Iraq and Afghanistan has documented that casualty survival is greatly improved when individuals other than physicians, nurses, physician assistants, and medics are trained and equipped to control external hemorrhage. The work of the Hartford Consensus has been reinforced by a national "Stop the Bleed" campaign led by the White House. This campaign followed multiple conferences convened by the National Security Staff to explore ways to improve survival in victims of active shooter and terrorist bombing incidents. The Stop the Bleed campaign emphasizes the use of tourniquets and hemostatic dressings by the lay public, acting as "immediate responders" when needed. These devices are now increasingly being packaged in trauma kits and preplaced in selected public venues, just as is done with AEDs.

## The Way Ahead

TCCC will always be a work in progress. New battlefield trauma care papers will be published, new technology and new leaders will emerge, and every generation of TCCC users will generate new and valuable insights into how best to care for our nation's combat wounded. The unique functional posture of the CoTCCC – continually reevaluating the prehospital trauma care literature and crafting recommendations based on both the available evidence and the wisdom of a broad range of subject matter experts – will help to ensure that its recommendations remain current. Our military men and women count on the Military Health System to take the best possible care of them if they are wounded in combat and the JTS and TCCC Working Group are our country's primary instrument to develop the concepts of care required to live up to that trust. Additionally, the experiences of the SEALs and the 75th Ranger Regiment underscore the fact that well-informed and pro-active line military leaders play an essential role in assuring that good trauma care concepts will be well-executed on future battlefields.

**Acknowledgments** The authors gratefully acknowledge the sustained efforts of our colleagues at the Joint Trauma System, in the CoTCCC, and in the TCCC Working Group to provide the best care possible to our country's combat wounded.

**Disclaimers** The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

**Release** This document was reviewed by the Director of the Joint Trauma System and by the Public Affairs Office and the Operational Security Office at the US Army Institute of Surgical Research. It is approved for unlimited public release (Figs. 1.1, 1.2, 1.3, and 1.4).

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Prehospital care.
2. Hypothermia prevention.


**Fig. 1.1** TCCC logo


**Fig. 1.2** Hartford Consensus logo

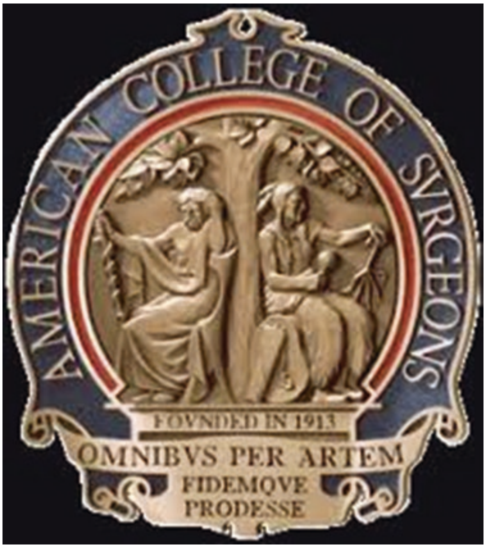



**Fig. 1.3** ACS logo


**Fig. 1.4** White House Stop the Bleed graphic

# Combat Triage and Mass Casualty Management

2

Jayson D. Aydelotte, John J. Lammie, Joseph G. Kotora Jr., Jamie C. Riesberg, and Alec C. Beekley

**Deployment Experience**

| | |
|---|---|
| *Jayson D.Aydelotte* | Staff Surgeon, 28th Combat Support Hospital, Ibn Sina Hospital, Baghdad, Iraq, 2007 |
| | Chief of Surgery, 47th Combat Support Hospital, Tikrit, Iraq, 2009 |
| *John J. Lammie* | Family Physician, 550th Area Support Medical Company, Division Support Brigade, Third Infantry Division, Taji, Iraq, Jan 2005–Jan 2006 |
| | Deputy Commander for Clinical Services, 28th Combat Support Hospital, Ibn Sina Hospital, Baghdad, Iraq, Feb–November 2007 |

J.D. Aydelotte (✉)
Associate Professor, University of Texas Dell Medical School,
Department of Surgery, Austin, TX, USA
e-mail: jdyadelotte@mac.com

J.J. Lammie
Womack Army Medical Center, Fort Bragg, NC, USA

J.G. Kotora Jr.
Navy Region Southeast, Naval Hospital Camp Lejeune, Emergency Department,
Camp Lejeune, NC, USA

J.C. Riesberg
Womack Army Medical Center, Special Warfare Medical Group (Airborne),
Ft. Bragg, NC, USA

A.C. Beekley
Thomas Jefferson University Hospitals, Paoli Hospital, The Lankenau Hospital, Division of Acute Care Surgery, Division of Bariatric Surgery, Philadelphia, PA, USA



M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_2

*Joseph G. Kotora* Battalion Surgeon, 1st Battalion/8th Marine Regiment, Ramadi, Iraq, 2007–2008

Blood Bank Coordinator, Navy Forward Resuscitative Surgical Suite (FRSS), Ramadi, Iraq, 2008

*Jamie C. Riesberg* Team Physician, Combined Joint Special Operations Task Force, Afghanistan, 2008

*In any emergency setting, confusion is a function of the cube of the number of people involved.*

Clement A. Hiebert

**BLUF Box (Bottom Line Up Front)**

- The five Rs: *Resources, Rehearse, Respond, Route, Reset*
- *Security* is the foundation of safe and effective care:
  The *best* medicine on the battlefield is *Fire Superiority*!
  Ensure effective enemy action is ended prior to rushing to treat
- Plan *before* the casualties arrive; rehearse the plan to build "muscle memory"
- Rapidly sort patients with ABCDE sweeps: 2As – arterial hemorrhage + airway, then B + C, then D + E (15 s)
- Rapidly reassess every patient for changes or mis-triage
- The triage officer (TO) should be one of your most experienced and organized personnel
- Triage provides greatest good for greatest number, *not* "sickest first"
- Use every resource (blood, X-ray, evacuation, personnel) appropriately
- Patient admin personnel and record keeping are essential to *Mascal* response
- Remember heart and compassion – for victims and for team

## Introduction

Although much of this book focuses on preparing for combat trauma care at the individual provider level, the most critical training for a UNIT to prepare to handle combat casualties is triage and mass casualty management. This chapter will share triage and mass casualty expedients from three combat perspectives representing different echelons of care. Every trauma patient triggers a triage or sorting to align available resources with needs. But when those needs surpass apparent resources, we declare a MASCAL or mass casualty and launch a series of rehearsed strategies to achieve the greatest benefit for the most patients. Intensity, number of casualties, and environment all contribute to this overload calculation: a single complex injury patient can eliminate a unit's ability to deliver additional casualty care, and two immediate surgical patients will max out many Level 2 facilities. Medical leaders can hone a unit's trauma-ready posture to expand its ability, as "chance favors the prepared team." This chapter reviews the "five Rs" to prepare a team for successful combat trauma response: resources, rehearsal, response, route, and reset.

## Resources

### Security

While security may not seem to be a direct medical responsibility, it is always your concern, since the current asymmetric battlefield entails risk at all echelons of care, from aid station to theater hospital. Ongoing enemy action at the scene will force limited "care under fire" response. Fire superiority can be the "best medicine" until the site is secure, but medical personnel pull triggers only if security elements cannot meet the demands. Avoidable injuries to the medical team can doom its mission. Security forces should quickly assess for catastrophic secondary attacks and establish a safe perimeter for the treatment facility or triage site. If chemical contamination is a risk, a sweep of incoming casualties may be required, but available chemical detectors will slow your triage and treatment process.

Your MASCAL plan should incorporate a thorough plan for providing safety and security to the patients and facility staff. The priorities should be on securing the area, controlling vehicular access, controlling pedestrian access, and assisting with the management of enemy or suspected enemy casualties. Although hospital units have traditionally been off-limits during conventional warfare, they are seen as a high-value target by enemy forces in current combat operations. All unknown vehicles or persons must be verified and searched prior to allowing them access to the facility. Enemy casualties should be searched and secured, even if it does delay care. Controlling access then becomes the most important security function, as people will naturally gravitate to the hospital area when there is a MASCAL situation. Although most are well intentioned, if you allow access to bystanders and nonessential personnel, you will only make an already chaotic situation worse.

### Context

The current military casualty triage and evacuation system uses a model of echelons of care with progressively increasing capabilities, from point of injury (Level 1) to Level 5 hospitals in the USA (Table 2.1). Your unit's role in the casualty care continuum in both military and civil contexts will shape its trauma response, whether it is Level 1 unit point of injury care on the forward battlefield, Level 2 lifesaving damage control surgery, or Level 3 vascular reconstruction. While not ironclad, Level 1 units are often first responders to civil and military events, with "on-scene care" and care under fire. Level 2 units frequently receive ground- and air-transported casualties, and Level 3 facilities are geared to receive air-evacuated casualties as "fresh trauma" from point of injury and Level 1 units and as stabilized casualties from Level 2 units which have already performed initial lifesaving surgical management. Local host nation hospitals may be able to receive and manage wounded national patients in order to augment a unit's MASCAL response.

**Table 2.1** Military echelons of care

| Echelon of care | Example | Surgical capability | Capabilities | Comment |
|---|---|---|---|---|
| Level 1 | Battalion Aid Station, Shock Trauma Platoon | None | "Aid bag," limited supplies, maybe ultrasound | Medics and PA or Primary Care doc; no hold capability |
| Level 2 | Forward Surgical Team (FST), Air Force Field Surgical Team, Navy Forward Resuscitative Surgical System (FRSS) | Limited | Damage control surgery, basic lab, basic X-ray and ultrasound, oxygen, simple blood FRSS has surgeon, orthopedics, anesthesia, ER, FP or GMO, psych, and dental | Patient holds beds, MEDEVAC drops patients here, may be mobile – may divide to send bounding element ahead |
| Level 3 | Combat Support Hospital, Theater Hospital, Hospital Ship | Yes, general and orthopedic surgery, often subspecialties | Multiple specialists, advanced lab and blood product support, advanced radiology and CT, physical therapy | Damage control surgery, more definitive management; stabilization and evacuation portal to Level 4 |
| Level 4 | Regional Medical Center (Landstuhl, Germany) | Extensive, excellent subspecialty support | Major medical center capabilities | More definitive surgical intervention; burns may bypass directly to Brooke Burn Center |
| Level 5 | National Medical Referral Center (Walter Reed, Balboa, Brooke) | Full tertiary care | Full rehabilitation and specialty intervention | Performs most delayed and "reconstructive" care |

## Trained and Ready Personnel

Medical personnel will benefit from trauma care experience prior to deployment. Advanced trauma life support (ATLS) training is a must but should be supplemented with additional combat and service-specific courses. Since units are often built with personnel who have minimal time together before deployment, common training can accelerate cohesive unit response in theater. Be sure to survey personnel in your unit and on the base to find capable people "hidden" in other units or in command and staff billets. You can often identify individuals with medical skills beyond their duty titles that can be helpful in MASCAL scenarios. Since many units receive and treat more civilian than military casualties, specialty skill sets such as pediatrics, obstetrics, or burn care can be invaluable.

## Culture

Competent cultural assistance is vital in international trauma response. Medically seasoned interpreters are essential team members at the bedside throughout the triage and treatment process. They play a huge role in shaping culturally sensitive care.

Unit members who learn basic local language greetings and health questions can enhance trust and effectiveness in the care of wounded nationals. A capable bicultural or host nation medical officer or authority can "sweep" the injured to identify family groupings or key individuals such as high-ranking government officials or celebrities. The same liaison can help disposition injured host nationals to national medical providers and facilities if medical personnel have cultivated relationships with them. In Afghanistan, tea with the local hospital director resulted in over 20 rapid patient transfers to his facility during a busy summer month, allowing quicker facility recovery and better support of coalition operations. In Baghdad, the combat support hospital (CSH) hosted shared continuing medical education (CME) for local physicians to build trust in sessions orchestrated by a contracted Iraqi-born civil medical liaison physician. US Marine Forces operating in Al Anbar routinely augmented medical missions in support of local Iraqi physicians and provided resources, medical supplies, and logistics that their healthcare infrastructure lacked, building trust bonds.

### Supply and Transport

Casualty care can consume large volumes of supplies, and resupply will be a major determinant of unit casualty response. Many units develop lists of trauma response supplies and cache them in strategic locations. Be sure to note expiration dates prominently if IV fluids or meds are part of these contingency stores. Define transportation and evacuation resources and routes. Transport options are exquisitely sensitive to tactical situation, terrain, and weather. A dust storm can eliminate rotary wing evacuation of casualties. Stabilization and rapid transport to a higher level of care are the main mission for Level 1 and nonsurgical Level 2 units without patient hold capability or resources to "sit on" casualties. If you depend on rotary wing evacuation, prepare ground evacuation or patient hold contingency plans in case aircraft are grounded.

## Rehearsal

### Plan

Analyze and plan for the mission, engaging all stakeholders to choreograph a shared response that remains flexible enough to match unique events. (See Fig. 2.1 for simple plan template.) The MASCAL mnemonic (minimize chaos, assess, safety, communication, alert, and lost) is a great starting point and guide (Fig. 2.2). Key considerations include security and protection needs, command and control, communication means and frequencies, casualty collection points (CCPs), medical resupply, litters and straps, and personal protective equipment posture. Landing zones need to be defined with marking devices at the ready, and lights are needed for outdoor night operations. Safe transportation routes into and out of the area must be clearly defined, with special attention not to endanger casualties and treatment

MASS CASUALTY PLAN FOR DATE

Unit
Location
Date

References:

a. MAP 8
b. Operations Order

Time Zone Used Throughout the Order:

TASK ORGANIZATION: See base order of organization of units.

1. SITUATION: Base units prepared to conduct coordinated emergency medical response operations during tactical and non-tactical disasters.

A. Enemy Forces. (threat assessment)

2. MISSION: On order, execute MASCAL operations for rapid treatment and evacuation of casualties.

3. EXECUTION:

a. All Medical Units – define mission, evacuation, goals
b. MASCAL – define, identify declaration authority

Define execution by 4 Phases of MASCAL Operation:

Phase 1 - Preparatory phase:
Prepare and train
Define communications

Phase 2 - Immediate response and incident notification:
First responder care
Notify base security element
Dispatch incident commander to scene
Notify medical units via communications net
Dispatch elements for site security, ordnance clearance, crowd and traffic control

Phase 3 – Coordinate medical response:
Provide care at MASCAL site: all casualties triaged, life-saving treatment initiated.
Initiate evacuation of urgent and urgent surgical

Phase 4 – Reception, staging and evacuation:
Evacuate and cross-level casualties
Document care and accurate reports to ensure 100% accountability of casualties

4. SERVICE SUPPORT: Define units' resupply procedures during and after the event

5. COMMAND AND SIGNAL

a. Command - define who is in charge
b. Signal – define frequencies, numbers, means of communication

Signed: Commander

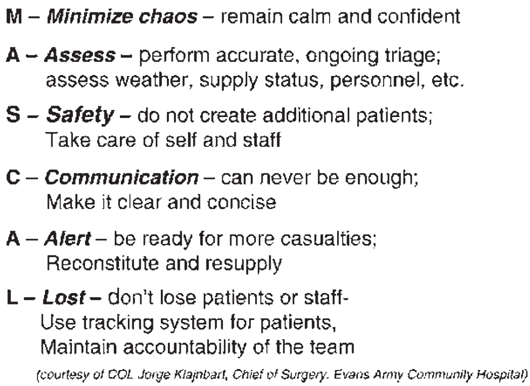
Annexes:

Response maps
Ground evacuation (NO FLY) Plan if air evacuation cannot be employed
Notification Matrix (radio, phone tree with frequencies, numbers)
Responsibility Matrix by unit (geographic area of responsibility or specific role))
Patient Care Matrix for rules of engagement for host nation casualties, combatants

**Fig. 2.1** Template for MASCAL plan

areas on the ground. Casualties will need to be disarmed, and suspected enemy combatants will need to be appropriately monitored. Many sites modify the Incident Command structure employed in emergency response at many US hospitals, where an overall incident commander directs coordinators with specific responsibilities such as triage, treatment teams, security, logistics, public affairs, manpower pool, security, transportation, and evacuation.

**Fig. 2.2** MASCAL mnemonic illustrating key points for mass casualty scenario management (Courtesy of COL Jorge Klajnbart, Cheif of Surgery, Evans Army Community Hospital)




Trauma readiness is a daily preoccupation, particularly tough for units with infrequent trauma and rare opportunities to put plans into practice. Rehearsal of the MASCAL plan with real people in litters or beds during exercises will identify vulnerabilities better than by brainstorm or tabletop drills. Practice with both continuous patient loads and sudden surges, as the demands are different. Nearly all exercise after-action reviews identify breaks in command, control, coordination, and communication as the major "opportunities to improve" these MASCAL plans.

## Response

### During the Event

Successful trauma response hinges on effective communication and use of available resources. Employ elements of your MASCAL plan with every injured patient to exercise procedures and to develop "muscle memory" for bigger events. Since the formal MASCAL plan is initiated only when the top medical official decides that resources cannot keep up with medical demands, many units never need to launch the full plan. But the overload may be hard to recognize if a "slow burn" continuous stream of casualties, no one by itself too much for the facility, steadily depletes resources (a particular risk for Level 1 and 2 units). Sudden "flood" MASCALs are usually easily recognized, even before the wounded arrive at the facility.

If advance warning is received, preposition personnel in accordance with your MASCAL plan and anticipated needs. Notify all on-duty personnel and make sure you have reliable methods in place (pagers, runners, public address system) to activate a full recall of all key off-duty personnel. Close proximity of living areas for personnel can minimize notification and response times. MASCALs rarely happen when your hospital is empty, so you must incorporate a plan for expanding bed capacity as well as relocation or discharge of current inpatients. Security forces can be deployed, and the manpower pool can be mobilized in advance to be ready as runners, litter bearers, blood donors, and other non-provider responders.

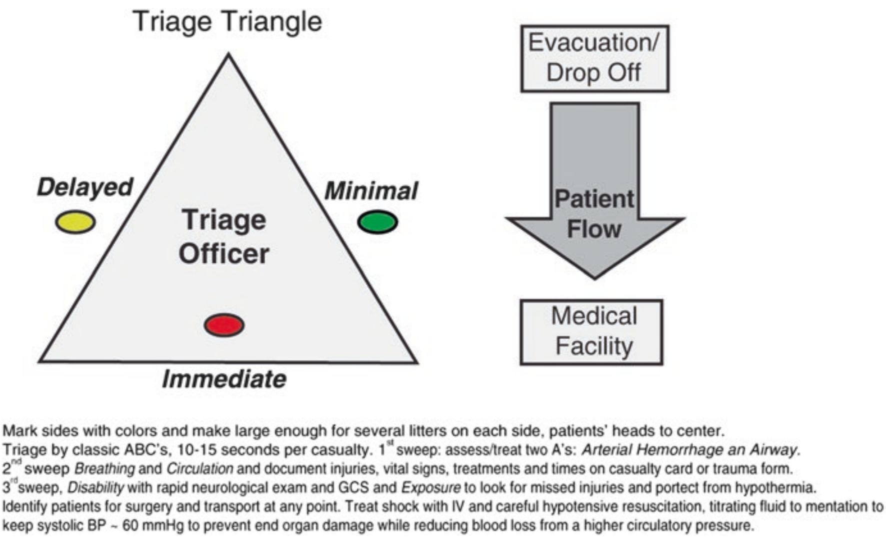



**Fig. 2.3** Triage triangle system used for field triage of multiple casualties and prioritization for evacuation

While any unit can quickly find itself in a "casualty scene" response, such as when local blast casualties flood its gates, Level 1 units may be more frequently called to initiate hasty on-scene triage and response near hostile fire. A quick survey of the scene will define security issues, as well as the number and nature of injuries. An effective tool in outdoor response is the *triage triangle* (Fig. 2.3), allowing the triage officer to move around the center to quickly assess each patient and to direct interventions as needed to "treat and transport."

Levels 2 and 3 triage is better optimized within the treatment facility with prepositioned personnel and equipment. You will almost never perform the television type of triage (such as seen on the popular series M.A.S.H.) where all the casualties arrive at once and you run from patient to patient barking orders. You will most often receive widely spaced waves of casualties of two to eight at a time, corresponding to the evacuation vehicle capacity. Do not expect them to arrive or to be off-loaded from the vehicles in order of acuity, which is why your job of continuous triage and reassessment is so critical. The spacing does allow time for each group to be evaluated and treated, but you must move casualties promptly out of the triage area to be ready for the next arrivals.

## Hospital Level Triage

### The Triage Officer

An effective triage officer (TO) is the key to MASCAL success and should be the unit's most experienced combat trauma provider. The most experienced combat trauma surgeon is ideal. No matter what the grade or specialty is, this person needs

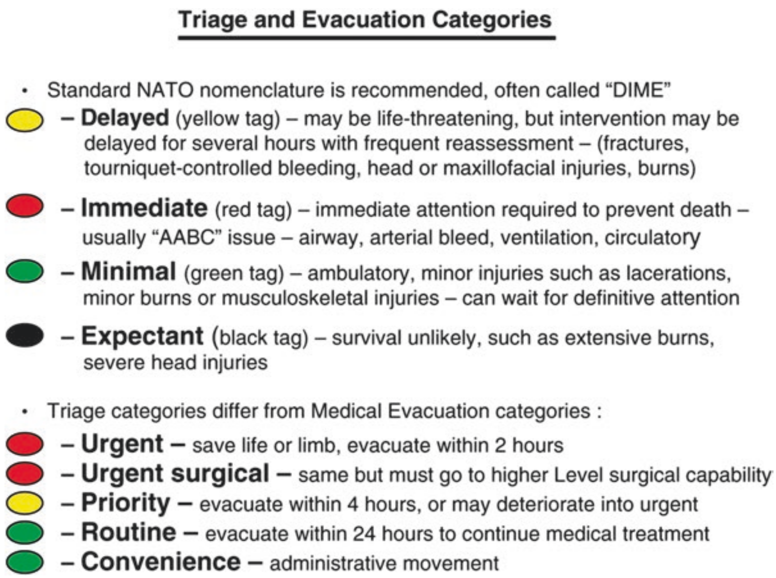



**Fig. 2.4** Color-coded scheme for DIME system of triage classification (*top*) and separate scheme used for medical evacuation (MEDEVAC) chain

to be the most comfortable provider making life or death decisions and have experience in trauma situations. This person may not be the most senior provider in the hospital, and a concerted effort among all the officers in the hospital should be made to select this person. The triage officer will make quick decisions on the ultimate location of a casualty. She will command the triage area and essentially run the emergency situation of the hospital during a MASCAL. The only wrong decision is indecision, and arterial bleeding and airway are trump cards as patients are sorted into classic NATO immediate, delayed, minimal, and expectant categories (Fig. 2.4). The TO sorts casualties, identifies immediate life threats, and directs the patients to the appropriate care areas. She will not only help sort the patients out but will guide all of her physicians to quickly move patients in and out of the Immediate areas and Operating rooms. This is one of the reasons the ideal person to perform this job should be a surgeon. A surgeon is the most well-equipped person to triage "at the door" and to the operating rooms. Utilizing a surgeon in this role frees up another clinical provider to give lifesaving care elsewhere in the hospital, mostly in the EMT section.

## Triage Categories

The traditional NATO triage categories, the so-called "DIME" (Delayed Immediate Minimal and Expectant) method (see Fig. 2.4), are designed to best utilize your treatment facility's space and personnel. Usually this translates into Immediate patients making their way through the emergency room or EMT section of your facility, Delayed patients making their way to another part of the hospital for initial treatment, and Minimal patients going to an entirely different location. However, one reality of medical life, deployed or otherwise, is there is a spectrum of comfort levels and abilities for providers, whether they are physicians, nurses, or medics. Likewise, there is a spectrum of what one would constitute as “Immediate.” For example, after an explosion event, a patient is brought to the hospital missing both legs. He has a penetrating injury to his abdomen and is crying out loud in pain. He appears pale. This is, in most TOs hands, an Immediate patient. However, a different patient with the exact same constellation of injuries is ashen and unconscious. This is also an Immediate patient but presents with a much more Emergent problem list. Under the traditional DIME method, both these patients would go to the Immediate area, where nurses, medics, and doctors are just sort of randomly assigned. But after the realization that there is a spectrum of ability and experience among providers, the hospital could assign specific groups of people to specific areas within the Immediate area, and the triage officer could triage the patient to the specific bed he thinks will stack the odds in their favor. This is what happened in Baghdad in 2007 during the surge. After multiple MASCAL incidents, the CSH personnel realized they needed to take advantage of the difference in Immediate patients as well as the experience/ability of the individual providers. This enabled them to move as many people through that hospital in a short amount of time, taking care to maximize the benefit in each location. They effectively created a new triage category, EMERGENT, although not named as such at the time. The triage officer applied two physical signs that drove the direction of the patient into the EMERGENT area or the Immediate area. He asked two questions to get at these signs:

1. Is the patient conscious?
2. Does the patient have a radial pulse?

By definition, he had to *touch everybody.* This is not normally taught in civilian training programs for mass casualty management but is essential in moving the most appropriate patients to the most appropriate location within your facility.

Delayed patients present another set of problems. Mostly these are patients that do not need your EMT section or emergency room RIGHT NOW but otherwise would have gone there if they were arriving by themselves. In the military world, these would be patients that are injured and cannot walk but do not have penetrating injuries above the knee or elbow and can talk to the triage officer without much difficulty. The delayed area will be manned mostly by nurses and medics, but one physician should help in this area. This area should expect to see twice the number of patients as the Immediate or EMERGENT areas during the event. Under-triaged patients (those that have discovered problems that need some immediate surgical intervention) are, quite frankly, an expectation in a big MASCAL event. The physician overseeing the delayed area should simply make the TO aware of the situation, and the TO will send someone to the delayed area to help treat the patient. Resist the urge to move the patient into the Immediate or Emergent areas as this will disrupt the triage process and usual patient flow.

Minimal patients will have injuries that are important enough to seek treatment but don't require any lifesaving interventions and only rare trips to the operating room. A good triage technique for identifying Minimal patients is to ask the casualties to "stand up." Any casualty who can stand and walk are, for the most part, triaged Minimal. Have them separated from the rest of the hospital but somewhere nearby. Adjoining troop medical clinics or clinic-type treatment facilities are great for this.

Expectant patients are not expected to survive, hence the ironic term. This is a relative situation in modern warfare. The traditional example of an expectant patient is a gunshot wound to the head in the Vietnam War. During that time ventilator management and modern neurosurgery were not as common around the battlefield as they are now. In fact, it is very rare to identify truly expectant patients in coalition forces. In Baghdad, for example, penetrating injuries or badly burned patients who could be resuscitated in the ED would be intubated and brought to the ICU where they would be placed on the ventilator and arrangements for movement to another facility would be made. It was incredibly rare to make a patient expectant at that time. In sharp contrast, burned and head injured local nationals present a different scenario, and the local medical rules of engagement (MRO) should be followed. For example, the LD100 (lethal dose where 100% of patients die) for burns of local Iraqi people in 2007 was 40% or 30% with an inhalation injury. These patients would be triaged expectant, extubated, and made comfortable in a separate section of the hospital. It is not a good idea to have them in the same areas as those that will likely survive.

## The Triage Area

The triage area should be located in a position that allows access to all incoming casualties and easy communication with the other key personnel and MASCAL leaders. This is often best achieved by creating a one way "funnel" for patient movement into the facility, with the TO positioned at the narrow point that only allows for one or two patients at a time. This position should be located at or near a centrally located casualty tracking board. The tracking board assures visibility for all casualties, serving as a hub for triage, treatment, nursing, and patient administrative personnel to update critical information and coordinate care. The TO's job does not end at the initial triage but includes continuous triage and prioritization of patients for movement to the CT scanner, operating room, ICU, and wards. We found that having the TO, the chief emergency department nurse, the hospital bed manager, and the senior anesthesia provider all located in this spot allowed for improved communication to prioritize and facilitate patient triage, bed assignments, and accountable movement from the ER to the OR or wards.

The TO performs rapid but focused individual patient assessments, usually spending about 15 s per casualty with each sweep. The sick are sorted to receive appropriate treatment; the minimally wounded are moved out of the stream, and the dead or hopelessly injured are sent to the expectant area or morgue. The TO then re-triages the casualties, rapidly checking for any change in status, adding detail to the exam, and looking for additional injuries. There will always be mis-triage!

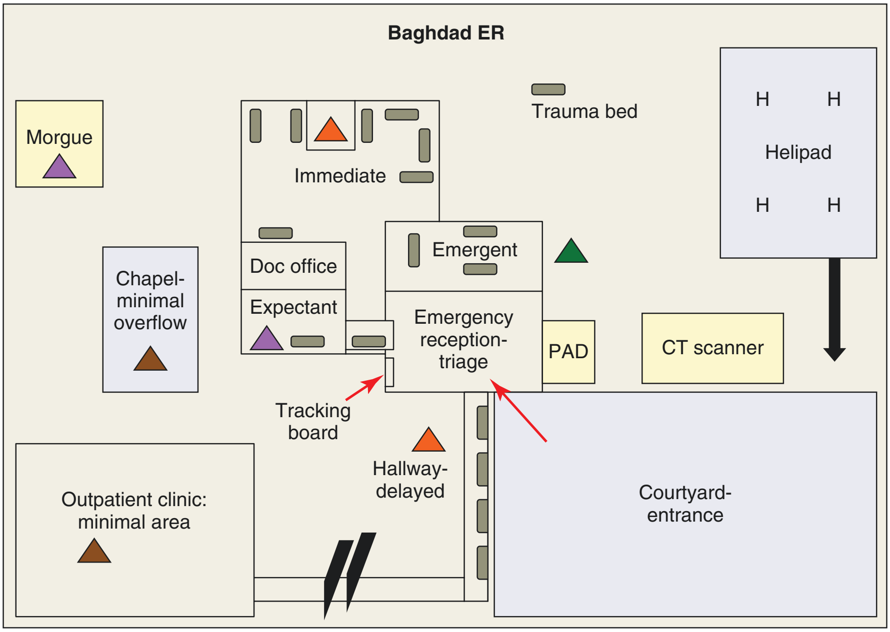



**Fig. 2.5** Physical layout and organization used for triage at the Level 3 Combat Support Hospital in Baghdad, Iraq, during Operation Iraqi Freedom

The key is to have a system in place to identify them early, notify the TO, and re-triage them appropriately. Having the TO in the triage area all/most of the time facilitates personal communication between the TO, hospital leadership, and clinical providers. There is little to be miscommunicated with eye-to-eye discussion.

Figure 2.5 outlines the setup and triage operation used at the Baghdad Level 3 hospital. In this model, the senior surgeon conducts hasty triage of casualties as they enter the emergency reception area, quickly assessing consciousness, mechanism of injury, and scope of apparent wounds. The most severe Emergent surgical patients are sent to the closest resuscitation bay with three beds. One emergency medicine provider is present in that room to help with intubation and other procedures. The other Immediate patients are sent to a seven-bed delayed area with similar intensive resuscitation capability. However, there may be only one emergency medicine provider or anesthesia provider to help with intubation or procedures for all seven of those beds. This forces the TO and clinical providers to “stack the deck” and put the most experienced providers in position to help the sickest patients. Other delayed and non-ambulatory patients are assigned litters in the hallway away from the emergency room. Minimal patients can be led to the outpatient clinic for evaluation and treatment. Don’t forget to use your primary care and outpatient assets – they are invaluable for managing these lesser injured patients. Patient administration personnel positioned at the entrance simultaneously places a trauma packet with each patient, while the nursing coordinator records the trauma number and nature of injury by the assigned bed number on a casualty tracking board. Medics immediately fasten the trauma number bracelets on casualties upon arrival to the assigned litter. Patient flow should ideally be linear, one way in, one way out, with security to control access to the triage and treatment areas. Disarm all casualties and confirm "safe" status in trauma bed. Have patient administration personnel maintain accountability for military equipment and weapons. Secure personal effects, to include any amputated body parts, and label clearly with patients' trauma numbers.

Identification of patients is critical, and many systems exist (SSN, trauma registry numbers, and others). Keep in mind that no system is infallible, and great care must be taken to avoid confusion as to patient identity. For example, confusion among three severely injured casualties with adjacent numbers and similar devastating injuries resulted in a mismatched blood transfusion, and a more random assignment of numbers was adopted to make distinctions among patients more apparent. The importance of careful confirmation of trauma registration number with identity bracelet prior to interventions such as blood transfusions cannot be overemphasized.

The Level 2 or 3 TO is also responsible for prioritizing patients for operative intervention. These decisions can be tough if casualties arrive in wave fashion, as someone with more urgent injuries may arrive in the next group. Once operating tables are filled, additional urgent surgical patients must be managed through temporizing measures with techniques from ATLS and Tactical Combat Casualty Care until the operating room is available. The TO should assign a personnel to specific trauma treatment beds, with orders to fully evaluate and stabilize their assigned patient before moving on to a different task. Avoid the "butterfly effect" where providers flit from bed-to-bed without taking responsibility to direct medical care or document findings, resulting in worthless duplication of assessment and delays in appropriate treatment.

Some of the incoming patients may have received various prehospital treatments or even surgical intervention at a Level 2 or local civilian hospital. Often they arrive with little to no documentation of what has been done to them. However, even if they arrive with complete records, they should be evaluated and triaged as if they were newly injured. Transport and evacuation time between facilities can result in dislodged lines, occluded airways, recurrent shock, or the presentation of missed or inappropriately managed injuries.

Rules of engagement during a multiple trauma or MASCAL event dictate life and limb-saving interventions only. The ATLS ABCs are very good, with control of major arterial bleeding as the first priority. Victims of penetrating trauma often do not need cervical spine stabilization, but blast and vehicle-injured patients usually do. The FAST (Focused Assessment with Sonography in Trauma) exam can be a helpful adjunct to rapidly identify surgical candidates with intra-abdominal hemorrhage, but it is operator-dependent and may not be definitive. Only chest and pelvis films are permitted during the triage and treatment phase; other films can be done later. Be sure to keep films with the patients, as they are easily lost as patients move through the trauma chain. Many trauma patients will need the CT scanner, as its use has facilitated more accurate trauma diagnosis and management, but few need it for immediate triage. CT candidates must be stable and resuscitated before going into the scanner. An on-site radiologist can expedite scanner throughput.

Military physicians are tasked to provide the same role of care in the deployed setting as in the USA. In the urgent resuscitation Level 1 environment, providers may be pushed to render lifesaving care outside their specialty training, but most Level 2 and 3 units are staffed with sufficient expertise. A MASCAL is not the setting to learn new techniques, and a capable provider should be engaged as soon as possible, particularly if a provider encounters difficulty in performing a treatment or procedure. For example, if a primary care or emergency provider has trouble with securing an airway, an anesthesia provider should be promptly summoned. Responsibilities and authority need to be defined in advance: an emergency physician should usually defer to the operating surgeon in triage and care decisions. When personnel step out of assigned roles, they can degrade the unit's performance.

Documentation of care is critical. Assign a recorder to each trauma table that can accurately complete the casualty card or trauma sheet. If documentation is left until after the event, fatigue and degraded recall may make accurate reconstruction impossible. In Baghdad, the CSH team found that despite its most diligent efforts, urgent surgical patients were rushed to the operating room without supporting documentation (another factor in the blood transfusion mismatch). The team developed a simple bright yellow cover sheet that had the pseudo-SSN, and key studies, meds, blood products, and diagnosis. This sheet always remained with the patient, even if more detailed trauma sheets needed to follow later.

In addition to the TO, an overall scene or incident commander or coordinator can maintain "big picture" focus to call for specific additional assistance and to maintain movement of patients out of the emergency treatment area in order to prepare for the next wave of casualties. Hemodynamically stable delayed patients can be admitted to a holding bed or ward to complete studies and treatment or surgery when OR and CT demands have slowed. Nonsurgical medical providers can care for delayed and minimal casualties away from the emergency area to decompress the scene. A surgeon should sweep these areas to prioritize delayed patients in the operative queue and to reassess clinical status.

High-visibility events may trigger immediate inquiry from higher headquarters or government officials, especially if "high value" or high visibility victims are involved. Frequent updates of senior officials and commanders may be required; build current contact lists of "need to know" officials before an event.

## Special Considerations: Mental, Behavioral Health, and Spiritual Needs

The wounded certainly benefit from ministry team comfort and encouragement, but unit and family members who accompany injured patients also have anxiety and grief burdens to be addressed while awaiting news about loved ones' status.

A chaplain can be an invaluable advocate and assistant to calm units and families and to keep them updated, but other personnel may also meet many of these needs with attentive compassion. Remember that members of a unit who bring their wounded buddies for care may be unaware of their own injuries due to the "adrenaline of battle." Have a low threshold to register them with trauma numbers and to appropriately assess them as casualties.

Psychiatric casualties present a difficult management challenge, particularly during a MASCAL scenario. Although not physically injured, they can significantly disrupt your team function and monopolize the time of key personnel that is needed elsewhere. You should be fully prepared for this; integrate a disruptive psychiatric casualty into your MASCAL practice exercises (your team will quickly realize how incredibly difficult they can be to manage), and have a designated mental health professional or team as part of your standard MASCAL response.

One of the hardest missions may be to care for your own injured personnel. While focus may be sustained during emergency evaluation and treatment, special attention for your personnel will be essential during the "reset" phase when the full weight of the strain and loss is experienced. Common responses you may encounter among your personnel are inappropriate or disproportionate outbursts of anger, major sleep disturbances with resultant fatigue, and major depressive symptoms. Do not ignore these warning signs or just hope that they will go away.

## Route

Transport and accountability must be inextricably interwoven. Dedicated transport personnel should meticulously record every patient's movement from the triage and treatment areas, noting the destination on a tracking board or log. It is very easy to lose control in the confusion of large events. In Baghdad, following the bombing of a high official's home, a final tally of casualties and dispositions took more than 2 days due to inaccurate record keeping. Any movement of military or contract personnel must include notification of unit commander or supervisor.

A patient transfer decision considers diagnosis, condition, level of care required, and expected prognosis and recovery. Most coalition combat wounds will require evacuation to a Level 3 facility, with subsequent transport to a Level 4 or 5 for follow on care and rehabilitation. Once patients reach a Level 4 facility, they are unlikely to return to theater. There is a big difference between "snatch and grab" point of injury evacuation to Level 2 or 3 facilities and inter-facility transport of critically ill or injured patients. Movement of these patients from one higher-level facility to another requires special planning and coordination, as many will require complex monitoring and care en route. If possible, avoid evacuating an unstable patient because military helicopters and tactical vehicles are poor resuscitation platforms (see Chap. 34). Adequate space must be assured for critical care attendant to be able to access monitors and lines.

## Reset

Triage stops when the last patient has been moved from the emergency triage and treatment area. Once transport has been finalized and patient documentation completed, the care team should begin to recover and to prepare for the next event. Recap the event and confirm accountability for all casualties. Call in the report to higher headquarters. Lead an after-action review to find points to praise as well as problem areas to improve to make the next response more effective. Do not neglect personal and patient safety concerns. The treatment area may need to be cleaned, and supplies must be rapidly restocked. Remember that "amateurs talk strategy while experts talk logistics" – if you run out of critical supplies and equipment, you are mission incapable.

## Ethics and Resiliency

Triage by its nature raises issues of distributive justice and beneficence. Combat triage may confront teams with challenges in deciding between care for a suspected or known enemy combatant and a US soldier. Expectant patients, particularly with burns and catastrophic head injuries, exact a huge toll on treatment teams and the victims' units and families. In OIF, severe burns of non-coalition personnel of more than 50% total body surface area were generally non-survivable, without Level 4 or 5 burn center support. A refusal to initiate care can be very tough. An ad hoc ethics committee process can be invaluable to help ratify these and other difficult decisions.

If possible, expectant and morgue areas should be in a covered location away from the rest of the patients. Position a nurse or medic to give any needed pain medications or fluids and utilize the ministry team or other capable personnel to ease anxiety and fear and to provide comfort. Preserve dignity and treat with the same respect as other patients. Reassess after other casualties have been triaged, as clinical status may have changed and post-event unit capability may enable more intense attention and care.

Multiple trauma events are stressful, and care for the responding team members is essential. Sleep rest cycles and meals cannot be neglected. Compassion and awareness are integral to the team refit and recovery process to address emotional needs in the wake of the horrors of devastating or fatal injuries. Unit ministry and behavioral health team attention may be as important to your team as medical resupply. Notify your higher headquarters if your facility is "black" due to staff or supply exhaustion or other constraints that temporarily prevent quality patient care.

## The Dead

Dead is the final triage category that is not often mentioned but is a very *real* part of battlefield medicine. In Baghdad and other hard facilities, dead people are/were moved to a morgue, which occupied a building separate from the hospital proper.

However, in the traditional CSH organizational structure, there is no morgue. There is no official training on where to put the dead. But this is a step that should be worked out on the trip *over* to your deployed location, not in the middle of a MASCAL. If you have the facilities, put your dead in a cooled container attached to, but not part of, the hospital. But if you don't already have that worked out, you will need to define a space for the dead. Several points to consider in finding this space:

1. Do not have this space inside your hospital proper. You are going to be involved in a mass-casualty situation where the mission of the organization is to mitigate death. It is counterproductive to have the dead in the way of the living and those caring for the living.
2. Have a space that is easily accessible to commanders and comrades in arms. Soldiers will want to come pay their respects and hold vigil until their team mate is transported home. Honor that action by providing an area that they can get to and spend the time they need to honor the fallen. This speaks to item #1 above; you do not want large groups of people occupying a hallway or common area.
3. The space should be large enough to accommodate ten or more bodies. A 20′ × 20′ tent would be adequate.
4. The space should be cooled with air conditioners if possible. There is an obvious reason for this, but it also facilitates a comfortable place to pay respects. Do not use the dining facility. While this facility may be appropriately sized and air-conditioned, this event is not likely to be over very soon, and the living will need to eat. Moreover, in a busy war, this will not be your last MASCAL, and it is harmful to morale if everyone knows this is where the dead are stored. For similar reasons, do not use the chapel. A reasonable location is the MWR (Morale, Welfare, and Recreation) tent. Usually these sites are very close but not in the hospital and are well air-conditioned spaces.

Overall, the dead are a reality of war. During a MASCAL you want everything to run as smoothly as possible. Knowing where the dead are kept ahead of time keeps the machine moving in a positive direction.

## Conclusion

Trauma triage and response are among the most important missions of US medical forces. While each unit will have unique perspectives and experiences, all will benefit from careful consideration of resources, rehearsal, response, routing of casualties, and reset. We have described a system of flexible response that can be scaled to one casualty or to dozens. Recognize the cost of trauma care, and assure rapid refit of your units' capabilities, heart, and soul. You will know the victory and thrill of a job well done, and you will be ready to do it again.

## Civilian Translation of Military Experience and Lessons Learned

Alec C. Beekley

**Key Similarities**

- The five Rs: resources, rehearse, respond, route, and reset are applicable in both civilian and military settings. The key to successful execution during a mass casualty event is advanced planning and rehearsal.
- Triage by highly experienced personnel, utilizing simple, hands-on/bedside techniques, are the best ways for quick and accurate triage in both military and civilian settings.
- Terrorist attacks with explosives or high-velocity weapons (e.g., Boston Marathon bombing, Orlando nightclub shooting) have blurred the lines between civilian and military mass casualty events.

**Key Differences**

- Civilian settings are more likely to have mass casualty events with blunt trauma mechanisms (e.g., train derailments, multiple vehicle pileups, and recently truck attacks into crowded areas).
- Civilian settings can often bring more resources to bear in mass casualty events, both in terms of personnel and hospital systems. Depending on the coordination and prior rehearsal of the locale's medical system, this could be a benefit or a drawback.
- Hospitals in civilian mass casualty events are more likely to be inundated with walking wounded, families and friends searching for loved ones, and nonhospital personnel who are trying to help. The "crowd control" issues in civilian settings may therefore be even more challenging that in military ones.
- The demand from the media for initial information, constant updates, access to involved providers and patients, and comments from hospital leadership will be enormous and overwhelming. Plan for the PR piece well in advance.

The chapter on combat triage and mass casualty management by Dr. Aydelotte and colleagues provides a "top to bottom" primer on mass casualty management that is as relevant to any civilian hospital system as it is to a forward military unit. As we read about mass casualty events around the world (seemingly on a weekly basis), coverage of this topic in such an organized fashion could not be more timely. There are a handful of topics presented which are worth emphasizing, comparing, and contrasting to the civilian experience.

## Security

The sorting and prioritization of casualties begins at the scene, not the hospital. However, the geographical and tactical situation at the scene may dictate which casualties are evaluated and evacuated first, and these are often not the worst injured. Depending on the mechanism of the event, casualties may be trapped in a hard to reach location, stuck in a damaged structure or vehicle, or trapped in a tactical situation where there is still active shooting. The result is a fluid and rapidly changing situation with both "known unknowns" and "unknown unknowns." An example of a "known unknown" is, "we know there are more casualties, we just don't know how many or what their status is yet." An example of an "unknown unknown" would be the presence of a second attacker or secondary explosive device. In their description of the Orlando Regional Medical Center response to the Pulse nightclub shooting, the surgeons describe knowing about additional waves of casualties still coming and then having an alert about an active shooter actually at the hospital (the former which turned out to be true, the latter which turned out to be false). These experiences emphasize the need for both scene and hospital security. Known in combat settings as "the fog of war," these events also illustrate the need for flexibility and ongoing communication. There should be a clear communication plan between EMS, local police and firefighters, incident command, and hospital personnel. The communication plan should have a backup if the first system fails. It should be rehearsed at least yearly.

## Triage Is a Process, Not a Destination or Event

Triage is a process that may (or may not) begin at the scene, potentially allowing distribution of patients to near and far treatment facilities based on acuity. Triage continues en route to treatment facilities, with transporting providers often providing insight into casualties' changing statuses. It occurs on arrival to the hospital and continues in order to prioritize existing and newly arriving patients for evaluation, ORs, and imaging studies. The authors' admonition to put your most experienced and organized provider (usually a surgeon) in the role of triage officer is therefore correct. His clinical skills, while potentially valuable if applied to a single patient in the OR, will provide much more value to the entire process. Most importantly, although we normally worry about under-triage of trauma patients, in a MASCAL scenario, it is over-triage that should be a primary concern (Fig. 2.6). Clogging the trauma bay with minimal or nonurgent injuries means delays for patients with truly urgent/emergent problems.

One of the other most important lessons for surgeons assigned to an individual patient is STAY WITH THAT PATIENT until reassigned to another. There is a tendency for surgeons to "drift" toward gurneys with heavy activity – *don't.* Be sure you have thoroughly assessed your patient, and be prepared to give a report on his status when the triage officer circles around again. If your patient is truly stable, he can be re-triaged to a Delayed or Minimal status, and you can be reassigned where needed.

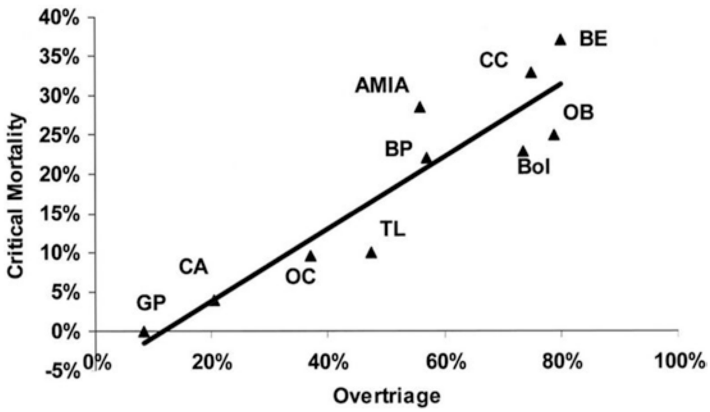



**Fig. 2.6** Graphic relation of over-triage rate to critical mortality rate, in ten terrorist bombing incidents from 1969 to 1995. Note the increases in the over-triage rate has a linear correlation to increased critical mortality (Reproduced from Frykberg ER. Medical management of disasters and mass casualties from terrorist bombings: how can we cope? J Trauma 2002;53(2):201–212; with permission from Wolters Kluwer Health, Inc.)

If you have drifted away to help on another patient, it is possible that (1) you did not completely assess your patient and (2) when the triage officer comes back, you will not be where you are expected to be.

## Rehearse, Rinse, Repeat

One of the first lessons learned described in the after-action review of the Boston Marathon bombing was "resist complacency." The authors of that comprehensive review cite superb city-wide planning and preparedness as key to the success of the response. It is critical that surgeons be engaged in the planning and rehearsal process; this should occur at least yearly. Expect to find issues with your system with each rehearsal, and expect that you still won't identify them all. The military authors of this chapter identified problems from their experiences that mimic issues reported in some of the recent mass casualty events. For example, it is important that your hospital's mass casualty has a plan for the placement and storage of the dead, preferably *away* from where living casualties are being treated. Establish a plan for dealing with the mental and emotional fallout of hospital personnel after the event. Establish a plan for dealing with anxious family and friends looking for their loved ones. Anticipate that something unanticipated will be a problem, and design a mechanism into your plan that can flex in response. Most civilian facilities (from my experience and discussions with colleagues) will NOT have performed realistic and wide-ranging MASCAL drills to test their system and their MASCAL plan. This should become a priority for the civilian trauma community.

## Final Points

Recent mass and multiple casualty events, such as the Boston Marathon bombing, the Orlando Pulse nightclub attack, the coordinated Paris terror attacks in November 2015, the Philadelphia Amtrak train crash in 2016, and the recent truck attacks in Nice, France, Turkey, and Berlin, Germany illustrate the wide variety of mechanisms, both accidental and purposeful, that may cause mass casualties. The only thing that seems certain is there will be more. Trauma care practitioners must lead the way in designing robust, flexible, coordinated responses to these events, both at the hospital and community level. In addition, trauma leaders are key for designing resilience and responsiveness into communities themselves, with efforts like the Hartford Consensus I-IV and Stop the Bleed campaign.

## Suggested Reading

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# 3 Initial Management Priorities: Beyond ABCDE

Daniel Grabo and Alec C. Beekley

**Deployment Experience**

| | |
|---|---|
| *Daniel Grabo* | Chief of Trauma, NATO Role III Multinational Medical Unit, Kandahar Airfield, Afghanistan, 2014 |
| *Alec C. Beekley* | Staff Surgeon, 102nd Forward Surgical Team, Kandahar Airfield, Afghanistan, 2002–2003 |
| | Chief of Surgery, 912th Forward Surgical Team, Al Mussayib, Iraq, 2004 |
| | Staff Surgeon, 31st Combat Support Hospital, Baghdad, Iraq, 2004 |
| | Director, Deployed Combat Casualty Research Team, 28th Combat Support Hospital, Baghdad, Iraq, 2007 |

*"How varied was our experience of the battlefield and how fertile the blood of warriors in rearing good surgeons."*

Thomas Clifford Allbutt

D. Grabo (✉)
Navy Trauma Training Center, LAC+USC Medical Center, Keck School of Medicine of USC, Department of Surgery, Los Angeles, CA, USA
e-mail: daniel.grabo@usc.edu

A.C. Beekley
Thomas Jefferson University Hospitals, Paoli Hospital, The Lankenau Hospital, Division of Acute Care Surgery, Division of Bariatric Surgery, Philadelphia, PA, USA


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**BLUF Box (Bottom Line Up Front)**

1. Prepare for combat trauma surgery by reading, review of case scenarios, familiarization with JTS Clinical Practice Guidelines and visualization.
2. Focus on one patient at a time. During multiple casualty events, stay with the casualty to whom you are assigned.
3. In combat trauma C comes before A and B. Assess for and control hemorrhage immediately; it is what will kill most of your patients.
4. Identify early on the patients who will require massive blood transfusion and would benefit from damage control resuscitation and surgery.
5. Assessment of A and B should be rapid in combat casualties; it is generally an "all or nothing" phenomenon such as cricothyroidotomy or tension pneumothorax. Intubation can often wait until you get to the OR.
6. Check tourniquets for adequacy and tighten or augment with pneumatic tourniquets, particularly for proximal amputations.
7. Perform a FAST exam early. Obvious abdominal injury in unstable patients should prompt abandonment of the FAST and rapid movement to the OR.
8. Portable chest and pelvis x-rays can be taken in the trauma bay and reviewed in the OR – they may provide valuable data.
9. Get help in the OR, particularly for multisystem combat casualties. Do your damage control procedures in tandem, not in series.
10. Intraoperative findings should match patient physiology – if they don't, you need to conclude the operation you are doing and look for the real hemorrhage sources.

Multiple casualties have arrived. You can hear more Blackhawks landing on the helipad outside. The first casualty has rolled into the next trauma bed after being assigned to your colleague by the triage officer. You notice the exposed brain bulging from a jagged hole in the frontal bone. Omentum hangs from wound on his left flank. The left lower extremity is missing from about mid-thigh – two tourniquets are in place side by side. The area around the litter is a bustle of activity.

The next casualty is brought into you. You have an initial wave of anxiety. You haven't been here long. Aside from an obvious open tibia/fibula fracture in his right leg, he is talking, telling you he is okay and to help his buddies first. Your cursory primary survey appears negative – airway intact, breath sounds clear, and palpable radial pulse. You begin to drift over to the first casualty. He is clearly going to need a lot of operations and your colleague is hard at work.

The scenario just described can happen any day at any surgical unit in Afghanistan, Iraq, or any other modern conflict. You may find yourself as the only surgeon or only one of two surgeons available to handle multiple severely injured casualties at once. Hence, any discussion on "initial management priorities" must take into account that these priorities may change based on the ratio of severely injured casualties to surgeons. One day, a casualty with a brain injury may get full resuscitative efforts; the next day, the same casualty may be made expectant due to the nature of the other casualties and the resources available. Triage and initial management priorities are not set in stone, but are dynamic processes that always take the local conditions and capabilities into account.

The process is triage, a simple sorting and prioritization that occurs with multiple casualties. This topic will be discussed further in another chapter. The process by which the surgeon approaches the individual multiply injured combat casualty, however, should also be thought of as a sorting and prioritization exercise. Every move you make, particularly in the first few minutes of the trauma evaluation, should be prioritized toward identifying life-threatening injuries and bleeding, followed by likely injuries that require immediate intervention, and lastly a detailed survey to identify occult or lower priority injuries. Even if the patient is "stable," proceed like he could become rapidly unstable in the next minute. You don't want to be shooting a femur x-ray when the patient becomes unstable and you realize you haven't done a FAST exam or a chest x-ray yet. Like all operations surgeons perform, this exercise can be simplified by breaking it down into a series of steps.

The first step, and perhaps the most important one, is *focus* on your patient. One of my most senior surgeon mentors and friends used to say that the surgeon must develop the ability to block out distractions, both internal and external. The surgeon's pounding heart, sweaty hands, and self-doubt are internal distractions. Each surgeon must figure out on his own how best to minimize and overcome the stress of caring for severely injured brothers and sisters in arms. Some surgeons do not suffer much from doubts ("often wrong, never in doubt"), but many of us do (if we are honest with ourselves). Some surgeons choose to mentally prepare by reading textbooks and others by presenting hypothetical surgical challenges and figuring out what to do with them. Choose a method and *prepare* ahead of time. Regardless of your background, prior deployments (or lack thereof), and civilian trauma experience (or lack thereof), you *will* be challenged by combat casualties. Mental preparation, study, and visualization can lessen the stress the first time. And *always* ask for help when needed – trauma is a team sport in the combat or disaster setting.

The casualty with exposed brain, evisceration, and a missing limb on the next litter is an external distraction. External distractions must be minimized in order for you to serve your patient best. The key point for surgeons new to the combat environment to learn is to *STAY WITH YOUR PATIENT*, particularly during multiple casualty events (which happen frequently). Focus on one patient at a time. The surgeon in the scenario at the beginning of the chapter is at risk for drifting away from his assigned casualty and missing important findings. If you are needed elsewhere, the triage officer will reassign you if your patient is truly stable. In the meantime, attend to your patient until you are confident that your work-up is complete or you have appropriately handed the casualty off to another provider.

## Initial Management Priorities

### Sick or Not Sick?

When the surgeon approaches a combat casualty for his initial evaluation, his first determination should be binary: Is this patient sick or not sick? In other words, is this patient at risk for dying? This should always be the surgeon's first assessment, regardless if the patient was triaged into a delayed or minimal status. This determination can be the one that leads the surgeon down the path to success – or to failure if this determination is wrong. Simple techniques are right most of the time. They require hands-on engagement with the patient. Talk to him: "How are you doing, bud? What happened to you? Can you hold up 2 fingers?" While you are asking these questions, feel for the casualty's radial pulse. A casualty who answers you, can hold up two fingers (GCS motor score of 6), and has an easily palpable radial pulse is usually not too sick.

Casualties that are initially deemed "not sick" can usually have a relatively thorough and detailed assessment, including CT scans and plain films for suspected injuries, or even be delayed in their management as the surgeon addresses the "sick" patient. Casualties that fail any of these initial assessments should immediately raise your level of concern and focus. They should be considered unstable and seriously injured until proven otherwise. Patients who fall into this category (unstable or "sick") should prompt the surgeon to perform a rapid search to find the source of their illness and think about moving them expeditiously to the OR.

## Identifying Triggers for Massive Blood Transfusion and Damage Control

Once the surgeon has deemed the casualty "sick" or unstable, he should consider early on if the casualty will likely require massive blood transfusion (>10 units PRBCs in 24 h) and likewise meets the criteria for damage control resuscitation and surgery. When initially presenting to the trauma bay, these patients are usually significantly injured and typically have these presenting physiologic parameters:

1. SBP < 110 mmHg
2. HR > 105 bpm
3. Hematocrit <32%
4. pH < 7.25

Patients with three of four above presenting factors have 70% predicted risk of massive transfusion; all four factors have 85% predicted risk. Additional risk factors for massive transfusion include: INR > 1.4 and St02 < 75%. Even in a combat theater hospital, there is increasing use of rotational thromboelastography (ROTEM). Although feasible in a combat environment, ROTEM should be used primarily in the fine tuning of management of coagulopathy in a combat casualty.

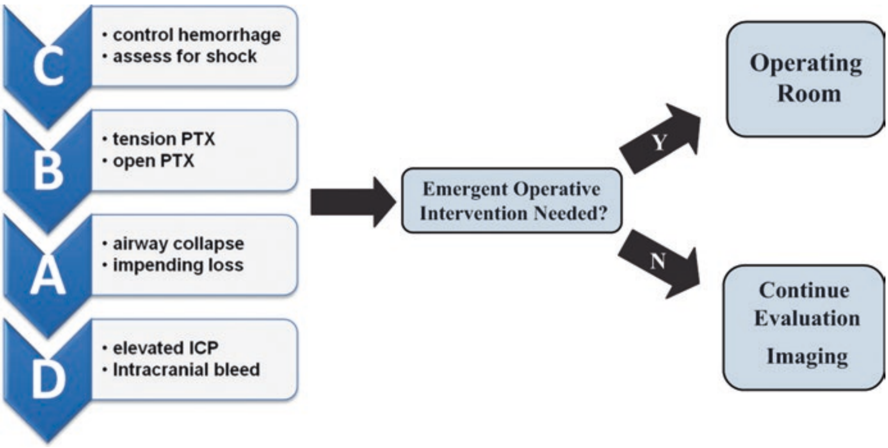



**Fig. 3.1** Algorithm for initial management and prioritization in combat trauma

When confronted with the individual patient whom the combat surgeon determines damage control as the plan of action, the priorities shift to the following:

1. Rapid hemorrhage assessment and control
2. Minimal use of adjunctive tests such as radiographs and FAST only to help delineate sources of hemorrhage and recognize injury complex
3. Controlled resuscitation: minimal crystalloids and preferred use of blood products in the proper ratios
4. Rapid assessment and correction of airway and breathing problems
5. Focused disability assessment and neurologic intervention
6. Control for hypothermia
7. Effective communication of the plan and early decision-making

## Hemorrhage Control Über Alles

Although the A of the Advanced Trauma Life Support ABCDE algorithm stands for "airway," in the combat casualty the airway is rarely the source of threat to life. This is particularly true if they have survived the evacuation process to reach you with an intact airway. When there is a significant airway issue, it is usually quite obvious and will be apparent that this has to be dealt with first. The biggest threat to a combat casualty's life is usually from hemorrhage, so in combat trauma the C should come first. Hence, the initial evaluation in the unstable casualty, while still involving a primary survey, must rapidly move to finding and treating the hemorrhage sources. These include external hemorrhage sources and intracavitary hemorrhage: into the chest, into the abdomen, and into the pelvis. In the end, these sources can all be found fairly quickly, usually in a matter of minutes with a focused physical exam augmented with basic and rapid imaging or interventions as needed. Figure 3.1 outlines the basic initial management algorithm and targeted priorities in the combat casualty.

One advantage of combat trauma is 95% of the mechanisms are penetrating. Casualties have holes in them. Their injuries are frequently obvious and often dramatic. Hence, unstable casualties with limbs missing, blood draining, abdominal evisceration, or large holes in the chest should pretty much go to one place – the OR. These obvious injuries should prompt the surgeon to establish intravenous lines, begin resuscitation, and activate the OR, but should not keep him from fully evaluating the casualty. Combat casualties may also suffer blunt or blast mechanisms (which may not create holes in the body), or they may have holes from head to toe. So, after a RAPID primary survey, at a minimum, these casualties should have the following:

1. *Inspection* of the entire body surface: Casualties must be exposed and their body surfaces examined. The critical part of this is the logroll. This step is easily overlooked, which can have grave consequences for the patient. A casualty may present with a normal-looking anterior and have a devastated posterior, the extent of which is only known once he is rolled. These wounds are seen with increasing frequency due to explosions going off under vehicles or behind foot patrols. Profoundly hypotensive patients may have stopped bleeding from posterior wounds, which can then re-bleed under the surgical drapes once the patient gets some resuscitation. Knowledge of these posterior wounds can be critical for the operating surgeon. For example, findings on abdominal exploration that are not compatible with the casualty's level of shock should prompt the surgeon to reexamine the posterior wounds. Additional attention should be paid to the axillae, groins, and perineum, so as not to miss a penetrating bullet or fragment wound.
2. *Tourniquets*, both limb and junctional, may have been applied after the patient had already become hypotensive. Less force than normal may have been required to stop hemorrhage, or if the hemorrhage had stopped spontaneously, the medic would have no cues to tell him how tight to make the tourniquet. Resuscitation may precipitate re-bleeding, so all tourniquets should be checked and consideration given to supplementing them with pneumatic tourniquets. Assurance of tourniquet adequacy should be done early – it will allow you to focus on finding and treating other non-compressible sources of hemorrhage.
3. *FAST* exam: This study can also be done almost immediately on casualty arrival and allows assessment of the abdominal, pericardial, and with proper training, the thoracic cavity. Usually, the FAST can be done directly after a quick evaluation of the airway and auscultation of the chest. Unstable casualties with positive findings on FAST exam need rapid transfer to the OR. For equivocal FAST images, a diagnostic peritoneal aspiration (DPA) with a 20-gauge needle can be performed in unstable patients if the source of hemorrhage is not yet clear. DPA can help rule out major hemorrhage into the abdomen.
4. *Portable chest x-ray*: This study can be done within minutes of arrival and the digital image viewed immediately. With auscultation of the chest cavity, life-threatening tension pneumothorax or massive hemothorax is easily ruled out. Add the evaluation of the chest by portable chest x-ray, and potentially

life-threatening problems like simple pneumothorax and hemothorax are identified. If your unstable patient has a clear chest x-ray – they are NOT dying from intrathoracic hemorrhage. Look elsewhere.

5. *Portable pelvic x-ray*: The portable pelvis film can usually be taken at the same time as the portable chest x-ray, but is of lower priority. It can provide valuable data about the status of the bony pelvis and sometimes about the location of projectiles. Performance of these films can occur without significantly interrupting other assessments and therapies, such as FAST exam and placement of central lines. However, pelvic fractures severe enough to cause instability from hemorrhage are usually obvious on physical exam, and you do not need to wait for your x-ray to begin intervention.
6. *Extremities* can be assessed quickly for long bone deformities. The only location in the extremities for substantial hidden blood loss is in the thighs. Obvious amputations, mangled extremities, active bleeding extremities, and expanding hematomas should prompt direct pressure and/or tourniquet placement if not already done.
7. *Controlled resuscitation* begins with establishment of large-bore intravenous access, and two large (14–16 gauge) antecubital lines will suffice to start. Usually, surgeons can rapidly place an internal jugular, subclavian, or femoral line 8.5 French short introducer catheter for rapid infusion of fluids and products. Remember that unlike civilian trauma, combat surgeons are often dealing with patients with three or even four severely injured limbs. Do not waste time trying to establish a peripheral IV in these cases. Instead, get a reliable large-bore central venous catheter in place as soon as possible. Emergency release blood products (Type O PRBC and Type AB or A thawed plasma) should be given in favor of crystalloid to unstable patients with obvious injuries. Early identification of the patient requiring massive blood transfusion should be paramount, and blood resuscitation (type specific) should then be given in a 1:1:1 ratio (PRBC/plasma/platelets) as early as possible. The use of tranexamic acid (1000 mg over 10 min followed by 1000 mg infusion over 8 h) should be considered early and within 3 h from injury for all combat trauma patients requiring massive blood transfusion. The addition of cryoprecipitate, ROTEM-guided therapy, and the use of recombinant factor VIIa are additional considerations for the massive transfusion or coagulopathic trauma patients that are more likely to occur in the operating room or ICU setting.

## Airway and Breathing

Relative adherence to the ATLS algorithm is certainly not discouraged. As a framework for evaluating trauma patients, it is validated and thorough. The reality of combat, however, dictates that casualties who lose airways from gunshot wounds or fragments from explosions rarely make it to surgical care alive. Many casualties with head injuries will get endotracheal intubation or cricothyroidotomy in the field and will arrive to the surgeon with an airway in place. Casualties that do arrive with impending airway loss from a penetrating neck injury are usually quite dramatic, and it becomes rapidly obvious that airway control needs to be attained.

Hence, for the vast majority of combat casualties, the airway is an all or nothing phenomenon. The casualties with "nothing" are usually beyond help by the time they reach the hospital; casualties with impending airway loss are usually quite obvious, and either endotracheal intubation or cricothyroidotomy can be rapidly performed; and casualties with an intact airway do not need any emergent airway intervention. In fact, rapid sequence intubation in the unstable combat casualty who otherwise has an intact airway may precipitate loss of abdominal muscle tone, loss of tamponade effects on abdominal hemorrhage, and cardiovascular collapse. The urge to intubate patients for no other reason than they are going to the OR soon anyway should be resisted. Give them muscle relaxants and vasodilatory drugs in a location where you can operate rapidly if need be. Avoid turning a non-issue into a life-threatening distraction from the casualty's real problem.

So, that begs the question: Who *should* have airway control established? There are a few special situations that should be discussed. The first is the patient who sustained severe mandible or maxillo-facial trauma. These casualties, when awake, may present in seated or leaning positions and may be maintaining their own airway by allowing injured tissues to be pulled away from the airway by gravity. For the short term, let them. Attempts to sedate them or lay them supine may be met with aspiration of blood and/or rapid loss of the airway. These casualties can usually have an awake, well-controlled nasotracheal intubation or a surgical airway done under local. On worst-case scenario, you have all the instrumentation and support you need to perform a rapid surgical airway if endotracheal intubation cannot be gained.

The second special situation to get early airway control is the casualty with suspected inhalation injury. Incendiary and chlorine-containing bombs have been used in the current wars, and casualties can be trapped in burning vehicles or buildings. These casualties may have facial burns, singed facial hair, soot in their throat and nares, and an unexplained tachycardia. They may have rapid deterioration over the first 12 h after injury due to airway swelling and edema or lung injury. Based on the patient history and these physical findings, surgeons should have a low threshold to electively intubate these casualties and perform an immediate bronchoscopic examination to assess the presence and degree of injury to the trachea and distal airways. This will greatly assist in determining treatment as well as the timing of future extubation.

Finally, the head-injured patient with deteriorating mental status or presenting GCS <10 and patients with direct but nonobstructing penetrating airway injury should be considered for establishment of early airway control, as they are at risk of sudden airway loss or aspiration, as well as hypoxic episodes which should be avoided at all costs in the head-injured casualty. Secure the airway as soon as possible, but again the principle applies that if they need to go immediately to the OR and their current airway is intact, put them on oxygen and secure the airway in the OR.

A final note on airway management: You will benefit more patients by becoming adept at performing adequate bag-valve-mask (BVM) ventilation than you will by performing emergent surgical airways. This maneuver is woefully underutilized in the initial trauma setting, and you will often observe the assigned "airway" personnel focused on preparing intubation drugs and equipment while no one is performing simple BVM ventilation. You should be able to indefinitely temporize most inadequate airway and breathing situations with good BVM technique, turning a panicked emergency procedure into a calm and controlled maneuver. The only real exception to this is the true mechanical airway obstruction, usually due to foreign body or severe facial fractures. The key technical aspect is to always lift the patient's face into the mask rather than push the mask into the face. Hook your fingers under the mandible of the jaw and lift anteriorly, sealing the mask around the mouth and nose. This is preferably done with both hands (two-person BVM), and then deliver adequate breaths with high-flow oxygen. You should immediately see improved oxygen saturation and auscultate adequate breath sounds.

## Tension Pneumothorax

Unfortunately, soldiers are still dying in the field or in the emergency department from untreated tension pneumothorax. It is critical that surgeons rule out this entity early in the work-up of the combat casualty. There is little downside to empiric placement of bilateral decompression needle thoracenteses or chest tubes in the dying patient. Surgeons must also remember to assess, by auscultation, the chest cavity. Remember, most of the wounds are from penetrating mechanisms, so there will often be holes in the chest – but casualties can get in motor vehicle crashes or falls after the initial penetrating mechanism or suffer primary blast injury and barotrauma. Learn how to do the rapid ultrasound scan for pneumothorax (see Chap. 6) – it is reliable and faster than x-ray.

## Open Pneumothorax

Open pneumothorax or the "sucking chest wound" can easily frustrate surgeons on their first deployment. It is, quite simply, seldom seen in civilian trauma. It is usually not much of a diagnostic challenge. There will be a big hole in the chest with audible air movement and/or gurgling from the wound. Patients can present in a well-compensated state, in which case their problem is primarily to irrigate the wounds and figure out how to establish surgical chest wall coverage or reconstruction. Keep in mind that patients with open pneumothorax usually have something big tumble through their chest cavity, and massive intrathoracic injuries may make these patients present in extremis. Patients can also present with impending asphyxia from the open pneumothorax physiology. Simply occluding the hole may not rescue these patients – they usually require establishment of an airway and positive-pressure ventilation, as well as immediate chest tube placement. This topic is covered in more detail in Chap. 18.

## Flail Chest

Massive blast and blunt chest injury can result in multiple rib fractures leading to the "flail" segment. Along with underlying pulmonary contusion and hemopneumothorax, ineffective respiration develops and leads to hypoxia and hypercapnia. While in the civilian setting there is a trend toward avoidance of endotracheal intubation, optimization of pain control techniques, and minimal use of chest drains, this approach is of little use in the combat casualty who will be traveling between the echelons of care often via fixed-winged aircraft at altitude and where resources and personnel for close observation are minimal. Thus, conservative management of endotracheal intubation and ventilator support and chest drains for hemopneumothorax along with minimal fluids are paramount.

## Focused Disability Assessment and Neurologic Intervention

A rapid neurologic assessment must be done on all combat casualties. This should take no more than a moment to calculate a Glasgow Coma Score and perform a basic pupillary exam. A detailed neurologic exam, however, is important in the suspected spinal cord-injured patient. When concerned for traumatic brain injury, attention must be paid to the prevention of secondary brain injury by ensuring adequate blood pressure (SBP > 90 mm Hg) and oxygenation/ventilation ($SpO_2 > 93\%$ and $PaCO_2$ 35–40 mm Hg). If there is evidence of acute clinical deterioration or increased intracranial pressure with evidence of herniation, such as Cushing's reflex (hypertension and bradycardia), unilaterally dilating pupil progressing to fixed and dilated, coma, lateralizing weakness, or decerebrate rigidity, consider the early use of osmotherapy (100–250 mL bolus of 3% HTS or 1 g/kg of mannitol depending on presenting vital signs). Hyperventilation to $PaCO_2$ 30–35 mmHg can also be used as a temporizing measure until definitive treatment can be initiated. If there is evidence of spinal cord injury, maintain strict spinal precautions including cervical collar and backboard. Ensure adequate spinal cord perfusion by first treating sources of hemorrhage and volume loss. Remember, vasopressors come later after the tank is filled. There is no role for steroids in either traumatic brain injury or spinal cord injury with neurologic deficit.

## Control for Hypothermia

Not enough can be said or written as to the importance as to early intervention to prevent hypothermia. Medics and corpsmen go to great lengths to ensure that their casualty arrives at the MTF with warming measures already in place. Simply applying warm blankets and warming the ambient temperature in the trauma room are an important start. Core warming techniques, such as using blood and fluid warmers and warming the ventilator circuit, are probably more effective at actually increasing the combat casualty's core temperature.

## Effective Communication and Early Decision-Making

The combat surgeon must make quick decisions, often with incomplete information. CT scans are not always available depending on the medical treatment facility, and, moreover, the patient's condition often prohibits the use of advanced imaging. Decisions must be made quickly and explained clearly. Roles must be assigned and the planned time frame of events must be communicated with consideration to providing optimal care given the circumstances as well as being prepared for impending new casualties that will be arriving. It is not uncommon to have to assign physicians, nurses, and medics to operate outside of their usual roles and comfort levels. For example, an internist might need to evaluate and treat a trauma patient in the emergency department. The orthopod might be assisting during a damage control laparotomy. Flexibility is required not only in the members of the team but also in the leader. Moreover, the combat surgeon must provide clear assignments and expectations as well as directions to the team. In multiple casualty incidents, rely on other members of the team, either physicians, nurses, or designated triage officer, who can help with patient flow in ensuring that the casualties who are delayed either go to radiology for advanced imaging such as CT scan or board in the ICU or ward pending the operating room. Again, clear expectations and "what to watch for and what to do" orders will be very helpful in multi-casualty incidents. It is also imperative to disseminate early on to the leadership and those in patient movement the plan to decompress the facility or "get patients out." This starts the process early of communication and planning with the higher echelons of care and patient movement elements.

## Massive Extremity Injuries

No matter what your specialty, the most common scenario you will encounter in combat trauma is the patient with a severely injured, mangled, or amputated extremity. You may not have an orthopedic surgeon immediately available during your initial evaluation, so you must understand the basics of the early evaluation and management. Unlike most civilian trauma, the injured extremity is often the source of life-threatening hemorrhage in these patients and should be immediately controlled as described above. Remember that the casualty with multiple traumatic amputations will often be severely volume depleted and struggling to compensate. Endotracheal intubation and induction can severely depress cardiac preload, and cardiac arrest can ensue. It is wise to support airway and ventilation as a few units of PRBCs are rapidly infused before induction of anesthesia or sedating and paralyzing agents are administered. It is also usually obvious that these wounds will require emergent management in the operating room, and there is very little that you absolutely have to do with them in the emergency department. Perform a basic assessment of the sensation and motor function of the extremity. Vascular status should also be assessed but may be compromised if there is a proximal tourniquet. Do not take the tourniquet down unless you are immediately prepared and able to reestablish complete proximal control. If you have time, obtain an AP and lateral x-ray which will help delineate bony injury as well as identify the presence and degree of foreign body contamination. *Do not delay movement to the OR for extensive extremity x-rays*; most of these injuries do not require an x-ray for the initial operative management or they can be assessed with C-arm in the operating room. Irrigate the wounds with betadine, wrap them, and splint the extremity to help minimize additional motion injury and pain. Administer antibiotics as soon as possible with both gram-positive and gram-negative coverage.

## Unexploded Ordinance

Your next patient arrives, another extremity wound with a big piece of metal embedded in the soft tissue. *No big deal – until you realize that it is actually an unexploded rocket-propelled grenade* (Fig. 3.2). It doesn't matter how good your residency or fellowship training was; this will be something you have not seen before or been prepared to manage. Check your pulse, take a deep breath, and then take care of your patient. Your efforts now should focus on (1) protecting yourself and your unit, (2) avoiding inadvertent detonation, and (3) removing and disposal of the ordinance. Immediately isolate this casualty, preferably by moving other patients out of the area. Notify your local explosives and ordinance personnel who may be invaluable in providing assistance and expertise about this particular explosive. If this occurs in a MASCAL situation, then this patient should be moved down on the priority list until you have taken care of the other urgent patients. You can safely x-ray the involved area if necessary, *but do not use ultrasound*! Turn off any cell phones or similar devices in the immediate area. Now prepare your team and OR for removal.

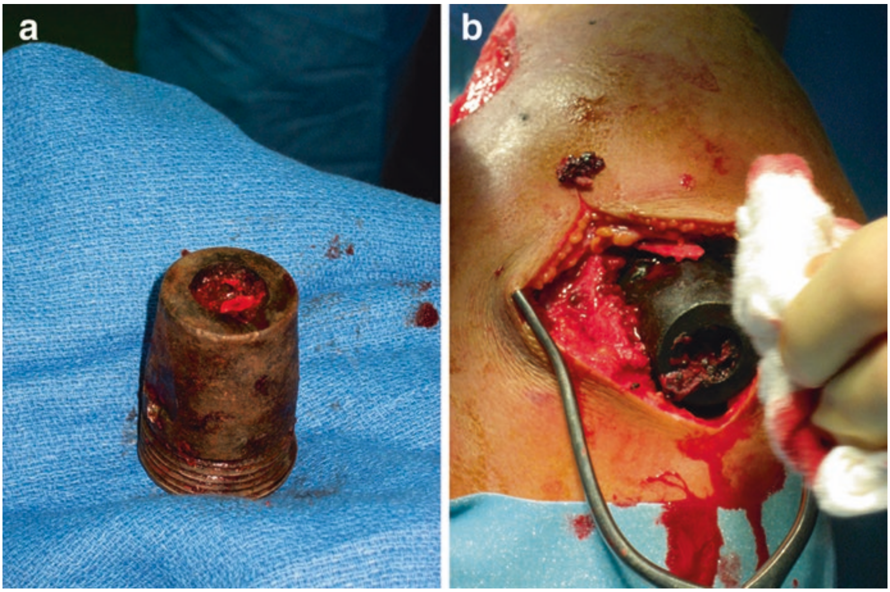



**Fig. 3.2** Unexploded rocket-propelled grenade (**a**) removed from a soft tissue wound (**b**) by a surgeon with a Forward Surgical Team in Afghanistan

Minimize the personnel involved in the procedure to only those absolutely necessary. All should be wearing full body armor and ballistic goggles. Create a hasty protective barrier (sandbags) around the patient, at least up to waist height. Ensure full chemical paralysis before starting. Do not use any electrocautery devices, and never use a defibrillator until the device is removed. Manual retraction and manipulation should be used as much as possible to avoid touching the device with any metallic instruments. A self-retaining retractor may be used if necessary but avoid any contact with the explosive. Gently encircle the device and remove it from the wound, handing it off to the ordinance personnel for disposal. Now you can control bleeding and proceed as with any other patient.

## Casualty Prioritization and Patient Flow

When faced with multiple casualties, it is imperative to understand the following:

1. Casualty triage: Who requires immediate surgical intervention versus who can be delayed?
2. OPTEMPO: Is the mission from which the casualties are arriving complete or will there be more? Are there parallel missions from which there can be potentially more casualties?
3. Resources: Personnel? Beds? Blood? Walking blood bank?
4. Exit strategy: How and when to decompress these patients? Enact this plan early.

An understanding of all of the above will help the combat surgeon mobilize resources (personnel, beds, blood) to care for current patients. In addition, he will be able to address patient flow through the emergency department, radiology (if available for CT scan or advanced imaging if stable) and to holding (ICU or ward) pending surgery. Moreover, he will be prepared to decompress the facility from the current surge of patients and prepare for the next wave or mass casualty incident. For example, are the current patients ready and able to move to the next level of care (role 2 to role 3 or role 3 out of theater via CCATT to role 4)? Additionally, for local nationals, are they able to move to a civilian medical facility?

## Operating Room Priorities

Obviously, a complete discussion of what may be necessary in the OR would extend far beyond the confines of this chapter and this book. Nevertheless, several simple strategies can help you prioritize the hemorrhage sources in the multisystem casualty.

1. Get help. Get another surgeon or six more. Get as many as you need to have one or even two surgeons addressing each hemorrhage source. We would routinely have two surgeons working on the abdomen, two surgeons on each lower extremity, and a surgeon working on a casualty's face. Combat trauma surgery is a team sport. The old adage, "You can call for help, but it's a sign of weakness," should

be thrown out and replaced with "If you don't call for help, you are doing your patient a disservice."

2. On occasion, multiple extra surgeons won't be available. Have a methodical plan to address each hemorrhage source. Tourniquets can usually keep extremity hemorrhage controlled while you look elsewhere. The abdomen is often the best place to start if signs point to an injury there. Exploration can rapidly tell you if the abdomen is the source of instability. If the abdomen is not full of blood and there is not a massive hematoma in the pelvis, time-consuming exploration of every small, non-expanding retroperitoneal hematoma or even control of bowel contamination can be delayed for several minutes while you look elsewhere for the source of hemorrhage in the unstable patient. Prep and drape all significant injuries, including extremities, into the surgical field. This will avoid the "bleeding under the drapes" phenomenon which has fooled many surgeons before you.
3. Patients that have had chest tubes placed have a readily available way to see if they have ongoing bleeding in the chest. While clotting of chest tubes can occur, it is relatively rare; and if in doubt, a second chest tube can be placed. Inspection of the diaphragms during laparotomy can help you identify tension pneumothorax or expanding hemothorax.
4. That leaves two areas – the patient's extremities and posterior wounds. Extremity hemorrhage, unless not controlled with tourniquets or clamps, will usually respond rapidly to resuscitation. The other hidden hemorrhage source in combat casualties is from posterior injuries – gluteal vessels, popliteal vessels, scalp, and posterior holes in the chest that allow drainage of thoracic blood. This fact highlights the importance of the complete inspection of a casualty's body in the trauma bay. These posterior wounds may be non-bleeding at the time of patient arrival, particularly in patients in shock – as resuscitation commences, these areas may begin to re-bleed. Hence, if minimal intra-abdominal or thoracic findings do not match a patient's deteriorating physiology, the operations should be halted and an additional search for hemorrhage begun (which may involve tearing down sterile drapes and rolling the patient again).
5. Always start with damage control measures as the default – non-definitive control of contamination, temporary closure of the abdomen, shunts in major arterial and venous injuries – and then make the patient prove that you don't need to use damage control measures. Remember, damage control may be necessary not because of the patient's physiology but because other casualties may need the OR table.

## The "Bloody Vicious Cycle"

One of the most important concepts in trauma is the "bloody vicious cycle" or "the lethal triad" of hemorrhage, acidosis, and coagulopathy. If your patient has any or all elements of this lethal triad, you should focus on addressing the root causes and halting the progression to irreversible shock. Simply attempting to directly correct these three factors will waste time and resources and may actually worsen the outcome. You can warm your patient all you want – if you haven't controlled bleeding or spillage, then it doesn't matter what temperature they die at. In fact, it may

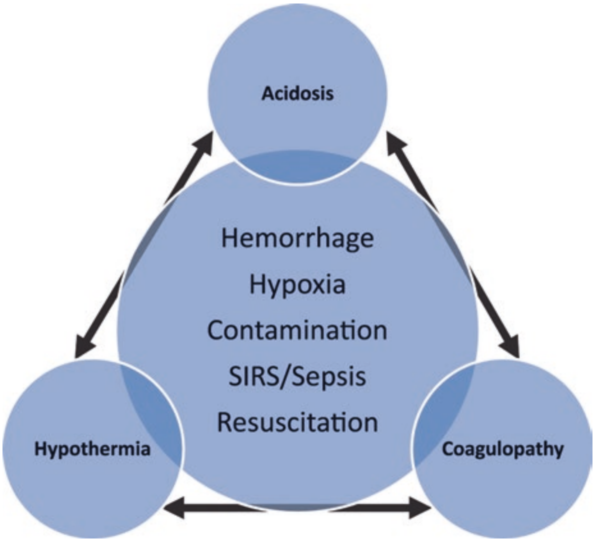



**Fig. 3.3** The "bloody vicious cycle" or "lethal triad." Treatment of the trauma patient should focus on the core causes of acidosis, coagulopathy, and hypothermia shown in the center circle

actually hasten their death. Push amp after amp of bicarbonate and you may make the pH look better, but you aren't treating the real problem or doing the patient any good. Figure 3.3 shows the elements of the lethal triad as peripheral factors which are driven by several core processes in the trauma patient. Address the core factors, and trend the changes in pH, temperature, and coagulopathy to tell you whether you are winning or losing the battle. Focusing your efforts on addressing these core factors is the only way you will defeat the "bloody vicious cycle."

## The Multisystem Combat Casualty: Putting It All Together

You may have noticed that obtaining a CT scan was not listed above in the initial management priorities. The reason for that, quite simply, is that the astute general surgeon can learn what he needs to know about an unstable casualty to make the decision to go to the OR from straight-forward bedside tests. The unstable patient with a head injury is best served by getting the source of his instability treated. That source is usually NOT his head injury. On occasion, this may result in the surgeon taking a patient to the OR for laparotomy only to find that the patient had an unsurvivable brain injury on post-laparotomy CT scan. THIS SHOULD NOT BE CONSIDERED A FAILURE. It was the correct decision based on the data available to the surgeon. A failure would be to take an unstable patient to the CT scanner for head CT scan under the mistaken belief that the patient had an unsurvivable brain injury, only to find that they did not. Surgeons must be prepared to make decisions based on incomplete data. This is triage applied to the individual patient – the sorting and prioritization of injuries to bring maximum resources to bear.

This algorithm of priorities for the surgeon evaluating the multisystem combat trauma patient is summarized below:

1. Focus on the patient in front of you.
2. Determine if they are “sick” or “not sick.”
3. If sick, look for massive transfusion triggers, and start early damage control resuscitation, minimal crystalloids, and blood products in 1:1:1 ratio.
4. Rapidly assess for and control hemorrhage.
5. Establish more definitive control of pneumothorax (chest tube).
6. Identify and treat airway problems.
7. In the OR, stick to damage control measures as the default. Make sure operative findings match the patient’s physiology – if injuries are minimal but the patient is still sick, you haven’t found and treated all the hemorrhage sources yet.
8. Only after all of the above have been treated and the patient deemed stable, elective CT scans and plain x-rays based on physical exam findings may be obtained to rule out non-life threatening injuries.

## Civilian Translation of Military Experience and Lessons Learned

Daniel Grabo

**Key Similarities**

- Principles of early and accurate assessment and treatment of immediately life-threatening injuries are paramount to success in both civilian and military settings.
- Key decision-making in both civilian and military settings involves distinguishing between patients “sick” and “not sick”; moving rapidly to a setting where life-threatening hemorrhage can be identified and controlled; and deciding early to institute damage control resuscitation principles.

**Key Differences**

- Civilian settings have more resources, which can either serve to enhance care or be detrimental if it causes providers to lose focus on the patient in front of them, confuse communication, or fail to focus on treating immediately life-threatening injuries.
- Civilian settings are less likely to have multiple casualty situations, although the increase in mass shooting events makes the ability to manage this important in both settings.

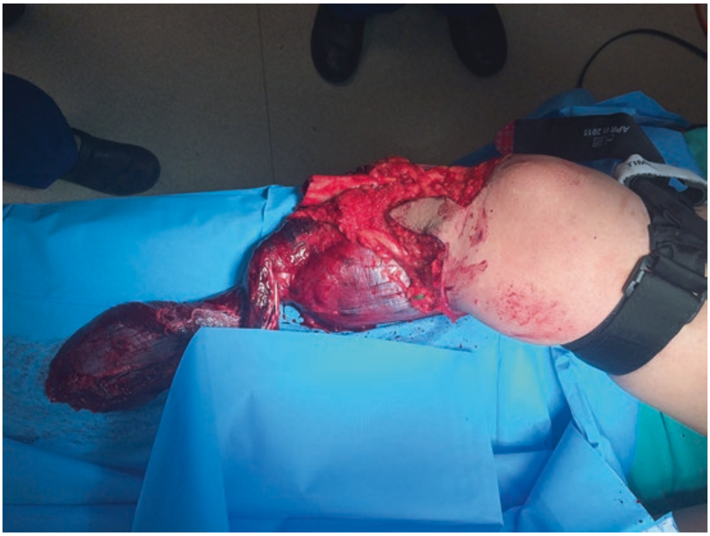


**Fig. 3.4** Civilian trauma patient with traumatic amputation after motor vehicle collision presents to an urban level 1 trauma center with tourniquet in place on her lower extremity for hemorrhage control after traumatic amputation much like an injury seen in battlefield trauma

The initial resuscitation phase of trauma care can be a very tense and overwhelming process. Surgeons in urban trauma centers often care for multiple patients injured by penetrating mechanisms on a daily basis. High-speed motor vehicle crashes and industrial accidents can leave patients with complex extremity wounds similar to those seen by combat surgeons, as seen in Fig. 3.4. At the disposal of the civilian trauma surgeon is a vast array of diagnostic tools including advanced imaging in the form of CT scans and MRI as well as ultrasound often performed by an experienced user. Additional diagnostic resources include all laboratory tests, including point of care and ROTEM, as well as well-trained physicians and nurses to provide continuous monitoring and examinations often with high-level devices. Moreover, resources such as surgical instruments and supplies, blood products and medication, as well as patient beds are in good supply. Personnel are often readily available and at the very least “on call” and able to come in to help.

With all these resources, the principles laid out in this chapter will serve well not only the battlefield surgeon in a role 2 in Afghanistan but also in a highly functioning level 1 urban trauma center in the United States or any other developed country, especially when faced with a seriously injured patient or multiple casualties. First and foremost, focus on the patient in front of you, and if you find yourself are leading a team caring for multiple casualties, ensure that you have appointed someone to be your “eyes and ears” leading the evaluation of each injured patient. Determine who is sick and not sick and triage or make decisions accordingly. Just as in a combat hospital setting, those who are sick ought to be dealt with first in the OR. Those who are not sick can often “board” in the ED or ICU pending OR or surgeon availability. These are also the patients who might be safely sent for advance imaging in the form of CT scan.

The initial assessment phase in the sick trauma patient whether in Kandahar or Los Angeles needs to be rapid and complete focusing on life-threatening injuries and issues. Hemorrhage investigation and control no matter where you are is paramount with keen clinical assessment, FAST, chest and pelvis x-ray, and tourniquets and binders where appropriate. Resuscitation must be started early preferably with blood products in 1:1:1 ratios, and when need for massive transfusion is expected, don't hesitate to use TXA early. Despite all the tools for evaluation and treatment of airway and breathing maladies that we may encounter in the civilian trauma bay, the plan put forth in this chapter is quite relevant as airway and breathing evaluation should be quick yet comprehensive with rapid definitive management. Loss of airway requires endotracheal intubation or cricothyroidotomy. Significant hemo- or pneumothorax requires chest tube drainage. These evaluations and procedures should not be prioritized ahead of hemorrhage assessment and control and must not be delayed for advanced imaging or procedures. Simple clinical exam, chest x-ray, FAST, and intervention ought to occur in rapid succession in the sick patient with attention to clean/sterile technique and pain control and sedation where appropriate.

Just as it is important to identify who is sick and who is not sick, it is important to determine early on the patient who will require massive blood transfusion and damage control resuscitation/surgery. By identifying certain presenting triggers such as: (1) persistent hypotension and tachycardia despite adequate resuscitation, (2) need for massive transfusion, (3) clinical coagulopathy, (4) acidosis, (5) hypothermia, and (6) increased injury severity, one can predict early the need for damage control. As such the surgeon and team can then initiate massive transfusion protocols, inform the operative team of the plan, and ready the OR for an abbreviated surgery and the ICU to prepare to receive a ventilated patient with open body cavities in need of attention to rewarming, ongoing resuscitation, and correction of coagulopathy.

Again, communication and leadership effectively bring the team together utilizing the correct resources to identify rapidly the life-threatening injuries in the trauma patient(s) and enable the team to provide the optimal care for the patient(s) given the resources available. Additionally, the leader prepares the system or facility for the next wave or patients from this incident or the next by moving the current patients through the system safely and effectively. This is all made possible with a rapid and effective initial assessment of the trauma patient.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Amputation.
2. Damage control resuscitation.
3. High bilateral amputations and complex dismounted blast injury.
4. Trauma airway management.

# Damage Control Resuscitation

# 4

Jacob R. Peschman, Donald H. Jenkins, John B. Holcomb, and Timothy C. Nunez

**Deployment Experience**

| | |
|---|---|
| *Donald H. Jenkins* | General Surgeon |
| | 355th EMEDS Masirah Island Oman Sep 2001–March 2002 |
| | 332 EMEDS Balad Iraq Aug 2004–Nov 2004 |
| | 44th MEDCOM Baghdad Iraq Nov2004-Mar 2005 |
| | USCENTCOM Baghdad Iraq and Bagram Afghanistan May 2006–Dec 2006 Balad Iraq May 2008 |
| *John B. Holcomb* | General Surgeon, Mogadishu, Somalia, 1993 |
| | General Surgeon, Joint Special Operations Command, 1990–1999 |
| | The US Army Surgeons General Trauma Consultant, 2002–2008 |
| | General Surgeon, 10th Combat Support Hospital, Baghdad, Iraq, 2006 |

J.R. Peschman
Mayo Clinic, Department of Surgery, Division of Trauma, Critical Care, and General Surgery, Rochester, MN, USA

D.H. Jenkins (✉)
Military Health Institute, The University of Texas Health Science Center at San Antonio, San Antonio, TX, USA
e-mail: Jenkinsd4@uthscsa.edu; dj53@msn.com

J.B. Holcomb
Department of Surgery, Center for Translational Injury Research, Memorial Hermann Hospital, Houston, TX, USA

T.C. Nunez
Vanderbilt University Medical Center, Trauma, Surgical Critical Care and Emergency Surgery, Nashville, TN, USA



M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_4

*Timothy C. Nunez* General Surgeon, 912th Forward Surgical Team, Baghdad, Iraq, 2003–2004 Chief Medical Officer and General Surgeon, 86th Combat Support Hospital, An Nasiryah and Baghdad, Iraq, 2005 General Surgeon, Bagram, Afghanistan, 2006

*The only weapon with which the unconscious patient can immediately retaliate upon the incompetent surgeon is hemorrhage.*

William S. Halsted

**BLUF Box (Bottom Line Up Front)**

1. Damage control resuscitation is intended for the 10% of combat casualties who require a massive transfusion.
2. Remote damage control resuscitation is the extension of DCR principles to the pre-hospital environment.
3. Assume the combat casualty is coagulopathic and acidotic on admission.
4. Early identification of the casualty who will require massive blood transfusion (≥3 units) is critical; the goal is to “stay out of trouble as opposed to getting out of trouble.”
5. Permissive hypotension, limited crystalloid resuscitation, and early, rapid delivery of predefined ratios of component blood therapy or fresh whole blood are the foundation of damage control resuscitation.
6. Multiple hemostatic adjuncts are available to you, both mechanical and injectable, so know when and how to use them. Use them early and often.
7. In austere locations where banked blood is a scarce resource, early utilization of a walking blood bank is necessary.
8. Your goal should be a balanced resuscitation while the casualty is rapidly bleeding.
9. The expediency and adequacy of repaying the oxygen debt of shock will impact survival and risk of multisystem organ dysfunction.
10. Make it automatic and foolproof! Establish a protocol that delivers all blood products as a “DCR pack” containing packed cells, plasma, and platelets in a 1:1:1 ratio.
11. Over-resuscitation is bad for the casualty – amateurs can resuscitate; experts know when to stop.

## Introduction

Treatment of active hemorrhage, hemorrhagic shock, and prevention of re-bleeding is the name of your game in combat trauma. There are two big killers on the battlefield: severe brain injury and hemorrhage. You can’t do a lot about the former, but through preparation and attention to detail, you can significantly impact the latter. Assume every injured patient you receive has active bleeding until proven otherwise. Look at your watch when the patient arrives, and keep that ticking clock in mind during your initial trauma evaluation and resuscitation. The whole philosophy of damage control resuscitation (DCR) can be summarized by the observation that "Patients bleed warm whole blood, not just red cells. Therefore, we should replace this with warm whole blood or the equivalent, not cold and coagulopathic packed red blood cells, starting from minute one of the resuscitation."

Hemorrhagic shock and exsanguination are responsible for a large number of deaths in civilian and military trauma, accounting for more than 80% of deaths in the operating room and nearly 70% of deaths in the first 24 h after injury. Fortunately, only approximately 10% of military trauma patient admissions will require a massive transfusion. Newer definitions of massive transfusion are being evaluated to better identify these patients earlier in the resuscitation process. These include rolling rate-based definitions, the "critical administration threshold" (CAT) of greater than 3 units of PRBCs in an hour. Others have used a similar approach, but broadened the definition to include 3 units of any resuscitation product. This group of patients who require massive transfusion will account for the majority of blood utilization in deployed military treatment facilities (MTF). The recent conflicts in Southwest Asia have been the major stimulus to the rapid development, evaluation, and acceptance of damage control resuscitation (DCR). Multiple authors have demonstrated improved survival by using increased amounts and earlier use of predefined ratios of blood products, early in the care of these severely injured patients, in both military and civilian settings with the goal of approximating what is provided by whole blood. Rapid processing and preparation of such a large amount of blood and blood products in a short period of time requires significant planning and prior coordination of personnel and dedicated resources to ensure delivery of these products in an immediate and sustained fashion.

Previous descriptions of the coagulopathy from trauma were based on laboratory data from the operating room, and the conclusion was that abnormal coagulation laboratory values were not found in the first hours after injury and were associated with dilution. However, we now know that at least 25% of trauma patients arrive at the trauma center with abnormal laboratory values suggesting a coagulopathy. However, by using the DCR approach, only 6% are clinically coagulopathic, but those patients have very high mortality rates. The coagulopathy of trauma is a separate entity characterized by nonsurgical bleeding that can occur with or without appropriate concentrations of coagulation factors. Therefore, it has become paramount to have strategies in place (DCR) to directly address this coagulopathy in the severely injured patient. Always assume that the severely injured casualty is coagulopathic on admission and should be treated accordingly.

## Damage Control

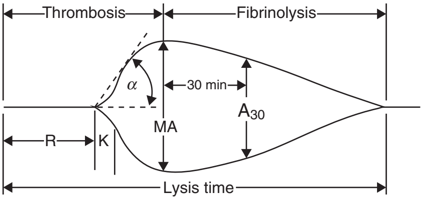
The damage control concept has been available as an alternative approach to management of the exsanguinating trauma patient who becomes cold and coagulopathic during laparotomy since the early 1980s. In the 1990s several authors applied the term "damage control" to this surgical resuscitation strategy and delineated damage control into three separate and distinct phases. Phase one consists of the abbreviated laparotomy, with the addressing of life-threatening hemorrhage and gross bowel spillage. The second phase involves the restoration of the patient to "normal" physiology through correction of acidosis, hypothermia, and trauma-associated coagulopathy. Phase three involves the return to the operating room for definitive repair and reconstruction of injuries temporized during phase one. Phase three occurs after restoration of "normal" physiology is achieved. Damage control resuscitation (DCR) spans all three of these phases and adds the pre-hospital as well.

The concept of DCR evolved out of this same approach. In the patients anticipated to need a massive transfusion, we have developed the concept of a special type of resuscitation (damage control resuscitation). DCR is composed of three basic components: (1) permissive hypotension – maintain palpable distal pulses in an awake patient, (2) minimizing crystalloid-based resuscitation strategies (prevention of ongoing hypothermia and dilution), and (3) the immediate release and administration of predefined blood products (packed red blood cells, plasma, and platelets) in ratios (1:1:1) similar to that of whole blood or the actual delivery of whole blood when blood components are unavailable. This aggressive delivery of blood products begins prior to any laboratory-defined anemia or coagulopathy in patients who have been identified as having life-threatening hemorrhage. This approach directly attacks the entire lethal triad which is often present in this small group of patients who are seriously wounded. However, no resuscitation strategy will work unless you are simultaneously addressing the source of the lethal triad – hemorrhage, shock, and hypothermia.

## Coagulopathy and Trauma

In civilian and military trauma populations, several authors have shown a significant laboratory-based coagulopathy already present at the time of admission. This represents a complex interplay of both hypercoagulability and hypocoagulability due to immunoinflammatory and hemostatic responses to injury. Several terms have been proposed to describe this pathophysiologic response, including acute coagulopathy of trauma shock (ACoTS), acute traumatic coagulopathy (ATC), and trauma-induced coagulopathy. Furthermore, the characteristics of this coagulopathy can change over time, with early evidence of activation of Protein C and depletion of fibrinogen. The cause of these changes has further been defined as primary (endogenous) vs. secondary (exogenous) which may be driven by aspects of our resuscitative efforts. This coagulopathy is driven by the shock state and is associated with a sharp increase in mortality, which makes it one of the immediate focuses of DCR.

Thromboelastography (TEG) is an old technology now in a resurgence in several fields including cardiac surgery, transplant surgery, and of course trauma. As opposed to common coagulation parameters such as PTT, INR, and ACT, TEG provides rapid assessment of the entire coagulation system (absent in the endothelium) which gives significant assistance to the clinician combating the coagulopathy of trauma. While an early empiric platelet- and plasma-first approach during damage




| TEG | Interpretation | Treatment |
|---|---|---|
| R | Time to amplitude > 2mm<br>Rate of initial fibrin formation<br>~Plasma clotting factor activity<br>↑Deficiencies or Inhibitors<br>↓Hypercoagulability | ↑R:<br><br>2-4 U FFP |
| K-time | R time to amplitude > 20mm<br>Time to form strong clot with cross-linking<br>Influenced by:<br>Clotting Factors<br>Fibrinogen<br>Platelets | ↑K/↓α:<br><br>2-4 U FFP<br>Consider:<br>Cryoprecipitate<br>rVIIa<br>PLTs |
| α angle | Speed of clot strengthening<br>Similar information to K-time<br>Decreased with:<br>↓Fibrinogen<br>↓Platelets | |
| MA | Maximum Amplitude<br>Final clot strength<br>Influenced by: | ↓MA:<br><br>Give PLTs |
| LY30 | Clot Stability<br>% decrease from MA after 30 minutes | ↑LY30:<br>Consider DIC therapy |

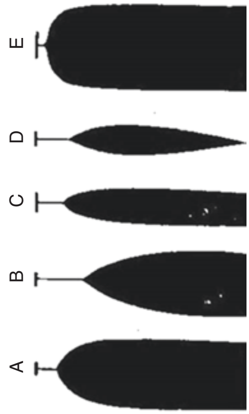



**Fig. 4.1** Thromboelastogram (TEG) reference with recommended blood product replacement strategy

control resuscitation is key in preventing the propagation of this coagulopathy, TEG may be the next step in an individualized and directed resuscitation strategy. We advocate checking it early and as often as needed. A quick reference for TEG interpretation can be seen in Fig. 4.1.

Currently, most resuscitations start with a ratio-driven approach and transitions to TEG-based (goal-directed) when bleeding slows enough that laboratory values are returned in a reasonable time from. Thus resuscitation is neither solely ratio driven nor goal directed but rather a combination of both, based on the rate of bleeding and local logistics. For now, TEG still faces some hurdles in widespread implementation. It requires surgeons, emergency physicians, and anesthesiologists comfortable enough with its use to interpret and make decisions with the information TEGs provide. Fortunately, this skill is easily learned. Additionally, TEGs have been traditionally time and personnel intensive for laboratories as they require special instrumentation, calibration, and to be run in controlled settings where ambient environmental conditions including vibration of the table they are being run on must be held constant to yield valid results. Fortunately, advancing technology is overcoming these obstacles, and in the near future, point-of-care TEG devices may find their way into the armamentarium of pre-hospital care.

## Identification of Patients Requiring DCR

It may be difficult for you to rapidly identify this group of patients. While there are currently no uniformly accepted criteria to identify the patients who will benefit from DCR, several groups have developed scoring systems (using a variety of anatomic, physiologic, and laboratory variables) to correctly identify the patient who will likely require a massive transfusion. While each of these scoring systems is quite accurate, there are two scoring systems which are most applicable to the setting of a combat support hospital or forward surgical team (Table 4.1). Each of these scoring systems relies on physiologic data, and each has its own limitations. The ability to apply these scoring systems will depend on your resources at your MTF. It is important to note, however, that each of these scoring systems should be used to augment, not replace, a surgeon's clinical gestalt and decision making. Many severely injured patients will obviously require DCR (the casualty with a systolic pressure of 50 and thoracoabdominal injures). However, many young patients in excellent shape will initially "fake you out." These patients "look good," right up until they undergo cardiovascular collapse. Trust your clinical judgment. You will find certain injury patterns help augment your decision making to initiate DCR (Table 4.2). For example, one experience-based rule used in the Baghdad CSH was to give one "code red" pack (4 units PRBC, 4 units FFP) per severely mangled or amputated extremity regardless of the initial clinical appearance. Be aggressive. In our opinion, it is better to start with an aggressive hemostatic resuscitation and then shut it off early, as opposed to waiting until you are certain a patient will require a MT and starting the hemostatic resuscitation late. To that end, scoring systems such as the revised Massive Transfusion Score are even being suggested as a marker to

**Table 4.1** Scoring systems to predict massive transfusion

| |
|---|
| Systolic blood pressure ≤ 90 mmHg |
| Heart rate ≥ 120 bpm |
| Penetrating mechanism |
| Positive fluid on abdominal ultrasound |
| OR |
| Heart rate > 105 |
| Systolic blood pressure < 110 |
| pH < 7.25 |
| Hematocrit <32% |
| Two factors present predicts >35% incidence of MT |

**Table 4.2** Injury patterns consistent with need for massive transfusion

| | |
|---|---|
| 1. | Uncontrolled truncal, axillary, or groin hemorrhage |
| 2. | Proximal amputation and penetrating truncal injury |
| 3. | Two or more proximal amputations |
| 4. | Severe hypothermia from blood loss |
| 5. | Extensive soft tissue defects with ongoing blood loss |
| 6. | Massive perineal wound or pelvic fracture with posterior disruption |

end MT if parameters correct at the 3- or 6-h mark. More investigation is needed, but you will remain safest if you keep in mind the philosophy "stay out of trouble as opposed to getting out of trouble."

Another useful tool at your disposal to identify patients in need of DCR is non-invasive tissue saturation oxygen monitoring ($StO_2$). This technology utilizes commercially available infrared spectrometry devices that provide real-time measurement of tissue perfusion which can be invaluable to the provider during a resuscitation. Initial $StO_2$ levels <70% or >90% taken at the time of arrival to the emergency department have been shown to correlate better than many traditional markers of resuscitation (i.e., tachycardia, lactate, base deficit) to predict the need for blood product transfusion, increased ICU length of stay and mortality in trauma and ICU patients. Its use in a pre-hospital setting has shown similar correlation in a yet to be published series. It can also be useful for its continuous real-time feedback, allowing you to gauge response to resuscitation efforts as they are being performed.

## Remote Damage Control Resuscitation

Ideally, DCR will start at the point of injury with first responders and pre-hospital medical personnel. This pre-hospital care has been termed remote or forward damage control resuscitation (RDCR). It is incumbent upon the medical officers to teach and direct our combat medics on the basic tenets of DCR for application in the setting. Tactical combat casualty care principles teach that casualties with severe hemorrhage are to be transported with limited crystalloid infusion and permissive hypotension. The patient who is awake or has a palpable radial pulse does not need much, if any, crystalloid en route to higher levels of care. Therefore, the medic can focus on prevention of blood loss using hemostatic adjuncts (to be discussed in more detail below) and hypothermia prevention. As you can see, two of three important components of DCR are under the immediate control of the combat medics. The third aspect of DCR, the rapid delivery of blood products, is usually currently under the control of physicians at the medical treatment facility level though this border is starting to blur as well and warrants further discussion.

When injury occurs in a far-forward environment or in a combat situation where immediate evacuation of casualties may not be possible due to an unsecured threat, your "golden hour" may have run out long before the patient hits the door. Considering that the clock starts ticking at the time of injury, the earlier all DCR principles can be put in place to start addressing the lethal triad, the better chance we have of achieving a favorable outcome for the injured patient. This is especially important in the setting of delayed (>60 min) or prolonged (>6 h) evacuations. *Stabilizing* a casualty by providing limited lifesaving interventions, stopping visible bleeding with direct pressure, permissive hypotension, and EVAC as quickly as possible to the nearest hospital for medical care are being augmented by starting *treatment* at the point of injury with the principles of DCR. Many topics discussed in this chapter as they apply to DCR such as mechanical and injectable hemostatic adjuncts and even blood product administration can be done pre-hospital. Storage and shelf life of blood products is the primary limiting factor and will be discussed in more detail later in this chapter as it applies to fixed hospitals. Suffice it to say, pre-hospital availability of blood products is primarily limited to medical evacuation teams, where the blood components are based out of a hospital where it can be appropriately stored and sent out with them when massive transfusion is anticipated. This may also present a potential application for the use of drones. At present the only freeze-dried product that is field ready is plasma, which has been used successfully by The Israeli Defense Forces at the point of injury as well as by both German and French Role 2 and 3 hospitals in Afghanistan. Under a special IND, some elements of the US Special Forces are carrying dried plasma pre-hospital. It provides hope for development of other components, though these are still likely years away from widespread application in the USA. Commitment from medical providers to the concept that care starts at the point of injury in the pre-hospital environment with dedication of resources (both tangible and time for training) will be the only way to close this gap.

## Hemostatic Adjuncts

If the name of the game is stopping the bleeding in the treatment of active hemorrhage, then you need to know what you're playing with. Hemostatic adjuncts can be broken down into two broad categories.

*Mechanical hemostatic adjuncts* refer to any mechanical device that can be used to stop or slow compressible or noncompressible bleeding including extremity, junctional, or abdominal tourniquets, procoagulant impregnated gauzes, and intravascular occlusive techniques such as REBOA (resuscitative endovascular balloon occlusion of the aorta). Tourniquets and hemostatic gauze products are standard parts of medical kits available to all troops including nonmedical given the risk to casualty and training required to use are both minimal. REBOA offers the unique advantage of addressing noncompressible torso hemorrhage though it requires more significant training. Its use has not grown as quickly as other mechanical adjuncts but offers huge potential to casualties requiring both DCR and RDCR.

*Injectable hemostatic adjuncts* refer to the class of medications and plasma derivatives that can be administered in low volumes to provide more immediate hemostatic effects when blood products are not immediately available. Most of these agents act to stabilize clot that has already been formed. When used in conjunction with the principles of limited crystalloid fluid and hypotensive resuscitation, they can limit ongoing nonsurgical bleeding. They can be administered via IV or IO in small volumes, and many do not have significant storage-related limitations. Several of these agents warrant more individualized discussion and as with mechanical adjuncts have applications in RDCR as well.

Tranexamic acid (TXA) is an anti-fibrinolytic agent which blocks the activity of plasminogen in clot dissolution and has been one of the more studied injectable hemostatic agents available. Both civilian and military studies demonstrate its efficacy in decreasing odds of death when used early (<3 h from injury) in severely injured patients undergoing massive transfusion. Use of the drug after 3 h causes increased death. Optimal dosing regimens and patient selection studies are still ongoing. At present, the JTTS does recommend consideration of TXA for any patient with combat-related hemorrhage requiring blood products and strong consideration in patients likely to need massive transfusion so long is it can be given within 3 h from the time of injury. Current recommendation for dosing is 1 g in 100 mL of 0.9% saline intravenously over 10 min followed by a second 1-g dose in 0.9% saline as an infusion over 8 h. It can be stored at room temperature, which greatly helps expansion of use to the pre-hospital setting.

The use of factor VIIa has been losing favor in recent years. While originally advocated by the Joint Theater Trauma Systems, in its most recent updated clinical practice guideline, the use of factor VIIa is left to the discretion of the treating physician for patients likely to receive massive transfusion in the setting of life-threatening hemorrhage and coagulopathy. Though reasonably safe, no compelling evidence exists to support it providing survival benefit. If desired, dosage is weight based at 100 mcg/kg intravenously. Try to achieve a pH of greater than 7.2 prior to administering the drug, but a pH of less than 7.2 is not an absolute contraindication, and you should still get some drug activity in this environment. Repeat doses may be given as needed, but should not be given if there was no evidence of any response to the first dose or as a "last-ditch" effort in the already exsanguinated patient.

Prothrombin complex concentrate (PCC) is a plasma-derived compound of vitamin K-dependent coagulation factors (II, IX, X, and variable levels of VII). It is available commercially in both 3-factor and 4-factor forms depending on the inclusion and activity of factor VII. The role of PCC in management of trauma-induced coagulopathy remains unclear and has been far less studied than other injectable agents discussed here. At present, its primary role is in the management of the acutely bleeding patient on anticoagulation therapy. Fortunately, this rarely applies in the combat setting. Its primary role outside of this setting is likely limited though may be used as part of a TEG-directed individualized resuscitation.

## Creation of DCR Protocol

The initial experience and data supporting the efficacy of a DCR strategy in the military started with the simple but somewhat radical proposition of giving more blood products and giving them earlier and balancing the plasma and packed call products from the beginning. Figure 4.2 demonstrates a wall chart from an OR resuscitation in the Baghdad Combat Support Hospital utilizing this approach but prior to a formal 1:1 DCR protocol. Note the balance of blood products (including whole blood) creating a ratio approaching 1:1:1. Retrospective review of the outcomes using this approach has demonstrated a survival benefit and stimulated further research into the most beneficial ratios and timing of products to use.

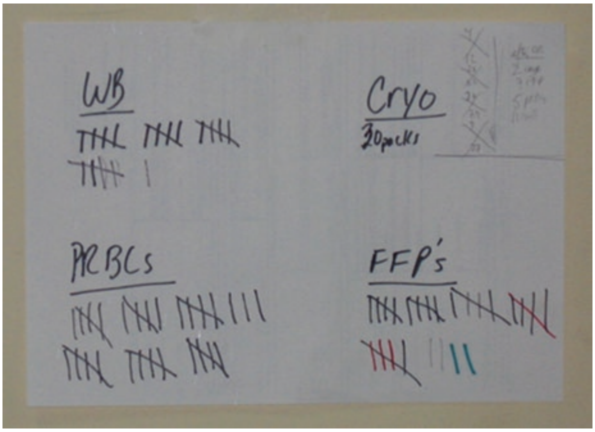



**Fig. 4.2** Operating room wall chart tracking a combat trauma resuscitation in Baghdad, Iraq. Note the balanced delivery of blood products, including packed cells, plasma, cryoprecipitate, and whole blood. If whole blood is not included, then platelet components must also be added

There is ongoing debate about what is the optimal ratio of blood products for the MT trauma patient. The clinical practice guidelines developed by the Joint Trauma Theater System (JTTS) advocate transfusion on a 1:1:1 ratio, essentially trying to recreate the transfusion of whole blood. Understanding the concept of a well-balanced and aggressive focused resuscitation is more important than the exact ratio, but sets a 1:1 target as an easily understandable goal. Recently the JTTS has also advocated strongly the use of banked RBCs with a shelf life of less than 14 days. There is a well-described storage lesion in refrigerated red blood cells. Older RBCs when given in large amounts are likely to have more profound deleterious effects on the recipient compared to blood less than 14 days old. Since 2008 the JTS advocates a "last in, first out" policy in regards to blood given in the framework of a MT protocol. This will provide the youngest blood possible in patients requiring a MT.

The *only* way to consistently deliver this large amount of predefined products in a rapid fashion is to have a well-thought-out MT protocol in place. In the ideal setting of a theater hospital or combat support hospital, this protocol should be created and monitored by a multidisciplinary team, including specialists from the emergency medicine, trauma, critical care, transfusion medicine, nursing, pathology, and anesthesia departments. The blood bank should function and be viewed as more than just a warehouse where blood products are stored and orders placed. To this aim, experts in transfusion medicine (when available) must be active participants in the resuscitation of the massively bleeding patient and development of protocols based on local resource availability. In the setting of a forward surgical team in more remote and austere locations, the multidisciplinary team is going to be a much smaller entity with the surgeon as the central figure in the administration of a MT protocol. In the austere location, you will need to utilize whatever resources you have available to administer a MT protocol. This will also include having an organized walking blood bank process, which will be discussed further in this chapter (Fig. 4.3).

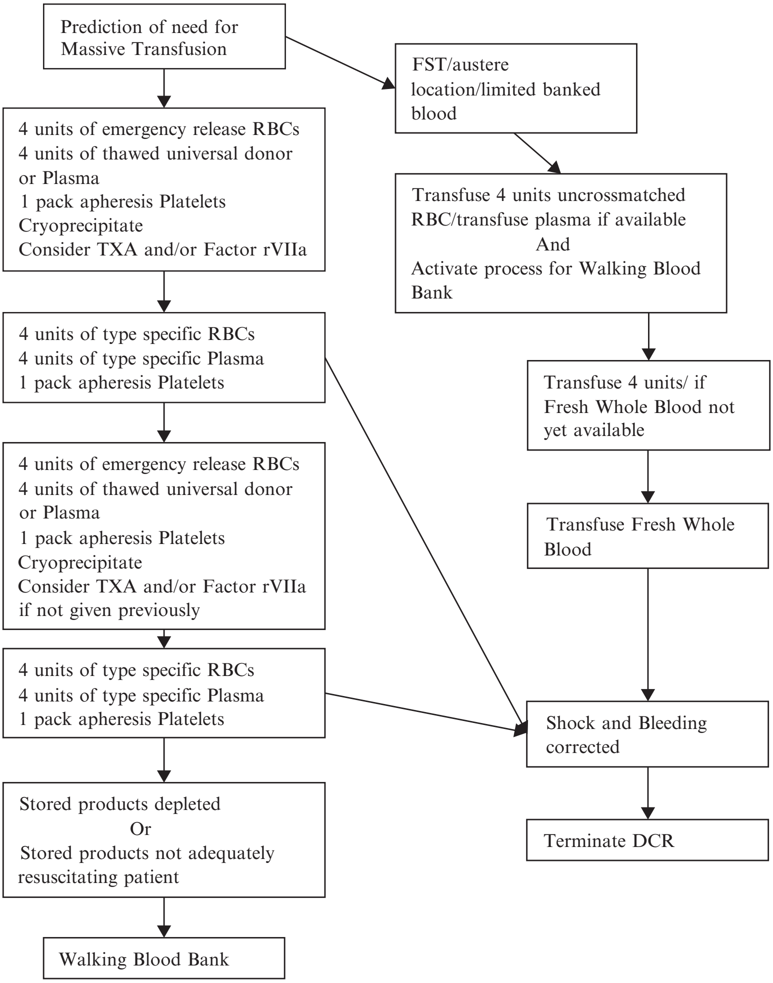



**Fig. 4.3** Massive transfusion protocol for level II/III facility

## Delivery of DCR

The next set of challenges is exactly how the products should be delivered. The MT protocol can be activated by the attending clinician. Your facility should have a set policy on how the blood bank will be notified, either with a phone call, runner, or blood banks responding to the resuscitative area as a member of the team. The physician makes this decision based on the previous described scoring systems, injury patterns, or clinical acumen. A type and screen is obtained as soon as possible to facilitate type-specific blood product administration. The blood bank will, upon receiving proper notification to activate the protocol, execute the MT protocol by providing a cooler with 4 units of universal donor plasma and 4 units of uncrossmatched RBCs and a six pack of platelets. Busy combat support hospitals will be able to keep a certain amount of thawed plasma available at all times. Keeping between 4 and 6 units of thawed plasma at all times in a busy MTF will facilitate the early delivery of all blood components and can even decrease wastage of plasma products. In addition, 1 unit of apheresis platelets should be released with every cooler. This cooler should be able to meet the patient in the emergency department or in the operating room. The blood bank then automatically begins preparing a second cooler. This cooler (and subsequent releases) contains 1 unit of apheresis platelets, 4 units of plasma, and 4 units of RBC. Also in your MT protocol should be a description of the indications and availability of tranexamic acid, recombinant factor VIIa, PCC, and cryoprecipitate. Pay special attention to the cryoprecipitate availability. As previously discussed, often forgotten is the hypofibrinogenemia present in ACoTS and what product best replaces fibrinogen. There is little debate that a high ratio of fibrinogen is needed in a MT protocol. Platelets and plasma will deliver some fibrinogen, but less than that present in an equivalent volume of whole blood. A single 150-ml (10-unit) bag of cryoprecipitate will provide six times more fibrinogen than platelets or plasma and will raise your patient's fibrinogen level by about 70 mg/dl. In DCR you will always be concerned with the volume of product given, and cryoprecipitate will provide this large fibrinogen bolus in ½ the volume of plasma and platelets and ¼ the volume of whole blood. We would suggest using cryoprecipitate in your MT protocol by automatically delivering it in every other cooler rather than waiting for it to be ordered separately based on a fibrinogen level. As each cooler of products is readied, the blood bank contacts the operating team to notify them that the next cooler is en route and will inquire as to whether to continue delivery of the MT coolers. This procedure will continue with each delivery of products. A key principle of these protocols is that the blood bank does not wait to receive an order for each cooler of products but instead continuously supplies products in a predetermined ratio until the MT is stopped by the physician at the bedside.

This seems to be as an appropriate place as any to address a couple myths about blood banking that can place unnecessary limitations on the implementation of a reliable and functional MT protocol. Since medical school, the basics of ABO blood type compatibility is hammered into the heads of new physicians. Type O is the universal donor, and type AB is the universal recipient for PRBCs, and the opposite is true for plasma. Unfortunately, the rarity of type AB blood makes banking of universal plasma for donation in uncrossed emergent settings a challenge. Newer research into blood cross-reactivity, stemming from the original use of low-titer type O whole blood in Vietnam, has revealed the safety and efficacy of the use of low-titer type A plasma and low-titer type O FWB in emergent settings. Additional limitations to blood and component availability have been storage concerns. Platelets in particular have traditionally been considered extremely temperature sensitive. This extended as far as not sending platelets in standard MT protocol coolers due to concerns of inhibiting their inherent function. Therefore, storage and handling at recommended temperature of 22 °C has been the standard operating procedure and subsequently carried with it several limitations. Transportation at optimal temperatures was difficult and required different handling policies compared to the other standard blood components of FFP and PRBCs. The other limitation this created was shelf life. At colder temperatures, blood products are more resistant to infection, so a standard pack of platelets kept at 22 °C was limited to a 5-day shelf life. All these factors made keeping platelets available for RCDR or even as part of a prepared trauma cooler in an emergency department impossible. Fortunately, newer research is showing this to be untrue. Platelets appear to have preserved function even with storage down to 4 °C and extension of the shelf life to 14 days. Universal adoption of these practices will greatly improve platelet availability for a platelet-first resuscitation strategy. Additionally, it opens up possibility for expanded use of cold-stored whole blood which similarly had been limited in application due to platelet function concerns.

## Termination of DCR

The delivery of blood products continues until it is determined by the operating team that the MT protocol can be discontinued. This decision will be made in the operating room or in the ICU. This decision is primarily a clinical decision made by the surgeon with the input of the anesthesia or critical care providers. The use of conventional tests such as prothrombin time, international normalized ratio, and partial thromboplastin time may not be readily available to make real-time decisions. The use of rapid thromboelastography may be able to fill this void of a coagulation test with results in real time, but its use has not yet been clearly defined. DCR is currently stopped when surgical bleeding is controlled, urine output and blood pressure increase, heart rate decreases, and use of pressor agents stops. Invariably stabilization in the patient's physiology occurs at this time, and normalization of conventional labs soon follows. In the near future, we may have more clearly defined objective data such as noninvasive tissue oximetry or rapid bedside coagulation profiles that can aid in the decision to terminate the MT protocol. Until then, clinical acumen usually performs as well or better than most expensive and time-consuming tests.

## Fresh Whole Blood

Primarily a tool of the military, the use of fresh whole blood has been used in combat theaters dating back to the Civil War, with widespread utilization in World War I. The US military has continued the use of fresh whole blood extensively in the ongoing conflicts in Southwest Asia. The military is able to show a favorable risk-benefit ratio in the use of fresh whole blood when compared to conventional blood products. Fresh whole blood is warm, the volume is close to 500 ml, and the hematocrit is 38–50% with 150–400 K platelets, 100% coagulation activity, and 1500-mg fibrinogen or exactly what the patient is losing. Also, fresh whole blood, as its name states, is fresh and does not possess the "storage lesion" of banked blood. The use of fresh whole blood is the ultimate 1:1:1:1 ratio. The use of fresh whole blood will depend on the resources you have available. Blood component availability is clearly different at the different levels of care. Combat support hospitals and theater hospitals will likely have the only robust blood banking capability in a combat theater. Forward surgical teams will likely only have a limited supply of RBCs. Forward surgical teams typically have no more than 10 units of RBCs and may or may not have plasma or platelets. This was certainly our experience in Iraq and Afghanistan. It is in this environment that a walking blood bank becomes an excellent (and often the only) option. We have transfused over 10,000 units of fresh whole blood in the ongoing conflicts in Iraq and Afghanistan with an excellent safety profile and data that suggests a survival benefit. However, the use of fresh whole blood is not without potential risk. There are several downsides to the use of fresh whole blood; transmission of blood-borne disease is rare but possible, there is a limited donor pool at small forward operating bases, and you must consider the small potential deleterious effects on the donor (who usually is a soldier with a job to do). Even with these known risks, we strongly encourage you to develop a walking blood bank program and the early use of fresh whole blood in austere settings requiring DCR.

## Organization of Walking Blood Bank

The process to obtain the fresh whole blood is something that needs prior coordination with your personnel and colocated units. You must have a prescreened donor pool. This must be done prior to its need as making up a donor pool when a casualty has arrived is difficult and time consuming, resulting in unnecessary delays in the initiation of hemostatic resuscitation. Your donor pool will typically be made up of hospital, forward surgical team, or colocated unit personnel. You should always make a point of getting to know the leaders of colocated units and getting their "buy-in" for blood donations. Include them in your planning of the walking blood bank so that when it is activated they know how to be an asset. This plan would include a predetermined method to facilitate the walking blood bank. A responsible individual from your unit (not a surgeon) must have access to the blood donor pool and be able to manage the walking blood bank. You must be able to notify your operating base that you need to mobilize donors. This may be as simple as having runners that go to soldier living areas, the DFAC, or the gym. You may have public address capability to get the word out. All military personnel will have HIV screening prior to deployment and immunization against hepatitis B, but even with this knowledge, you should be using the rapid screening kits to evaluate for HIV, hepatitis, and HLV. These rapid immunoassays are not as accurate as we desire, but a positive result can be helpful. It is best to screen ahead of time all the possible donors with a standard questionnaire (DD572) to insure they are eligible low-risk donors. This donor list will constantly have to be updated, donor's type retested and checked as personnel will move out of your area of operations. The timeframe for this will need to be determined based on the location of your MTF.

## Collection of Fresh Whole Blood

When the decision to utilize fresh whole blood has been made because of lack of blood components or the blood bank has been exhausted, you notify your preassigned individual or individuals to mobilize the donors and begin collection of fresh whole blood. The process will be set up by each facility to meet its specific needs based on the MTF location. The basic tenets will require proper identification of individuals in the donor pool, confirmation of an up-to-date screening questionnaire, and ensuring that they have not recently donated. If your location has the ability to screen for blood-borne infectious disease, this should be done, and this does not obviate the need for samples to be collected and sent for testing at a later date at an approved reference laboratory. Once the patient has rapidly been deemed fit to provide a donation, the walking blood bank personnel will crossmatch the donor to the recipient (dog tag blood type cannot be trusted), check the donor for significant anemia, and then proceed with collection of up to 500 ml of whole blood into a CPDA-1 bag (commercial collection bag with anticoagulant citrate phosphate dextrose adenine). Try to keep this collection area as un-chaotic as possible; a clerical error leading the transfusion of the incorrect blood type could lead to a devastating hemolytic reaction. This collection area may be within a few feet of the casualty, but you still need to properly label this unit of blood. Then the unit is walked over to casualty and infused. With practice, this entire process can take less than 25 min. The termination of the walking blood bank is essentially the same as what was done to stop the blood bank-driven component therapy protocol. Use the combination of clinical judgment and conventional testing to determine when DCR should be terminated.

## The Aftermath of DCR

The concept and execution of DCR have been praised as one of the biggest recent advances in combat and trauma medicine, but it is not “magic.” It will not salvage all bleeding patients or make up for lapses in decision making and surgical technique. You must also be aware of the short- and longer-term implications of a DCR strategy. It will tax your blood bank, particularly if used indiscriminately. The ideal ratios and types of products to administer are still being evaluated, but a lot has been learned over the last decade. We still do not know the full impact of transfusing additional blood products on longer-term complications such as infectious disease transmission, nosocomial infection rates, and immunosuppression. It does appear that the rates of ICU complications such as ARDS and multi-organ failure are decreased compared to the days when excessive crystalloid was infused. It appears that the incidence of TRALI can be decreased by using male-only plasma donors (decreased antibody levels compared to multiparous female donors), but this is often not an option due to supply and demand. You should be aware of all of these factors to best utilize this important and lifesaving strategy.

## Forward Surgical Team Specifics

Some forward surgical teams (FSTs) will be colocated with level 3 facilities (combat support hospital) or with medical companies that will provide them material and support. However, in remote theaters, such as Afghanistan, FSTs are often in austere locations and may be split between two locations leaving just ten personnel with very little logistical support. This may seem to be an exceedingly small amount of resources in one location, but these small remote teams have performed well. In regards to DCR in a remote location, the physician will not have the robust blood bank to deliver component therapy to casualties. Fresh whole blood will be utilized in the most seriously injured who you suspect will require a massive transfusion. With proper preparation and utilization of colocated US personnel, these teams can handle the most seriously injured combat casualties.

In conclusion, the key concept in DCR is to be aggressive with early component therapy and/or whole blood. All the available information suggests that this has saved many lives on the battlefield. In our opinion, it is better to start with an aggressive hemostatic resuscitation and then shut it off early, as opposed to waiting until you are certain a patient will require a MT and starting the hemostatic resuscitation late. The triage philosophy "stay out of trouble as opposed to getting out of trouble" holds true in these situations.

**Acknowledgment** We would like to acknowledge Dr. John B. Holcomb and Dr. Timothy C. Nunez, the authors of this chapter as published in the first edition of *Front Line Surgery*: *A Practical Approach*. Their knowledge and experience have been preserved throughout this chapter in its original form.

## Civilian Translation of Military Experience and Lessons Learned

Donald H. Jenkins

**Key Similarities**

- Hemorrhage is among the leading causes of trauma-related mortality and a primary point where preparation and early intervention can improve outcomes.
- DCR principles must start in the pre-hospital setting with a well-developed system for providing RDCR.
- Resource availability provides a challenge to RDCR and DCR care.

**Key Differences**

- Care of civilian trauma patients is commonly complicated by significant medical comorbidities and pre-injury medication regimens, especially anticoagulants.
- Walking blood banks for FWB administration in emergent situations are essentially nonexistent in civilian hospitals, increasing reliance on component-based resuscitation and ratios.

Lessons learned during times of war have historically been major drivers in the advances in civilian medical care. When the National Academy of Sciences released "Accidental Death and Disability: The Neglected Disease of Modern Society" in 1966, now commonly referred to as the "White Paper," the hard look at the inadequacy of pre-hospital and early care of the trauma patient in the USA became all the more apparent. Experts at the time who had served in Korea and Vietnam asserted that if seriously wounded, odds of survival were better in the combat zone than on the average city street at that time. Much of this difference was attributed to the "excellence of initial first aid, efficiency of transportation, and energetic treatment of military casualties" [21]. Though we have made great strides in improving care of the injured patient, these areas, identified in 1966, remain as points where we are still working.

Initial first aid as provided in the setting of trauma focuses on control of bleeding. While military service provides a predefined audience of servicemen and women to whom training can be provided in the use of hemostatic gauze and tourniquets, training to the general civilian population is much more difficult. Despite military findings that tourniquets were efficacious with little training while offering little risk to the casualty, adoption in the civilian setting has been much slower. Reasons for this slower adoption may be from concern for patient harm when tourniquets are applied incorrectly by untrained emergency medical personnel and bystanders. Fortunately, this has been disproven in recent studies, and use has been adopted and incorporated into pre-hospital and advanced trauma life support (ATLS) training. Unfortunately, this training still only reaches healthcare providers who already care for the trauma patients. Fortunately, programs, such as the American College of Surgeons' Hartford Consensus, now in its fourth iteration, have implemented its "Stop the Bleed" program to train first responders and nonmedical providers in hemorrhage control for mass casualty situations as well as to advocate increased availability of hemostatic dressings and tourniquets and to eventually equal the widespread public awareness of the use of CPR and automatic external defibrillators (AEDs).

Efficiency of transportation has improved, with well-developed private and hospital-based ground and air transport systems capable of moving severely injured patients to appropriate levels of care often within minutes of the time of injury. This has allowed a shift of focus to not just the speed at which a patient is moved but the care provided in route. Expansion of the arsenal of the pre-hospital provider to diagnostic and therapeutic options previously only available in the ED, OR, or ICU is possible. We have had significant success with this process by approaching pre-hospital care not as a separate entity but as a direct extension of care provided in our ED or ICU. This includes initiating early evaluation with $StO_2$ monitors and providing blood components (3 U PRBCs and 3 U FFP) to every flight team in our healthcare system. This required a coordinated effort with our blood bank to insure little to no product waste. FFP has proven invaluable as an adjunct in treatment of our anticoagulated population with traumatic brain injury. Development of protocols and predefined hemodynamic and clinical triggers, many of which are identical to in-hospital MT protocol triggers, has allowed for the administration of these products without a physician present in the field. The next steps in care potentially will be the availability of cold-stored whole blood and TXA administration.

The area where we continue and must continue to show our commitment to trauma patients is in the energetic care of the providers. None of the advances in civilian or military trauma care discussed throughout this chapter would have been possible without the determination and enthusiasm of trauma heathcare providers. It will only be with this determination that the holy grail of civilian application of military trauma concepts can ever be achieved, the development of walking blood banks. FWB is the best resuscitative fluid; however, the logistics of providing it, including identifying available type-specific donors in a system capable of performing rapid screening for blood-borne illnesses, has remained elusive. This was the initial driving force behind ratio-based resuscitation strategies. The goal was to approximate individual blood components as close as possible to whole blood. This has been studied extensively in multiple prospective and retrospective trials, the most recent being the PROPPR trial which revealed that there likely is a limit in efficacy when attempting to approximate whole blood with reconstituted products in the range of PRBCs:FFP:Plts of 1:1:1 to 1:1:2. The closest civilian system to the military walking blood bank is that seen on the Royal Caribbean Cruise Line. Due to the impracticality of maintaining stored blood products, fleet-wide protocols have been established to utilize a walking blood bank. Donation flowcharts start with related family members and work down an algorithm to pre-identified and screened employee donors and have proven to be the most efficient way of managing a situation requiring massive transfusion, with success in over 37 cases so far. Their success gives some hope to civilian-based systems, but again has been difficult to translate to large academic trauma center with large pool of potential donors, let alone remote critical access hospitals. Overcoming the obstacles to developing this type of system will be challenging, but if as a community, trauma providers continue to show the dedication to the improvement in trauma care we have over the last 50 years, we will make it possible.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Damage control resuscitation.
2. Fresh whole blood transfusion.
3. Frozen blood.

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# 5 To Operate or Image? (Pulling the Trigger)

Matthew J. Martin and James W. Davis

**Deployment Experience**

| | |
|---|---|
| *Matthew J. Martin* | Chief of Surgery, 47th Combat Support Hospital, Tikrit, Iraq, 2005–2006 |
| | Chief, General Surgery and Trauma, Theater Consultant for General Surgery, 28th Combat Support Hospital, Baghdad, Iraq, 2007–2008 |
| | Commander, 655th Forward Surgical Team, FOB Ghazni, Afghanistan, 2010 |
| | Chief of Surgery, 758th Forward Surgical Team, FOB Farah, Afghanistan, 2013 |

> *"God gave you ears, eyes, and hands; use them on the patient in that order."*
>
> William Kelsey Fry

One of the common attributes of great trauma surgeons is that they seem (to us mere mortals) to have the ability to magically sort out who needs emergent intervention without all of that "new-fangled technology" that has replaced the physical examination and clinical judgment. I had the great opportunity to train under one such legendary figure and quickly realized that the strongest predictor that the patient needed to go emergently to the operating room was when he pulled his cloth scrub cap out of his back pocket and put it on.

M.J. Martin (✉)
Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA
e-mail: traumadoc22@gmail.com

J.W. Davis
University of California, San Francisco, CA, USA

Surgery UCSF/Fresno, Community Regional Medical Center, Department of Surgery, Fresno, CA, USA



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We all learned to watch closely for this tell-tale sign and how incredibly accurate it was for predicting life-threatening injuries just by simple observation and examination. However, with close observation I came to realize that he was able to do this in large part by applying a basic set of rules and principles governed by common sense and a deep understanding of trauma mechanisms and anatomy. Although no chapter or guidelines can hope to replicate that level of judgment built on decades of experience and hard-learned lessons, you can easily adopt the principles and algorithms outlined here to manage the most challenging group of patients you will ever encounter – combat trauma patients.

The sharp decline in penetrating trauma volume and the increase in nonoperative management of most injuries have inadvertently created a widespread disease pathology among surgeons and surgical trainees – *catatonia*. I define this as “the inability to make definitive management decisions without the use of detailed computed tomography imaging, coupled with a fear of the “exploratory” operation.” If there is one overriding principle to guide you in managing combat trauma, it is to abandon or adjust the civilian trauma algorithms that you have learned. Combat trauma is in many ways the polar opposite of civilian trauma – penetrating mechanisms predominate, severe and multi-compartment injury is more common, and the majority will require some form of operative intervention. It is very different than being at a Level 1 trauma center in the USA, where the majority of trauma is blunt mechanism and you have all of the “bells and whistles” available to you. The goal of this chapter is to help you make the early and critical decision of “what next?” after the initial trauma evaluation and learn to be comfortable “pulling the trigger” to go to the operating room even in uncertain situations. I have yet to have a case where I regretted going right to the OR, but I have certainly had and seen many cases involving regret (and avoidable morbidity or mortality) about going to the CT scanner instead of the OR. In the stable patient, these approaches may save you time and resources; in the unstable or bleeding patient, these approaches may save his or her life.

**BLUF Box (Bottom Line Up Front)**

1. There is no more critical early decision than whether to proceed immediately to the operating room or to perform more evaluation and imaging.
2. Time is your enemy; start the clock on patient arrival, and proceed as if every minute is another unit of blood lost.
3. Patients die in CT scan; therefore, a hypotensive trauma patient belongs in the operating room ASAP.
4. Detailed head-to-toe imaging is not an emergency and not required to manage nearly all life-threatening injuries.
5. Unless you have clinical evidence of elevated intracranial pressure, the chest and abdomen trump the head injury and a head CT scan can wait.
6. Trust your physical exam, your training, and your instincts.
7. Discard the civilian blunt trauma mindset – it will leave you with a dead patient.
8. You can identify and localize exsanguinating hemorrhage in 5 min or less without leaving the resuscitation room or operating room.
9. See the chapter on ultrasound – this is one of the most useful imaging modalities you will have available to you, but *only* if you know how to use it.

## The Stable Patient

Even in a combat or disaster setting, the majority of patients that reach your facility alive will present with relatively stable hemodynamics. The decision here to proceed with further imaging or go to the operating room has much less urgency than in the unstable patient, but can still result in added morbidity or mortality. Remember that young and healthy trauma victims (such as soldiers) can maintain surprisingly normal vital signs with large volumes of hemorrhage right up to the point of rapid decompensation. You should still evaluate these patients as if they potentially have ongoing hemorrhage. Do not move them for imaging until you are satisfied that they are truly stable and do not have large volume chest, abdomen, or pelvic bleeding. Your physical exam and basic imaging (x-ray and ultrasound) evaluation for hemorrhage is described in detail in the section "The Unstable Patient" and in Fig. 5.1.

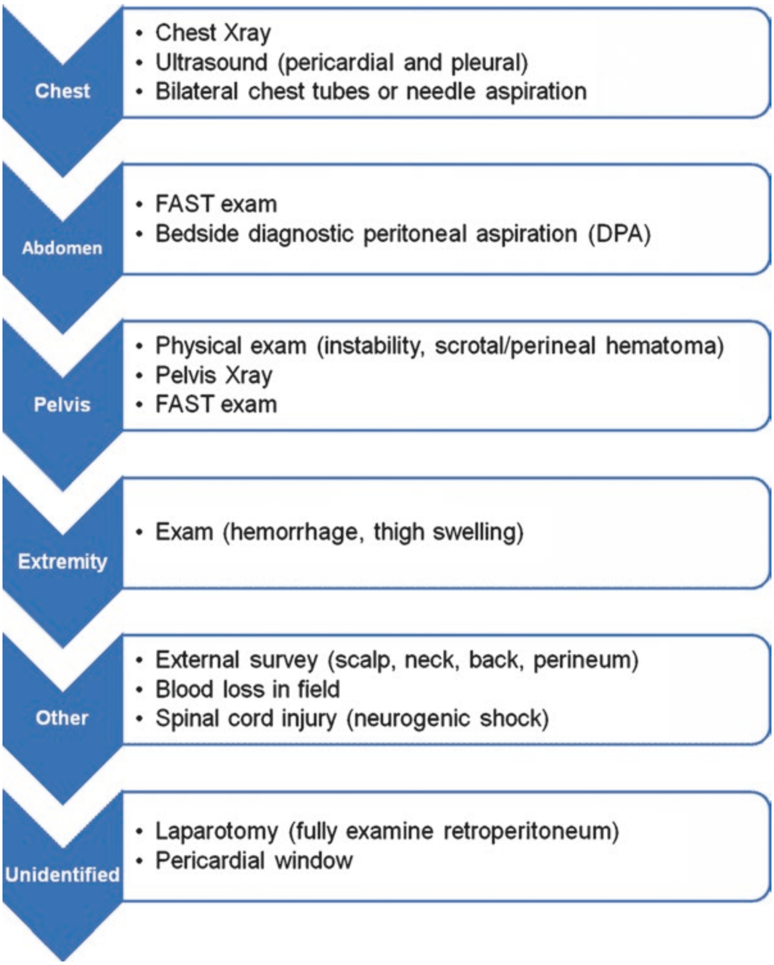


**Fig. 5.1** Approach for rapid identification of hemorrhage in the unstable trauma patient

Assuming this workup is negative, you now have to decide on performing more imaging studies or moving to the operating room. This decision should be based on the patient's identified injuries as well as the likelihood of unidentified injuries and their urgency or lethality. If the patient has no identified injuries that require an operation, then proceed with imaging as dictated by the mechanism and initial evaluation. If the patient has one or more injuries that clearly will require operative intervention, then there are three factors you must weigh into your decision: (1) the nature and urgency of the operative injury, (2) the other areas of potential injury, and (3) the lethality of these potential missed injuries. In the end these decisions should all come down to an educated analysis of the odds and probabilities of each course of action and choosing the one with the greater upside and the more acceptable downside.

If you do move directly to the operating room, you should always maintain a plan for how you will proceed in the event of an unexpected decompensation or manifestation of injury in another anatomic area. For sudden hemodynamic instability, bilateral chest tubes with a laparotomy and pericardial window rule out almost all potential operative sources of occult large-volume hemorrhage. If the patient manifests sudden evidence of neurologic deterioration due to rising intracranial pressure (dilated pupil, hypertension/bradycardia), then you must decide between terminating the procedure and obtaining an emergent head CT or performing a concurrent blind craniotomy or burr holes. See the chapter on neurosurgery for more detailed discussion of this scenario. Calling for help is the first and best maneuver you should perform in that situation.

If you decided to perform some additional imaging on a stable patient before proceeding to the operating room, then keep these principles in mind. The patient can deteriorate at any point and will usually choose the least opportune time to do it. Make sure you have continuous observation and monitoring throughout the imaging process. Be fully prepared to pull the patient off of the imaging table and move to the operating room if there is any deterioration. Only perform the studies that you absolutely need prior to the operating room, and prioritize the order of those studies in case of clinical deterioration and termination of imaging.

## The "Rule-Out" Head or Spine Injury

One of the most frequent refrains overheard at heated trauma M&M discussions is "I was concerned about a severe head (or spine) injury." This is usually in response to a question about why a particular patient bled to death on the CT table while obtaining detailed images of a normal brain or nonoperative brain injury. This is even more of an issue in the combat or disaster scenario, where severe and multisystem injuries are the norm. The siren song of the "quick head CT" has lured many a trauma surgeon to disaster, so be wary. Unlike almost all other areas of surgery, in trauma you must often proceed based on incomplete and imperfect information. In these scenarios you have to then fall back on your common sense augmented by knowledge of odds and probability. In a patient with both head and truncal injuries, the overall odds of performing a lifesaving surgical intervention are always going to favor addressing the truncal injuries as the priority. Patients who require both a therapeutic truncal procedure (laparotomy or thoracotomy) and craniotomy are fortunately extremely uncommon. For combat- or disaster-type injuries, the patient who is awake, alert, and talking to you is exceedingly unlikely to have any type of operative brain injury, and a head CT should be a low priority.

In the patient who is unstable or quasi-stable, the only thing that should make you consider obtaining a head CT before moving to the operating room is the evidence of catastrophic intracranial hemorrhage. Know how to recognize the clinical signs of rising or elevated intracranial pressure. This includes a depressed GCS (<10) or a rapid decline in mental status along with one or more characteristic physical exam findings – dilated and fixed pupil(s), motor posturing, or hypertension and bradycardia with altered respirations (Cushing's triad). If the ICP is elevated enough to cause these signs, then there will always be a depressed mental status! Therefore, a unilateral dilated pupil in an awake and alert patient is not from elevated ICP and herniation. Hypotension in these patients is from hemorrhage until proven otherwise, and the best thing you can do to help preserve neurons is control bleeding and reverse the hypotension.

Spine imaging in the severely injured patient is a pure time waster. If you have time to waste, then image the spines. Otherwise, maintain spinal precautions while you deal with life- or limb-threatening injuries, and fully evaluate the spine later. Even in a patient with a clear spinal cord injury, you are highly unlikely to find anything on CT scan that will change your early management or operative priorities. Remember that the best thing you can do for your patient's spinal cord is to prevent hypotension and hypoxia – and this is done in the operating room and not in the radiology department. Once you have hemorrhage and contamination controlled, you can deal with the brain or spine injury. Involving your neurosurgeon or spine surgeon early (if you have the luxury of having one) can be a great help, but always maintain focus on your management priorities and the big picture.

You also must adapt your practice to match the realities of your setting and your patient population. If you are at a Role 2 facility (Forward Surgical Team or equivalent), then you will most likely not have a CT scanner, so you will not have to worry about this option. Although you may think that this is a severe limitation, my experience has been that trauma care in this setting makes you acutely aware of how much you can easily manage with only your physical exam, ultrasound or x-ray, and good decision making. You are also more likely to be seeing patients brought directly from the point of injury, where rapid evaluation and intervention are critical. If you are at a Role 3 facility, you will likely have a CT scanner and have many more personnel and resources for trauma care. You also may be taking care of many more patients that are transfers from another Role 2 or Role 3 facility and who have already had initial resuscitation and surgical intervention. So in this setting, there may be less of a focus on immediate lifesaving operative interventions and more focus on performing a full tertiary examination and obtaining complete CT scans to identify and characterize all of the injuries.

## The Unstable Patient

This is the scenario where those key early decisions truly determine life or death. The hemodynamically unstable combat trauma victim is bleeding to death – period, end of story. If you have an easily identified and obvious source of the bleeding, such as bilateral leg amputations, then you can proceed with temporary (tourniquet and/or hemostatic dressing) followed by definitive (surgical) hemorrhage control. But what do you do with the patient who has holes everywhere and is hypotensive? This is now known as "non-compressible truncal hemorrhage" or NCTH and often presents a far greater challenge than extremity or junctional bleeding. The first step is realizing that this patient almost certainly belongs in the operating room and as soon as possible. Start to mobilize your resources in that direction to get things moving. Do not take this patient to the CT scanner – even for just a "quick head CT." You will often regret it, while you will rarely regret moving to the operating room. Now you need to figure out where the bleeding is and do it quickly. You should be able to do a rapid head-to-toe survey for hemorrhage in about 3–5 min using only physical examination, basic x-rays and/or ultrasound, and a 20-gauge needle.

Figure 5.1 demonstrates a simple algorithm for the approach to this patient. This is based on two main principles: (1) there are a limited number of body compartments that can contain enough blood to exsanguinate, and (2) the signs of exsanguinating hemorrhage in any of these compartments are not subtle. If you have a normal physical examination and x-ray or ultrasound of that compartment, it is highly unlikely to be your bleeding source. The cranium cannot contain enough blood to cause hypotension from hemorrhage, and hypotension from brain injury should be a diagnosis of exclusion, not a primary hypothesis. However, beware of the bleeding scalp wound or skull fracture building up an unrecognized pool of blood on the floor.

A normal chest x-ray essentially rules out major thoracic hemorrhage, so train your x-ray techs to fight their way in and get the film immediately upon arrival. Ultrasound of the chest is highly reliable (in skilled hands) for hemothorax and pneumothorax and easily integrated into the standard FAST exam (see Chap. 6). In addition, the pericardial view should identify any effusion that has become large enough to cause tamponade. If you are not skilled at abdominal and thoracic ultrasound, then getting skilled should be a priority. Alternatively, bilateral chest tube placement or bilateral needle aspiration (fifth intercostal space, midaxillary line) can make the diagnosis and potentially be therapeutic. Physical examination of the abdomen and pelvis may identify massive distension or pelvic bony instability, but is not highly sensitive. A normal pelvis x-ray rules out hemorrhage from pelvis fractures. A negative FAST exam can provide reassurance, but is *not definitive* for ruling out the abdomen. If no other source has been identified and the patient remains hypotensive, perform a diagnostic peritoneal aspiration (DPA) using a 20-gauge needle. Blood will accumulate in the paracolic gutters and pelvis, so aspirate one or more of these areas, and if gross blood is found, then proceed with laparotomy. Do not worry about damaging the bowel with your aspiration; a 20-gauge needle hole will seal itself. Even if all of these are negative, the retroperitoneum remains a potential source of bleeding. However, most retroperitoneal injuries that bleed enough to produce instability will have ruptured into the peritoneal cavity and produce positive findings on the workup outlined above.

If no obvious source has been identified at this point, then begin looking for less likely candidates. The only possible extremity compartments that can hold enough blood to produce shock are the thighs, and this should be obvious on exam. A full external survey should be performed including the back and the perineum – both potential areas for large volume hemorrhage. External blood loss prior to arrival should be considered, but this usually corrects rapidly with resuscitation. Neurogenic shock from spinal cord injury should be considered only if there is paraplegia or quadriplegia present and after ruling out any other surgical cause. Finally, if the patient remains unstable from an occult source, then proceed to the operating room for abdominal exploration, and you should also consider performing a pericardial window.

## The Sirens of Combat Trauma Imaging (Specific Pitfalls and How to Avoid Them)

In Greek mythology, the Sirens were creatures who would use their seductive voices to lure unsuspecting sailors to doom on the rocks surrounding their island. In combat trauma you must resist the siren song of those around you (and in your own head) luring you to apply the "usual" trauma imaging evaluation to all patients. This often takes a concerted effort on your part and may result in some consternation from those who apply a universal cookie-cutter approach to trauma. Although the individual circumstances and different injury patterns you will encounter are infinitely variable, I will provide you with several specific examples that seem to be often repeated.

1. *The mangled extremity* – this is the patient with one or more mangled or amputated extremities. They usually have tourniquets on and may be stable or quickly stabilize with initial resuscitation. They clearly need to go to the OR, but often are brought for a whole body CT. Pitfalls are that their wounds will continue to bleed, or will start to rebleed as their blood pressure rises with resuscitation. In addition, they often need to be intubated to facilitate pain control and positioning for the CT scan, so you have now lost the physical exam, or they become severely hypotensive with induction. Most of these patients should go right to the operating room after the initial trauma evaluation and bedside imaging, and postoperative CT scans can be obtained if needed.
2. *The pin cushion* – this is the patient with multiple small fragment wounds to the trunk and extremities. CT scan is very useful in these patients for differentiating superficial wounds from deeper penetration and injury, particularly in the neck. However, the patient with these wounds and significant abdominal pain or tenderness does not need a CT scan before laparotomy. A normal chest x-ray rules out any immediately life-threatening thoracic process, so the chest CT can wait. Similarly, a normal pulse exam is very reliable for ruling out a *significant*

**Fig. 5.2** Massive perineal blast wound with destruction of the sphincter complex and exposed distal rectum. These patients should be brought immediately to the operating room to prevent rapid exsanguination

extremity vascular injury and does not require time-consuming CT angiography prior to dealing with more pressing injuries.

3. *The massive perineal wound* – these will be some of the most difficult patients you will ever manage and can bleed to death from these wounds in a matter of minutes (Fig. 5.2). These have also become one hallmark in the constellation of injuries that characterize what is now termed "complex dismounted blast injury" or CDBI. Unfortunately, they are becoming more common due to explosive devices detonating under seated vehicle passengers or service members on foot. These wounds can be particularly deceptive because of their location on the perineum and gluteal areas and may not be fully appreciated until the patient is rolled to inspect their back. The bleeding will also be less obvious due to the posterior location and can easily accumulate a large pool of blood before becoming obvious to the bedside provider. These patients belong in the operating room as soon as possible and should almost never be delayed to obtain more imaging. The abdominal exam, FAST exam, and pelvis x-ray should provide all the information you need to proceed to the OR for wound management with or without laparotomy. Most of these are going to require a laparotomy for colonic diversion anyway, so the abdominal CT is redundant and unnecessary. If CT is absolutely necessary, you must be able to watch for hemorrhage from the perineum, while the imaging is being done.
4. *The single gunshot wound(GSW)* – although this patient is becoming less common than the blast injured patient, any combat situation will provide ample ballistic injuries to manage. The majority of these will require operative management

of the injured area and usually do not require any more extensive imaging than plain films. I often hear the justification of "unpredictable trajectories" as an indication for extensive CT imaging. Although I agree that the projectile may take an unusual path due to patient positioning during injury or bony deflection, the bullet will still obey all the laws of physics. It will not stop in mid path, reverse course, or make hairpin turn into another cavity. The following scenarios involving isolated GSWs almost never need CT imaging and should be taken expeditiously for operative intervention:

Neck wound with hard sign of vascular or aerodigestive injury
Chest wound with large volume hemorrhage (initial >1,000 cc or continued bleeding)
Abdominal wound with evisceration or peritonitis
Extremity wound with hard sign of vascular injury or compartment syndrome

## Final Points

Expert trauma management is all about prioritization, anticipation of worst-case scenarios, and playing the odds. It is not just with the initial ABCDs of the evaluation, but in every subsequent decision or intervention you make in the acute setting. In these chaotic situations with imperfect and incomplete information, you will never be right 100% of the time. Even after a decade plus of combat operations, the most common source of potentially preventable death in both the prehospital and in-hospital settings is bleeding, and this should be fully appreciated during your initial evaluation and decision-making process in the combat environment. By adopting an approach that appreciates and anticipates both the positives and negatives of each decision, you can maximize your outcomes while also minimizing the impact of any adverse events. The usual slow, methodical, and exhaustive evaluation schemes used in diagnostic medicine and civilian trauma will not serve you or your patient well, so as Basil King famously said; "Be bold, and mighty forces will come to your aid!"

## Civilian Translation of Military Experience and Lessons Learned

James W. Davis

"Operate or image?" This is the everyday challenge in trauma centers around the USA all too often. The pendulum has swung substantially from the 1970s when the exploratory laparotomy was considered completing the physical examination for the trauma patient to the current state of seemingly attempting nonoperative management of almost every patient.

The preceding chapter by Dr. Martin makes a number of excellent points. This commentary will attempt to emphasize and not belabor these points, particularly as they relate to civilian trauma practice.

Many trauma centers have adopted an algorithmic approach to the rapid evaluation of trauma patients. At our institution, it's labeled "6 in 10," the six major tasks that must be completed in 10 min or less. These include airway established, check vital signs, head-to-toe physical exam (strip 'em and flip 'em), IV access with labs, basic radiographs, and definitive care plan.

The physical examination is not cursory; every part of the patient must be checked for wounds; the range of motion on the joints on all the extremities is evaluated; and the perineum and rectum are evaluated. This examination with the results of the basic radiographs (chest x-ray and pelvis, when indicated), FAST exam, and basic labs (especially the base deficit as part of the arterial blood gas) should have the trauma team leader able to decide the crucial question of OR, angiography, or CT scan.

There are some common pitfalls. However, no patient is "too sick for the OR," and the CT scan is the worst place to run a resuscitation on a crashing patient.

## The Unstable Patient

These patients belong in the operating room. It is very tempting for the less experienced trauma surgeon to want confirmatory studies. Quickly examine the patient; get a chest x-ray to confirm of rule-out massive hemothorax, a pelvic x-ray (blunt trauma); and do a FAST. If your FAST is equivocal, do an open diagnostic peritoneal aspirate. Activate your massive transfusion protocol.

If the patient is unstable from a pelvic fracture and does not have cavitary bleeding, then a determination can be made between angio-embolization and preperitoneal pelvic packing and it should be based on time. If the patient cannot be in the angiography suite within 30 min, they belong in the OR.

## The Metastable Patient

This is the blunt trauma patient that was hypotensive in the field, received some IV fluids, maybe 1 or 2 units of PRBCs, and now has a systolic pressure greater than 100 mm Hg and a positive FAST exam. These are the patients on which the trauma surgeon can be tempted to get more imaging (CT scans). In a study by Bilello et al., almost 80% of the patients with a base deficit −6 or worse had repeat hypotension (crumped) and a fivefold increase in mortality [1]. In the patient with field hypotension, a base deficit of −6 or worse and a positive FAST go to the OR, not the CT scan.

I recently had a young male patient with a gunshot wound to the right pelvis and a tender abdomen. The initial radiograph revealed the bullet fragment on the *left side* of the pelvis. The resident had read the journal articles on imaging of gunshot wound to the abdomen to determine patients that might be managed nonoperatively and wanted to get a CT [2]. We went to the OR, found over a liter of blood in the abdomen and multiple bowel injuries necessitating resection. In some trauma centers, under strict protocol, some gunshot wounds to the abdomen (tangential injuries that do not penetrate the cavity, right upper quadrant injuries that injure the liver) may be managed nonoperatively. This approach requires the resources for quality imaging with multi-detector row CT scans, completely stable patients, and the ability for frequent serial exams.

## The "Crowd Pleaser"

This is the patient with visually compelling injuries that draw everyone's attention. This may include the mangled extremity or traumatic amputation. The "spectacular" distracting injury can divert the focus and delay evaluating the patient for the life-threatening injuries. The principles of evaluation and resuscitation remain the same. Control the active hemorrhage with compression and tourniquets as needed, and do not neglect to evaluate the patient for the life-threatening intracavitary hemorrhage. Remember from the chapter that as perfusion is restored, hemorrhage may resume as well.

## Summary

Rapid resuscitation and evaluation are the hallmarks of excellent trauma care, military or civilian. With the concerns for domestic terror-related incidents, the lessons of military trauma care are applicable for the civilian surgeon as well. Although the pendulum has swung far to the side of imaging, there are patients who only require one scan – with the #10 scalpel blade. The safest place for the severely injured trauma patient is the operating room.

## References

1. Bilello JF, Davis JW, Lemaster D, Townsend RN, Parks SN, Sue LP, et al. Prehospital hypotension in blunt trauma: identifying the "crump" factor. J Trauma. 2011;70:1038–42.
2. Lamb CM, Garner JP. Selective non-operative management of civilian gunshot wounds to the abdomen: a systematic review of the review of the evidence. Injury. 2014;45:659–66.

# Ultrasound in Combat Trauma

# 6

Michael D. Perreault, Jason D. Bothwell, and Benjamin Harrison

**Deployment Experience**

| | |
|---|---|
| *Michael D. Perreault* | Brigade Surgeon, 4/2 Stryker Brigade Combat Team, Baghdad and Taji, Iraq; 2009–2010 |
| *Jason D. Bothwell* | EMT Chief, 47th Combat Support Hospital, COB Speicher, Iraq; 2005–2006. EMT Chief, 115th Combat Support Hospital, FOB Dwyer, Afghanistan; 2011 |
| *Benjamin Harrison* | EMT Chief and Theater Consultant for Emergency Medicine, 28th Combat Support Hospital, Ibn Sina Hospital, Baghdad, Iraq; 2006 |

*"Failure to immediately recognize and treat simple life-threatening injuries is the tragedy of trauma, not the inability to handle the catastrophic or complicated injury."*

*F. William Blaisdell*

**BLUF Box (Bottom Line Up Front)**

1. Never delay transport to the OR for *any* radiologic study in an unstable patient with clear indications for immediate operative intervention. However, US can give quick and useful data in patients who are foregoing CT scan en route to the OR.

(continued)

M.D. Perreault (✉) • J.D. Bothwell
Madigan Army Medical Center, Department of Emergency Medicine, Tacoma, WA, USA
e-mail: michael.d.perreault.mil@mail.mil

B. Harrison
St. Anthony's Hospital, Department of Emergency Medicine, Gig Harbor, WA, USA



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2. US is much more sensitive than supine CXR for the detection of pneumothorax and hemothorax in blunt/penetrating trauma in experienced hands, and US should not be delayed for plain radiography in most situations.
3. US should be performed after the ABCs have been addressed: think "ABC-U."
4. Serial EFAST examinations add to the sensitivity of the test. Do an initial EFAST on arrival, and repeat the exam in 60–90 min, or if the patient's status changes. Hemoperitoneum and hemothorax may take time to accumulate.
5. US is operator-dependent, so always consider the skill and experience of the US operator and his/her confidence level when interpreting US findings.
6. Injuries on today's battlefield often include varying combinations of burns, penetrating trauma, and blunt trauma. In severely burned patients, the EFAST can quickly identify or rule out other life-threatening injuries as you aggressively manage the patient's thermal wounds.
7. US can give vital information that providers can use in making immediate triage decisions, particularly in the setting of multiple unstable or potentially unsalvageable trauma patients.
8. Use "down time" during your deployments to get comfortable (or proficient!) with US.

## Why Ultrasound?

Ultrasonography as a tool in wartime trauma management first gained widespread use during the First Gulf War, and its use has grown substantially over the past decade and a half of conflict. While most recently graduated surgeons and emergency physicians seem to embrace this modality, it can be challenging for providers who did not receive US training in their residency. Most are familiar with US, but lack the training and hands-on experience to really apply it at the bedside. That's the rub; not only does the trauma doctor need to know how to interpret and act on US images, he/she must also learn the skill of obtaining usable images *in an acceptable amount of time*.

This brief chapter is not designed to take the place of proper US training or an US course, but rather to give an overview and some references/reminders for US applications. Despite feeling comfortable or even competent performing US, true proficiency will only come through performance of dozens of extended trauma ultrasound exams. Furthermore, these skills will degrade if not practiced continually. There is a big difference between thinking a patient probably has a pneumothorax on US and actually knowing it exists (*and* placing a chest tube based on your US findings without obtaining other radiologic studies). If you are a deploying surgeon or physician who will be managing any type of combat casualties, then you *must* become familiar with the basics of ultrasound and the standard trauma exams (focused assessment with sonography for trauma or FAST) *before* you deploy.

With very little additional time and effort, you can add the skill set of basic thoracic imaging to perform the extended FAST exam (EFAST).

The great news is that most of us will be deployed with easy access to an ultrasound machine, and deployment is the perfect time to refine/maintain our US competency. Tap into the US expertise of skilled ultrasonographers in your unit – be it the radiologist, emergency physician, or trauma surgeon. Apply the skills you know and practice repeatedly on your medics or EMT patients until you feel very comfortable with the probe positioning and the images you obtain. If time allows, as you refine your skills, go back to the stable trauma patient who has already had a positive CT finding and perform a US. Alternatively, bring the machine to the ICU and perform exams on patients with known intraperitoneal fluid (usually postop) or cardiac effusions. Recognizing positive findings and learning how intraperitoneal blood, pericardial blood/fluid, or intrathoracic blood/air looks on US is a critical part of attaining proficiency. Most of us won't attain proficiency until we have performed and interpreted numerous positive EFAST scans, in addition to our "training" scans on normal patients. Once you have developed the basic skills of image acquisition, start working on efficiency. If you cannot do this quickly in a trauma resuscitation, team members can get annoyed and the slow ultrasonographer usually gets pushed out of the way. You must be able to obtain the information both accurately *and* efficiently, or this modality isn't very helpful.

*Before* you deploy, make certain that your unit will have at least one functioning US machine, or have your unit purchase one. If deploying with a CSH, get your command and supply personnel to help purchase multiple machines. US machines in the CSH will likely be in constant demand from intensivists, radiologists, and other providers. There will be times when you need an US for the evaluation of a critical patient, but they may be tied up in other parts of the hospital. Think about this in advance, since it can be very hard to get additional or upgraded US units in theater. Also have your supply folks consider the wear and tear, and coordinate with the manufacturers for replacement parts and repair ahead of time.

## Advantages of US

1. Essentially replaces diagnostic peritoneal lavage (DPL) for the detection of hemoperitoneum (quicker, noninvasive, less complications) in most scenarios.
2. Tells you if there is significant blood in the abdomen, chest, or pericardium, allowing you to more quickly perform necessary interventions (including exploratory laparotomy or emergent thoracotomy).
3. Identifies pneumothorax quickly and easily. This is very useful in managing patients in the field, or at a role I or II facility where US is the only available radiologic modality.
4. Shows us what is happening at a given point and time and allows for trending. Serial EFAST scans (after rolling the patient or after placing them in Trendelenburg position) increases the sensitivity in the stable patient.

5. Can be done quickly and at bedside; no need to send unstable patients to the “black hole” of radiology; gives additional, immediate data in patients being taken straight to the OR.
6. No contrast or radiation exposure.
7. Easily moved from patient to patient, allowing rapid triage in a MASCAL setting.

### Disadvantages of US (for the Average Ultrasonographer)

1. May miss small hemoperitoneum (100–200 ml detectable in pelvis view, 250–500 ml detectable in hepatorenal view).
2. Does not normally identify the *site* of intra-abdominal bleeding
3. Does not show hollow viscus injuries well.
4. Does not reliably show retroperitoneal bleeding.
5. Does not tell us if free fluid present is blood, ascites, urine, or (in chest) pleural effusion.
6. Relatively insensitive in pediatric patients (although helpful if positive).
7. Can be difficult to perform US in certain patients due to body habitus, air, etc.

## How to Perform an EFAST

The EFAST (Extended Focused Assessment with Sonography for Trauma) is the basic US exam used to evaluate thoracoabdominal injury. There are four basic views that are traditionally obtained in the FAST exam: right upper quadrant (RUQ), left upper quadrant (LUQ), pericardium, and pelvic. The “E” or extended portion of the EFAST came about after thorax scanning for pneumothorax was added later. Evaluation for hemothorax is more commonly being performed as part of the FAST. Search for blood above the diaphragms as you do the RUQ/LUQ abdominal views. Below is an explanation of basic techniques for obtaining views. Realize, however, that the EFAST is a dynamic process, not a series of 4–6 images. Slide the probe around and look at each view from different angles to increase your sensitivity. Placing the patient in Trendelenburg position may increase the sensitivity of your RUQ view if you are unsure if there is fluid on the pelvic view. Also, recall that a negative EFAST, particularly early in the evaluation, might still be missing accumulating blood in the intraperitoneal or thoracic space and that results should not be used in isolation when managing a trauma patient. EFAST should be repeated in certain clinical settings if initially negative. We should view US as a dynamic process and interpret results in light of the patient’s clinical picture and stability. Free intraperitoneal or intrathoracic fluid (unlike fluid within organs) tends to form collections with sharp edges or triangles as it settles between structures, rather than rounded edges seen within a viscus. Free fluid will also change size with patient repositioning and accumulation or drainage of fluid from that space.

## Basic Terms, Knobology, and Probe Selection

Not to get too technical, but we need to use certain terms to communicate in US lingo. Basically, an US probe (transducer) pushes out acoustic waves and detects reflected waves (from dense matter) that bounce back to the US probe. US waves that pass through homogenous materials do not reflect back to the probe and are termed *anechoic* (completely black, implies homogenous fluid such as urine, unclotted blood, or water). Most other organs and structures in the body are represented in shades of gray (or degrees of echogenicity), as sound waves pass through them with varying degrees of reflection back toward the probe. The more *hypoechoic* the structure, the more fluid filled and homogenous they are (and the darker they appear on US). *Hyperechoic tissue* is generally more dense and reflective (higher impedance, like bone), showing up white or lighter-gray on US. Isoechoic means that the adjacent tissue has similar appearance (or echogenicity) due to similar degrees of impedance. Examples of varying degrees of echogenicity from darker to lighter (anechoic to hyperechoic) are water-fat-liver-tendon-bone. Remember that air is the sonographer's enemy; sound waves transmit poorly through air (due to scatter) in comparison to fluids and solid organs and thus limits our exams when present. Large amounts of air in the intestine can render an abdominal US meaningless if we cannot navigate around it. Conversely, echodense structures such as the liver provide excellent sound wave transmission and can serve as a window to examine deeper structures.

The knobs on the US machine vary greatly depending on the make/model of the machine, so get to know your machine so you can tell which knob does what. The most important knob (other than the power switch) is the gain. *Gain* is basically how much amplification comes from the transducer. The more you turn it up, the more white all structures will appear on the screen. Inappropriate gain can make interpretation difficult, so adjust the gain until images look "about right" (yes, this is subjective and the more scans you do, the better idea you will have of what your images should look like). The other important knob to find is the depth. Adjust the *depth* knob to ensure the area you are imaging fits in the middle of the screen and isn't too deep (image of interest appears small at the top of the screen – hard to see details) or too shallow (area of interest extends beyond bottom of screen). There are usually markers on the side of the image that give a scale in centimeters for depth. A normal starting depth for the abdominal portion of the EFAST is in the 12–19 cm range. The other buttons can be useful in some situations, but not mandatory for doing a basic EFAST exam.

Probes come in different sizes, shapes, and design (Fig. 6.1). There is a basic trade-off to be considered when selecting a probe – the higher the frequency, the better the resolution and image quality, but the less penetration you get. Conversely, lower-frequency probes have greater penetration, but the images have lower resolution. Most EFAST views should be performed using low-frequency probes (2–5 MHz), while the high-frequency probes (5–10 MHz) are great for pneumothorax studies and superficial applications (soft tissue, vascular access). A high-frequency probe is best for pneumothorax scans, but the abdominal/low-frequency probe can


**Fig. 6.1** Examples of different types of US probes. The probe to the left of the image is a linear (higher frequency) transducer useful for superficial applications and lung imaging. The probe in the center is a phased-array transducer useful for cardiac and deep "between-rib" applications. The probe to the right of the image is a curvilinear (lower-frequency) transducer useful for deeper (intra-abdominal) applications

also be utilized. A smaller footprint, phased-array transducer (looks like a square box) can be used to allow imaging between ribs without interference for the EFAST views, although some prefer the larger, curve-shaped, low-frequency abdominal probe because of better image quality. All probes have a *transducer indicator* for orientation; the image on the US screen has a colored dot that correlates with the end of the transducer that has the marker. The general convention is to orient the indicator toward the patient's right side (for transverse/axial imaging), or toward the patient's head (for sagittal and coronal imaging).

It helps to be familiar with the characteristics of each probe, and choose the one with which you feel most comfortable when performing an application. As an aside, make sure the trauma team members know how to clean the probes and to keep them off the ground and secured when moving the unit. A damaged probe can cost tens of thousands of dollars (and weeks of repair) if the cord is run over or the probe is dropped.

## RUQ (Perihepatic or Hepatorenal) View

Opinions vary, but this is probably the view you want to obtain first in *blunt* trauma, as solid organ injury causing hemoperitoneum/hemothorax are more likely. Free intraperitoneal blood is most often identified in Morison's pouch, between the liver and right kidney. This is a relatively easy site to see abnormalities in, even for the novice sonographer. This view reliably detects volumes of about 600–700 ml of blood and 250–500 ml if the patient is in Trendelenburg position. Place the probe

**Fig. 6.2** Proper probe position for the right upper quadrant (hepatorenal) view. Note the sonographer's grasp of the probe near the probe surface. This grip provides probe stabilization with the sonographer's hand in constant contact with the patient's body

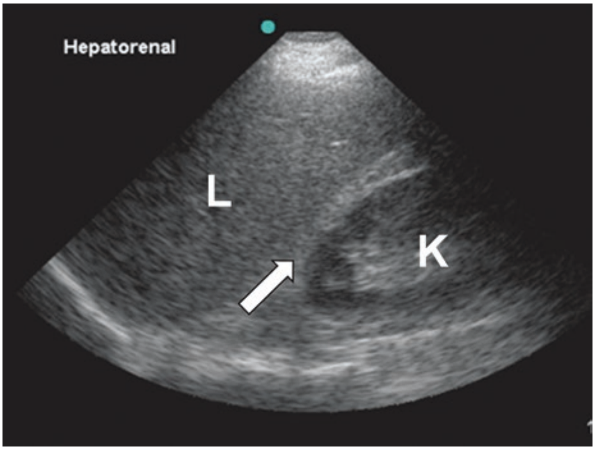


**Fig. 6.3** Normal right upper quadrant (hepatorenal) view. Note the normal-appearing hyperechoic line (*arrow*) between the liver (*L*) and right kidney (*K*)

longitudinally (with the marker dot directed cephalad) near the midaxillary line between the 8th and 11th interspaces; this is the more typically used *intercostal* approach (Fig. 6.2). Slight counterclockwise rotation may aid in obtaining images between the ribs. A *subcostal* approach may also be used, but may require the patient to be cooperative and take deep breaths, which many cannot do. In either approach, angle, slide, or rock the probe until the right kidney is seen in a longitudinal axis (coronal plane), with the hyperechoic, hepatorenal, peritoneal reflection in between (Fig. 6.3 for normal RUQ view). The normal appearance (negative exam) should look like the kidney capsule is directly abutting the liver edge with nothing in-between. Intraperitoneal blood appears (acutely and classically) as an anechoic (black) stripe between the liver and kidney (Morison's pouch) and may have varying degrees of echogenicity based on degree of clot and fibrin stranding (Fig. 6.4). To assess for other bleeding sites, direct or slide the US probe cephalad

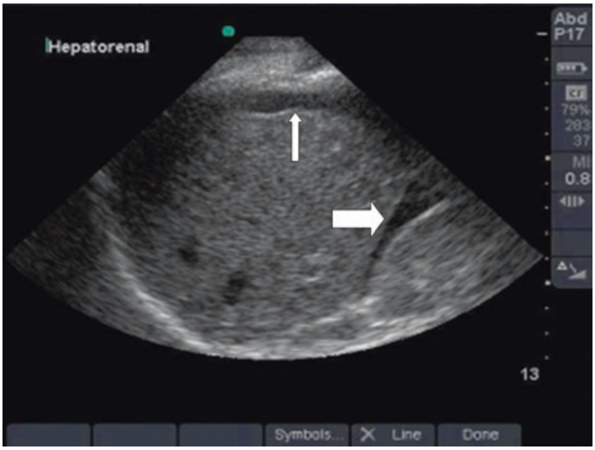


**Fig. 6.4** Positive right upper quadrant scan, with *dark stripe* of blood in Morison's pouch (*large arrow*) and above liver in the right subphrenic space (*small arrow*)

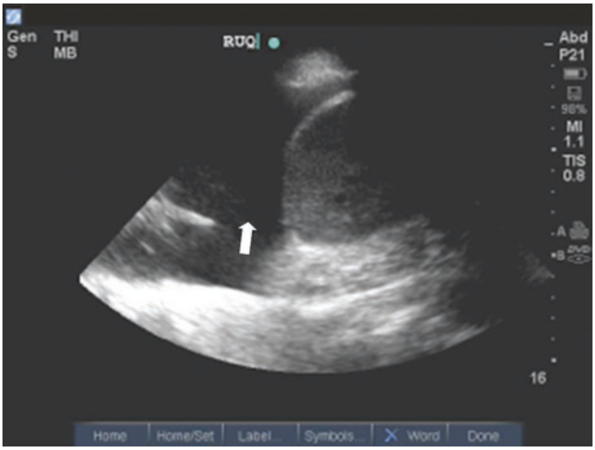


**Fig. 6.5** Right-sided hemothorax, with hypoechoic collection of blood seen above the diaphragm (*arrow*)

and posterior, through and above the diaphragm, in a coronal plane. This allows you to assess for bleeding within the liver parenchyma and subdiaphragmatic space, as well as for hemothorax above the diaphragm. Blood or fluid in the thorax will have a V-shaped appearance, while subdiaphragmatic blood will be crescent shaped (Fig. 6.5). Studies have shown that US is more sensitive at detecting small amounts of fluid in the hemithorax than supine CXR. Remember on both the RUQ and LUQ views that identifying blood in the chest requires dynamic imaging to identify the location and movement of the diaphragm during normal respirations.

## LUQ (Perisplenic or Splenorenal) View

This view is obtained with an intercostal approach. When placing the probe, start "more posterior and more superior" in comparison to the RUQ view. Reach over the patient, and place your right knuckles on the gurney near the left posterior

**Fig. 6.6** Proper probe position for the left upper quadrant (splenorenal) view. Note the sonographer's hand placement with knuckles on the gurney, more posterior and superior than the RUQ probe placement

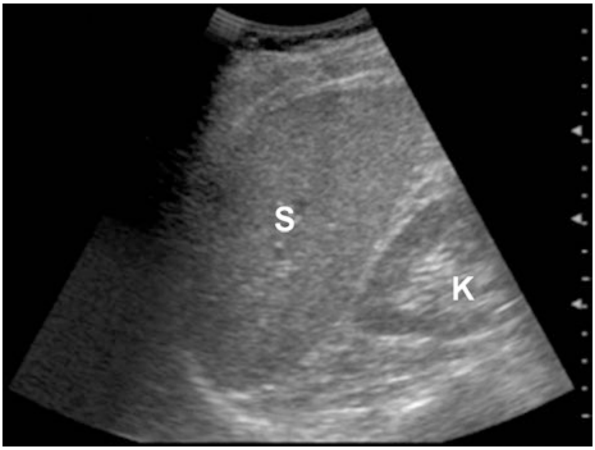


**Fig. 6.7** Normal left upper quadrant (splenorenal) view showing the spleen (*S*) and the left kidney (*K*). Note the curvilinear, *hyperechoic line* (diaphragm) above the spleen

axillary line at the 9–10th interspace with the marker dot pointed cephalad to view the splenorenal junction (Fig. 6.6 for proper probe position and Fig. 6.7 for normal LUQ view). Slight clockwise rotation may aid in obtaining images between ribs. Sweep the probe anterior and posterior, as well as cephalad and caudal, to look for bleeding from a splenic injury. Similar to the RUQ view, you will look for any blood (black stripe) building up between the kidney and spleen. But you are not done there. Remember that on this side blood most often collects in the subphrenic space, so it is vital to also look above the spleen (Fig. 6.8). In doing so, we can see hypoechoic/anechoic fluid both below the diaphragm (hemoperitoneum) and above it (hemothorax) all in one view. While not the primary purpose of the EFAST, splenic parenchymal injury can also often be visualized as you perform this view.

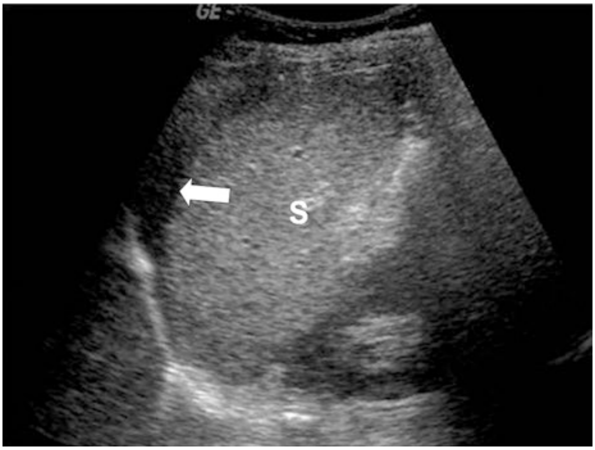


**Fig. 6.8** Positive left upper quadrant scan, with *dark stripe* of subdiaphragmatic blood (*arrow*) seen above the spleen (S). Note the crescent shape of blood, as compared to hemothorax, which has a sharper or "v" shape

**Fig. 6.9** Proper probe position for the transverse pelvic view. Note the sonographer's hand placement with caudal angulation of the probe to visualize the bladder

## Pelvic View

In most patients, this is the most sensitive view for detecting intra-abdominal bleeding; as little as 100–200 ml of blood is detectable for a positive scan. Since a full bladder helps image quality, try to perform the EFAST before Foley catheter placement. If a Foley catheter has already been placed, infuse 200 ml of fluid into the bladder and clamp the catheter. Place the probe just above the symphysis pubis in the midline and angle the probe caudally to look into the pelvis (Fig. 6.9). Obtain both *longitudinal* (probe indicator pointed cephalad) and *transverse* (probe tip to the patient's right) views (see Fig. 6.10 for normal view). In females, free fluid is seen just posterior to the uterus if there is a small amount, but may surround the uterus if there are large volumes. In males, free fluid is seen behind or above the bladder (Fig. 6.11). A common false positive comes from overreading the seminal vesicles in males, which lie between the bladder and the prostate; notice their appearance and location as you practice on normal patients.

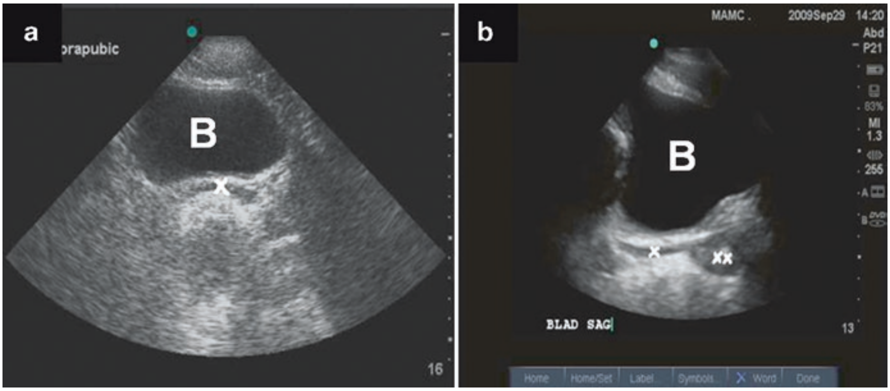


**Fig. 6.10** Normal transverse (**a**) and longitudinal (**b**) pelvic views in a male patient (*B* bladder, *x* seminal vesicles, *xx* prostate gland)

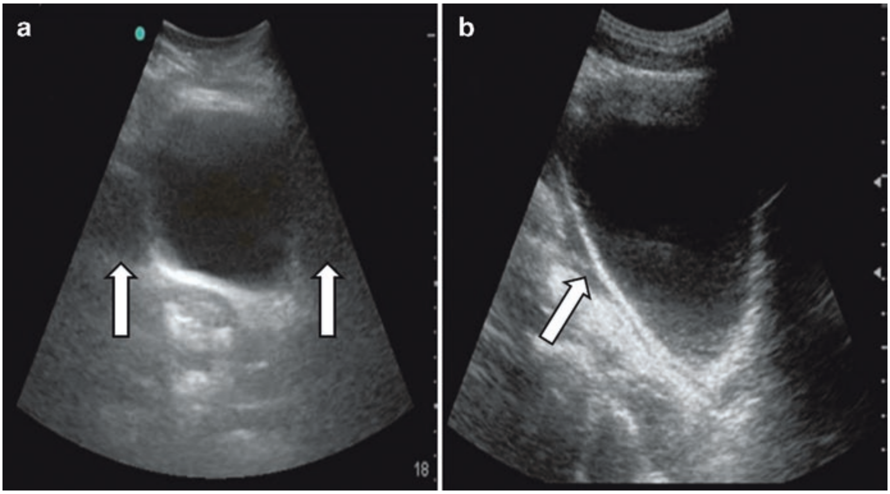


**Fig. 6.11** Positive transverse (**a**) and longitudinal (**b**) pelvic views. Hypoechoic blood is seen on either side of the larger, anechoic (*black*) urine-filled bladder in (**a**) (*arrows*). In (**b**), the *dark stripe* of blood outside the bladder (*arrow*) tracks along the intestines and the posterior bladder wall, unlike the rounded edges of urine contained within the hyperechoic bladder walls

## Pericardial View

In patients with penetrating trauma who are in extremis, you should do this view first, since hemopericardium would prompt you to perform emergent pericardiocentesis, thoracotomy, or sternotomy. The pericardium can be viewed using either the *subcostal* or *transthoracic* views. If the patient can tolerate it, the subcostal view is performed by placing the probe in the subxiphoid space with the beam directed at the left shoulder and the probe indicator toward the patient's right shoulder (Fig. 6.12).

**Fig. 6.12** Proper probe position for the subcostal pericardial view. Note the sonographer's overhand grip of the probe. This overhand grip allows the US beam to be directed at a shallower angle to better visualize the heart. If an underhand grip is used, the bulk of the hand may not allow the proper angle to appropriately visualize the heart

For morbidly obese patients or those with significant abdominal pain or upper abdominal injury, try the transthoracic view. The parasternal long-axis view of the heart is usually performed with a phased-array probe obtained by placing the probe at the left fourth to fifth intercostal space just left of the sternum (Fig. 6.13 for the proper probe position and Fig. 6.14 for a normal parasternal long-axis view). Point the transducer indicator to the patient's right shoulder (10:00 position), and manipulate it until all four chambers of the heart are seen. Pericardial blood shows up as a black stripe between the myocardium and the hyperechoic pericardium (Fig. 6.15). Pericardial fat can show up as a dark stripe anterior to the right ventricle, but doesn't surround the entire heart. Slow and fine hand movements can greatly improve your image, or move to a different interspace if you cannot obtain a good ultrasound window at that position.

## Pneumothorax Scan

US, in experienced hands, is about twice as sensitive as supine CXR in evaluating for pneumothorax in the trauma patient. Basically, you are looking for the normal pleural interface (parietal and visceral pleura) sliding across each other. This pleural line is just deep to the rib shadows and is seen as a white or hyperechoic line (Fig. 6.16). When air is present between this interface, as in a pneumothorax, the

**Fig. 6.13** Proper probe position for the parasternal long-axis pericardial view. Note the sonographer's use of a phased-array probe to better see between ribs, and the hand stabilization against the chest wall

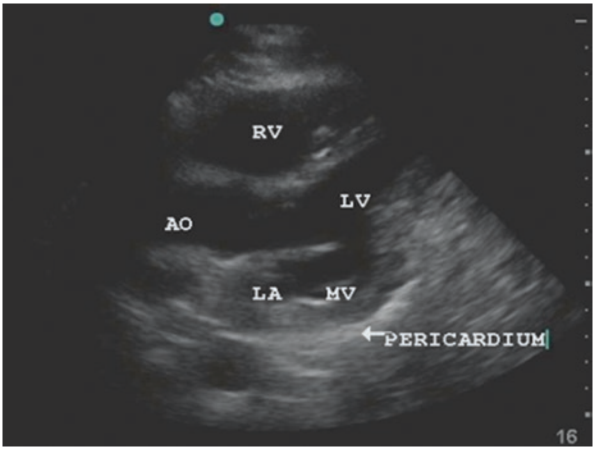


**Fig. 6.14** Normal parasternal long axis view of the heart. *RV* right ventricle, *AO* aorta, *LV* left ventricle, *LA* left atrium, *MV* mitral valve

normal "lung sliding" is absent. This sliding can be evaluated using color power Doppler (CPD) or M-mode; however, neither is necessary if you can see normal sliding. Another normal finding is "comet tail" *artifacts*, which are white projections that are caused when US waves hit the normal pleural interface. These "rays" project down to the lower edge of the screen and are not seen if air is present. CPD,

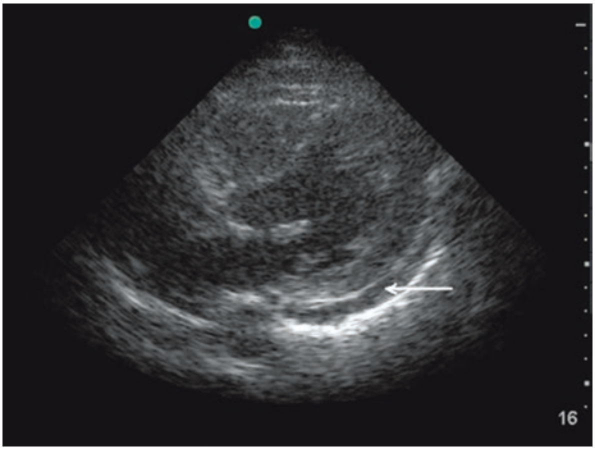


**Fig. 6.15** Parasternal long-axis view of the heart with *dark stripe* of pericardial effusion (*arrow*)

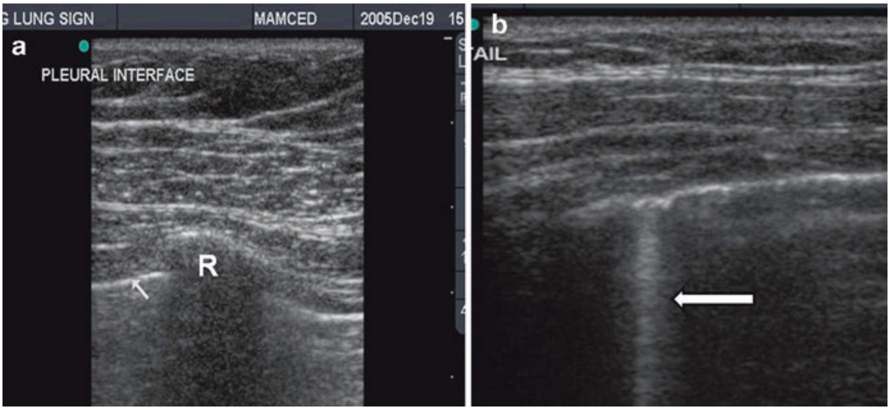


**Fig. 6.16** Ultrasound evaluation for pneumothorax performed on anterior chest wall in midclavicular line. (**a**) The hyperechoic pleural line (*arrow*) is identified on the deep surface of the rib (*R*) which demonstrates posterior shadowing. Visible sliding pleural motion on real-time exam of this area rules out a pneumothorax. (**b**) Another finding of a negative examination is a comet-tail artifact (*arrow*)

M-mode, and comet tails all require motionless patients and therefore are of marginal utility in the austere environment (e.g., in a Humvee, FLA, Blackhawk, or if the patient can't hold still). The higher-frequency (5–10 MHz), linear transducers show shallow anatomy best and conform nicely to the chest in most patients and should be used to evaluate for pneumothorax. In the supine patient, air should collect anteriorly, so place the probe at the midclavicular space, identify the ribs first as landmarks for appropriate depth, then identify the pleural line just deep to the ribs, and look for normal lung sliding (Fig. 6.17). Repeat this two to three times in different anterior, sagittal planes for each hemithorax, sliding caudal over the anterior chest to the costal margins for each scanning plane. Pause between each interspace

**Fig. 6.17** Proper probe position for the pneumothorax scan. Note the sonographer's use of a high-frequency linear probe, initially positioned at the highest point of the anterior chest

to confirm sliding, then as soon as you see normal sliding, move on. This should normally take less than a minute per hemithorax as long as you are sure there is normal sliding. For patients with hemodynamic instability or high suspicion of pneumothorax (penetrating shrapnel wounds, crepitus, etc.), place a tube thoracostomy if no sliding is seen. Occasionally, patients may arrive at your treatment facility with needle thoracostomies placed in the field. US demonstrating normal underlyinglung sliding indicates no pneumothorax and may obviate the need for immediate (or any following CT confirmation) tube thoracostomies. False-positive findings may be seen with (1) main-stem bronchus intubations (no sliding on opposite, normal lung), (2) patients with previous underlying lung disease with adhered pleura/scarring (usually older, civilian casualties), and (3) normal lack of sliding near the pericardial-pleural interface on the left.

## Making Clinical Decisions with EFAST Findings

In combat, US findings are acted upon primarily based on the type of injury, clinical stability, and operating environment available. Patients with hemodynamic instability and clear indications for surgery should be taken emergently to the OR without significant delay for imaging. In penetrating injury, perform an EFAST when immediate surgery isn't clearly indicated, especially if multiple penetrating wounds are present, or when high velocity GSWs or other projectiles may have traversed multiple body cavities. In these patients, US may help to prioritize surgical interventions such as pericardiotomy, thoracotomy, laparotomy, or sternotomy. In patients going for emergent/urgent laparotomy, US can quickly rule out pericardial blood or pneumo-/hemothorax en route to or in the OR. EFAST findings can prioritize patients for evacuation and in mass casualty settings as well. In stable patients with blunt trauma, CT (if available) is a reasonable next choice when an EFAST shows intraperitoneal blood, and nonoperative management is being

**Fig. 6.18** Proper probe position for the inferior vena cava scan

considered. CT should always be performed for an equivocal/indeterminate EFAST exam (if available) as long as the patient is stable. If CT is not available, then close observation with serial exams or a diagnostic peritoneal lavage (DPL) can be performed. In the unstable patient with an equivocal or indeterminate EFAST exam, you can quickly rule out abdominal hemorrhage as the source by performing a diagnostic peritoneal aspirate (DPA). Using either a standard DPL catheter or simply a syringe with an 18-gauge needle, aspirate as you penetrate the peritoneum (pelvis and/or paracolic gutters) with the needle. Any return of gross blood is positive and should prompt a laparotomy. See Chap. 5 for more on operative decision making, but try to do a quick EFAST if time allows in even the most critical patients since you can quickly get a lot of useful information that may guide the sequencing of initial surgical resuscitation.

## Other Useful Applications

### Evaluation of Hemodynamic Status/Central Venous Pressure (CVP) Measurement

US has additional utility in evaluating the patient in undifferentiated shock, looking for evidence of cardiac contusion/infarction, hypovolemic shock, pulmonary embolus, and cardiac tamponade. While specific echocardiography findings are outside the scope of this chapter, these are skills that can easily be picked up with some "off-the-cuff" training by the intensivists, cardiologists, emergency physicians, and trauma-trained surgeons with whom you may deploy. To estimate the CVP in any of these scenarios utilizing US, place the low-frequency probe in the sagittal plane (probe held longitudinally, marker cephalad) in the subxiphoid region to see the right atrial-vena caval junction (Fig. 6.18 for proper probe position and Fig. 6.19 for a normal IVC view). The IVC immediately adjacent to the right atrium (RA)

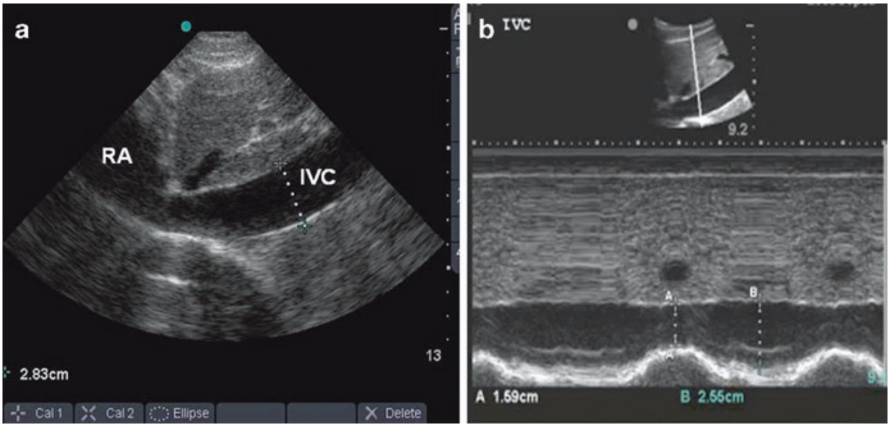


**Fig. 6.19** Ultrasound evaluation of the inferior vena cava for volume assessment. (**a**) The inferior vena cava (*IVC*) is demonstrated as it enters the right atrium (*RA*) in longitudinal section, and the measurement of 2.8 cm suggests adequate intravascular volume. (**b**) M-mode evaluation of the vena cava is used to compare the diameter at inspiration (A) to that at expiration (B). Note that this vessel shows less than 50% collapse, again indicating adequate intravascular volume status

responds directly to the pressure of the right atrium and is a rough estimate of RA pressure. CVP *estimate* may be made based on the IVC size (normally 1.5–2.5 cm diameter) and response to inspiration in the following manner:

1. Total or significant IVC collapse at inspiration → Low RA pressure, patient needs volume resuscitation and/or hemorrhage control.
2. Normal sized IVC and moderate collapse (less than 50%) → Normal RA pressure.
3. Large-sized IVC and little or no IVC collapse → High RA pressure volume overload, cardiac tamponade, heart failure.

IVC estimation can be a helpful adjunct, but it should not be used as a sole-deciding factor early in the resuscitation. Make initial management decisions based on the patient's hemodynamic stability, history, and clinical evaluation of injuries. IVC estimation may certainly be useful later in the postoperative phase, as when receiving patients from an FST/FRST after damage control resuscitation or other "used" trauma. This is a very subjective measurement that also requires you to see many normal studies to recognize abnormals.

## Triage

Mass casualty scenarios are always a possibility on today's battlefield. Most commonly, "mini-mass-casualty" scenarios are encountered when explosive devices injure several or more patients that you are called to assess. US can be an invaluable tool in gaining a lot of useful information in a short amount of time. If the surgeons and emergency physicians are busy leading the resuscitations, other trained team members can serve in this role. Radiologists, OB-GYN doctors, nurses, and even combat medics can be trained to perform EFAST when your trauma team and usual sonographers are tied up.

### Procedural

Central venous catheter placement under US guidance is becoming the standard because data suggest there are fewer complications than when placing them using traditional landmark-based methods. If time allows in the stable patient, this is a great time to refine this skill as well. Other common procedures such as thoracentesis, paracentesis, percutaneous abscess drainage, and pericardiocentesis are greatly enhanced by the addition of ultrasound guidance. The principles of needle guidance are the same in these procedures as in central venous catheter placement, and developing this skill can pay major dividends.

### Foreign Body/Soft Tissue/Musculoskeletal Applications

US can be very useful in identifying soft tissue foreign bodies, differentiating cellulitis from abscess, and evaluating other soft tissue injuries and infections. With practice, you can assess for long-bone fractures and dislocations without plain x-rays in even the most austere settings.

### Other

While outside the scope of this chapter, other relatively easy scans that may be performed in the austere setting include gallbladder (stone/infection), hydronephrosis from kidney stone, AAA, and pregnancy scanning for confirming an intrauterine pregnancy (effectively ruling out an ectopic pregnancy except in a rare heterotopic pregnancy). Many other applications, such as retinal detachment or ocular foreign bodies, compression studies of the lower extremity venous system for DVT, and testicular ultrasound are easily performed with the basic US system that most units deploy with.

## Advances and Future Applications

Recent innovations in miniaturization are leading to ever smaller and more portable US devices and transducers. With this portability come opportunities to expand US applications far forward, to the team or platoon level on the battlefield. Improvements in battery technology and life span will also extend the useful operational time frames of these devices. US use in ever more austere environments will assist in far-forward emergency care and triage.

With the expansion of US usage, training down to the medic level will be necessary. Many hospital-based nurses and medics are already currently utilizing (and are quite adept with) US to assist with peripheral venous access in emergency rooms and inpatient wards. Training programs in the special operations community are teaching specialized US applications to 18Ds that will continue to push the limits of US use as devices become lighter and more portable.

Advances in secure communication and data transmission are also making real-time telesonography possible. With this capability, images obtained in the field may be transmitted and interpreted by awaiting trauma teams, thereby speeding treatment and disposition. These innovations will only improve with time.

## Final Thoughts

In conclusion, the utility and applications of ultrasound technology in combat trauma have been solidly established and continue to rapidly expand. The flexibility, portability, and ease of use of modern ultrasound platforms make this an ideal imaging modality which is becoming a standard adjunct to the physical examination. Advances in technology, communications, and training will greatly enhance the availability and incorporation of US in the prehospital setting, potentially altering the course of initial emergency management. Your investment of time in developing a solid foundation of ultrasound skills will pay great dividends in any forward-deployed or disaster scenario you may face.

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# Part II

# To the Operating Room

# The Bowel: Contamination, Colostomies, and Combat Surgery

# 7

Robert B. Lim, Eric Keith Johnson, and Scott R. Steele

**Deployment Experience**

| | |
|---|---|
| *Robert B. Lim* | Staff Surgeon, 126th Forward Surgical Team, OIF I, Iraq 2003 |
| | Chief Medical Officer, 126th Forward Surgical Team, OIF III, Kirkuk, Iraq 2004–2005 |
| | Chief Medical Officer, 250th Forward Surgical Team, OEF X, Shindand, Afghanistan 2010 |
| | Deputy Commander of Clinical Services, 31st Combat Support Hospital, Role IIe, OEF XII, Herat, Afghanistan 2010 |
| | Chief Medical Officer, 274th Forward Surgical Team, OEF XIII, Jalalabad, Afghanistan, 2012 |
| | Staff Surgeon, 555th Forward Surgical Team, GHOSTT operations, US Special Operations Command, Afghanistan, Operation Resolute Support, 2015 |
| | Chief Medical Officer, 541st Forward Surgical Team, US Special Operations Command, Iraq, Operation Inherent Resolve, 2017 |
| *Eric K. Johnson* | Staff Surgeon, 10th Combat Support Hospital, Baghdad, Iraq 2005–2006 |
| | Task Force Surgeon, US Special Operations Command, Afghanistan, OEF 2007, Iraq, OIF, 2008 |

R.B. Lim (✉)
Tripler Army Medical Center, Department of Surgery, Honolulu, HI, USA
e-mail: rob_lim@hotmail.com

E.K. Johnson
Uniformed Services University of the Health Sciences, Tacoma General Hospital, Department of Surgery, Fox Island, WA, USA

S.R. Steele
University Hospitals Case Medical Center, Department of Surgery, Cleveland, OH, USA



M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_7

| | |
|---|---|
| *Scott R. Steele* | Staff Surgeon, 47th Combat Support Hospital, Tikrit, Iraq, 2006<br>745th Forward Surgical Team, Amarah, Iraq 2008, 541st Forward Surgical Team, Orgun-E, Afghanistan, 758th Forward Surgical Team, Qal-E-Naw, Afghanistan |

*"If you do a colostomy there will be someone to tell you why not primary anastomosis; if you do a primary anastomosis there will be someone to tell you why not colostomy."*

Mosche Schein

**BLUF Box (Bottom Line Up Front)**

1. Control of contamination from gastrointestinal tract injuries is a priority during damage control, but hemorrhage control comes first.
2. Combat wounds are typically different than civilian trauma – and should be treated that way.
3. Damage control bowel surgery means staple off or whip stitch closed. In the unstable trauma patient, control hemorrhage, control contamination, and *get out of dodge!*
4. High-velocity injuries and multiple small fragments can result in injured bowel that looks okay – have a low threshold for a planned second look operation.
5. Missed injuries kill. Pay special attention to the posterior stomach, duodenum, and jejunum near the ligament of Treitz and base of the mesentery for vascular rents.
6. The debate about colostomy versus primary anastomosis rages on, but in combat injuries you should divert much more liberally, particularly in the presence of multiple abdominal injuries.
7. Even on the battlefield, there are different echelons of care which play a role in surgical decision making.

## Does the Patient Have a GI Tract Injury?

The answer to this question is often obtained in the operating room, although in the modern combat support hospital, you will usually have access to a CT scanner and may know the answer ahead of time. The bigger issue to address remains: does this patient need to go to the operating room? A combat casualty that presents with a penetrating mechanism and a wound that violates the peritoneal cavity requires abdominal exploration, period. Hemodynamic stability may buy you time to better evaluate the situation with adjunctive studies. Yet, the bottom line for the *unstable* patient with a suspicion of intra-abdominal trauma based on injury pattern and mechanism remains that if the pattern and mechanism point to the abdomen, then a laparotomy is in order. You will figure out what is damaged in the operating room, and preoperative imaging

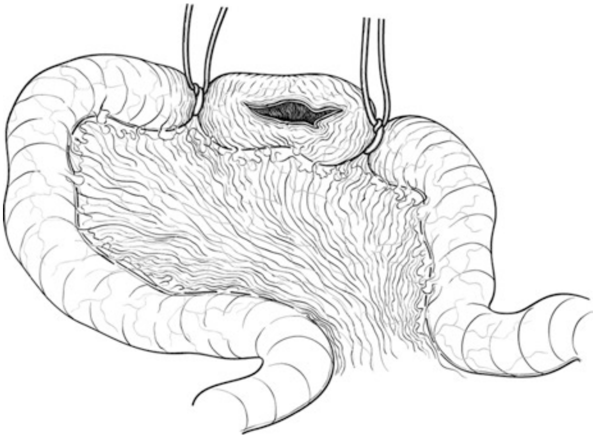

**Fig. 7.1** Rapid control of bowel contamination using umbilical tapes passed through a small mesenteric window and tied to occlude the lumen

will add little benefit. In fact, "stable" is often really a misnomer for the combat casualty with a penetrating wound to the abdomen. They may appear clinically well for the moment, but that can change quickly. Unfortunately, you will likely encounter a situation where a patient with a penetrating abdominal wound has to wait in line for the operating room either from a mass casualty event or expended resources. Don't forget this patient – assign a nurse or medic to reevaluate him frequently in your absence, as they may push themselves to the "front of the line." In fact, repeat triage is standard and a mandatory part of mass casualty management.

Trust your physical exam and clinical judgment; you will rarely regret it. If the patient is awake and alert, do a careful physical exam of the abdomen. In these mostly young and healthy patients, the abdominal exam is highly reliable for identifying peritonitis. If you push on their belly in two separate places and they have a clear severe pain reaction, that is peritonitis. No CT scan is needed to "confirm" your exam or to look for other abdominal injuries. Your careful exploration should be better than any CT scan. If they are not examinable, then you have to rely on injury patterns and possible imaging studies but should have a low threshold for exploration.

In contrast, if one is located in a remote area, has a hemodynamically normal patient with an isolated penetrating wound to their abdomen, and is able to reliably and expeditiously (i.e., make it to a higher level of care within 60 minutes) transfer a patient, then it is reasonable to delay an operation until they reach the more secure and better resourced combat support hospital. This would allow the forward surgical team to remain equipped to treat a truly unstable patient. Communication with the gaining institution is paramount with all transfers, so they know exactly what type of injured patient they are receiving.

## What to Do Once in the Operating Room?

Make a big enough midline incision so that you may adequately explore all quadrants of the peritoneal cavity. You will likely encounter lots of blood and contamination and perhaps a large retroperitoneal hematoma, but don't let this affect you. Have a systematic approach to packing the abdomen and exploring it one area at a time. Control hemorrhage first and then spend time controlling contamination. Many of these casualties will require a “damage control” approach to treatment. We found it useful to have an egg timer in the room that was set for 45 min. When that timer went off, we knew it was time to start “cleaning up” and ready the patient for transport to the ICU. You want to be fast, but not furious. Calm and focused gets you out of the OR faster and safer than panicked and hurried. Don’t get in such a hurry that you miss a major injury that will lead to the patient’s demise. A small missed injury may be forgivable when you go back later and find it, but a major missed injury is a mistake that may not give you another chance.

We employ two useful techniques to quickly control contamination from bowel injuries. In the umbilical tape approach, mesenteric windows are created on the proximal and distal sides of the injury, which the tape is then passed through and tied (Fig. 7.1). This works well when you have focal areas of injury, but is not as effective when you have a long segment of injured small bowel or colon that is laden with succus or stool. The second approach requires the use of gastrointestinal anastomotic stapling devices. In this approach we rapidly create mesenteric windows on both sides of the injury and then fire the staplers through the windows effectively closing and dividing the bowel at these points. We then fire additional staplers across the mesentery of the injured bowel, staying close to the bowel wall and using vascular loads. You can resect injured segments of small bowel in less than 60 seconds using this technique. Alternatively, you can take the mesentery with the serial creation of windows and placement of clamps. To make this maneuver faster, take large bites of the mesentery with each clamp (3–4 cm) for en masse ligation and only clamp the proximal side. Use your hand to control bleeding from the distal side until the specimen is excised.

Colonic resection in mobile areas can be accomplished almost as quickly with the same techniques. Injuries to the colon at points of retroperitoneal fixation such as the ascending and descending colon simply require a moderate amount of mobilization to achieve the same end. You can also employ the use of atraumatic bowel clamps to assist when there are multiple areas of contamination to deal with or to close small anterior holes. In the “damage control” setting, this is all that is initially required. A quick washout and temporary abdominal closure is all that remains between the patient and critical care in the ICU. *Do not* get bogged down by small bleeders in this situation. Just focus on getting your cold, coagulopathic, and acidotic casualty to the ICU where these problems, also known as the lethal triad, can more effectively be addressed.

In addition to operating quickly and efficiently, one must again consider their location when deciding how best to do damage control. Operating in the far forward setting mandates only doing damage control surgery as the subsequent operation will be at a higher echelon of care typically only 1–2 h of transport away. There, a second look if only to wash out an opened abdomen is expected; but certainly a second look to look for occult injuries, to mature ostomies, or to put the bowel back in continuity is the norm. Transferring out of the combat theater often takes much longer, and as such, the patients should be hemodynamically normal and their injuries much more stabilized to tolerate the trip that may be several hours away.


**Fig. 7.2** Resection of part or all of the greater curve is accomplished rapidly with a stapled sleeve gastrectomy. Ensure you leave at least 3–5 cm of antrum to avoid dysmotility and obstruction problems (Modified from *Endocrinology and Metabolism Clinics of North America*, 37(4), Brian R. Smith, Phil Schauer, Ninh T. Nguyen, Surgical approaches to the treatment of obesity: bariatric surgery, 943–964, Copyright 2008, with permission from Elsevier)

## Injuries to the Stomach

You must expose the entire stomach and use both inspection and palpation to evaluate for injuries. Your high-risk areas for a missed injury are high at the gastroesophageal junction or along the lesser curve. If there is a hole in the stomach, then always find the other hole or explore it well enough to convince yourself 100% that there isn't another one. There is a classic triad of injuries here that include the stomach, the spleen, and the diaphragm so one should look for these associated injuries. Retract the left lobe of the liver anteriorly and open the avascular gastrohepatic ligament to examine the lesser curve. The lesser sac should *always* be opened and inspected, which allows evaluation of both the pancreas and the posterior stomach. Divide several inches of the gastrocolic ligament along the greater curve at the midpoint to enter the lesser sac. Retract the greater curve anteriorly and to the right to examine the posterior stomach, and insert your entire hand into the lesser sac to palpate for injuries. Squeeze the stomach or insufflate with air via the nasogastric tube to look for extravasation of fluid or food particles.

Most nondestructive injuries to the body of the stomach can be managed through simple mobilization of the organ and closure of the hole with a single firing of a TA or GIA stapler. Injuries involving the lesser and greater curvatures of the stomach may be addressed by a wedge resection of the injury using two firings of a gastrointestinal anastomotic stapling device. The stomach possesses a tremendous amount of redundancy, which is to the surgeon's advantage. Destructive injuries to the greater curvature may be managed using a sleeve gastrectomy technique as long as a reasonable lumen is preserved (Fig. 7.2). The patient may lose some weight in the long run, but they will be alive.

Severe injuries to the antrum may require antrectomy and reconstruction. Our advice here is to keep the procedure simple and complete. Beware of leaving retained antrum on the duodenal side of the resection if you plan on using a Billroth II or Roux-en-Y reconstructions. Take only what you need to take since the indication for resection is trauma. Our preferred reconstruction is gastrojejunostomy with Braun enteroenterostomy because of its simplicity. Utilize GIA staplers as much as you can, but sutured anastomoses can be quite useful in the setting of edematous bowel and where staplers are not available. Injuries to the gastroesophageal junction can be quite complex and difficult to treat. Utilize gastroesophageal anastomosis only when absolutely necessary as this anastomosis can be difficult to construct and comes with a high risk of leak. The circular stapling device can simplify this problem, but nondestructive injuries are probably best managed with primary closure (over a bougie dilator); nasogastric decompression; buttressing of the esophageal repair with by the surrounding muscle, fascia, or pericardium; and closed suction drainage. Assess any potential damage to the vagus nerves that may require you to perform a pyloroplasty, although this is rarely needed. Don't waste time on steps like this in the damage control setting. You do not need to leave drains at the initial damage control procedure if you have adequate closure of the defect and are planning a vacuum type temporary closure and second look operation. A closed suction drain should be left adjacent to your repair prior to fascial closure or at your last exploration prior to placing the patient in the evacuation chain. Eventually this patient may need feeding tube placement also.

## Injuries to the Small Intestine

You have done a damage control laparotomy on a soldier who was injured when a roadside bomb detonated under his vehicle. He had about 100 small fragment wounds to his torso and bilateral amputations. You "ran the bowel" in standard fashion and fixed several mesenteric tears before your temporary closure. He is now febrile to 103F and oliguric in the ICU. When you reopen his abdomen in the OR, you find enteric contents throughout the belly from several pinhole-sized enterotomies. Don't let this scenario happen to you or your patient. The number one principle for managing small intestine injuries is to *find all the holes*. This is easy with a high-velocity gunshot wound that blew apart the terminal ileum, but can be extremely difficult with multiple millimeter-sized fragment wounds. This mechanism is not seen in civilian trauma, where the rapid hand-over-hand running of the bowel is fine to rule out bullet-sized holes.

For these types of combat injuries, you must identify the obvious injuries and then diligently search for the less obvious ones. Pinhole-sized enterotomies from fragment wounds may look like a speck on the serosal surface or a tiny hematoma that you would otherwise leave alone. The other common area for missed injury is

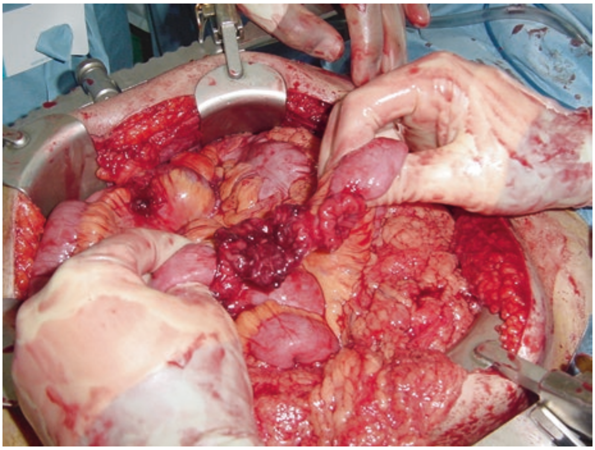

**Fig. 7.3** Multiple destructive bowel injuries from a high-velocity gunshot wound

a perforation into the mesenteric border, which may look like a small mesenteric hematoma or discoloration at the bowel margin. Firmly grasp and elevate the bowel as you run it. Milk each segment manually to observe for spillage or leakage of air. Even though you may be in damage control mode, take the 5 min to slowly and carefully run the entire small bowel. Explore any area of question on the serosal surface or at the mesenteric border. If you are still not sure if there is an injury, you can insufflate air or saline via a 20-gauge needle into that segment of bowel while occluding proximally and distally. Oversew any areas of concern as you proceed along the bowel. When you identify an injury or serosal tear that requires repair, do not proceed with a plan to come back and fix it after running the rest of the bowel. Either repair it right away, or mark it with a suture to repair later. In the heat of battle, there are many distractions that could result in you forgetting about the injury, with disastrous consequences.

These injuries are the simplest to manage from the technical aspect, but there are a few pitfalls with which to be familiar. The primary goal of trauma surgery is to save the life of the casualty, but you must also consider the long-term consequences of the procedure you perform. You must try to preserve small bowel length, but you cannot do this at the expense of the patient. If it needs to be resected, then you must resect it and deal with the consequences later. The first step once you have identified the injuries is to classify them in your mind as “destructive” or “nondestructive,” which will determine your repair options. In general, destructive injuries involve 50% or more of the circumference or have disrupted the mesenteric blood supply enough to result in ischemia (Fig. 7.3). These injuries should prompt resection. Other indications for bowel resection are multiple closely clustered injuries to a focal segment, a large complete mesenteric defect (“bucket-handle” deformity, Fig. 7.4), or failure of a prior primary repair.

If the injuries are amenable to primary repair, then proceed with a definitive repair technique. You should debride the injury margin sharply to viable, bleeding

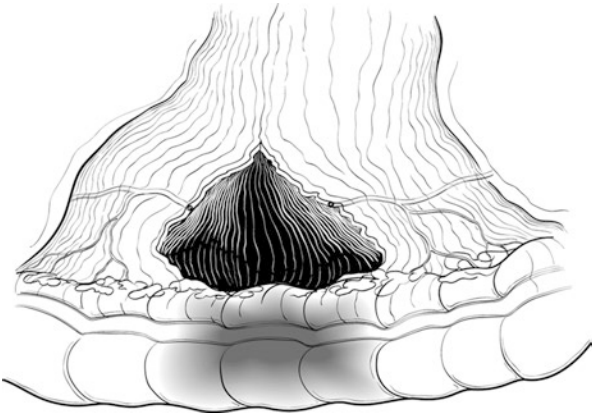

**Fig. 7.4** Mesenteric injury ("bucket handle" deformity) with intact bowel wall. This injury should prompt resection

**Fig. 7.5** Bowel injury from a blast fragment demonstrating small enterotomy and larger surrounding area of thermal injury (*white tissue*). The entire thermal injury must be debrided

edges, and then repair them in a transverse fashion such that the bowel lumen is not narrowed. Look for a white discoloration of the serosa surrounding larger fragment holes – this is a thermal burn and must be entirely excised prior to repair (Fig. 7.5). Primary repair can be done with suture or TA staplers, but remember that the stapled method will almost always result in more narrowing than a sutured repair. Injuries that are not amenable to primary repair should be resected and ultimately reanastomosed using a side-to-side technique that can be performed with linear staplers or sutures. Sutured anastomosis may be more secure when confronted with severely edematous bowel, but otherwise it is based on surgeon preference and the importance of speed (stapled is always faster). A rapid technique for performing the stapled anastomosis and resection at the same time using only two stapler firings is shown in Fig. 7.6. If you are resecting a very large segment, or multiple segments, remember to measure and record the amount of small intestine that remains intact.

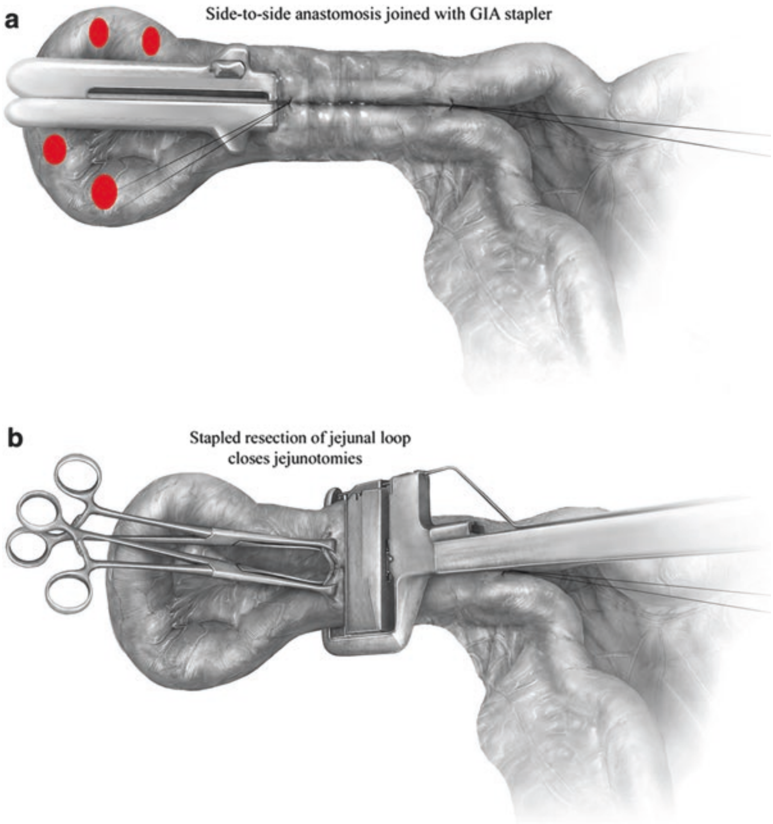


**Fig. 7.6** Double-stapled technique for simultaneous resection and bowel anastomosis. The bowel proximal and distal to the injured segment (*circles*) is opposed and an anastomosis is created with a linear stapler (**a**). The resection is then completed by firing a linear stapler transversely, incorporating the two limbs of the injured segment and the common enterotomy for the anastomosis (**b**) (Modified from *Operative Techniques in General Surgery*, 9(1), Stapled small bowel anastomoses, Guillaume Martel, Robin P. Boushey, 13–18, Copyright 2007, with permission from Elsevier)

A *minimum* of 100 cm of small bowel in the absence of the ileocecal valve or 75 cm with an intact ileocecal valve is preferred to maintain adequate nutrition via the enteral route. It is also ideal to preserve as much of the terminal ileum as possible since it has specific functions that are not present in the jejunum.

Another issue we often face is whether or not to preserve the ileocecal valve. Obviously its preservation is preferred, but when the integrity of this portion of the intestine is in question, then it should just be resected in the combat casualty. If the bowel looks marginal at the first laparotomy, it will look worse at the next. High-velocity missiles do a tremendous amount of collateral damage, and you will often be forced to remove more intestine than you would in the civilian trauma setting. Preserve the structure if you can, but place an anastomosis no closer than 5 cm proximal to the valve to avoid constructing an anastomosis at the site of a potential distal obstruction. If the valve itself is injured, we would not recommend trying to repair it. Perform an ileocecectomy and an anastomosis or a diverting ileostomy as clinically indicated.

## Injuries to the Colon

Colonic injuries are common and are associated with higher rates of infection and postoperative complications than other GI tract injuries. You will certainly encounter colonic injuries that are tempting to repair primarily. *This is not civilian trauma!* Forget what you learned by reading the recommendations for the treatment of penetrating colonic injuries in civilian trauma patients. We recommend resection of penetrating colonic injuries caused by high-velocity missiles in all but the smallest of injuries – and even then consider resection. You do not need to perform the typical oncologic procedures, but you should resect the injury with a significant margin of normal-appearing bowel. Ensure that the remaining bowel has a good blood supply via the ileocolic, middle colic, inferior mesenteric, or marginal arteries through collateralization. One common scenario that is encountered is injury to one of the main vessels supplying the colon. When this occurs, you must assess the viability of the effected region of the colon. If there is any question, then it should be resected. The marginal artery will keep just about any portion of the colon alive as long as it is preserved. Always consider the watershed areas of the colon (splenic flexure and sigmoid) carefully when confronted with this situation.

You will inevitably encounter the situation where a projectile penetrates the mesentery adjacent to the colon, but does not result in a colotomy. Take caution in this situation. Often the result is injury to a portion of the marginal artery and cavitation effect on the bowel wall (see Fig. 7.4). The colon will appear viable but may not remain so after your procedure is complete. This is where combat surgical judgment is paramount. Our recommendation is to perform a segmental resection in this situation with an anastomosis if clinically indicated. Ileocolonic and colorectal anastomoses are the easiest to construct and are the most reliable.

Mandatory colostomy for all combat-related colon injuries was historically practiced by the military based upon the dismal outcomes with early attempts at primary repair or anastomoses. As with most "mandatory" dictums in surgery, this practice is not supported by current data or experience from both combat and civilian trauma but still has some supporters. On the other side of the argument, the current civilian practice has moved toward primary anastomosis for almost all penetrating colon injuries. The "truth" for combat colon injuries lies somewhere in the middle of these positions, but we clearly should be more conservative than our civilian counterparts with attempting primary anastomosis. The decision to perform an anastomosis is often a difficult one and is based on good clinical judgment and an assessment of the tactical situation. You have to take into account the portion of colon injured, the stability of the patient, the level of contamination, the mechanism of injury, and the presence of associated injuries. You should also consider whether you are going to be able to observe the patient closely

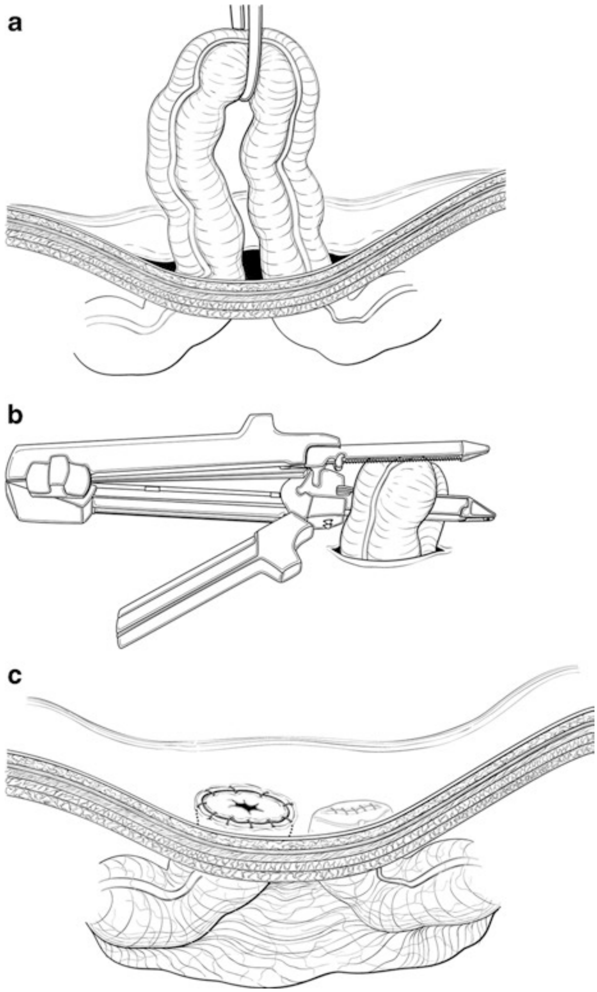

**Fig. 7.7** Technique for a stapled “end-loop” ostomy. The ostomy loop is delivered through the fascial defect (**a**) and divided with a linear stapler (**b**). The proximal staple line is excised and the ostomy matured to the skin, while the distal stapled end is left in the subcutaneous position for easy subsequent closure (**c**)

postoperatively, or whether you will be placing him into the medical evacuation chain. Right-sided injuries may often be reanastomosed in patients that are hemodynamically stable, non-coagulopathic, warm, and non-acidotic. Anastomosis in the setting of massive transfusion, multiple colonic injuries, or associated injuries such as a pancreatic injury *should not* be performed. These patients are better served with ileostomies or colostomies or a damage control procedure with the bowel initially left in discontinuity and reexamined following resuscitation. Perform a tactical retreat and return to fight another day.

In general, there remains a lot of debate regarding the use of stomas or primary anastomoses for left-sided injuries. As above, there are certain situations where it is clear that you should bring up an ostomy (i.e., massive transfusion, multiple injuries, etc). For the remainder of the injuries, you should evaluate them on an individual case based on other factors. If there is any doubt, left-sided injuries should not undergo reanastomosis in the setting of combat trauma. You may "get away" with this once, but you will live to regret it if you make this a matter of practice. There will be many situations where only a small amount of colon requires resection, and the easiest method of reconstruction is to perform a colo-colostomy. Also, do not forget about the option to perform a primary anastomosis and use a proximal stoma (i.e., loop ileostomy), as this can divert the stool while distal healing takes place. Figure 7.7 demonstrates an easy technique to perform a completely diverting and easily reversible "end-loop" ostomy. Remember that the anastomosis may still leak, but proximal diversion minimizes the resulting clinical sepsis. This also makes the subsequent operation for ostomy reversal a much easier and lower risk procedure. Hand-sewn or stapled techniques both work well, but we recommend you follow the same rules stated above for creating an anastomosis.

It is also important to keep in mind the differences in culture and support when dealing with the local national population with colon injuries. Stomas are viewed in different, and often untoward, ways in many societies. As such, patients are commonly faced with limited supplies and technical and emotional support and may be viewed as outcasts within their own population. They can also be expected to have little to no access to high-quality medical or surgical care in the future and may never have the chance for ostomy reversal. While this may cause you as a surgeon to be more apt to perform a primary anastomosis, this must be weighed against the increased risks of concomitant underlying malnutrition, comorbidities, tobacco use, and limited medical support should the patient leak. Helping your situation, many local nationals will be able to stay under your care for longer periods of observation than coalition troops undergoing medical evacuation within 24–36 h. Based on this very different risk/benefit analysis (compared to US soldiers or civilians), many deployed surgeons have thus adopted a more liberal policy for doing primary anastomoses in local national casualties. Although these considerations are rarely discussed, and may be even more difficult to grasp, you need to take these into account when encountering this injury pattern in the local population.

## Injuries to the Rectum

In general, diagnosing and localizing rectal injuries can often be difficult, but addressing rectal injuries should be fairly straightforward. The basic principles of proximal diversion and distal washout will work in most situations. Presacral drainage has been debated over and over, but we feel that it is not necessary in the majority of cases. Perhaps the only case is for a large sacral injury with a lot of spillage and then for only a short time initially to evacuate the fluid. The real challenge with these injuries can be their identification. A patient that presents with a suspicious pattern of wounding (penetrating gluteal, trans-pelvic wound, multiple perineal

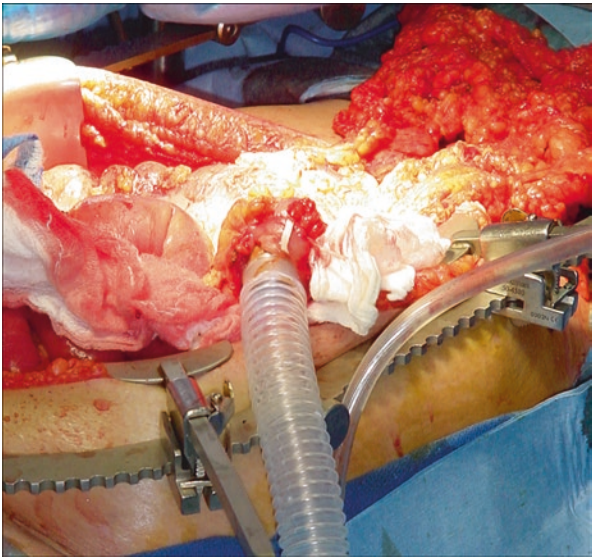

**Fig. 7.8** Simple technique for on-table bowel lavage using ventilator tubing (disposable ventilator circuit set) secured in the bowel lumen with an umbilical tape

fragments), as seen with complex dismounted blast injuries, or hematochezia should undergo rigid proctoscopy to identify an injury. A patient with blood in the rectum on proctoscopic exam without an identifiable proximal source has a rectal injury until proven otherwise and should be treated as such. For those patients undergoing preoperative CT scans, look for perirectal edema or stranding, pelvic fragments, and air or fluid in the pararectal space, all of which may indicate rectal injury. As such, these casualties should be approached as if they have a rectal injury. Rectal injuries are managed differently depending on whether the injury is intra- or extraperitoneal. Intraperitoneal rectal injuries can be managed in the same manner as left-sided colonic injuries. The injury should be resected leaving a Hartmann's pouch distally, and a colostomy can easily be created from the proximal sigmoid colon. In select situations (rare in combat) you can consider a colorectal anastomosis, but we would recommend strong consideration of a proximal diverting loop ileostomy if this option is chosen.

Extraperitoneal injuries present a different challenge. The simplest and most straightforward method of managing these injuries is to create an end-loop colostomy (see Fig. 7.7) and perform a distal rectal washout. A loop of sigmoid colon is chosen for colostomy formation and is delivered onto the anterior abdominal wall through a properly sited stoma aperture. Flow into the efferent limb of the stoma is prevented by stapling across the distal portion with a transverse firing of a TA-60 stapler. Prior to the firing of this stapler, a large-bore catheter is placed into the afferent limb of the stoma, and saline is flushed through, while an assistant keeps the anal sphincter open to prevent any resistance to flow (often with the use of a rigid proctoscope). This cleans out the distal rectum and makes presacral drainage unnecessary. Ventilator tubing borrowed from anesthesia can be placed into the open bowel and secured with an umbilical tape to perform an on-table lavage (Fig. 7.8). The TA-60 stapler is then fired and the colostomy is matured. Presacral drainage is talked about more often than done. The problem with presacral drainage is that you have to enter the presacral space from a perineal approach and you have to dissect into the area of injury. The drain must be placed in this area to be effective. Because of the difficulty with this approach, the drain is often malpositioned and ineffective. There is no need to expose and resect extraperitoneal injuries. They will typically heal after a period of diversion, and those that don't can be approached in the elective situation. Whatever you do, do not spend any amount of additional time trying to identify and repair an extraperitoneal rectal injury that will do just as well with diversion alone. This will only lead to prolonged operative times, increased blood loss, and onset of the lethal triad of acidosis, hypothermia, and coagulopathy, if it is not already present.

You may encounter the scenario where the casualty has a destructive rectal injury associated with pelvic hemorrhage or a massive perineal wound. This is more complex and will usually require some extraperitoneal resection and pelvic packing to control hemorrhage. Most often the exposure has been performed for you by the missile or fragment that caused the injury. The best move in this situation is to pack the pelvis with laparotomy pads to control hemorrhage and attempt to control contamination to the best of your ability. This will almost always be a patient who undergoes a damage control procedure with a stay in the ICU for rewarming and resuscitation. Once the patient has been stabilized and has met your criteria for resuscitation, you may return to the OR and "clean" up. This will often require resection of devitalized extraperitoneal rectum and maturation of a colostomy. The patient is often left with a very short Hartmann's pouch in this setting. Pelvic exposure is often difficult to obtain and can be improved through the use of a simple technique that we advocate. We use a Bookwalter or similar self-retaining retractor system to assist with retraction of the midline incision. The small and proximal large bowel can then be wrapped in a moist towel and packed cephalad. A handheld large malleable retractor is then bent into a U or horseshoe shape and placed at the pelvic inlet. This works very nicely to keep the pelvic inlet widely exposed and prevents the bowel from "creeping" into the operative field. This will provide adequate pelvic exposure for any possible scenario and is particularly useful if you are operating without the assistance of a second surgeon to aid exposure.

Finally, we recommend a colostomy in those patients with a large perineal injury that disrupts the anal sphincter causing continence disturbances. Also, those patients with complex pelvic fractures, spinal cord injuries, and open pelvic and perineal wounds in which fecal soilage may lead to an increased risk of infection and difficulty with wound care should all undergo stoma placement.

## Timing of Reconstruction After Damage Control

This is a subject that can be debated vigorously. We think that it should be summarized in two questions: when do you go back to restore small bowel continuity and gastric continuity and create stomas; and how do you decide whether or not to restore colonic continuity? Obviously the less time the patient spends with bowel ending blindly, the better. Damage control is performed to avoid a lengthy initial procedure in the operating room that the patient is too unstable to endure. These patients often either present with or develop hypothermia, coagulopathy, and acidosis. They are unstable and often require a massive transfusion of blood products. They are too sick to withstand the surgical insult, and any repair performed at the time of initial surgery is likely to fail. For this reason, our initial goals are simply to control hemorrhage and contamination and leave the operating room. The care provided in the ICU will eventually result in the correction of the lethal triad or the patient will expire. There is no preordained time frame for the patient to return to the operating room. They are ready to return when they are no longer cold, coagulopathic, and acidemic. That may be in 8 h or it may be in 2 days. In general, we would prefer to go back to the operating room within 48 h, at least for a washout. Aggressive resuscitation will commonly facilitate this, often within the first 24 h. Yet, correction of the patient's physiologic milieu will be the determining factor.

When the patient does meet the criteria to return to the OR, they may still not be in optimal shape for restoration of GI continuity. If the bowel is markedly edematous, it is probably not the optimal time to perform an anastomosis. If all that needs to be completed is a colostomy, that can certainly be done the first time they return to the OR. Abdominal closure is often not possible and must be delayed until appropriate. A temporary abdominal closure is employed until no longer necessary. It is probably not wise to leave multiple sections of blind small bowel and colon for much longer than 72 h. Once this time period is reached, you should consider beginning your reconstructive plan if you haven't already. Gastric and small bowel reconstructions are less fraught with complication and can be performed using staplers or sutured techniques even if the gut wall is edematous. The real judgment comes into play with restoration of colonic continuity. As stated previously, we recommend diverting many left-sided resections. This may include the use of a primary colo-colostomy and diversion of the fecal stream proximally with the use of a loop ileostomy. Restoration of right-sided resections can be performed if they are appropriate to perform soon after the first damage control procedure. If the patient has a prolonged resuscitation or the bowel remains very edematous after the first 72 h, we would recommend diversion with an ostomy and mucous fistula or long Hartmann's pouch.

## "Used" Trauma

The somewhat indecorous term "used trauma" refers to a trauma patient a surgeon has received in transfer that has had operative therapy at the sending facility. The usual associated sentiment is "all the interesting, fun, or dramatic operations have been done; now I'm the one left with the tedious task of getting the patient through the insult!" You may at some point receive patients who have undergone a laparotomy for bowel or other abdominal injuries at an outside facility. If this was a US or coalition military medical unit, then you will usually receive adequate documents to sort out what was done. However, you will also receive patients who were treated at a local facility with vastly different practices, supply situation, and trauma capabilities compared to a modern US facility. They will often arrive poorly resuscitated or in extremis and with either indecipherable medical records or no documentation whatsoever. Two local practices that were commonly encountered in the local management of abdominal injuries were (1) to leave open colon wounds in situ with a small drain placed adjacently and close the abdomen and (2) to bring out the injured portion of bowel to the skin as a makeshift ostomy. You will also encounter patients who had a colostomy performed as a routine part of the trauma laparotomy and who have no bowel injuries or true indication for diversion. It was not uncommon to reexplore the abdomen in these patients and find extensive dead bowel or ongoing soilage with resultant sepsis and/or death.

*Treat these transfers like a fresh trauma and assume nothing!* Start resuscitation, administer antibiotics, and prepare your operating room. Work them up from head to toe as if they had just been injured and not received any care or evaluation. All of these patients should undergo immediate exploratory laparotomy to sort out their anatomy, treatment of injuries, missed injuries, and extent of abdominal soilage. In many cases you will find an abdominal disaster brewing or in an advanced stage and should initiate a full damage control strategy. In other cases, you may find no significant injuries and may even be able to perform immediate reversal of an inappropriately placed ostomy.

## Tractotomies/Treatment of Entrance and Exit Wounds

Penetrating trauma resulting from high-velocity missiles that injure the bowel often leads to infection. There is often considerable spillage of GI content, and the exit wound, if present, is often severely contaminated with this material. You are not done when you finish addressing the gastrointestinal injury. You must address the wounds – particularly the exit wound. There is often considerable tissue destruction in the vicinity of the exit wound. When this is combined with GI contamination, a sort of “perfect storm” for infection occurs. The exit wound should be debrided to ensure removal of all devitalized tissue, along with extensive irrigation of the remaining wound, with pulse lavage, if available. This wound should then be observed serially for signs of infection. Any high febrile episode or foul drainage from the wound should be reevaluated in the operating room. Necrotizing soft tissue infections are not uncommon in this scenario and are best managed early and aggressively in their course.

## A Word About Antibiotics

Combat wounds are dirty by definition as blast or IED injuries will typically have soil, foreign bodies, and projectiles in the wounds. To date, there have been no quality studies evaluating the role of antibiotics for these wounds, but it is likely that most, if not all, wounded patients receive antibiotics during their initial resuscitation and around the time of surgery and ICU care. Similarly, there are no quality studies evaluating the efficacy of antibiotics for wounds complicated by bowel contamination in combat. Furthermore, the initial surgery may be done in a tent or in a setting without positive pressure ventilation such that the ambient air alone carries a high concentration of infectious agents, which makes the risk of infection even higher. All of this means that a second- or even third-look operation, even if just to wash out the abdominal compartment, is part of the routine treatment of bowel-injured patients to ensure that all gross or visible contamination is treated. Antibiotics should be used routinely in addition to the surgical washouts.

## Civilian Translation of Military Experience and Lessons Learned

Scott R. Steele

**Key Similarities**

- Following the standard principles of maintaining adequate blood supply, avoiding tension, apposing healthy bowel segments, and performing a technically appropriate operation are keys to excellent outcomes when performing a bowel anastomosis.
- The decision to repair versus doing damage control may be similar to what the remote rural surgeon faces.

**Key Differences**

- Access to diagnostic equipment such as radiology and endoscopy may not be available in the combat environment and lead to higher rates of exploration.
- High-velocity injuries of the colon and rectum may be better treated with diversion.
- Resource allocation and remote location associated with the military setting pose additional challenges that may require a change in management plan (i.e., damage control surgery implementation or having a low threshold for abdominal exploration with even the seemingly innocuous penetrating abdominal wounds).

### Discussion

Many of the lessons learned in combat have direct relevance to the civilian sector and are easily applied in both environments. Specifically, regarding bowel injuries, the majority of patients in both settings can still be safely managed in primary fashion using direct repair or bowel resection and anastomosis. Regardless of the situation, traditional principles of a safe and proper repair/anastomosis must still be adhered. More extensive injuries in either setting do not necessarily mandate proximal diversion. However, patients with significant and sustained hypotension, large transfusion requirements, concomitant major comorbidities or associated injuries, and uncontrolled abdominal sepsis may benefit from diversion, as outcomes are generally inferior regardless of the method of repair. Alternatively, definitive reconstruction or diversion can be delayed in the setting of the severely injured patient at significant risk of hypothermia, coagulopathy, and acidosis – the lethal triad – by invoking the principles of damage control surgery. Prevention of further fecal contamination and hemorrhage control through the use of clamps, staplers, umbilical tape, or even a "whip stitch" can rapidly accomplish the immediate goals in these severely injured patients and allow for resuscitation and delayed management of the bowel injury when the patient is more stable.

Nevertheless, variations in care based on the combat versus civilian sector appropriately exist. Military trauma is often associated with high-velocity wounds, multiple associated injuries to adjacent or distant organs from fragments, and significant burns that may result in wide-ranging physiological variations. These fluid requirements may lead to significant bowel edema that can impact healing in the setting of primary repair. In addition, the associated thermal damage to the bowel from high-velocity wounds may evolve over time, resulting in areas of delayed injury presentation that may result in a leak. Collateral damage to adjacent structures may result in a high morbidity that can have a direct impact on the bowel anastomosis.

The military surgeon must also consider the environmental differences that can dramatically impact the treatment plan. Initially, the lack of diagnostic equipment such as multi-slice CT scanners or endoscopy may cause the military surgeon to proceed with abdominal exploration at a much higher rate. Diagnostic laparoscopic equipment is almost routinely unavailable as well. Therefore, rates of negative exploration may be much higher in combat, where conservative "watch and wait" strategy is impossible due to the surrounding circumstances. Moreover, while a missed injury may result in detrimental outcomes in both settings, the resultant consequences in theater may be much more severe. Supply limitations and remote locations often play a role in the combat environment and pose additional challenges for which the military surgeon must be aware. Injured soldiers may be required to have prolonged transportation within and between theaters, resulting in segments of time where constant high-level attention may not be available or direct access to the operating room is not possible. In light of these differences, diversion may be a more sound or attractive option, even when primary anastomosis is possible. Furthermore, the combat environment is littered with instances of multiple casualties and limited surgical personnel. The military environment, similar to a mass casualty in a remote rural environment, must not only take into consideration the patient's anatomy, physiology, and injury pattern but also the number and degree of other incoming casualties, blood and other product availabilities, as well as holding capacity and evacuation needs for all injured personnel.

In an effective civilian trauma setting, the higher levels of care should have good communication and awareness of the capabilities of the smaller surrounding hospitals. Stabilization of intestinal injuries may be the only thing possible for the smaller community hospital. Subsequently, planned second looks and transferring of patients with open abdomens should be expected, particularly if there are multiple other traumatic injuries. Subsequently, open and collegial feedback of such cases should be considered and implemented to help improve the system for future events.

## Final Points

Just as any infantryman goes into battle with an assortment of weapons, ammunition, and techniques, you must go into the operating room armed for the various scenarios you may encounter. Don't make the mistake of treating combat casualties like you would with victims of civilian trauma. The anastomosis that looks great when constructed will be leaking in 48–72 h, and you will scratch your head and wonder why. They are just sicker patients. The mechanisms of injury are more severe and are often combined in additive or exponential fashion. It is not uncommon to see a patient that has a combination of blunt, blast, burn, and penetrating trauma. They will not react or heal like someone who was wounded with a 9 mm pistol or was in a car accident. There will be times when you can revert to the standard methods, but when confronted with a very injured and very unstable casualty, you have to assume and prepare yourself for the worst.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Management of war wounds.

# Liver and Spleen Injury Management in Combat

8

Brian Eastridge, Lorne H. Blackbourne, Katherine M. McBride, and James R. Dunne

**Deployment Experience**

| | |
|---|---|
| *Brian Eastridge* | Trauma surgeon<br>947th Forward Surgical Team<br>Afghanistan<br>2002 |
| | Deputy Commander Clinical Operations<br>General and trauma surgeon<br>94th General Hospital<br>Landstuhl Regional Medical Center<br>2003 |
| | Trauma surgeon<br>Director, Joint Theater Trauma System<br>67th Combat Support Hospital<br>Mosul, Iraq<br>2004 |
| | Director, Joint Theater Trauma System<br>USCENTCOM<br>Iraq/Afghanistan 2007 |

B. Eastridge (✉)
University of Texas Health Science Center at San Antonio, Department of Surgery, San Antonio, TX, USA
e-mail: eastridge@uthscsa.edu

L.H. Blackbourne
Department of Surgery, Joint Base San Antonio, Brooke Army Medical Center, San Antonio, TX, USA

K.M. McBride
Memorial University Medical Center, Department of Surgery, Savannah, GA, USA

J.R. Dunne
Memorial University Medical Center, Trauma Services, Savannah, GA, USA


M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_8

| | |
|---|---|
| | Director, Joint Theater Trauma System<br>USCENTCOM<br>Iraq/Afghanistan<br>2010 |
| | Trauma surgeon<br>911th Forward Surgical Team<br>Afghanistan<br>2014 |
| *Lorne Blackbourne* | Trauma surgeon<br>Special Operations Command<br>2001, 2002, 2005, 2006, 2007 |
| | Chief, General Surgery and Trauma<br>31th Combat Support Hospital<br>Baghdad, Iraq<br>2004 |

**BLUF Box (Bottom Line Up Front)**

1. Sometimes your clinical judgment is all you have.
2. Remember the clock started long before the patient got to you…prevent and treat the lethal triad.
3. Damage control resuscitation and damage control surgery…temporizing therapy saves lives.
4. Solid organ injury in the abdomen in combat is almost exclusively a surgical disease.
5. Keys to a successful operation: exposure, exposure, exposure. Big problems require big incisions, and they heal side to side not end to end.
6. Spleen: if it is injured, it belongs in the bucket.
7. Liver: pack, pringle, pray. If it is not bleeding, don't mess with it.
8. Packing is an art. Be an artist.
9. Retrohepatic hemorrhage: make the diagnosis early, communicate with the folks above the drapes, *total hepatic isolation*, repair.
10. You can't repair or resect until you've *fully* mobilized. *Exposure* is the key element to a successful operation. Don't chase your target; bring your target to you.

## Introduction

The management of hepatic and splenic injuries on the "home front" has changed dramatically over the last two decades. The impetus for this change has been driven largely by improvements in diagnostic and interventional capabilities facilitating nonoperative therapeutic strategies for blunt abdominal trauma. Management of these same injury patterns on the battlefield presents unique challenges unlike those experienced in civilian trauma care. The deployed surgeon is frequently faced with managing these injuries in the context of severely poly-traumatized casualties or multiple casualties, all of which must be evaluated using sound clinical judgment and only a modicum of diagnostic information. In the civilian setting, most trauma surgeons identify solid organ injury with high tech multi-detector CT scans. Management of all but the most severe of these solid organ injuries is relegated to the interventional radiologist to control arterial hemorrhage by virtue of angioembolization. Having limited medical care resources in the austere combat environment, the military surgeon must expect and prepare to operate on splenic and hepatic injury. The basic premise for the management of these injuries is simple. In general "do not let the skin stand between you and the diagnosis," particularly in the unstable patient with the potential for abdominal injury. Have a "battle plan" in mind before the scalpel is placed to the skin: control bleeding, control contamination, and get out.

## Basic Concepts

Although each patient and injury is unique, the application of a standard and conservative approach will optimize management, minimize the risk of missed injury, and improve outcomes. "Conservative" in this circumstance means "surgery." All penetrating injuries to the peritoneum require exploration. In contrast to the civilian trauma setting, there is a limited role for nonoperative management of blunt splenic injury on the battlefield with the exception of low-grade injuries. Several studies derived from the data from military operations in Iraq and Afghanistan demonstrated that blunt splenic injury, particularly AIS grades 1–3, could be successfully managed nonoperatively with appropriate selection of stable patients without other indications for laparotomy. These management decisions were predicated on a low op-tempo environment, whereby combat casualties could spend as much time as necessary in the hospital at the strategic evacuation platform to ensure they remained hemodynamically stable with stable hemoglobin concentrations. The failure of nonoperative management was low with no deaths attributable to the requirement for subsequent surgery. Splenic injury in the context of hemodynamic instability, falling hemoglobin, or any sign of clinical deterioration is basically an "old school" surgical disease. Blunt hepatic injury can be managed nonoperatively, particularly if the hematoma is intraparenchymal and there is no gross extravasation of contrast. Just as in blunt splenic injury management, in the mature theater with strategic air evacuation, do not evacuate the liver injury casualty to level IV until you are comfortable with their clinical status.

Before delving any deeper into the specifics of the surgical management of the liver and spleen injury, it is important to be familiar with a few of the broad overarching concepts with respect to abdominal injury. The battlefield trauma surgeon must have a keen understanding of tactical combat casualty care (TCCC), damage control resuscitation, and damage control surgery, including being facile with exposure techniques. After injury in a combat zone, casualties are attended to by self, combat life savers, medics, and corpsmen in austere environments with limited resources.

These prehospital providers have been provided the tools and training for airway management, compressible junctional hemorrhage control, and peripheral hemorrhage control. However, no current capability exists to control noncompressible truncal hemorrhage. The most common cause of potentially survivable injury leading to death on the battlefield is hemorrhage, and the majority of the hemorrhage is noncompressible bleeding within the chest, abdomen, and/or pelvis. Medical evacuation and operational contingencies may further protract casualty arrival to the military medical treatment facility such that many casualties with abdominal injury will arrive in shock with attendant hypothermia, acidosis, and coagulopathy. The surgeon needs to act quickly to counteract the further evolution of the "lethal triad" of trauma. Metabolic acidosis is a consequence of inadequate tissue perfusion often from hemorrhage in the combat casualty. Hypothermia is due to the lack of intrinsic thermoregulatory capacity, also secondary to the decreased availability of oxygen to develop cellular energy. This hypothermia can also be exacerbated by cold climate. Coagulopathy results from consumption, dilution, ongoing blood loss, interrelationships with intrinsic thermoregulatory mechanisms, and acid/base balance. If not corrected, this lethal triad will be uniformly fatal. Consequently, it is vitally important to have substantial resuscitative resources in addition to surgical resources at facilities that provide damage control surgical capability.

Contemporary military data suggests that the requirement for a massive resuscitation can be predicted by simple parameters available clinically or with point of care testing in the resuscitation area of the medical treatment facility (MTF):

- Pattern recognition
  - Bilateral proximal amputations
  - Truncal bleeding and one proximal amputation
  - Large chest tube output
- Base deficit (BD) ≥ 5
- INR ≥ 1.5
- Systolic blood pressure (SBP) ≤ 90 mmHg
- Temperature ≤ 96 °F

In circumstances that warrant massive transfusion, the damage control resuscitation concept, which is a combination of permissive hypotension and hemostatic resuscitation, should be utilized. With this paradigm, crystalloid infusion should be minimized and the ongoing resuscitation conducted with a balanced ratio of plasma to red blood cells to platelets (if available). The availability of component therapy will usually be adequate at level III facilities depending on the stage of the conflict, but supply may be taxed in mass casualty scenarios. In contrast, level II facilities are frequently not well resourced with blood and blood products. In situations where the demand exceeds the limited supply of blood component resources, the surgeon should liberally call for fresh warm whole blood when utilizing the damage control resuscitation concept. See Chap. 4 for a detailed discussion of these concepts and practices.

## Diagnosis

Penetrating abdominal trauma does not require an extensive diagnostic evaluation, and the patient almost exclusively belongs in the operating room for an exploratory laparotomy. If the mechanism is single or with several projectiles (gunshot wounds), then plain x-ray of the chest and pelvis is helpful to identify locations of the missiles or fragments. Don't forget to do a pericardial ultrasound unless you have already decided to do a pericardial window in the OR. In the "unstable" patient, just go to the OR and figure it out there. A more common scenario in modern conflicts will be the patient presenting with multiple small wounds from an explosive device, many of which may be superficial, as well as a blunt component from the blast or vehicle crash. Evaluate these patients with a good physical exam and a trauma ultrasound (FAST) to triage them to CT scan or the OR. The FAST has proven very effective for the assessment of abdominal injury in guiding further diagnostics and surgical management after battlefield injury. Patients with unstable vital signs or peritonitis should go right to the OR; otherwise, a CT scan is very helpful for delineating the number, location, and depth of penetration of the projectiles as well as any intra-abdominal injury.

Once you have diagnosed an injury to the liver and/or spleen, now comes decision time. The number one factor is always patient stability, followed by your physical exam and imaging findings. In the combat setting, these clinical decisions will be influenced by the availability of interventional capabilities (usually none), blood bank capability, the ability to closely and serially observe the patient (usually limited, particularly in forward environments), bed and ICU capacity, and evacuation chain status. All of these factors usually weigh much more heavily in favor of operative management rather than observation only. You can consider nonoperative management for low to moderate grade injuries (grades 1–3) with no evidence of bleeding and no other injuries requiring operation, and in a patient you can observe for at least 48–72 h. Otherwise the best option is usually to "heal with steel" in the operating room.

## Exposure

Though many alternatives are available, the midline incision is the most expedient and versatile incision for opening the abdomen. This incision can easily be extended into a median sternotomy for exposure and control of the intrapericardial inferior vena cava which may be necessary, particularly in patients with retrohepatic vena cava injury. Remember that once the peritoneal cavity is entered, the exploration should proceed in a methodical fashion by order of priority: hemorrhage control, contamination control, and definitive repair if possible/warranted. Subcostal extension of the incision may be useful for optimum exposure, particularly for management of hepatic injury.

Do not skimp on your exposure! Exposure and expedience are the two critical factors to improve damage control surgical outcomes. Attempting a limited incision laparotomy approach is usually a waste of time and effort – in patients who often don't have extra time to spare. To adequately mobilize, pack, and potentially definitively manage liver and spleen injuries, the upper extent of the incision must be at level of the xiphoid, so make a full laparotomy incision from the start. As a side note, if you get called to assist on a difficult laparotomy, the most effective contribution you can usually make right away is to extend the incision and thereby improve exposure.

## Evacuation and Packing

Should you begin your laparotomy by doing a full four quadrant packing, or just suction out the blood to identify the bleeding area and get to work? The dogmatic factions that adhere steadfastly to their particular technique will never completely agree on the best approach to the trauma laparotomy with hemoperitoneum, but each has its applications and advantages. Many very experienced trauma surgeons have discarded the mantra of trauma to "pack all 4 quadrants" and either do focused packing in the area of injury or do no packing and simply evacuate the clot in order to identify the injury that is bleeding the most significantly. This approach has merit for injuries to a single area or vessel that you can quickly identify and control and, likewise, avoids wasting time and supplies. It is a less effective and inappropriate technique for injuries to multiple areas with large-volume hemorrhage and patient instability. What is clear is that haphazardly pushing a handful of laparotomy sponges into a large pool of blood does nothing for exposure or hemorrhage control. Packing is an art, so be an artist.

Before you open the peritoneum, make sure the OR tech has several packs of lap sponges ready to go (unfolded) and more available. Your suction will potentially become clogged immediately or overwhelmed with the volume of blood, so it will have limited utility early in the case. If you encounter a large volume of hemoperitoneum, then the initial goal is evacuation. This can be accomplished by scooping out large clots with your hands followed by rapidly placing two or three packs at a time into and then immediately out of the abdomen. This will rapidly absorb the blood from the operative field even with high-volume bleeding and allow you to plan your next move based upon where the hemorrhage is coming from. Once evacuation of the majority of the hemoperitoneum is completed, the abdomen can then be packed.

Packing the left upper quadrant to control splenic bleeding should accomplish two goals: (1) minimization of hemorrhage and (2) medialization of the spleen into the surgical field for better visualization and surgical access. This is best done from the patient's right side with manual or self-retaining retraction of the left costal margin (Fig. 8.1). Use one hand to mobilize the spleen and retract it inferiorly, and then place several packs in the space between the spleen and diaphragm. Next cup the spleen and retract it toward you, placing packs between the spleen and the left-sided retroperitoneum and abdominal wall. Often just these two maneuvers will control hemorrhage, but if not then additional packs can be placed directly over the spleen.

Packing the right upper quadrant to control liver bleeding is more difficult and may require mobilization of the liver as well as properly placed packs to effect any substantial compression (Fig. 8.2). The most effective way to immediately control a

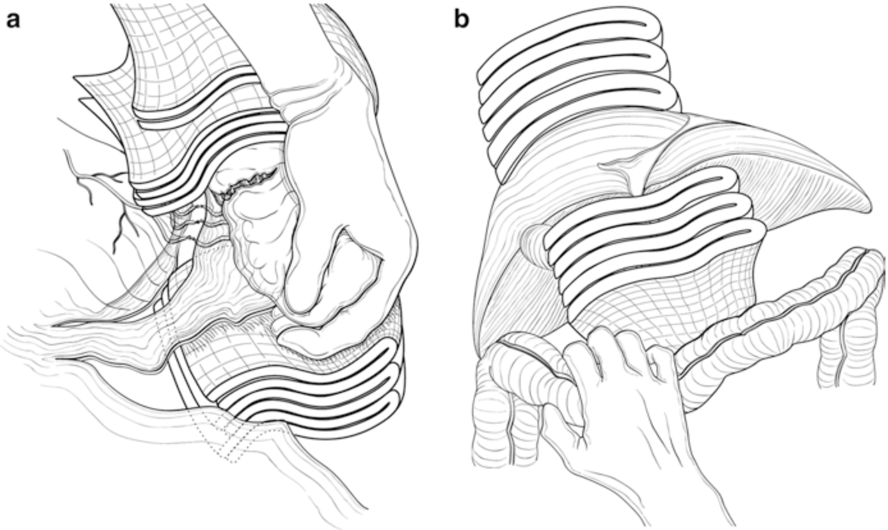


**Fig. 8.1** Packing of abdominal solid organ injuries. (**a**) Retract the spleen inferiorly and medially to pack above and behind the organ first, then you can add packs over the top. (**b**) Packing of the liver requires packs above and behind the dome as well as inferiorly. This will also mobilize the liver into your surgical field

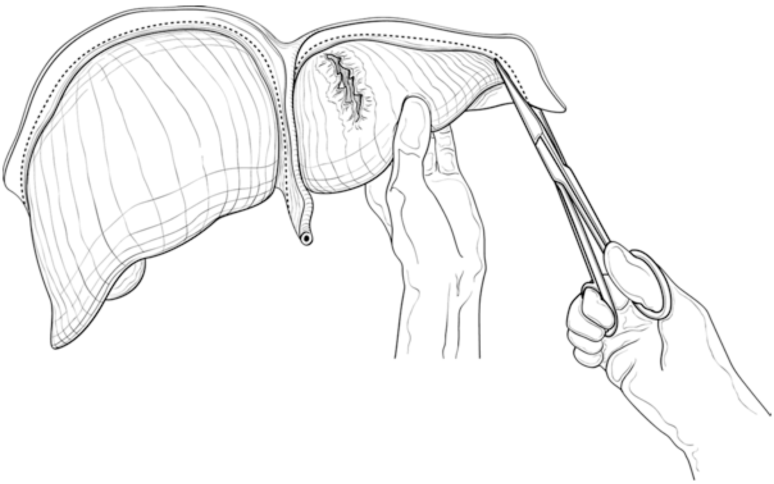

**Fig. 8.2** The liver will be only minimally mobile until you release the ligamentous attachments to the anterior abdominal wall (falciform), diaphragm, and lateral abdominal wall

major hepatic laceration or "burst" injury is with your hands and manual compression. Do this prior to performing a full mobilization and packing in the unstable patient to allow some anesthesia catch-up time. Next quickly divide the falciform ligament and continue straight down the coronary ligament with electrocautery or scissors, allowing retraction of the liver away from the abdominal wall and diaphragm.

The liver, and particularly the right lobe, should now be mobile enough to retract inferiorly and medially into your field. Place packs behind and above the right lobe and left lobe if needed.

## Spleen

The spleen should be carefully evaluated by gentle traction of the organ caudally and medially. With this manipulation technique, the spleen can be mobilized to near the midline in an atraumatic fashion. Any injury to the spleen should be investigated thoroughly. Small capsular tears or lacerations that are non-bleeding or those in which the bleeding can be controlled with simple electrocautery or topical hemostatic agents can usually safely be left in situ. However, higher-grade splenic injuries in the military operational environment not amenable to simple hemostatic surgical techniques should be treated with splenectomy. Unlike the civilian environment in which some of the intermediate grade splenic injuries can be managed with surgical salvage therapies such as hemisplenectomy, extensive suture repair, or prosthetic wraps, the contingencies of the combat environment, especially the evacuation intervals without the capacity for surgical therapy, preclude the utilization of splenic salvage.

Once the decision has been made to perform a splenectomy, the spleen is retracted medially and the ligamentous attachments to the colon, left kidney, peritoneal surface, and diaphragm are taken down. Not infrequently, the dissection plane has already been developed by the splenic hemorrhage, and this mobilization can be done bluntly. Once mobilized, the vascular attachments to the spleen should be ligated sequentially. The major vascular pedicle into the hilum should be suture ligated with a heavy braided suture. Alternatively, a linear stapler with a vascular staple load can be used to rapidly divide the hilum providing excellent security and hemostasis (Fig. 8.3). Always assess the tail of the pancreas – if it is injured or intimately adherent to the splenic hilum, simply fire your stapler proximal to this to include the pancreatic tail with the specimen. If there is any question about injury to the tail of the pancreas, a closed-suction drain should be placed. VERY IMPORTANT: do not underestimate the capacity of the short gastric vessels to cause problems. After the spleen has been removed, it is important to reexamine the splenic bed and the greater curvature and fundus of the stomach to ensure that all short gastric vessels have been ligated and adequate hemostasis achieved. It is important to note that gastric distension will overcome poorly tied ligatures.

## Liver

If hemorrhage is emanating from the right upper quadrant, the strategy is different. Since the liver is not a resectable organ in toto, efforts are focused upon hemorrhage control in situ. Do not attempt a major hepatic resection in a damage control setting unless you have no other option! The first technique to control bleeding is hepatic

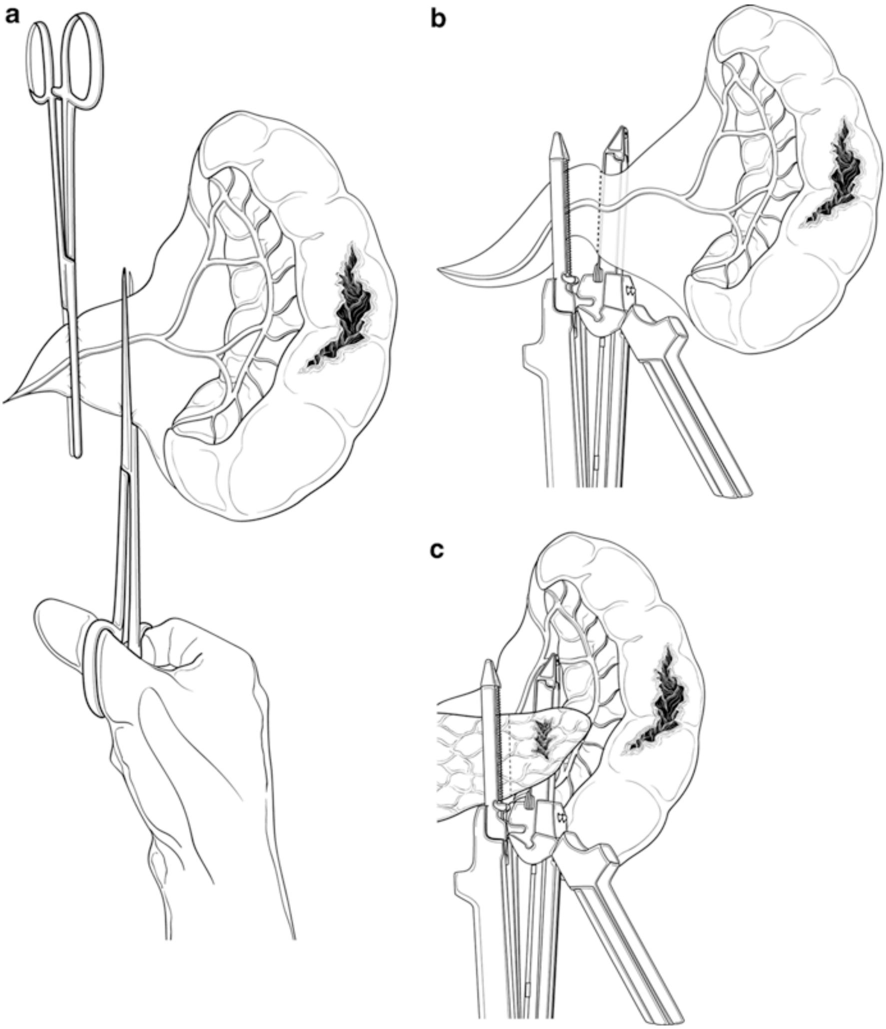


**Fig. 8.3** Techniques for a trauma splenectomy include (**a**) en masse hilar clamping and ligation, (**b**) linear stapled splenectomy, and (**c**) linear stapled splenectomy with distal pancreatectomy

packing and is done with laparotomy pads around the liver to grossly restore the anatomy of the liver as described above. An adjunct to this technique is the addition of topical hemostatic agents into/around the hepatic laceration. In many instances, this is the only technique that is required to control hemorrhage. It is vital for the surgeon to understand the solid organ packing concept and be facile with the technique.

If packing or reconstitution of the hepatic anatomy by compression is ineffective, then a Pringle maneuver should be applied. This maneuver is the initial hepatic vascular control technique and is effected by the surgeon passing the left hand into

Morrison's pouch posterior to the porta and subsequently placing the left thumb on the gastrohepatic ligament so that only a small veil of tissue is present between the thumb and forefinger. At this point, a window is created in the gastrohepatic ligament, and an umbilical tape passed to encircle the porta. A Rummel tourniquet can be utilized for subsequent temporizing control. The porta hepatis can similarly be controlled with a vascular clamp, but these tend to be cumbersome as they are less maneuverable. The Pringle maneuver is both a diagnostic and therapeutic technique. By compressing the porta hepatis, the hepatic inflow from the common hepatic artery and the portal vein are compressed. As a diagnostic strategy, this is a useful tool because if the bleeding is controlled by the maneuver, then the hemorrhage is largely intraparenchymal vascular (portal venous and hepatic arterial) in nature. If, on the other hand, the Pringle fails to control the hemorrhage, then the hemorrhage is likely due to hepatic vein or retrohepatic vena cava injury. From a therapeutic standpoint, if the hemorrhage is controlled by the technique, then that allows the surgeon gross hemostatic inflow control while attempting to develop more definitive control measures. In general, the Pringle maneuver can be applied for approximately 60 min. Start your timer and keep track of the duration of liver ischemia!

The management of parenchymal liver wounds depends upon the site and severity of the injury. Devascularized peripheral or segmental injuries should be managed by resectional debridement. This resectional debridement can be done with finger fracture techniques and direct suture ligation of remaining structures or with a GIA stapler utilizing a vascular load. However, there is no role for anatomic surgical resection in the acute post-injury setting. If hemorrhage is coming from deeper within the liver substance and is not amenable to packing alone, then a limited hepatotomy may be developed by incising the overlying Glisson's capsule followed by finger fracture of the hepatic parenchyma with direct ligation of vessels and biliary structures. Once the main vascular structures are isolated and controlled, packing and adjunctive topical hemostatics are often useful to maintain hemostatic control. An adjunct for management of dead space within these large hepatotomies, particularly at subsequent operation, is the placement of a pedicled omental flap within the wound and closure of the overlying hepatic parenchyma. This is accomplished utilizing 0-chromic suture on a liver needle taken in deep bites through the peripheral liver substance to close the hepatotomy.

One noteworthy injury that can be extremely challenging in the austere environment is the transhepatic missile injury with hemorrhage. The quandary in this instance is that the bleeding site could be anywhere along the tract, and a large hepatotomy is not feasible. In this circumstance, it may be possible to tamponade the deep parenchymal hemorrhage with a balloon tamponade device. This device can be fashioned by cutting several side holes in a red rubber catheter and then passing the red rubber catheter through a Penrose drain. The Penrose is subsequently tied down onto the red rubber catheter utilizing heavy silk ties both proximally and distally. The improvised tamponade device is then passed gently through the hepatic wound tract. Once through the tract, the red rubber catheter is clamped distally, and the Penrose is inflated with saline to effect intrahepatic tract tamponade. Then the proximal end of the red rubber catheter is clamped. One last potential therapeutic option in the patient with ongoing arterial hemorrhage from deep within the liver substance which is difficult to control either due to depth or the degree of hepatic destruction is selective ligation of the associated major branch hepatic artery. Often, the portal vein can maintain the viability of the liver substance. If the diaphragm has been violated in conjunction with the hepatic injury, the diaphragm should be repaired in order to minimize the potential development of a bronchobiliary fistula (a very morbid and frequently lethal complication).

"Audible bleeding" with the Pringle applied requires prompt decision and action. First, you must consider context. Management of an injury to the retrohepatic vena cava or hepatic venous complex requires a tremendous amount of resources including blood/blood products, OR time, personnel, and equipment, many of which are in limited supply, particularly in mass casualty scenarios or in the forward operational environments. Faced with this circumstance, deployed surgeons may have to make an on-the-table decision to triage this patient as "expectant." This incredibly difficult situation is one that few surgeons are prepared for or have experience with but is the right decision if one critical patient will utilize critical resources that could salvage multiple others in imminent need. If resources are readily available, then once the diagnosis is made, there can be no wasted steps or time. If packing will control the hemorrhage, then pack and get out of the OR. Often, packing will not ameliorate the hemorrhage, and the surgeon much quickly begins steps directed toward total hepatic isolation. It is incumbent upon the surgeon to *communicate* with anesthesia providers about the gravity of injury, including the necessity for large bore access above the diaphragm.

To begin the procedure, the aorta should be cross clamped at the diaphragmatic hiatus in order to preferentially perfuse the heart and brain. The retrograde endovascular balloon occlusion of the aorta (REBOA) technique may be a useful surrogate to accomplish the same goal. A right medial visceral rotation and a Kocher maneuver are performed to gain access to the infrahepatic/suprarenal IVC and encircle with a Rummel tourniquet or vascular clamp. To control the suprahepatic IVC, perform a median sternotomy and pericardiotomy and encircle the IVC immediately below the right atrium. Once again, it is critically important for the anesthesia providers to have good intravenous access above the diaphragm in preparation for clamping the IVC. Once the liver inflow is controlled, the liver can be fully mobilized by taking down the falciform ligament and the right triangular ligament. Having done this, the liver can be "rolled" and reflected to the left for exposure of the retrohepatic vena cava and hepatic veins for repair. Atriocaval shunting may be a damage control alternative, particularly in the resource constrained environment, but this is a "last ditch" effort. To perform an atriocaval shunt, the surgeon uses the isolation techniques mentioned previously. However, instead of clamping the vena cava above and below the liver, a large chest tube has several side holes cut proximally where the bypass conduit will rest in the right atrium. A purse-string suture is placed at the apex of the right atrium, and then the atrium is incised. The chest tube is fed down through the atrium down the vena cava so that all of the distal drainage ports are below the infrahepatic Rummel tourniquet which is then snugged down upon the chest tube. The proximal chest tube should be positioned so that all of the newly cut side holes reside within the right atrium Then, the suprahepatic Rummel tourniquet is then cinched down and the atrial purse-string tied securely. Then proximal end of the chest tube can be used for high-volume infusion. With all this being said, the outcome of the battlefield casualty with retrohepatic vena cava/hepatic vein injury is almost uniformly fatal.

Always be thinking about the patient's clinical status. Does anesthesia need to catch up? Is the patient cold, coagulopathic, and acidotic? If hemorrhage is controlled and the patient requires further resuscitation, it is often best to terminate the procedure and take the patient to the intensive care unit for further resuscitation. The abdomen should be left open with the skin closed with a vacuum pack, running suture, or towel clips. The advantage to the former, particularly if closed-suction drains are placed under a vacuum-assisted closure, is that the surgeon can follow ongoing blood loss as a diagnostic strategy to time reoperation. The advantage of the latter is the tamponade effect created by the temporary abdominal closure. If the abdomen is closed, care should be taken to monitor the casualty for signs and symptoms of the evolution of abdominal compartment syndrome such as increasing abdominal distension/tightness, oliguria, increase in airway pressures or difficulty ventilating, or increased bladder pressure. If abdominal compartment syndrome develops, this mandates expeditious release of intra-abdominal pressure. This is done most safely in the operating room, particularly if the nidus for the increased intra-abdominal pressure is ongoing hemorrhage.

## Post-op Pearls

There is nothing special about the postoperative resuscitation of the liver or spleen injury patient. Just continue an aggressive damage control resuscitation strategy. If a damage control laparotomy was performed, the timing of the second-look laparotomy should be dictated by the patient physiology and not an arbitrary time period. There are several specific pitfalls to anticipate after operating on a damaged liver or spleen. The most significant problem in the postoperative period is recurrent hemorrhage, which should prompt an immediate return to the operating room. With respect to the spleen, this is most commonly due to bleeding from short gastric vessels or branches of the splenic hilar vessels. In the case of liver injury, it is frequently the same area of injury that is now bleeding again. Adjunctive techniques such as large mattress hepatorrhaphy sutures (+/− pledgets) are very effective for controlling parenchymal bleeding, and topical hemostatic agents or advanced hemostatic dressings (combat gauze, QuikClot, etc.) have been used with success in many cases. If a large bile leak is noted, you should make all attempts to identify and suture ligate the culprit duct. If it cannot be identified, then pack the omentum in the area and widely drain it.

Since there is a significant incidence of complication such as biloma, abscess, pseudoaneurysm, and arteriovenous or biliary fistula with severe liver injury, an interval CT scan once evacuated from the battlefield is probably warranted. Always make sure that the postsplenectomy patient receives appropriate vaccinations, preferably during the same hospitalization. Delay in vaccination will decrease the number of patients who actually receive their immunizations. Be familiar with the theater trauma system clinical practice guidelines!

The basic tenet to the management of the casualty with liver or spleen injury is to have them survive THIS operation. It is a long chain of survival for the combat casualty, and all of the links must be strong.

## Civilian Translation of the Military Experience and Lessons Learned

Katherine M. McBrideand James R. Dunne

**Key Similarities**

- Operative approaches and techniques to treat liver and spleen hemorrhage in the operating room are the same in military and civilian settings.
- The decision to operate rather than observe liver and spleen injuries in military settings may be similar to what the remote rural surgeon faces.
- High-velocity penetrating injuries of the liver and spleen may be better treated with operative therapy, regardless of setting.

**Key Differences**

- Access to diagnostic equipment such as computed tomography and interventional radiology techniques are frequently not available in the combat environment and lead to higher rates of exploration.
- The majority of liver and spleen injuries in civilian settings are managed without operation.
- The majority of liver and spleen injuries in civilian settings are from blunt trauma; the majority in military settings are from penetrating trauma.
- Resource allocation and remote location associated with the military setting pose additional challenges that may require a change in management plan (i.e., damage control surgery implementation or having a low threshold for abdominal exploration with even the seemingly innocuous penetrating abdominal wounds).

Dr. Eastridge's chapter on liver and spleen management in combat outlines the surgical management of injuries to these organs. It raises some key points which are ubiquitous from the combat setting to the rural hospital and even to the level 1 trauma center in an urban setting. There are also similarities from the austere environment of the combat setting and the rural hospital that are quite different from the management at a level 1 trauma center.

One major difference between the “home front” and the combat setting is the ability to safely observe patients with serial exams and laboratory values. Due to the limited holding capacity on the battlefield, patients are often triaged, undergo damage control surgery, and are transferred to the next level of care and eventually out of theater in a relatively short time frame. On the “home front,” the algorithm for care often depends on the access to adequate resources and personnel. In rural hospitals with limited manpower and blood product availability, damage control surgery for critically injured patients followed by transfer to a higher level of care may be the patient’s best option for survival. However, at centers with interventional radiology, a fully functioning blood bank, 24/7 in-house support staff, and the ability to serially monitor patients, observation or minimally invasive techniques may be just as successful.

Currently, over 80% of blunt splenic and hepatic injuries in the United States can be managed nonoperatively. However, the rates of failure for nonoperative management of blunt splenic trauma are higher with each grade of splenic injury. In addition, level 2 trauma centers tend to have higher rates of failure of nonoperative management for blunt splenic and hepatic trauma than level 1 trauma centers. Therefore, consideration of hospital resources including manpower along with appropriate patient selection is key to successful management of these patients. For patients who require a laparotomy, intraoperative splenic salvage techniques, such as splenorrhaphy and partial splenectomy, are viable options in level 1 and level 2 trauma centers. Operative management for blunt hepatic injury is limited to hemodynamically unstable patients and those with the need for laparotomy for other injuries, since mortality after surgery still approaches 50%.

Interventional radiology has also become a key tool in the armamentarium of the trauma surgeon at larger centers. Patients with solid organ injuries can often be successfully managed with interventional techniques, without the need for a laparotomy. The main advantage of these procedures includes their noninvasive nature and their ability to be repeated if necessary. Angiographic embolization for the treatment of solid organ hemorrhage has become the mainstay of treatment for solid organ injuries in the stable trauma patient at centers where this resource is available. Angiography for blunt splenic trauma can be successful in up to 95% of patients when applied selectively in stable patients with a blush or pseudoaneurysm on CT or nonselectively for any grade 3, 4, or 5 splenic injury in the stable patient.

Damage control resuscitation has been a major advancement in the management of hepatic and splenic trauma. In the combat setting, this often is associated with damage control surgery. Massive transfusion in these cases is frequently fresh whole blood donated within an hour after injury. Fresh whole blood is not currently available in most civilian hospitals; however, some hospitals have access to modified whole blood that has been stored and is leuko-reduced resulting in nonfunctioning platelets. This modified whole blood has been shown to have similar outcomes and transfusion volumes to the balanced component therapy of most massive transfusion protocols (1:1:1). Most rural hospitals, however, typically only have two units of packed red bloods cells if at all, let alone the ability to institute a massive transfusion in a 1:1:1 fashion. As the trauma centers grow in size, their ability to perform more of a controlled resuscitation improves. For example, level 1 trauma centers have the capability to perform both massive transfusions and damage control surgery followed by continued resuscitation in the intensive care unit under the guide of a trained intensivist. This is followed by the ability to quickly return to the operating room once the patient stabilizes or if their condition continues to deteriorate.

An additional difference between the combat and civilian setting is the mechanism of injury. Penetrating trauma rates average around 11% for civilian centers but approach 70% in combat settings and often involve an increased percentage of high-velocity wounding mechanisms compared to civilian penetrating injuries. Due to these differences, operative management in the combat setting is often required in order to identify and treat multisystem injuries.

There are many similarities and differences in the management of solid organ injuries when comparing treatment in a combat setting compared to that in a civilian setting. There are more noninvasive options available in the civilian setting, especially in levels 1 and 2 trauma centers. However, the combat setting and the rural hospital are similar in that they often result in more operative interventions due to lack of resources when compared to larger trauma centers. Over the years, there have been many advances in the treatment of these patients thanks to the military. Patient selection and a thorough understanding of available resources will be key in the proper application of these advances moving forward both in the combat setting and back here at home.

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1. Management of war wounds.
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# 9 Pancreatic and Duodenal Injuries (Don't Mess with the…)

Matthew T. Hueman and Thomas M. Scalea

**Deployment Experience**

| | |
|---|---|
| *Matthew T. Hueman* | March 2017–August 2017 Chief Medical Officer and Trauma Surgeon, 240th Forward Surgical Team, Iraq |
| | Jul 2014–Nov 2014 Chief Medical Officer and Trauma Surgeon, 250th Forward Surgical Team (Theater Response Force, 2nd Battalion, 504th Parachute Infantry Regiment, 82nd Airborne Div), Afghanistan |
| | Jul 2011–Jan 2012 Trauma Surgeon, 946th Forward Surgical Team, Forward Operating Base Sharana, Afghanistan |
| | Aug 2009–Feb 2010 Chief Medical Officer and Trauma Surgeon, 8th Forward Surgical Team, Forward Operating Base Shank, Afghanistan |
| | Aug 2006–Mar 2007 Trauma Surgeon, 8th Forward Surgical Team, 399th Combat Support Hospital, Forward Operating Base Diamondback, Mosul, Iraq |

*"For pancreatic trauma: treat the pancreas like a crawfish, suck the head … eat the tail."*

Timothy Fabian

M.T. Hueman (✉)
Walter Reed National Military Medical Center, USU Walter Reed Department of Surgery, Bethesda, MD, USA
e-mail: matthew.t.hueman.mil@mail.mil

T.M. Scalea
University of Maryland School of Medicine, R. Adams Cowley Shock Trauma Center, Baltimore, MD, USA


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**BLUF Box (Bottom Line Up Front)**

1. Do as little as possible to control hemorrhage and contamination at the initial operation. Damage control with a bailout solution is a sign of good judgment.
2. The traumatically injured patient will not survive a complex pancreatico-duodenal surgery at the initial operation, even in the hands of an experienced pancreas surgeon.
3. Generally, indications for a trauma laparotomy will also be present if the patient has a pancreas and/or duodenal injury. The trauma laparotomy is the deployed wartime surgeon's CT scan.
4. Missed injuries kill. Always explore the pancreas and duodenum during a trauma laparotomy, as they can sometimes be hidden.
5. Right-sided upper abdominal retroperitoneal hematomas are vena cava, pancreas, and/or duodenal injuries until proven otherwise. Pancreaticoduodenal trauma often is associated with injuries to other surrounding structures. Prepare your team and the patient and then explore.
6. Drains, drains, drains. If you suspect a pancreatic injury, place drains. Drains are excellent bailout solutions to allow your patient to make it to a higher echelon of care. Drains may be the only required treatment.
7. Leave the abdomen open with a temporary abdominal closure to expedite the patient's return to the ICU, allow for drainage of contamination, and allow the next echelon of care to reassess.
8. At the initial operation, repair the duodenal injury primarily if at all possible. If not possible, place a large Malecot drain into the injury and close the injury around it.
9. Assume the duodenal repair will leak. Place external drains. Do not perform any "triple-tube" drainage or pyloric exclusion or complex reconstruction at the initial operation. Additional treatment can be done at higher echelons if needed.
10. Avoid pancreatico-enteric anastomoses at all costs. Do not perform one in the wartime theater.

The comfort in performing complex operations in different parts of the body does not prepare you for the chaos of combat casualty care, for the stark limitations imposed by the austerity of far-forward combat trauma care, and for the experience and judgment required to understand the optimal care of the traumatically injured wartime patient. Whether you are an experienced pancreas surgeon or an experienced surgeon with minimal exposure to pancreas surgery, pancreaticoduodenal trauma will humble you. The keys to success in managing these extraordinarily challenging and relatively rare injuries are to prepare well in advance by reading and reviewing techniques and scenarios; keep the management principles as simple, straightforward, and quick as possible; try to delay complex or time-consuming reconstructions; and get help early.

You *must* prepare yourself before you deploy by, at minimum, reading books about both trauma care and far-forward war surgery, cover to cover. While reading, you should mentally rehearse every single step of a trauma laparotomy and the steps to gain hemorrhage and contamination control.

The need for damage control exists within the patient as well as external to the patient, especially for multiple casualty events, which are a common occurrence. The need for damage control can even be external to the forward surgical team and apply to the region of trauma care formed by the CSH and FSTs. The limited resources and logistics impact not just the care of the individual patient but the care of other patients. Getting the patient off of the operating table to the intensive care unit (ICU) may not only be best for the patient but best for the care of the multiple casualties in your emergency "room" awaiting life- and limb-saving operative care.

So, adopt a damage control mindset from the start. Less is more. Stop the bleeding, control contamination, and leave drains. Replace blood loss with blood. Leave the abdomen open with the temporary abdominal closure technique of your choice. Try to keep the operation under an hour.

If you succeed at those goals, you should be very proud of your team. And you will be an important part of the best echelon *system* of trauma care that the world has ever witnessed. Because for the rest of this chapter, I will assume that you are at an austere, far location with a forward surgical team, without a CT scanner. Please recognize that you and your team are only one stop among likely four or more overall stops the patient will make along the journey to recovery. Do as little as possible to fix the current problem; sometimes more is needed but be judicious. Allow more definitive reconstruction to be done at higher echelons, preferably out of the theater of war.

## Making the Diagnosis

In both civilian and wartime trauma, pancreatic and duodenal injuries are fortunately relatively uncommon, presumably due to their protected retroperitoneal locations. In both civilian and wartime trauma, pancreaticoduodenal injuries are most often the result of penetrating trauma. The majority of pancreatic penetrating injuries are associated with major vascular injury. In general, the patient with penetrating abdominal trauma and pancreaticoduodenal injuries will have nonspecific indications for trauma laparotomy (shock, peritonitis, positive FAST, or diagnostic peritoneal lavage (DPL), etc.). If it is not initially obvious upon entering the abdomen, the only diagnostic study required to identify these injuries is a complete, thorough trauma laparotomy exploration; subtle bile staining may be the only initial clue that there is a pancreaticoduodenal injury. Free bleeding and/or bile or enteric contamination into the peritoneal cavity from the right upper quadrant may herald the diagnosis. You may see an ominous right upper abdominal hematoma in the region of the pancreas, which heralds not only pancreaticoduodenal trauma but the possibility of one or more large blood vessel injuries. Moreover, you may see a combination of free bleeding and contained expanding or non-expanding hematoma.

With the advent of body-armor and heavily armored mine-resistant ambush protected (MRAP) vehicles decreasing the amount of penetrating trauma cases, you may also see patients with pancreatic and/or duodenal injuries from blunt trauma to the abdomen in the wartime environment. Patients with a history of blunt or blast trauma with direct trauma to the upper abdomen, especially with an associated lumbar spine fracture, are at risk for these notoriously hidden but deadly pancreaticoduodenal injuries. Identification of such injuries in this setting requires a high index of suspicion. These patients can be very difficult to assess as they may have no obvious indication for urgent trauma laparotomy, especially in the far-forward setting without a CT scanner and robust lab capabilities. These patients can be very challenging to diagnose even in the civilian setting, despite robust capabilities (endoscopic retrograde cholangiopancreatography (ERCP), CT scans, etc.), because even these sophisticated capabilities are not sensitive enough in a significant percent of cases. Serial amylase measurements are of limited value in the civilian setting to diagnose pancreatic injuries and you should not even think of using them in the deployed setting. In addition to simply not being available, not being particularly sensitive or specific, it is challenging to track serial measurements across echelons of care.

In the far-forward setting, you are limited in your evaluation of blunt trauma to your understanding of the mechanism of injury, vital signs, physical exam, FAST, DPL, urine output, and/or rudimentary labs. While a focused abdominal sonogram for trauma (FAST) is not sensitive, it may provide evidence for free intraperitoneal fluid. In the hemodynamically stable patient, especially for whom an abdominal exam is not obtainable or reliable due to sedation or central nervous system injury, a diagnostic peritoneal lavage (DPL) remains an important tool in the far-forward setting. Even in the face of a negative or equivocal FAST, DPL may reveal subtle bile staining or other indication of injury. In the absence of these nonspecific indications for trauma laparotomy, the combination of mechanism of injury and high index of suspicion should allow you to focus on a select group of patients for closer observation.

In general, you should have a low threshold to consider an exploratory laparotomy on wounded patients in the deployed setting. A positive FAST exam in an injured patient in the deployed setting equals a trip to the operating room for a trauma laparotomy, no matter what the mechanism of injury was (e.g., blunt) or the hemodynamic stability of the patient. Although the civilian literature is replete with the nonoperative management of selected pancreatic and other solid organ injuries, there is, in general, limited role for the nonoperative management of trauma in the wartime setting, as we simply do not have the advanced adjunctive tools, resources, personnel, or continuity of care in our echelon of care, severely resource-limited environment.

If your evacuation times are short (e.g., around 30 min), carefully selected, hemodynamically stable patients who sustained blunt trauma with negative FAST exams and no clear indication for trauma laparotomy but for whom you maintain a concern for pancreaticoduodenal and other intra-abdominal injuries can be evacuated to higher echelons of care where CT scanner capability can be used for further assessment. This plan obviously requires a functioning CT scanner and qualified CT scan interpreter (e.g., radiologist) to exist at the next echelon. However, if the transport time is long, and/or requires at least one additional stop to transfer to another helicopter ("tail to tail"), or the conditions (weather and/or combat) are poor for transport, your continued observation may result in a less favorable situation for the patient if they have an undrained pancreatic and/or duodenal injury. The tissue damage from an untreated leak may significantly limit options for the patient. So if your clinical evaluation is suspicious, especially if the patients has any evidence of a worsening clinical picture overall, the patient may be better served with an exploration to preserve future options. The trauma laparotomy is the deployed wartime surgeon's CT scan.

## Anatomy: The Key to the Battle Plan

You must understand the anatomy of the complex right upper quadrant to be able to control both hemorrhage and contamination. The heat of battle in the operating room is not the time to brush up on your anatomy. You must also have an understanding of how to manage multifocal bleeding. For example, if you see free bleeding into the peritoneal cavity, control that first before you unroof or explore any retroperitoneal hematoma. Do not explore a retroperitoneal hematoma without ensuring that you and your team are ready to provide rapid blood replacement for the patient. Use a combination of packing, manual pressure, judicious clamping, hemostatic sutures, and the Kocher and the Cattell-Braasch maneuvers to control bleeding in the right upper quadrant. If the patient is in extremis and/or you cannot control the bleeding, ligating the portal vein is a bailout option.

The head of the pancreas and duodenum sit on top of the inferior vena cava and right renal vessels. The proximal portion of the duodenum is anterior to the neck of the pancreas; the neck of the pancreas sits right on top of the confluence of the superior mesenteric vein, splenic vein, and inferior mesenteric vein as they become the portal vein after the confluence joins and heads cephalad. Bleeding in these locations is not controllable until you open up the correct surgical planes. To at least initially control superficial head of pancreas bleeding and control of portal-mesenteric vein bleeding with manual pressure, you must perform a wide Kocher maneuver. This maneuver will lift the head of the pancreas complex out from being on top of the vena cava, and you will be able to squeeze the head of the pancreas from above and below in between your fingers and thumb.

While taking out an anatomy atlas can be useful in the deployed setting when encountering injuries in locations you do not normally operate, it is best if you have done this review well in advance, ideally on your typically long trip to get to your deployment location. However, taking out an atlas while trying to control multifocal large blood vessel bleeding in the right upper quadrant is a clear recipe for failure. Review the anatomy now. You should know the basic maneuvers to expose the pancreas and the critical *surgical* anatomy of the pancreas and duodenum (Fig. 9.1). This is an area that is often relatively unfamiliar to general surgeons, so spend some time reviewing it and mentally rehearsing maneuvers before you deploy.

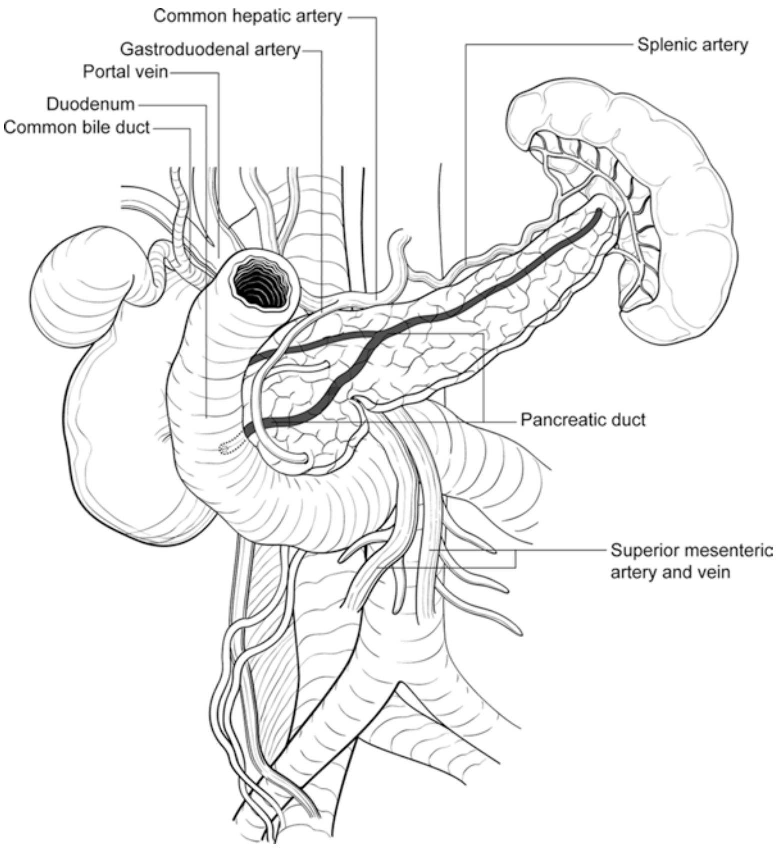


**Fig. 9.1** Surgical anatomy of the pancreaticoduodenal complex

The Kocher maneuver is the most important maneuver to both explore the head of the pancreas and duodenum for trauma as well as help control bleeding from the pancreaticoduodenal arcade, portal and mesenteric veins, and superior mesenteric artery. Extension of the Kocher maneuver into the Cattell-Braasch maneuver with a right medial visceral rotation allows you to address vena cava injuries as well.

While many argue that exposure of the head of the pancreas and the second/third portion of the duodenum should be done by first mobilizing the hepatic flexure of the colon inferiorly and medially (Fig. 9.2a), it is preferable to attack with a Kocher maneuver first and lift the second portion of the duodenum out of the retroperitoneum (see Fig. 9.2a) and divide the posterolateral attachments of the duodenal C-loop as you retract it anteriorly and medially. If you simply continue to pull the distal duodenum toward the patient's right, you can expose the infra-pancreatic superior mesenteric vein without mobilizing the colon. Be mindful that the C-loop of the duodenum is sitting right on top of the vena cava as you begin this maneuver. Slide your hand behind the head of the pancreas and bluntly mobilize and palpate it

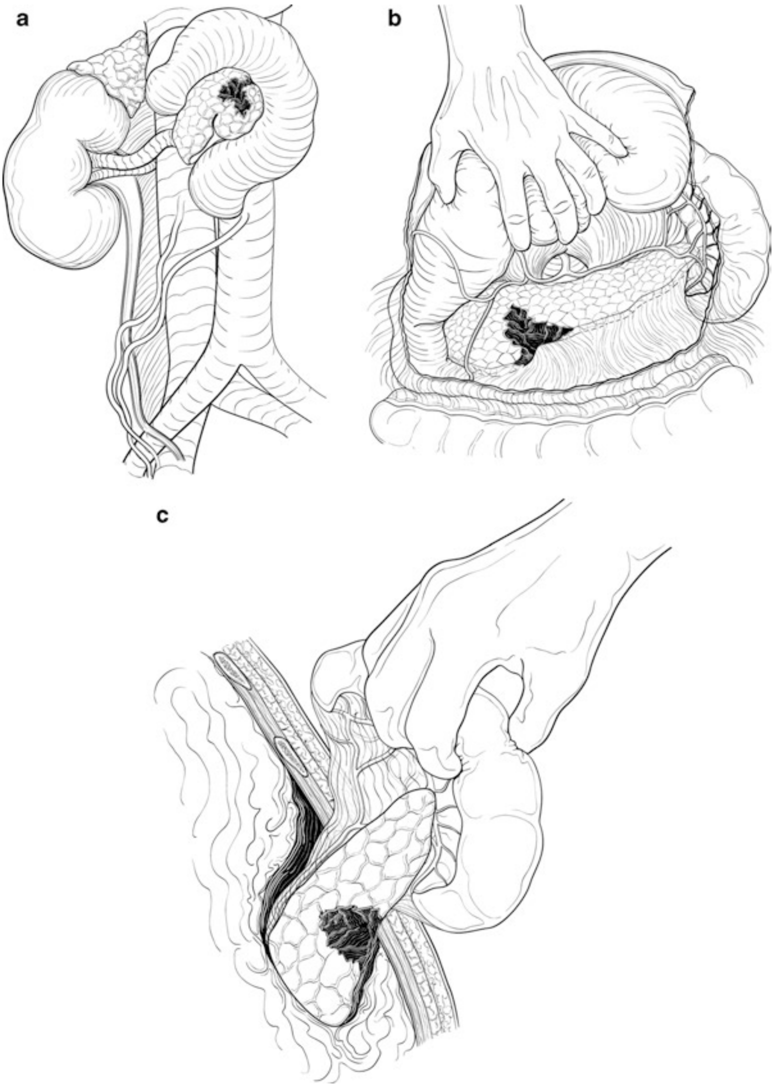


**Fig. 9.2** Surgical exposure of the pancreas and duodenum. (**a**) Exposure of the head of the pancreas and duodenum is obtained via a generous Kocher maneuver. (**b**) Exposure of the body and tail of the pancreas by entry into the lesser sac. (**c**) Complete exposure of the tail of the pancreas requires lateral to medial splenic mobilization

to assess for injury, if it is not obvious after mobilizing it. With this extended Kocher maneuver, you should be able to lift the head of the pancreas and duodenum out of the retroperitoneum. Starting with this Kocher maneuver first is especially important if you have brisk bleeding or a retroperitoneal hematoma in this location, as it will help you gain control with manual pressure.

If a Cattell-Braasch maneuver with right medial visceral rotation is required, either for visualization or to control deeper bleeding from the vena cava and/or renal pedicle, you should sharply open the white line of Toldt along the ascending colon and continue this around the flexure, retracting the colon inferiorly and the gallbladder superiorly. Once that first layer is opened, the rest can usually be rapidly done with blunt finger dissection and bovie. If you have not already performed an extended Kocher maneuver, you can follow the colon mesentery to the base and this will lead directly to the C-loop of the duodenum. Once the right colon is mobilized, you have exposed the anterior surface of the duodenum and pancreatic head. Some argue that if this appears completely normal, no further mobilization is required. In combat trauma, it is preferable to have complete visualization and mobilization, so if you have not already performed a Kocher maneuver, rapidly but carefully divide the posterolateral attachments of the duodenal C-loop as you retract it anteriorly and medially, as previously described above. Exposure of the body of the pancreas is easily obtained by opening the gastrocolic ligament and retracting the stomach superiorly and anteriorly (see Fig. 9.2b). You can also visualize most of the tail of the pancreas through this window in the lesser sac. To fully mobilize the tail and splenic hilar vessels, the lateral attachments of the spleen are divided, and the spleen and pancreas are mobilized to the midline together (see Fig. 9.2c). Further exposure of the posterior pancreas and the fourth portion of the duodenum can be obtained by opening the retroperitoneum along the inferior border of the pancreas and dividing the ligament of Treitz.

Fig. 9.1 demonstrates the critical anatomy in this area. The vena cava and right renal vein will be immediately posterior to the duodenal C-loop. To control bleeding from the confluence of the portal and mesenteric veins, you may have to divide the neck of the pancreas. The first major vessel you encounter when exposing the body of the pancreas will be the splenic artery running (often tortuous) along the superior pancreatic border. The splenic vein is *posterior* to the pancreas, so additional mobilization will be required to expose this vessel, and you must take great care when dissecting circumferentially around the body of the pancreas. There are multiple small pancreatic branches entering the splenic vein, and these will be the usual sources of bleeding during mobilization. The splenic vessels and the tail of the pancreas will then converge in the hilum of the spleen, with a wide variety of anatomic variants. Beware that the pancreatic tail may be intimately associated with the spleen and that the splenic vessels may enter the hilum as multiple smaller branches rather than single large trunks. You may need to perform a distal pancreatectomy and splenectomy in order to control both bleeding and pancreatic leak.

## The Body and Tail of the Pancreas

Injuries to the body and tail of the pancreas can range from contusions to lacerations to complete division or disruption. Once bleeding has been controlled, the main concern is focused on controlling a leak from the injured pancreas. While a lot of civilian literature encourages sophisticated studies to assess for pancreatic ductal injury as the primary determinant of treatment, such as on-table pancreatography, there is simply no room for such acrobatics in the far-forward, wartime setting. Intraoperative evaluation is often not fruitful to determine whether a major ductal injury exists, even in the most experienced of hands. The good news is that even major ductal injuries can be controlled with external drainage with a surprisingly good outcome. If you are in doubt whether a pancreatic injury is present but are suspicious, you should place an external drain and assume one exists. If the body and tail of the pancreas are disrupted or significantly divided or you are highly suspicious for a major ductal injury, a distal pancreatectomy and splenectomy is decisive and if performed with a stapled technique, should be quick. If you are in doubt and the bleeding is controlled, and/or for damage control reasons internal and/or external to the patient that you feel the operation should be abbreviated, then simply choosing to externally drain and not performing a distal pancreatectomy is a safe and effective solution even in the face of a visibly significant pancreatic injury. Just simply evacuate the patient to the higher echelon with an open abdomen with temporary abdominal closure and external drains with clear communication and documentation of your intraoperative evaluation and concerns. In almost all situations where you have identified a pancreatic injury and controlled bleeding, external drainage is the key and may be the only required treatment, even in the face of a major pancreatic ductal injury. Ensure you look for associated injuries to surrounding organs, like the anterior and posterior surfaces of the stomach, to ensure you have not missed any other sources of contamination. If you do perform a distal pancreatectomy, there is no role for a spleen-preserving approach in the far-forward setting. It is technically challenging, lengthens operative time, and puts the patient at more risk for unrecognized re-bleeding during the challenging air transport from one echelon to the next echelon of care (from your location to a regional combat support hospital to Germany to the United States is a long journey back home).

The technical aspects of a distal pancreatectomy and splenectomy are straightforward (Fig. 9.3): always leave an external drain after resection of the injury. Try to preserve as much distal pancreas as possible; transect just proximal to the injury ensuring you are in normal uninjured pancreas. The pancreas should be approached by dividing the gastrocolic ligament and elevating the stomach to expose the anterior surface of the pancreas. A hematoma of the body and/or tail of the pancreas should be opened to evaluate the anterior surface of the pancreas directly. The spleen and tail of the pancreas can be swiftly brought to the midline by placing the hand behind the spleen and pulling the spleen and pancreatic tail up as one unit, sliding the fingers in the retroperitoneal space behind the pancreas. Once the spleen is elevated, the short gastric vessels between the spleen and stomach can be divided quickly with clamps and the retroperitoneal surface packed with sponges.

An important anatomic consideration is that the cephalad and especially the caudal borders of the pancreas to the left of the middle colic vein are, in general, in an avascular "free zone" plane, with no significant vessels in the area other than the splenic artery (at the cephalad border which should easily be mobilized with the body of the pancreas). With the body and tail of the pancreas now mobilized, the

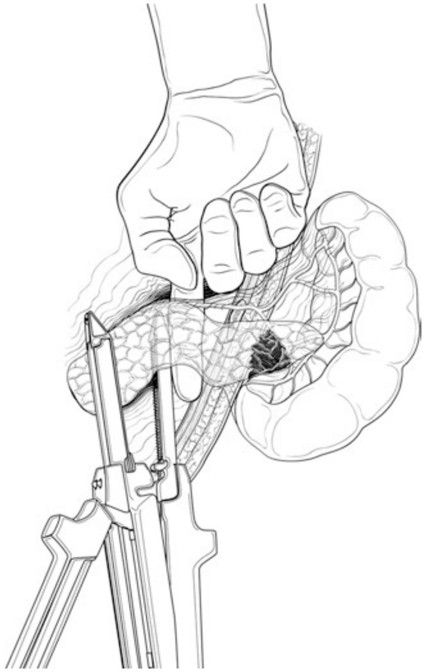

**Fig. 9.3** Technique for a stapled distal pancreatectomy. Use a finger or blunt instrument to encircle the pancreas and guide a linear stapler through the retropancreatic tunnel

short gastric vessels divided, and the retroperitoneal attachments along the superior and inferior edge of the pancreas divided by electrocautery, the pancreas can now be divided with a linear stapler.

Try to individually control the splenic artery and splenic vein with either suture ligation or staples before using the linear stapler to divide the pancreas. The closer you are to the neck of the pancreas, the more careful you should be to be sure you have identified the splenic artery and not the common hepatic artery before ligating it. This distinction can be confused by even experienced surgeons. If the splenic artery is not obviously coursing along the superior edge of the pancreas, excessive time should not be wasted in looking for it, and simply dividing the pancreas and the vessels en masse with the stapler is safe and effective.

A tri-staple thick staple load (the "black" load with dynamic staple height) is ideal for pancreatic division, but it is unlikely you will have that with you in the deployed setting. A medium staple load (linear stapler with a blue load) works well to divide the pancreatic parenchyma proximal to the injury, after you ligate the splenic vessels (and some even use it to effectively divide the splenic vein and artery along with the pancreas with one staple load, although if possible divide the vessels individually). An alternative approach is to identify the pancreatic duct and ligate it and then use 3-0 or 2-0 silk sutures in a U horizontal mattress fashion with pledgets and overlap each suture along the cut edge of the pancreas, but it is likely you will not have pledgets while deployed. The stapler is quicker which is better in the damage control mode. If you take the vessels with the pancreas in one staple load, inspect the stump for any bleeding or direct visualization of the structures; you can then oversew the artery, vein, and sometimes even the pancreatic duct.

Occasionally, a stapler will fracture the pancreatic body and you will be looking at raw edges of the pancreas. This should not raise undue concern or action beyond oversewing the duct if it can be visualized and placing a drain along the edge of the pancreas. Any retroperitoneal bleeding should be minor and easily controlled. If a topical sealant such as fibrin glue is available, it can be applied over the cut edge of the pancreas and may assist in hemostasis or sealing parenchymal leaks.

While a distal pancreatectomy-splenectomy may control the leak from the injured pancreas, the procedure itself has a risk of a pancreatic leak. The main goal of managing pancreatic trauma is not necessarily not to have a pancreatic leak but to control a pancreatic leak and convert into a controlled fistula. Generally, a pancreatic fistula is not life-threatening and the majority can be treated non-operatively with full recovery with drainage alone. Do not take an excessive amount of time to perform a pancreatic procedure to avoid a pancreatic fistula, as it may hurt your ability to perform quick damage control surgery and thus potentially cost a patient his life. Adequate drainage is all that you need to achieve in the early management of a pancreatic leak. If you are in damage control mode and plan to return within 24 h, then you do not even have to place a drain – just pack and do your temporary abdominal closure. You should certainly always leave a closed suction drain prior to performing your definitive fascial closure or final exploration of the abdomen.

## Injury to the Head of the Pancreas

Typically, injuries to the head of the pancreas involve contusions or deep lacerations and may be associated with a duodenal injury. If there is significant bleeding, assume that a portal or mesenteric vein is injured. Even if you remove the head of the pancreas as a frequent part of your elective practice, your patient will not survive the procedure in a trauma. Thus, despite the complexity of the injury, the management of most pancreatic head injuries is really simple: stop hemorrhage, control contamination with drains, and get out fast (temporary abdominal closure). A Whipple procedure should only be contemplated when essentially the injury has already performed the resection for you, and then it should be done in multiple stages. A pancreatic enteric anastomosis should be avoided at all costs and not even be contemplated until the patient is back in their home country, away from the war.

The majority of bleeding from the head of the pancreas can be controlled by simple suture ligation with little concern of ligating the superior mesenteric artery or other large blood vessels due to their deep posterior position. If the patient is in extremis, you can ligate the portal vein as a bailout solution. As described in the anatomy section of this chapter, the only way to access the retro-pancreatic portal vein is by dividing the neck of the pancreas overlying the portal vein. From here bleeding can be controlled with vascular control of the splenic vein, superior mesenteric vein, and the portal vein at the region of the portal triad. Be aware that there are a couple of large branches (below the neck of the pancreas is the right gastrocolic vein and above the pancreas is the right posterior-superior pancreaticoduodenal vein) as well as multiple small branches running from the head of the pancreas directly into the portal vein. *Given the extensive dissection required for direct access and the typical amount of bleeding associated with portal vein injury, suture ligation through the substance of the pancreas is likely the only lifesaving maneuver.* As previously described in the anatomy section, if there is ongoing bleeding from the head of the pancreas, a Kocher maneuver will allow for anterior and posterior compression of the head of the pancreas for temporary hemostasis. Once bleeding is adequately controlled, closed suction drains should be placed and the operation terminated. In all circumstances, there is no role for a pancreatic-enteric anastomosis at the initial operation, even in the experienced hands of a pancreas surgeon. No attempt at bowel anastomosis to the pancreas should be made while the patient is still in the wartime theater. Even if technically possible, you do not have the appropriate and robust adjuncts, such as interventional radiology for drainage. A pancreatico-enteric anastomosis typically requires a more extensive dissection of the pancreas with division of the intestine and results in a higher fistula rate when done in the acute setting. Importantly, a leaking pancreatico-enteric anastomosis results in a much more difficult follow-on operation, which the patients generally require, if only to simply close the abdomen. Simply laying drains around the pancreas will handle the large majority of injuries and allow for a subsequent thorough evaluation of the pancreatic anatomy when the patient is stable and when the needed surgical expertise is available.

## The Pancreatic Duct

The civilian literature is replete with complex techniques and algorithms to assess the status of the pancreatic duct, including intraoperative ERCP or intraoperative direct pancreatography. You will never have the need nor the capability to do this in combat trauma, especially at a desolate, austere location in your forward surgical team tent. While a visual inspection unfortunately is not a good enough tool to reliably assess whether the pancreatic duct is involved, it does not matter: just drain it externally and leave the abdomen open with a temporary abdominal closure for reassessment at higher echelons of care. If the injury is particularly destructive and can be resected completely with a distal pancreatectomy and splenectomy, then resect. If the injury is in the head of the pancreas, just drain it. No matter what you do, you should widely drain the area. If you are particularly experienced at intraoperative assessment of pancreatic duct injuries, you are at a combat support hospital with a lot of resources and personnel, the duodenum has already been traumatically opened, the patient is stabilized, and it seems critical to evaluate the duct for injury, you could consider cannulating the pancreatic duct (Fig. 9.4). Use a butterfly needle or angiocatheter and inject contrast material and/or methylene blue dye. Allow several minutes for distribution of the contrast and observe for blue staining of the tissues or fluoroscopic evidence of contrast extravasation.

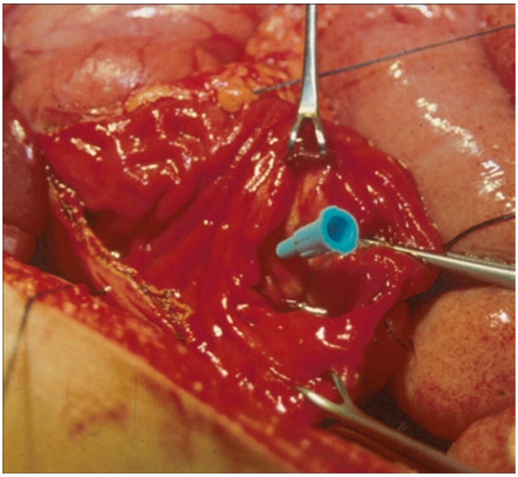

**Fig. 9.4** Cannulation of the ampulla of Vater to perform intraoperative ductography (Note that this should usually only be done if the status of the duct is truly in question and there is already a duodenal injury present and you have the experience and resources to perform the evaluation)

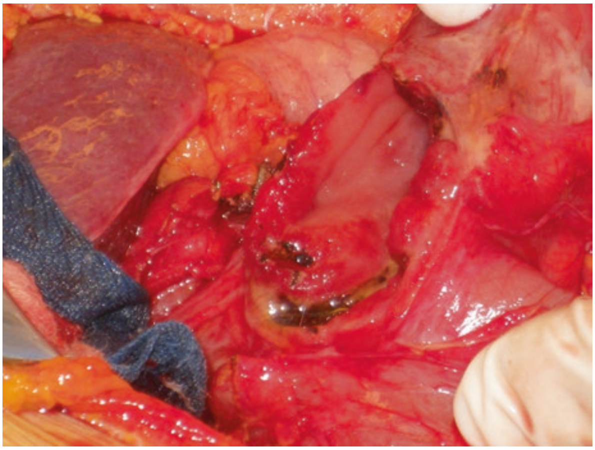

**Fig. 9.5** Large laceration (>50% circumference) to the second portion of the duodenum

## Duodenal Injuries

Duodenal injuries can range from simple lacerations to complex injuries with involvement of the duodenum, pancreas, and common bile duct (Fig. 9.5). You should perform a Kocher maneuver to ensure that you have completely evaluated the possibility of a duodenal injury, so that you can be sure you have fully examined the posterior wall of the duodenum (Fig. 9.6). No matter what the stability of the patient is, or the extent of the duodenal injury, you should try to achieve at least temporary closure of the duodenal injury. If the patient is unstable, then just whipstitch it closed and figure out a definitive repair at a second-look operation. For definitive repair, you must assess the injury and decide if you can do a simple repair or a more complex procedure will be required. Your goal is an adequate closure that preserves

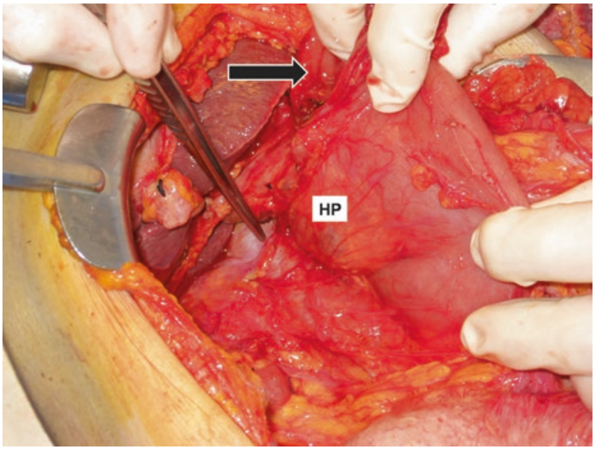


**Fig. 9.6** Injury shown in Fig. 9.5 (*black arrow*) after mobilization of the duodenum and head of pancreas (*HP*) via a Kocher maneuver. Forceps are pointing to the inferior vena cava

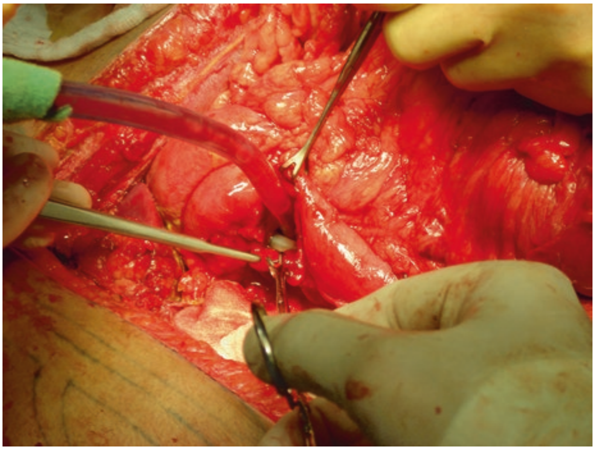

**Fig. 9.7** Simple laceration of the duodenum ready for suture repair (Note that the nasogastric tube has been advanced through the area of planned repair for postoperative decompression)

the luminal area (at least 50%), protects the surrounding structures (i.e., ampulla and distal common bile duct), and allows adequate drainage. Either way, assume your repair will leak and *always* leave a closed suction drain (or two) in the area.

Simple lacerations of the duodenum can be closed primarily in one or two layers after debriding the wound edges (Fig. 9.7). Many surgeons prefer a two-layer closure with interrupted 3-0 PDS and 3-0 Lembert silk sutures, if a second layer is feasible; if not, use a single layer in inverting fashion. Close in a transverse fashion, even if the laceration is in a longitudinal orientation. If the laceration is too long to allow for a transverse closure without undue tension, just close it longitudinally. If the duodenal injury is on the inner wall, you should identify the sphincter of Oddi and avoid injury to this structure during closure. Drains should be placed after any closure of the duodenum, pancreas, or biliary tree; assume these repairs will leak.

For more extensive injuries to the duodenum with loss of a portion of the duodenal wall or requiring a complex closure of the duodenal wall, you can consider duodenal diversion with either triple tube therapy (gastrostomy tube, retrograde duodenostomy tube through proximal jejunum, and feeding jejunostomy) or even formal pyloric exclusion. The overall pendulum in civilian trauma care has heavily swayed against pyloric exclusion and more in favor of selective triple tube therapy or even just external drainage. The duodenal wall which cannot be closed primarily can be addressed in two ways: the first way is to place a large Malecot tube into the duodenal injury and secure it with a purse string silk suture. This Malecot tube can then be brought out through the abdominal wall for a controlled fistula; generally this method will often leak around the Malecot, so it is even more important to emphasize that you still should leave closed suction drains in the area. This method is the fastest and simplest option for a damage control scenario. Other options include the often described technique of bringing a loop of jejunum up to the duodenal defect and perform a "serosal patch" by suturing the margins of the defect to the serosal surface of the jejunal loop. This technique is not recommended as it has a high failure and leak rate. A very reasonable second choice, if the patient is stable, is to bring a loop of jejunum up to the defect and do a formal end-to-side or side-to-side anastomosis between the duodenum and the jejunum. This final method allows for a better repair with less risk of leak and less chance of luminal obstruction.

Although the pendulum has shifted heavily against formal diversion procedures such as pyloric exclusion procedures in civilian trauma, in wartime trauma care you should have a lower threshold to consider adding an additional procedure, either triple tube therapy or even pyloric exclusion, following any complex or high-risk type of duodenal repair, as the destructive nature of wartime trauma arguably makes it a different disease. It is important to point out that the urgency for the patient is to control bleeding and contamination and that either triple tube therapy or pyloric exclusion procedures can be done at a second-look operation and do not have to be done immediately with the duodenal repair. If there are concerns about the repair, or the repair is very complex, and especially if you suspect or know the patient has a concomitant pancreatic injury, then perform triple tube therapy or even consider formal pyloric exclusion. Be more inclined to consider a formal pyloric exclusion procedure if the patient had concomitant duodenal and pancreatic injuries, especially if the duodenal repair is complex. If you do decide to do a formal pyloric exclusion, I recommend exclusion of the duodenum with a transverse non-cutting staple line (TA-60 blue load) across the very distal stomach and completion of a loop or Roux-en-Y gastrojejunostomy. Another excellent option is to make a longitudinal gastrotomy adjacent to the pylorus, evert the pylorus into the gastrotomy and sew it closed (prolene or PDS suture), and if feasible use the gastrotomy as the site of your gastrojejunal anastomosis (Fig. 9.8). I would also recommend a feeding jejunostomy for nutritional support in these patients at the time of definitive closure. For large non-expanding hematomas overlying the head of the pancreas, I recommend placement of drains overlying the pancreas and adjacent to the duodenal sweep, with gastrostomy and jejunostomy placement. No attempt should be made to unroof this injury if there is no evidence of ongoing bleeding. If there is a strong concern for an associated duodenal injury under the hematoma, then you can perform intraoperative upper endoscopy with the duodenum submerged in saline to evaluate for any leak.

One final unique injury pattern you may encounter in combat trauma is that of multiple small fragment wounds to the duodenum. This can result in multiple

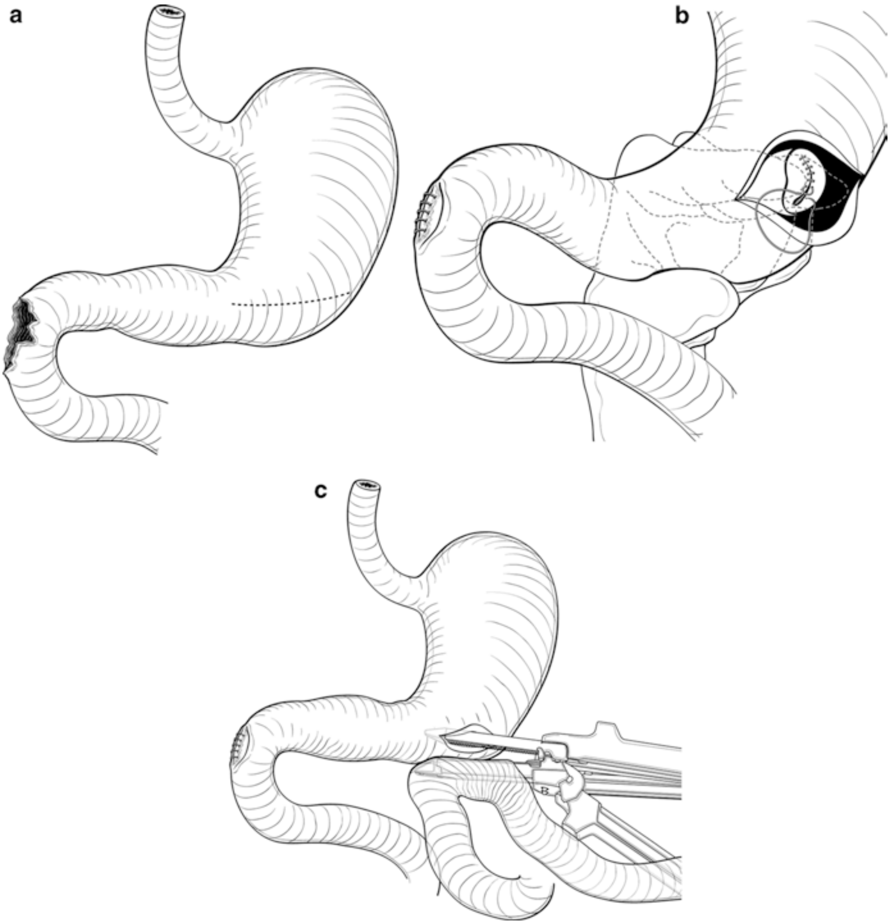


**Fig. 9.8** Technique for sutured pyloric exclusion. (**a**) Incision on antrum. (**b**) Pylorus is everted and sutured closed. (**c**) Gastrojejunostomy using the initial incision, duodenal injury closed

injuries of various sizes, from an obvious laceration to a subtle pinhole defect. Full mobilization of the duodenum should be performed, and air or methylene blue instillation is useful for identifying occult perforations. A particularly difficult injury to identify and manage is a perforation of the mesenteric/pancreatic wall of the duodenum. You cannot mobilize the pancreatic head away from the inner duodenal wall to adequately expose and repair these injuries. If you suspect or identify one of these injuries, then an excellent option is to open the duodenum by performing a longitudinal duodenotomy along the anti-mesenteric border and inspect the inside surface for injury. Always locate the major ampulla before suturing things closed if you are in the second/third portion. You can easily repair these defects with full-thickness interrupted sutures from the inside and then close the duodenotomy with running or interrupted silk suture.

## The Trauma Whipple

The basic rule for the trauma Whipple is just don't do it! However, rarely you may need to do so. Very rarely, you may encounter a patient that survives an injury that is best managed with this approach, but even then the Whipple procedure should be done in stages. Injuries for which you might consider a multiple-stage Whipple include major devascularization of the middle portions of the duodenum or a destructive injury of the pancreatic head and/or duodenum and/or bile duct that is simply not amenable to simpler reconstruction. Even if you identify such an injury pattern, your best option is to control bleeding, control contamination with adequate drainage, and disturb the surrounding tissues as little as possible. Approach with a damage control mindset and bring the patient back to the ICU for resuscitation and stabilization. At that point, you can start the discussion of the case with your colleagues, both near and far; our video-teleconference capabilities allow for you to gather the most experienced people. If the team's determination is that a major resection and reconstruction is the best option, you and your team can now proceed in a more elective setting with a stable patient (Fig. 9.9). Ideally the patient can be transported to a higher echelon of care to a center with even more expertise and resources. Even in a combat support hospital, you will not have all of the modern adjuncts immediately available for postoperative problems, such as percutaneous drainage or ERCP and stenting. If the patient is going to be evacuated to a higher level of care, you should leave the abdomen open for a re-exploration and evaluation at the next facility. Avoid pancreatic enteric anastomosis at all costs, and avoid performing one in the wartime theater. Ensure adequate drains are placed and that a secure route for nutrition is obtained, with either a feeding jejunostomy or nasojejunal feeding tube. One anecdotal report of a trauma Whipple with pancreatico-enteric

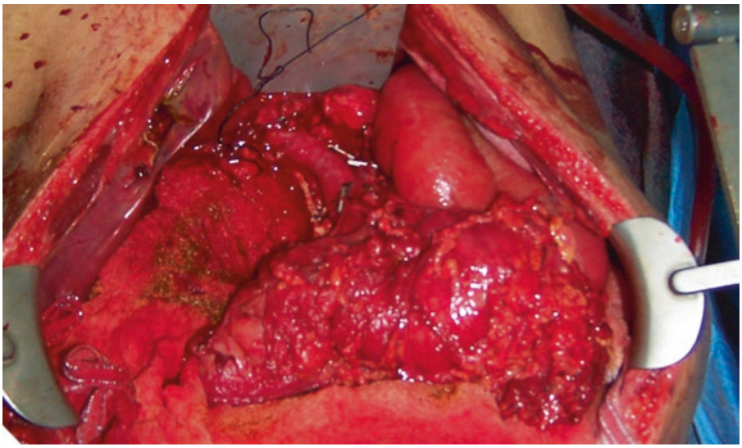

**Fig. 9.9** Intraoperative photo of resected head of pancreas and duodenum immediately prior to reconstruction at a combat support hospital. The patient underwent initial damage control surgery with no attempt at resection and subsequently underwent a delayed Whipple procedure (48 h later), which allowed interim stabilization and operative preparations

reconstruction performed in the wartime theater resulted in widespread leak from the anastomosis with associated severe inflammatory response syndrome; a completion pancreatectomy was performed, and autologous islet cell transplantation resulted in near-normal endocrine sufficiency. While that report is anecdotal, the completion pancreatectomy performed by an experienced pancreas surgeon was significantly more difficult due to the previous attempt at a pancreatico-enteric anastomosis, which is a different type of leak than "just" a leak from the pancreas, as it includes the activating enzymes in the enteric contents.

In summary, pancreatic and duodenal injuries are arguably the most challenging injuries that you will encounter in a far-forward, austere setting during wartime. Despite the intensity of the challenge, the principles outlined in this chapter are simple: stop the bleeding, stop the contamination, and lay drains. Experienced help may not be physically close to you but is almost always available by phone or other communication, even when deployed in a far forward region. *Always* seek out this experienced help, even if you too are experienced; sometimes just transporting the patient to the next higher echelon of care is the best way to get this help, once the patient is stable. Simple injuries of the duodenum can be repaired primarily. More extensive duodenal injuries may require a tube in the injury itself as well as require triple tube therapy with gastrostomy tube, retrograde duodenostomy tube, and feeding jejunostomy or even formal pyloric exclusion. Even in the face of some instability of the patient or extensive injury, you should try to achieve at least temporary closure of the duodenal injury. Do not undertake complex repairs of the pancreas and duodenum in the acute setting. And remember the caveat we first learned as surgery trainees: eat when you can, sleep when you can, and don't mess with the pancreas; and now you know the corollary: mess with the pancreas and duodenum as little as possible to fix the problem.

## Civilian Translation of Military Experience and Lessons Learned

Thomas M. Scalea

Pancreatic and duodenal injuries are relatively rare. This is true whether the patients are injured far forward or in the United States. Thus, even relatively experienced trauma surgeons do not commonly treat major pancreatic or duodenal injury. The increased level of imaging sophistication has made us diagnose injuries we never realized existed before including those to the pancreas and duodenum. These are for the most part minor and virtually never require operative therapy. The injuries discussed in this chapter are major pancreatic and duodenal injuries, those that require operative care. These can be challenging.

The two injuries that usually prompt a phone call to me from one of my junior partners are major liver injuries and pancreatic and/or duodenal injuries. When treating these injuries, there is no room for excessive ego. A mistake or indecision almost always results in either a poor outcome or death. Younger surgeons should take the opportunity to learn from their senior partners. Even if consultation is not immediately available, such as in far-forward situations, these cases should be carefully reviewed at a later time to ensure that all learn the important lessons that can be gleaned from these discussions. We review virtually every one of these at my weekly conference with the fellows.

## Operative Exposure

Pancreatic and duodenal injuries are often diagnosed at the time of exploration, particularly in the case of penetrating trauma. Often, the only clue to the presence of a pancreatic and/or duodenal injury is the presence of a central retroperitoneal hematoma. I believe that exposure is king here. In the case of a lesser sac hematoma, I widely open the lesser sac by dividing the gastrocolic omentum. I mobilize the greater curve of the stomach all the way to the GE junction. Only with that degree of exposure can a surgeon actually truly evaluate the body and tail of the pancreas.

When I need to evaluate the duodenum and head of pancreas, I virtually always perform a full right-sided medial visceral rotation. While a Kocher maneuver may suffice for a number of injuries, I prefer the wider exposure. Unroofing a concomitant injury to the vena cava results in torrential hemorrhage. The right-sided medial visceral rotation is necessary to get good exposure to the cava and all the retroperitoneal vascular structures. When I perform this maneuver, I come all the way around the hepatic flexure and onto the transverse colon. Residents and fellows that I have trained know that I fully mobilize the right colonic mesentery, lifting the colon toward the ceiling and applying pressure on the retroperitoneum, usually with a sponge on a stick. The retroperitoneum then falls away and the colonic mesentery is quickly mobilized without injuring it, down to the aorta.

When mobilizing the distal pancreas, I virtually always perform a left-sided medial visceral rotation prior to mobilizing the spleen and pancreas. Similar to the right side, I believe the additional exposure is valuable, particularly if a vascular structure has been injured as well. Often I may perform bilateral visceral rotations, as well as widely opening the lesser sac. This may be necessary to truly delineate all injuries and provides the best exposure to the entire duodenum and pancreas, as well as associated structures.

## Operative Care of Pancreatic Injuries

Dr. Hueman details nicely most of the operative maneuvers that are used to control pancreatic injury. I would provide several other thoughts. A distal pancreatectomy is a straightforward operation if done correctly. The plane behind the pancreas is avascular, thus, the spleen and pancreas can be mobilized together. They should be mobilized fully up to the area of pancreatic injury. I ligate the splenic vessels at the level of the pancreatic injury before doing the pancreatic resection. There are many branches of the splenic vessels, so I ligate the vessels a number of times slightly more proximal to the pancreatic resection to avoid postoperative hemorrhage from one of these small vessels which may not be visible at the time of operation, particularly if the patient is in shock. I gently mobilize the vessels off the superior margin of the pancreas with a right angled clamp and ligate them with a heavy tie.

One topic that is often discussed is the decision-making as when to do a pancreatic resection. Injuries that involve the main pancreatic duct require definitive therapy, usually resection. Virtually all others can be treated with simple drainage. A number of diagnostic tests have been proposed to determine whether there is injury to the pancreatic duct. Virtually none of them are accurate. The only study that definitively images the pancreatic duct is ERCP. That is clearly not available far forward and is not easily available even in most major trauma centers except during the day. Unfortunately, I always seem to be doing these cases in the middle of the night.

One option is to leave the patient open and do the ERCP the following day. However, I believe that a well-trained surgeon can determine the presence or absence of the major pancreatic duct simply by looking at the pancreas. The duct runs at the junction between the superior 2/3 and inferior 1/3 of the gland. If the duct is injured, pancreatic juice can often be seen leaking from the pancreatic injury.

Some advocate cutting off the tail of the pancreas in an attempt to visualize the pancreatic duct and perform a dye study through it. The pancreatic duct is tiny at the level of the pancreatic tail. This is simply not a wise strategy. I absolutely never open the duodenum to cannulate the pancreatic duct to do a contrast study. First, it is difficult to do. Second, the ability to obtain accurate images is not good. Third, opening the duodenum unnecessarily in the face of major pancreatic injury creates the very real possibility that the duodenal repair will then leak, creating a disastrous situation.

I actually do not think it matters what instrument is used to divide the pancreas for a pancreatic resection. Any stapler will work. I usually use whatever the scrub tech hands me. If the stapler is not available, simply dividing the pancreas with a scalpel or a pair of scissors also works just fine as well. Regardless of what is used to divide the pancreas, it will bleed. I individually ligate these bleeders with 3-0 sutures. Surgical hemostasis can be supplemented with fibrin glue. The glue also helps treat the almost universal leaks from the cut pancreas. Some talk about visualizing and then ligating the pancreatic duct; I think this is a myth. In 35 years of high-volume practice, I have seen the pancreatic duct once. Draining the pancreatic remnant is wise. They all leak. As this is a low-pressure system, virtually 100% of these low-volume pancreatic fistulae close spontaneously. Since many patients with a pancreatic injury have a complication, I always place a GJ tube. That allows me to vent the stomach and feed the patient enterally.

I also agree that many injuries to the pancreatic head can be temporized with drainage and transfer. This is particularly true when a young surgeon is alone and senior help is not available. However, virtually all major pancreatic injuries leak if not dealt with definitively. The lesser sac saponification is impressive, even 1 day later. If at all possible, I prefer to do definitive pancreatic surgery at the time of initial presentation. While this may not be feasible far forward, it certainly is feasible in

Role 3 hospitals that often have senior surgeons and have good blood banks. Trying to do definitive pancreatic surgery days later with terrible lesser sac edema and pancreatic necrosis is extremely difficult and fraught with complications. In fact, sometimes the edema is so bad that it is impossible to do the pancreatic anastomosis. Those patients then virtually never end up with definitive reconstruction as the process continues to worsen.

When I perform the pancreatic anastomosis, I inkwell the distal pancreas into the end of the proximal jejunum. The size match is almost always quite good. I try to place two layers of sutures, usually with 3-0 Vicryl. I do the choledocho-jejunal anastomosis with interrupted 4-0 Vicryl and use a pediatric feeding tube as a stent. This decompresses the biliary system and gives access to study the bile duct later. I put in a GJ tube for gastric decompression and feeding access. I always leave several external drains. When doing a Whipple for pancreatic injury, much of the dissection is done for the surgeon by the injury. There is often a concomitant injury to the superior mesenteric vein or major branches of it. There is only one way to truly visualize the SMV behind the pancreas and that is to divide the pancreas. I gently get an index finger underneath the inferior margin of the pancreas and try to bluntly dissect the pancreas off the SMV. I then thread a Penrose drain underneath the pancreas on my finger and use that as a guide to put a TA stapler behind the pancreas and use that to divide it.

## Operative Care for Duodenal Injuries

In the past, we have utilized many rules to care for duodenal injuries. Most of these were not based on evidence. I have a relatively simplistic approach. Virtually any duodenal laceration can be closed primarily. I close them transversely in two layers after debriding devitalized tissue. It is important to remember that the area of tissue damage is always larger than the surgeon originally thinks. Pyloric exclusion was originally popular and was recommended for injuries in excess of 50% of the duodenum. I have virtually abandoned the use of this technique. The stomach often fails to empty through the gastrojejunostomy, even though it is widely patent. The one time I do consider pyloric exclusion is in the case of a devastating injury to the duodenum and a concomitant injury to the pancreas. In that case, the pancreatic secretions activated by the bile and gastric secretions can cause duodenal leak.

Instead of pyloric exclusion, I usually decompress the duodenum and place a feeding access. I decompress the duodenum with a tube placed into the proximal jejunum retrograde. I generally use a soft red rubber catheter and thread it around the ligament of Treitz, tacking the jejunum up to the abdominal wall with a Witzel tunnel that can later be injected with contrast to image the duodenum. A GJ tube can decompress the stomach and provide feeding access in patients with complicated duodenal injuries. I place this right through the duodenal repair. Alternatively, a feeding jejunostomy can be placed distal to the decompression tube. In the case of true devastating injury to the duodenum, one can consider a Whipple or simply closing the duodenal injury around a large tube. Finally, if the duodenal injury is confined to the anti-mesenteric border, duodenal resection and primary anastomosis is a real option. One must fully mobilize the duodenum to be able to get the edges to come together without tension. I have not utilized serosal patches.

## Summary

Major pancreatic and duodenal injuries are rare. I am hopeful the readers will find my comments and perspective useful when dealing with them.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Management of war wounds.

# Operative Management of Renal Injuries

# 10

Carlos V.R. Brown and Joseph M. Galante

**Deployment Experience**

| | |
|---|---|
| *Carlos V. R. Brown* | Officer in Charge and Trauma Surgeon, Naval Surgical Detachment, Ramadi, Iraq, 2006–2007 |
| *Joseph M. Galante* | Trauma Surgeon, Forward Surgical Team, UK Role 3 Camp Bastion, Afghanistan, 2010 |

*"A chain is only as strong as its weakest link.... The obvious weakest link in the severely wounded in this war (WW II) was the kidney."*

Edward D. Churchill

**BLUF Box (Bottom Line Up Front)**

1. Standard evaluation of the abdomen with FAST or DPA may be unreliable in the casualty with a kidney injury due to its retroperitoneal location.
2. Prior to exposing either kidney in an attempt to repair, or particularly if you expect to perform a nephrectomy, you should palpate the contralateral kidney.
3. If you encounter significant bleeding from the kidney, you can control hemorrhage by compressing the renal parenchyma in your hand.

(continued)

C.V.R. Brown (✉)
Division of Acute Care Surgery, Department of Surgery and Perioperative Care, Dell Medical School, University of Texas at Austin, Austin, TX, USA
e-mail: CVRBrown@seton.org

J.M. Galante
Division of Trauma, Acute Care Surgery and Surgical Critical Care, UC Davis Medical Center, Sacramento, CA, USA


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(continued)

4. The hemodynamic status of the casualty is the most important variable that affects decisions during an operation to treat a renal injury.
5. Complex renal repair or salvage is not an option in the unstable or "semi-stable" patient – you will lose the patient while trying to salvage the kidney.
6. Nephrectomy is always an option for a casualty with a severe renal injury and should not be considered a last resort but rather a lifesaving procedure.
7. Know when to not poke the skunk – *lateral* zone II retroperitoneal hematomas that are not expanding in a *stable* patient do not need to be explored (yes, even in penetrating trauma).

## Introduction

This chapter will cover the operative management of renal injuries encountered during the care of combat trauma casualties. Renal injuries may seem daunting to the elective general surgeon not accustomed to operating in the retroperitoneum or on the genitourinary system, but they are relatively easy to manage in the acute setting. However, a basic understanding of management of renal injuries is essential for the combat surgeon as the kidney may be injured by any mechanism, particularly in the setting of penetrating or blast injury. You are highly unlikely to have a urologist or transplant Surgeon immediately available to assist you, but you can expertly manage renal trauma without them. This chapter will review indications for operation and renal exploration, operative exposure and injury evaluation, repair and resection (partial and nephrectomy) of the injured kidney, and postoperative complications.

## Indications for Operation and Renal Exploration

The patient with a renal injury is rarely obvious at initial presentation. The casualty will present with abdominal trauma, either blunt or penetrating, and you must efficiently sort out whether this casualty needs an emergent laparotomy or merits further evaluation. However, like all combat casualties, hemodynamic stability is the driving force behind indications for operation. A hemodynamically unstable casualty with penetrating abdominal trauma mandates emergent exploratory laparotomy. Similarly, a hemodynamically unstable casualty who has sustained blunt or blast injury requires emergent laparotomy if the instability is attributable to the abdomen (positive focused assessment with sonography for trauma [FAST exam] or diagnostic peritoneal aspirate [DPA]). The retroperitoneum is not easily evaluated by FAST or DPA, however. Thus, a casualty with blunt or blast injury in whom other sources of hypotension have been ruled out and instability persists may require a laparotomy to definitively rule out an intra-abdominal or retroperitoneal source of hemorrhage.

In casualties with abdominal trauma and hemodynamic instability who are taken directly to the operating room, the presence of a renal injury will be discovered at the time of laparotomy. However, if you place a urinary catheter and see gross hematuria, then your index of suspicion for a genitourinary injury is obviously heightened. Your most likely diagnosis will be a bladder injury, but you must always assume the possibility of a major renal injury. Conversely, do not depend on gross hematuria as a clue – normal appearing urine is a common finding with even high-grade renal lacerations. Like any casualty requiring laparotomy, those with a suspected renal injury should be in the supine position with both arms abducted, prepped, and draped widely (chin to mid-thigh, table-to-table), and you should access the abdomen via a generous midline laparotomy from xiphoid to pubis. Upon entering the abdomen, you should proceed as with any casualty with intra-abdominal injury: evacuate hemoperitoneum, stop the bleeding, control contamination, and repair injuries. A renal injury will be suspected by the presence of a zone II (lateral to the midline) retroperitoneal hematoma. However, you should address any intraperitoneal hemorrhage before attacking a renal injury, as Gerota's fascia and the retroperitoneum provide tamponade for most renal hemorrhage. If the hematoma has ruptured or is actively bleeding through a hole in Gerota's fascia, it can usually be controlled by direct pressure with a lap sponge or hemostatic packing.

Once you have addressed the intraperitoneal bleeding, you can turn your attention to the lateral retroperitoneum. You should explore the retroperitoneum in any hemodynamically unstable casualty with a zone II hematoma, whether from blunt or penetrating trauma or those who will undergo evacuation. You do not want something that might unleash during flight. After blunt trauma, you may choose to observe hemodynamically stable casualties with a zone II hematoma as long as the hematoma is not pulsatile and not expanding during a period of observation. If you choose not to explore a zone II hematoma, that casualty will require postoperative imaging with a CT scan to fully determine the extent of renal injury. In general, you should explore all zone II retroperitoneal hematomas secondary to penetrating trauma. However, you may consider not exploring the retroperitoneum if the hematoma lies in the lateral portion of zone II (Fig. 10.1), away from renal hilar structures (artery, vein, ureter, renal calyx). This approach should be reserved for very select cases and only considered in hemodynamically stable casualties. Always have a clear idea of what you are looking for or expecting with retroperitoneal hematomas. A zone II hematoma is assumed to be either due to an injury to the renal vascular pedicle or to the renal parenchyma. If the hematoma is lateral to the renal hilum, then you can assume it represents a parenchymal injury which we know can usually be managed without surgical intervention. However, in the combat scenario, you must also consider your ability to closely observe the patient postoperatively and how soon he will be placed into the evacuation chain.

In casualties with suspected intra-abdominal injury that present and remain hemodynamically stable, the presence of a renal injury will usually be discovered at the time of CT scan of the abdomen. CT scan is the definitive imaging used to evaluate renal injuries and if available obviates the need for any other diagnostic tests such as an intravenous pyelogram (IVP). You can use the CT scan to grade

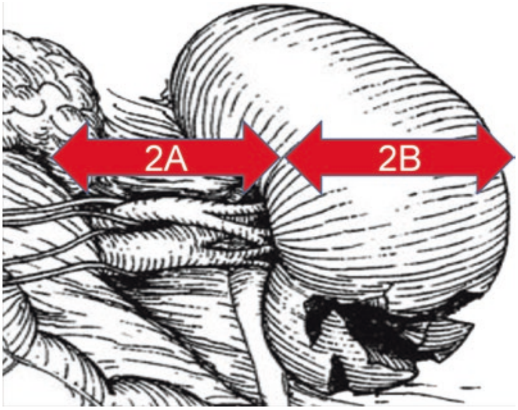


**Fig. 10.1** Zone II retroperitoneal injuries can be broken down into a medial subzone (*2A*) that contains the critical vascular structures and collecting system and a lateral (*2B*) subzone that only consists of renal parenchyma. For stable penetrating trauma patients with a nonexpanding zone 2B hematoma found at laparotomy, consideration should be given to observation as opposed to mandatory exploration (Reprinted from *Urologic Clinics of North America*, 33, Master VA, McAninch JW, Operative Management of Renal Injuries: Parenchymal and Vascular, 21–31, Copyright 2006, with permission from Elsevier)

**Table 10.1** American Association for the Surgery of Trauma organ injury severity scale for renal trauma

| Grade[a] | Type of injury | Description of injury |
|---|---|---|
| I | Contusion | Microscopic or gross hematuria, urologic studies normal |
| | Hematoma | Subcapsular, nonexpanding without parenchymal laceration |
| II | Hematoma | Nonexpanding perirenal hematoma confined to renal retroperitoneum |
| | Laceration | <1.0 cm parenchymal depth of renal cortex without urinary extravagation |
| III | Laceration | >1.0 cm parenchymal depth without collecting system rupture or urinary extravasation |
| IV | Laceration | Parenchymal laceration extending through renal cortex, medulla, and collecting system |
| | Vascular | Main renal artery or vein injury with contained hemorrhage |
| V | Laceration | Completely shattered kidney |
| | Vascular | Avulsion of renal hilum which devascularizes kidney |

[a]Advance one grade for bilateral injuries up to grade III

renal injuries according to the American Association for the Surgery of Trauma organ injury severity scale for renal trauma (Table 10.1). You can use the grade of injury seen on CT scan to determine need for operative management of the renal injury. In general, you may manage grade I and II injuries non-operatively and most will heal without consequence. You can also treat grade III and IV lacerations without operation. However, if other intraperitoneal injuries seen on CT scan require operative intervention, you should explore the grade III/IV laceration at the time of laparotomy. If you discover a renal vascular injury (grade IV or V) or a grade V laceration (shattered kidney) on CT scan, you should take the casualty for laparotomy and renal exploration. You usually will not have access to advanced interventional radiologic support or even adjuncts such as cystoscopy and stent placement. Take this into consideration when applying the civilian paradigm of nonoperative management of these injuries.

## Exposure and Injury Evaluation

During the initial laparotomy, your exposure to the kidney will be greatly facilitated by placing a self-retaining retractor such as a Balfour or preferably a Bookwalter. Surgical equipment may vary significantly depending on your unit and supply chain (particularly in a far-forward detachment), so I encourage you to open your surgical instruments and retractors to familiarize yourself before your first operation. Prior to exposing either kidney in an attempt to repair, or particularly if you expect to perform a nephrectomy, you should palpate the contralateral kidney. If you feel a normal kidney on the unaffected side, you can feel comfortable in performing a nephrectomy on the injured side if needed, without fear of making the casualty dialysis-dependent. In the unusual case that you palpate an abnormal kidney (absent, atrophic, polycystic) on the unaffected side, you may consider performing an on-table IVP to determine if the abnormal kidney is functional. However, trying to routinely perform an on-table IVP in order to evaluate the function of the uninjured kidney is unnecessary, technically difficult, often inadequate, and most importantly time-consuming. Ditto for the oft-touted "one-shot IVP" in the emergency department for penetrating trauma patients. Don't waste time and effort on these mostly useless studies, especially down range.

Once you have palpated a normal contralateral kidney and are ready to approach the injured side, you may use one of two approaches for exposure of the kidneys. You may either (1) obtain initial renal vascular control followed by renal exploration or (2) initially explore the kidney and obtain renal vascular control after complete mobilization of the kidney. Both approaches have pros and cons and should be individualized based on the casualty and the surgeon's experience and expertise. In general, the first approach is preferable in a stable patient without ongoing hemorrhage, and the second approach is preferred when time is of the essence. Obtaining initial vascular control has the benefit of securing definitive vascular control prior to exposing the injured kidney, allowing you to secure inflow and outflow if exsanguinating hemorrhage is encountered from the kidney. Figures 10.2 and 10.3 demonstrate the maneuvers and anatomy to obtain renal vascular control. However, there are several downsides to obtaining vascular control prior to renal exposure. First, a small minority of renal injuries will require vascular control prior to repair, making this maneuver unnecessary in most cases. Second, obtaining vascular control in the midline can be technically challenging, particularly in the

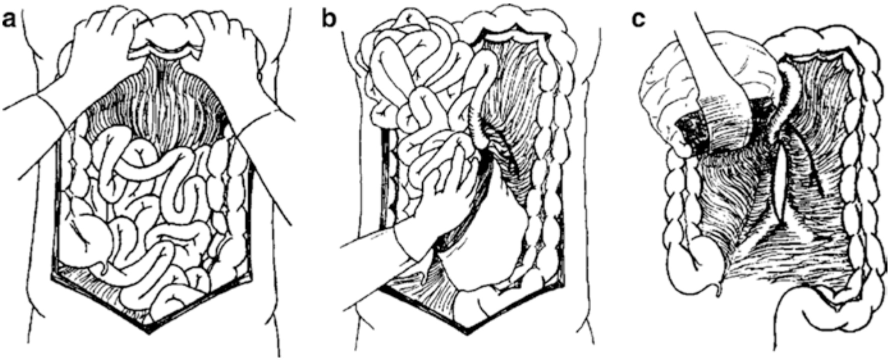


**Fig. 10.2** Exposure for proximal renal vascular control is obtained by superior retraction of the transverse colon (**a**), evisceration and retraction of the small bowel to the *right upper* quadrant (**b**), and opening the retroperitoneum longitudinally along the aorta (**c**) (Reprinted from *Urologic Clinics of North America*, 33, Master VA, McAninch JW, Operative Management of Renal Injuries: Parenchymal and Vascular, 21–31, Copyright 2006, with permission from Elsevier)

setting of a large retroperitoneal hematoma and for the surgeon inexperienced in vascular or urological surgery. Finally and most importantly, obtaining initial vascular control is definitely time consuming, even in experienced hands, and can delay definitive renal repair or a potentially lifesaving nephrectomy. For these reasons, while managing renal injuries in the setting of combat surgery, you should first efficiently expose the injured kidney and then obtain vascular control of the renal pedicle if necessary (Fig. 10.4).

The kidney is exposed in a similar fashion on the right and left sides. You mobilize the right or left colon medially by taking down the white line of Toldt, a maneuver that is facilitated by the retroperitoneal hematoma. The majority of this mobilization can be done rapidly with your hand and aggressive blunt dissection, retracting the colon and colonic mesentery to the midline. After mobilizing either colon medially, sharply open Gerota's fascia widely in a longitudinal fashion *lateral* to the kidney. Once you have entered Gerota's fascia, you should be able to bluntly and easily mobilize the entire kidney and renal hilum into the operative field allowing you to completely inspect the kidney and vasculature structures for the extent of injury. Grab the kidney with your entire hand and lift it up and out of the retroperitoneum. There will usually be superior and inferior fibrous bands that can be rapidly divided with electrocautery allowing full mobilization. The kidney should now be suspended in the midline, attached only by the renal hilum containing the artery, vein, and ureter. If you encounter significant bleeding from the kidney, you can control hemorrhage by compressing the renal parenchyma in your hand. While you (or your assistant) compress the kidney, you can obtain control of the renal vasculature manually or by placing a vascular clamp across the renal artery and vein en masse. Now you can evaluate the extent of injury to the parenchyma or vasculature and plan your surgical approach to repair or resection.

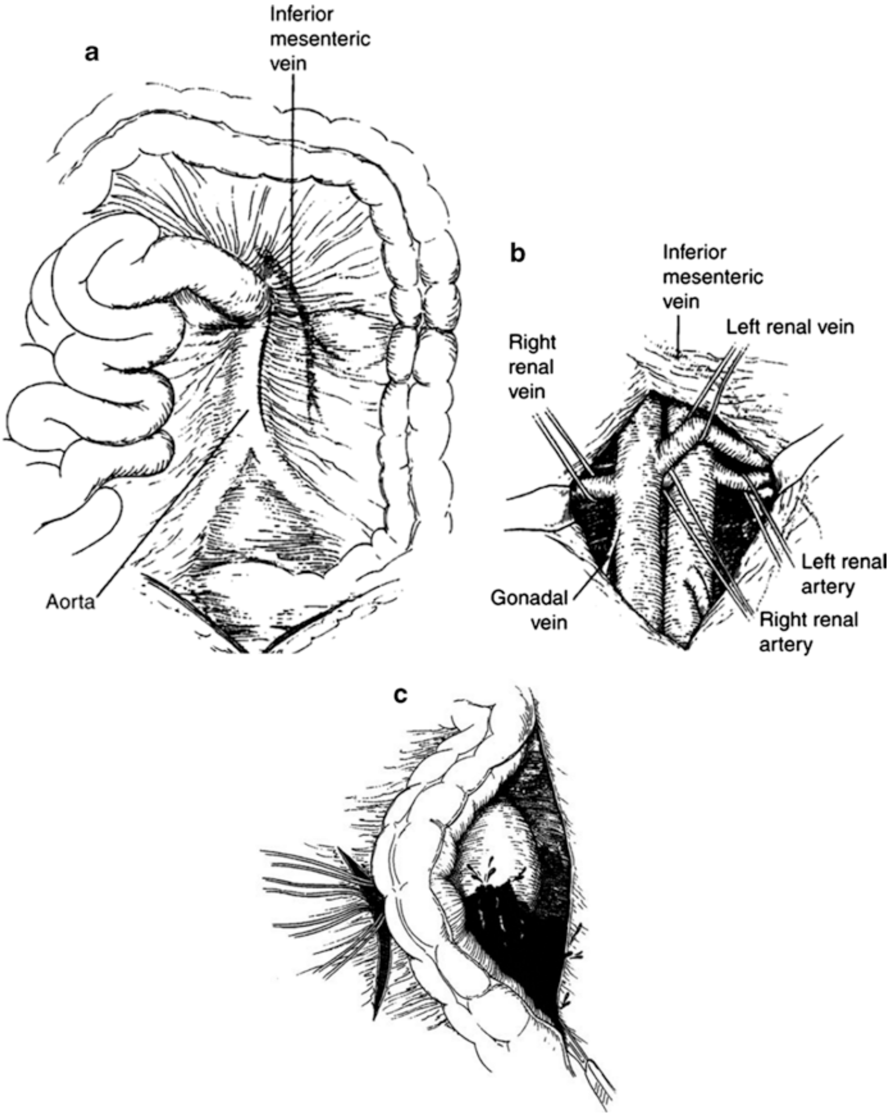


**Fig. 10.3** The retroperitoneum is opened longitudinally directly over the aorta (**a**) which should first expose the left renal vein. Both renal veins (anterior) and arteries (posterior) can now be identified and controlled with vessel loops (**b**). The colon can now be mobilized medially and Gerota's fascia opened to explore the kidney (**c**) (Reprinted from *Urologic Clinics of North America*, 33, Master VA, McAninch JW, Operative Management of Renal Injuries: Parenchymal and Vascular, 21–31, Copyright 2006, with permission from Elsevier)

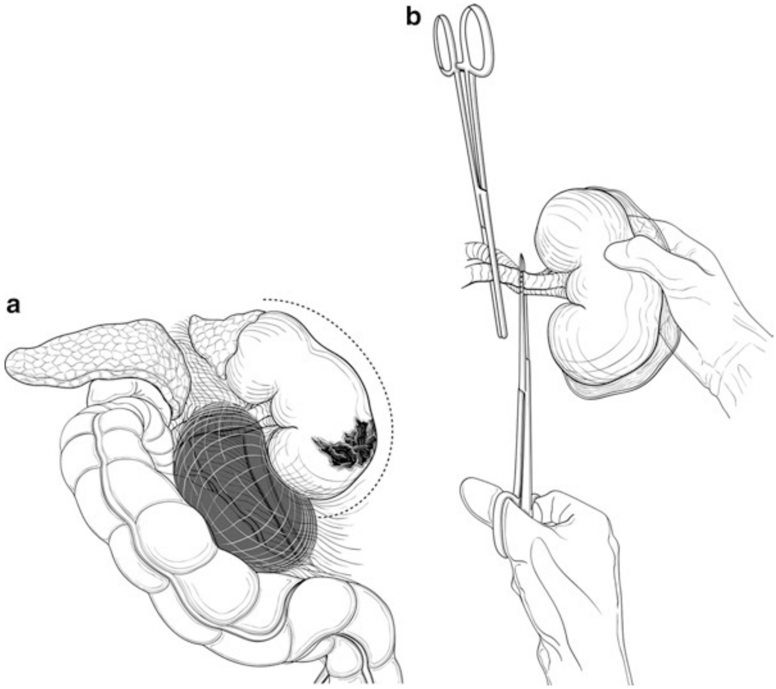


**Fig. 10.4** Rapid renal mobilization is obtained by opening Gerota's fascia on the lateral border of the kidney and lifting the kidney out of the retroperitoneum (**a**). It will now be suspended by only the renal vessels and the ureter, which can be clamped and divided if nephrectomy is required (**b**)

## Repair and Resection

Several factors need to be considered when formulating an operative plan for managing renal injuries. The hemodynamic status of the casualty is the most important variable that affects decisions during an operation to treat a renal injury. A hemodynamically stable casualty may allow you to perform a more complex (and more time consuming) repair of an injured kidney or renal vasculature if necessary. On the contrary, if you are faced with a hypotensive casualty with a renal injury, you should make no attempt at a complicated repair, and the only reasonable options are a quick and simple repair of lower grade injuries or a nephrectomy for more severe injuries. A critical and lethal error may occur when performing a complex renal repair in a hemodynamically unstable casualty with ongoing hemorrhage, causing you to lose the casualty while trying to salvage the kidney. Finally, palpating a normal kidney on the uninjured (contralateral) side should make you comfortable in performing any procedure necessary to address renal hemorrhage, including a nephrectomy.

Beware the curse of too many consultants! If you happen to have additional surgical subspecialty expertise available for consultation, then use them liberally as needed. A urologist or vascular surgeon can certainly add a degree of expertise and familiarity with exposure and advanced techniques beyond the scope of most general or trauma surgeons. This is particularly true if you are contemplating renal preservation with some type of complex parenchymal or vascular repair. However, remember that they will usually also bring a tendency toward thinking in terms of "elective" surgery and may not fully grasp the impact of prolonging the operation or the extent and degree of other injuries that need to be addressed. Furthermore, these consultants may be less likely to consider the fact that this patient will likely be leaving your site within 24 h to travel by air for 10–12 h. You are the one who has the big picture and a deep understanding of emergency trauma surgery, so stay in control and make sure the operation stays on track.

## Parenchymal Injuries

Many renal parenchymal injuries you encounter during exploration of the injured kidney can be managed with minimal intervention. Any contusion or subcapsular hematoma should be left alone. If you encounter parenchymal lacerations not involving the urinary collecting system, you may manage them by sharply debriding devitalized tissue, obtaining hemostasis with cautery or suture ligature as needed, and reapproximating the renal capsule if possible. Suture ligatures and reapproximation of the capsule should be performed with absorbable, monofilament suture in order to avoid future renal calculi formation. Pledgets should be used if the tissue is friable or your sutures are unable to be tied securely without tearing. If no standard pledgets are available, you can easily make them by excising a piece of peritoneum and cutting it into small squares. If you cannot easily reapproximate the renal capsule without tension, you can handle the raw parenchymal surface by applying tissue glue or a topical hemostatic agent or by suturing an omental flap to the edge of renal capsule (Fig. 10.5).

If the renal injury involves the collecting system, you should attempt to perform a watertight repair with chromic suture to avoid a postoperative urine leak. If you have any question regarding violation of the urinary collecting system, you may inject a few cc's of methylene blue into the renal pelvis and observe the parenchyma for extravasation of dye. Once you have completed repair of the urinary system, you can manage the parenchymal defect as detailed previously. If the injury involves the superior or inferior pole of the kidney, you may perform a partial nephrectomy of either pole and manage the urinary system and parenchyma as described. This should only be undertaken if you are confident that the risk of bleeding after the repair outweighs the risk of nephrectomy. Following any renal repair, with or without obvious injury to the urinary system, you should leave a closed suction drain in a dependent portion of the renal fossa to drain any postoperative urine leak.

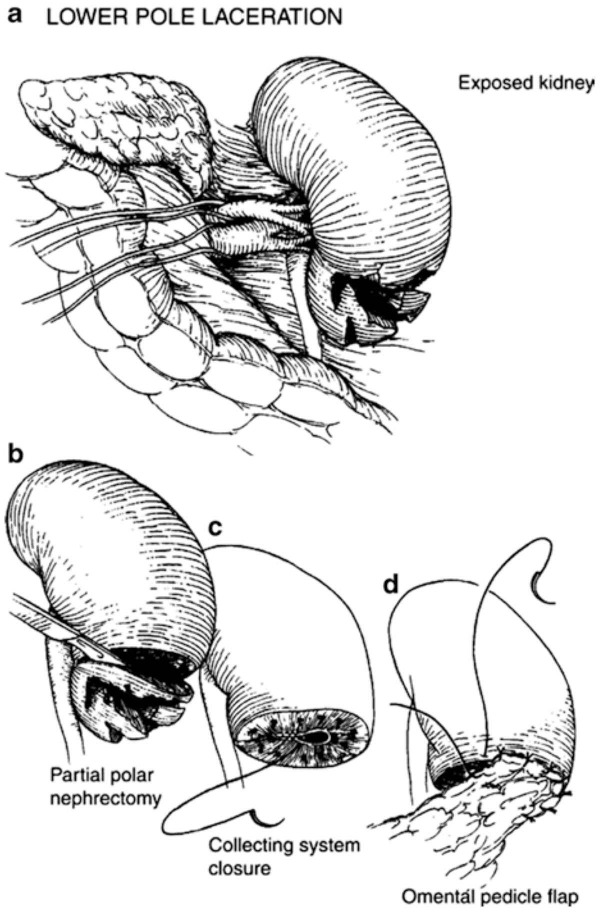


**Fig. 10.5** (**a**) Exposure of a lower pole renal laceration, (**b**) sharp debridement of the injured segment, (**c**) watertight closure of the collecting system with absorbable suture, and (**d**) coverage with an omental pedicle flap (Reprinted from *Urologic Clinics of North America*, 33, Master VA, McAninch JW, Operative Management of Renal Injuries: Parenchymal and Vascular, 21–31, Copyright 2006, with permission from Elsevier)

## Vascular Injuries

Renal vascular injuries are much less common than parenchymal injures, but as a combat surgeon you are more likely to encounter this difficult injury than in civilian practice due to the high rate of penetrating trauma seen by military surgeons. Renal vascular injuries may involve the renal artery, renal vein, or present as a combination injury. Management of renal artery injuries follows the same principles as other arterial injuries: proximal and distal control of the injured vessel, thrombectomy, debridement of devitalized tissue, followed by definitive repair.

For arterial injuries, you should obtain proximal and distal control of the injured renal artery after mobilization of the kidney as described above. After mobilization, you can control bleeding from an injured artery manually or with Debakey forceps. A few anatomic points to keep in mind: the renal veins maintain an anterior position to the renal arteries bilaterally and may need to be mobilized to clearly visualize the arteries. In addition, the left renal vein will be longer than the right, while the right renal artery will be longer than the left due to their relationship to the IVC and aorta, respectively. To access the right-sided vessels, open the retroperitoneum longitudinally along the right border of the vena cava as you retract the kidney laterally. The right renal vein should be the first large branch you encounter, and the artery can be found posterior to the vein. On the left, exposure of the renal vessels requires mobilization of the ligament of Treitz. The renal vein can be identified by division of the ligament of Treitz with retraction of the duodenum superiorly or by identifying the gonadal vein inferiorly and following it to its junction with the renal vein. Again, the artery is located posterior to the vein. You should encircle the artery in a vessel loop and occlude it with a fine vascular clamp; consider using an angled Debakey clamp or bulldog. Do not forget that multiple or accessory renal arteries are commonly encountered, but there should be a dominant vessel to the organ.

Once you have obtained proximal and distal control of the artery, you should check for antegrade and retrograde bleeding and pass an embolectomy catheter as needed. Though you will not always need to pass a catheter into the proximal artery due to brisk bleeding and lower likelihood of retained clot, you should always pass an embolectomy catheter in the distal end of the artery to ensure no thrombus is present. Now you may debride any devitalized tissue from the edges of the injured artery. You may repair an arterial laceration or incomplete transection with interrupted 5-0 prolene sutures. If the artery is completely transected, you can perform a primary (tension-free) reanastomosis or place an interposition graft with reversed saphenous vein. If you are not experienced in performing a vascular anastomosis, you should place a temporary arterial shunt with plans for a definitive reconstruction as soon as possible at a higher echelon of care. If you encounter an injury to the renal vein, you may perform a venorrhaphy if there is a small laceration and the resultant stenosis will be less than 50% (Fig. 10.6). If the injury to the vein is significant, you should ligate it and not attempt any complex venous reconstructions. Remember that on the left side, ligating the vein at the junction with the IVC is preferable to ligating it closer to the kidney, as this may allow drainage via the adrenal and gonadal collaterals. Obviously, endovascular approaches to renal vascular injuries are not often feasible down range due to lack of equipment and inexperienced personnel.

## Nephrectomy

Nephrectomy is always an option for a casualty with a complex renal injury and should not be considered a last resort but rather a lifesaving procedure. Indications for nephrectomy include hemodynamic instability, ongoing hemorrhage or need for

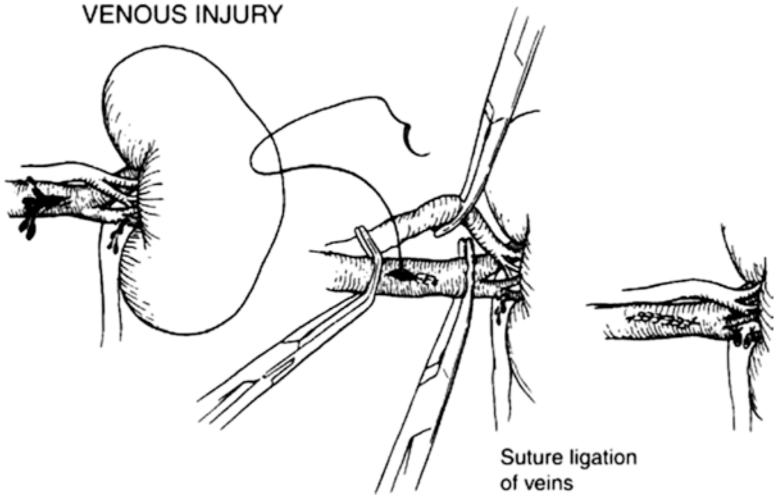


**Fig. 10.6** Left renal vein laceration (*left panel*) managed with proximal and distal control followed by lateral venorrhaphy (*middle*). Small bleeding veins are suture ligated, and the repair is completed (*right*) (Reprinted from *Urologic Clinics of North America*, 33, Master VA, McAninch JW, Operative Management of Renal Injuries: Parenchymal and Vascular, 21–31, Copyright 2006, with permission from Elsevier)

transfusion (from the kidney or any other source), unreconstructable renal injury including vascular, parenchymal, or urinary collecting system, complex renal injury requiring more operative time to repair than the casualty will tolerate, and severe associated intra-abdominal injury. In order to perform a nephrectomy, you should manually elevate the kidney as previously described, allowing you to visualize the renal artery and vein. If you have time and exposure, independently dissect and expose the artery and vein and divide each between clamps, suture ligating the proximal end. If not, clamp the hilum en masse and suture ligate the vessels as a bundle or fire a linear stapler with a vascular load across the hilum. Now the only attachment of the kidney should be the ureter, which is identified and divided after simple ligation.

The adrenal gland lies just superior and medial to the kidney bilaterally. A blast or cavitation effect which injures the kidney may also severely injure the adjacent adrenal gland. The adrenal has a variable arterial supply and often has branches coming off the renal artery, particularly on the left. Venous drainage is similar. The veins drain into the renal vein on the left and the IVC on the right. This blood supply and location of the adrenal need to be accounted for when doing a damage control nephrectomy. One often is able to easily remove the injured kidney and control the renal artery and vein, only to find new hemorrhage from arterial and venous branches to the adrenal or the adrenal gland itself. In these situations, one can place packing in the superior aspect of the renal fossa to tamponade the hemorrhage or perform a complete or partial adrenalectomy.

## Complications

As with any operation, complications such as bleeding and infection (including abscess) may occur in the postoperative period following surgery for an injured kidney. However, several complications specific to renal injuries merit further discussion. Some decline in renal function is usually seen, and a doubling of the serum creatinine can be expected in the first several days. With a normal functioning contralateral kidney, this should return to baseline or slightly above baseline. Urinary leak is the most common complication you will encounter after an operation for renal injury. As mentioned previously, you should leave a closed suction drain after any renal repair, and urine emanating from the drain confirms the diagnosis of a urine leak. The majority of urine leaks will heal spontaneously within a few days and require no specific intervention. If the leak persists after several weeks, the casualty may need a ureteral stent or percutaneous nephrostomy to aid in sealing the leak. If you identify an undrained collection of urine (urinoma) on postoperative imaging, you should drain the urinoma percutaneously and manage the same way as a urine leak. If you have performed a complex renal repair or reconstruction, the casualty may be at risk to develop hypertension in the late postoperative period. The casualty should be educated as to the risk of long-term blood pressure elevation and should receive lifelong screening for hypertension.

In conclusion, combat surgeons are much more likely to be faced with managing significant renal or renal vascular injuries in the operating room than their civilian counterparts. The key to success lies in familiarizing yourself with the local anatomy before you have to deal with it in the operating room in a bloody and distorted field and applying the main principles of emergent trauma surgery. Keep it simple, stay focused on the whole patient and not the individual organ, communicate with and lead your team, and always have a backup plan or bailout option in case of disaster.

## Civilian Translation of the Military Experience and Lessons Learned

Joseph M. Galante

**Key Similarities**

1. FAST is not reliable to diagnose renal injuries.
2. When renal injury causes hemodynamically instability, the patient requires a nephrectomy.
3. Assessment of contralateral kidney by palpation is critical prior to performing a nephrectomy.
4. Lateral retroperitoneal hematomas in hemodynamically stable patients do not need to be explored, even with penetrating trauma.

**Key Differences**

1. The civilian patient population is more diverse and has different mechanisms of injury.
2. Experts are available to assist with more complex repairs in stable patients.
3. Endovascular and percutaneous approaches are an option on an immediate and delayed basis.
4. Military patients are typically taken on a 12-h evacuation flight.

The approach to renal trauma in a civilian is significantly different from that in a military setting. There are multiple reasons for the different approaches ranging from patient variables, including age and underlying comorbidities, to available resources. These differences are the same regardless of which organ system is injured.

The civilian mechanism for renal trauma includes firearm injuries, but motor vehicle crash, bicycle crash, and auto vs. pedestrian mechanisms account for many injuries. The combined penetrating and blunt mechanism, along with the kidney's anatomical location, often predispose civilian patients to having concurrent injuries.

The first question in the military and civilian setting is: does a patient have a renal injury? FAST and DPA are not reliable diagnostic studies to definitively identify or exclude a renal injury because of the kidney's retroperitoneal location. A formal ultrasound of the abdomen can be used to image the structure of the kidney, but this is not the same as a FAST. In the hypotensive dying patient with a renal injury, the diagnosis is often made during exploratory laparotomy.

Normotensive patients in the civilian setting, unlike the military, can undergo an abdominal CT scan to diagnose renal injuries. The CT has two advantages. First, administering IV contrast reveals the extent of the injury including the vascular, parenchymal, and collecting system structures. The CT angiogram has replaced formal angiography. Second, the CT provides information on the function of the contralateral kidney and provides insight into other concomitant injuries.

Nonoperative management is an option in the civilian setting because patients often have lower grade renal injuries, do not require a protracted evacuation, and have an operating room available if they decompensate. There is no universally accepted strategy for nonoperative management in civilian practice. Specifically, the need for ICU monitoring, the role for percutaneous management of urine leaks, or even endpoints signaling failure of nonoperative management are all debatable. Penetrating injuries use nonoperative management infrequently because there are often other intra-abdominal injuries.

The nonoperative approach can be augmented with minimally invasive or percutaneous options. These options, which include ureteral stent placement, percutaneous drainage, and angioembolization, require expertise and resources not seen in many military setting. In the civilian setting, the ability to place a ureteral stent and percutaneously drain an urinoma often avoids a larger operation. The timing for when to initiate drainage and duration of the stents and drains are not widely agreed upon in the civilian setting. Despite these questions, the interventions are useful and laparotomy is rarely required.

Angioembolization is an option in the civilian setting. Angioembolization is the selective embolization of renal artery branches that have been injured. There are reports of high renal salvage rates with selective angioembolization even in patients with high-grade injuries. Given the resources required, angioembolization is not applicable in the austere military setting.

When the nonoperative approach fails and an operation is performed, it is not mandatory to explore all lateral hematomas overlying the kidney, even with penetrating trauma. There are reports of only selectively exploring penetrating injuries to the kidney in stable patients with no notable difference in outcome.

When the patient is dying from a severe kidney injury, the only option to save the patient's life is a nephrectomy. Palpation of an existing kidney on the contralateral side is ideal, but in the civilian setting, the function of the uninjured kidney is unknown without imaging. If there is no kidney, do not risk the patient's life to avoid hemodialysis. Aside from the dying patient, all attempts must be made to identify the function of the contralateral kidney.

The operative approach to the kidney is the same as described in a military setting. In a trauma, the easiest approach is from lateral to medial. The kidney is an easy organ to remove and can be done as quickly as a splenectomy, sometimes even faster. One must account for the adrenal gland and its varied vascular inflow and outflow when performing a damage control nephrectomy.

In the civilian setting with a hemodynamically stable patient, nephrectomy is not the only option. Urologists and close postoperative monitoring are available permitting more complex renal salvage maneuvers, such as partial nephrectomy and renal parenchymal repairs, as acceptable options. One must be cautious not to allow complex repairs to increase intraoperative time significantly.

Renal salvage with vascular injuries is more complicated. The civilian setting has more resources with vascular expertise and endovascular options for repair. Despite the expertise and resources, open repair of renal vascular injuries only have a 25–35% salvage rate. Endovascular repair or stenting is still evolving in renal trauma management. Several factors have slowed the adoption of endovascular stenting for renal trauma in the civilians, including the presence of concomitant injuries and the need for post-procedural anticoagulation.

Overall, there are more options to diagnose and to treat civilian renal trauma, but basic principles of operative approach and management are the same as in the military setting for hemodynamically unstable patients.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Management of war wounds.
2. Damage control resuscitation.

## Suggested Reading

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# Major Abdominal Vascular Trauma

# 11

Niten Singh, David R. King, and David V. Feliciano

**Deployment Experience**

| | |
|---|---|
| *Niten Singh* | General Surgeon, 31st Combat Support Hospital, Balad, Iraq, 2003–2004 Vascular Surgeon, 28th Combat Support Hospital, Baghdad, Iraq, 2006–2007 |
| *David R. King* | General Surgeon, Combat Support Hospital, Baghdad, Iraq, 2008 |
| | General Surgeon, Forward Surgical Team, FOB Delta, Iraq, 2008 |
| | General Surgeon, Combat Support Hospital, Haiti, 2010 |
| | General Surgeon, Forward Surgical Team, FOB Shank, Afghanistan, 2011 |
| | Trauma Surgeon, Joint Special Operations Command, Afghanistan, 2016 |

N. Singh
Harborview Medical Center, University of Washington, Department of Surgery, Seattle, WA, USA

D.R. King (✉)
Massachusetts General Hospital, Division of Trauma, Acute Care Surgery, and Surgical Critical Care, Boston, MA, USA
e-mail: dking3@partners.org

D.V. Feliciano
IUH Methodist Hospital, Department of Surgery, Indiana University, Indianapolis, IN, USA


M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_11

**BLUF (Bottom Line Up Front) Box**

1. Proceed directly to the operating room if there is suspected abdominal vascular trauma in an unstable patient.
2. The best imaging of abdominal vascular injury is with your eyes – don't delay laparotomy for unnecessary imaging.
3. The first principle of damage control surgery is control hemorrhage – don't worry about the bowel if the iliac artery is bleeding.
4. Permissive hypotension is tolerated well and often makes arterial bleeding easier to control.
5. Packing of solid organ injuries is useful; however, packing of arteries that are partially transected is often ineffective.
6. Finger control of bleeding is better than packing and blind clamping.
7. Do not delay vascular exposures.
8. Suction is not a method of vascular control and generally has no role in emergent damage control. Use laparotomy pads for visualization.
9. Preop you should be thinking about how to get proximal and distal control. Intraop you should be thinking about inflow, outflow, and what conduit to use.

## Introduction

Management of major vascular bleeding in the abdomen poses significantly different challenges in the resource-limited combat environment. Deployed settings for surgical care vary widely, and the surgeon must be prepared to tackle major abdominal bleeding with few resources and no imaging. In most resource-limited, mass casualty situations, a very aggressive surgical posture must be assumed. This means rapid exploration of the abdomen for any suspicion of bleeding and avoidance of imaging whenever possible. Body cavities can be interrogated surgically (or in some cases with ultrasound) to exclude life-threatening hemorrhage, and this is often necessary when no imaging is available or when imaging is impractical due to a number of casualties.

## The Basics in the ER

Sometimes forgotten in the chaos of multiple unstable patients in the ER is the basic premise that the majority of patients in a combat environment are best served in the operating room. Patients with penetrating abdominal wounds or fragmentation generally belong in the operating room. Those with blunt injuries, with a negative FAST exam, and that are conversant can be observed or imaged as needed, but certainly triaged into a pool of patients who, for the moment, do not need an operation. Patients who are hemodynamically unstable and have any form of abdominal or thoracoabdominal injuries should be taken to the operating room.

There are three major points to remember in the basic work-up of combat casualties: (1) a chest X-ray (if available) rarely takes any time and can exclude massive hemorrhage into the bilateral pleural spaces; (2) obtain a blood sample for typing and crossmatching (if fractionated blood products or fresh whole blood is available); (3) a central venous line should be placed in the jugular or subclavian vein rather than the femoral vein if abdominal vascular injury is suspected.

Resuscitation should be limited to blood and blood products and antifibrinolytics. Crystalloid use should be absolutely limited or eliminated. Resuscitative endovascular balloon occlusion of the aorta can be considered if supradiaphragmatic hemorrhage has been excluded preoperatively. In trained hands, this takes just minutes and may be lifesaving.

## In the OR: Getting Started

It is often easier to drape a patient if both of their lower extremities are prepped circumferentially. It may sound cumbersome, but with the number of personnel in some combat ORs, it is not difficult. Placing two down sheets and a groin towel and wrapping both feet in towels allow easy access to both legs if greater saphenous vein is needed and can allow another team to do the harvest without crowding the abdominal team. The proximal extent of the prep should include the chest to the clavicles or the chin if thoracic wounds are present. A laparotomy sheet or two split sheets can be centered over the abdomen and cover the prepped area. If vein harvest is required from the legs or proximal control in the chest is needed, the overlying drape can be cut and the area easily accessed. The prep is very quickly performed with betadine paint alone and/or with single applicator prep. During this time, you should focus your thoughts on your plan, take a moment to collect yourself, and make sure the patient has blood products and adequate vascular access.

If you find yourself operating alone with an assistant who happens to be an 11B, prep from chin to knees and drape appropriately. You won't be doing anything fancy.

## In the OR: Injuries Encountered

Upon performing the laparotomy, any number of scenarios can occur, but most can generally be grouped into one of the following situations:

1. Free blood with isolated major vascular injury *(rare)*
2. Free blood with succus and hollow viscus injury or solid organ injury *(more common)*
3. Retroperitoneal hematomas and no major intra-abdominal injury
4. Retroperitoneal hematoma and intra-abdominal viscus injury
5. Pelvic hematoma

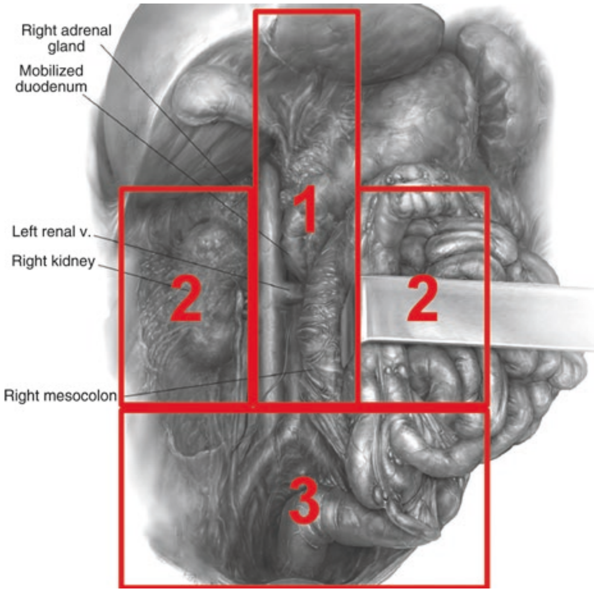


**Fig. 11.1** Zones of the retroperitoneum. Zone 1, central retroperitoneum which contains the vena cava, aorta, and their major branches. Zone 2, lateral (or renal) space which contains the renal vessels and kidneys. Zone 3, pelvis which contains the iliac artery and vein system (Modified from Cook PR, Dilley RB. The Inferior Vena Cava and Iliac Veins: Management of Operative Injuries, Obstruction, and the Palma Procedure. Operative Techniques in General Surgery 2008; 10:154–163, with permission from Elsevier)

The retroperitoneum is divided into three zones in the abdominal cavity (Fig. 11.1). Remember that the zones are all about major blood vessels, so if you see a large hematoma, you generally know what vessel(s) you are worried about. As soon as you have identified the zone of injury, your next step is to rule in or rule out an injury to the primary LARGE vessels in that zone. *Zone 1* encompasses the entire central region of the retroperitoneum and is subdivided into *supramesocolic* and *inframesocolic*. This zone contains the aorta, IVC, celiac, SMA, and IMA and is in close proximity to the pancreas and duodenum. *Zone 2* is the left and right portions of the retroperitoneum and contains the left and right kidneys and the renal vessels. *Zone 3* is the pelvic portion of the retroperitoneum and contains the iliac and femoral vessels. The main purpose of this classification is to trigger an automatic plan based on the retroperitoneal zone that is found to have hematoma during laparotomy. Many times the hematoma will be crossing zones, but it is usually clear which zone it originates from. It is also not unheard of in combat injuries, particularly explosive mechanisms with multiple fragments, to have vascular injuries in more than one zone. A few generalities regarding hematomas encountered in the retroperitoneum are listed below.

## Hematomas in Different Zones

1. For *blunt* trauma *ONLY*, do not open zone 2 or 3 hematomas and retro-hepatic hematomas unless expanding or pulsatile, or patient instability with no other sources.
2. *OPEN and explore* all penetrating hematomas except for the retro-hepatic hematoma (unless it is ruptured, pulsatile, or rapidly expanding).
3. There are exceptions to these rules (discussed below), but they are unusual.

Although this is a fairly simplistic algorithm, since many of the injuries you will encounter are penetrating, you *WILL* explore these hematomas. Often these injuries are not going to "sneak up on you"; they will likely be filling the abdomen with blood.

The only scenario in penetrating trauma where you may want to delay opening a hematoma is in the patient with multiple injuries who is unstable. If the size and extent of the hematoma does not explain the patient's unstable physiology, you may want to leave that hematoma alone initially and look for the hemorrhage source that is really killing the patient. These other sources could include previously quiescent extremity hemorrhage (blood loss "under the drapes"), blood loss into other cavities (such as the chest), scalp hemorrhage, or cardiac tamponade.

## In the OR: Operative Technique

Most penetrating abdominal vascular injuries are noted in conjunction with hollow viscus injury. Therefore, if there is massive blood and succus or stool encountered, the initial tasks are identifying the vascular injury and controlling it with finger pressure or clamping after gaining appropriate proximal and distal control. Wide, aggressive vascular exposures should be the norm.

### Zone 1 Supramesocolic Injuries

If a zone 1 supramesocolic injury or hematoma is encountered, a left medial visceral rotation should be performed (Mattox Maneuver) (Fig. 11.2). This maneuver allows visualization of the entire abdominal aorta from the hiatus to the bifurcation. The exposure involves mobilization of the left colon, dividing the lienosplenic ligament, and bluntly elevating the left colon, left kidney (optional), pancreas, and stomach. Once the peritoneum along the line of Toldt is opened, the rest of this maneuver can be rapidly done with blunt hand dissection and bovie. Sweep everything medially until you feel the vertebral bodies. Once the viscera are all rotated up off the retroperitoneum, there is usually a thin plane of tissue along the side of the aorta which must be opened to directly expose aortic adventitia and aortic branches. If there is active bleeding from this area when entering the abdomen or opening a hematoma, the aorta can be blindly compressed by your assistant at the aortic hiatus with a hand

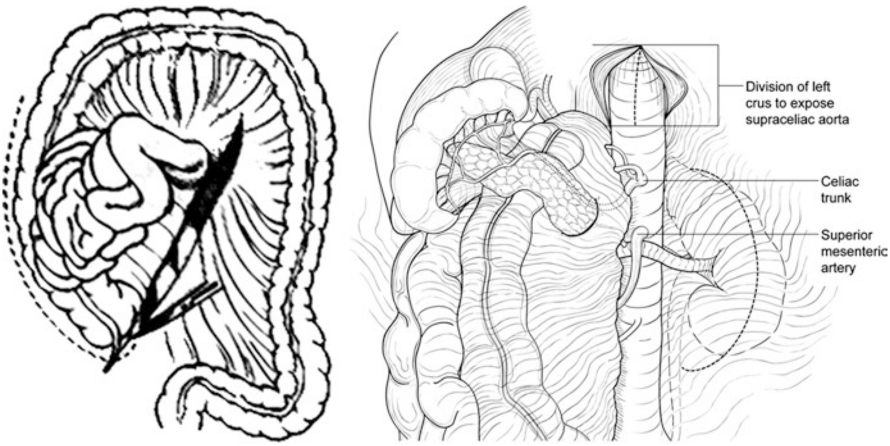


**Fig. 11.2** Left medial visceral rotation. Open the lateral attachments of the descending colon (*white line* of Toldt) and spleen sharply, and you can then bluntly dissect these structures anteriorly and medially (roll them toward you) until you come to the aorta and spine

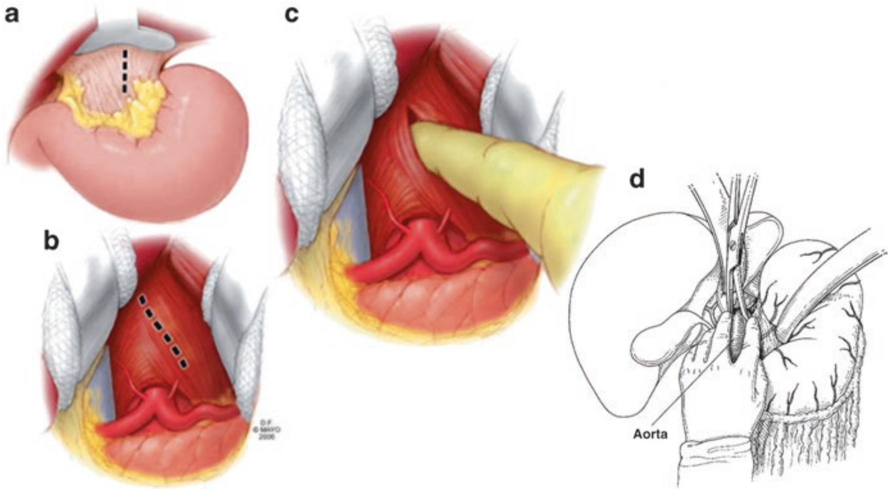


**Fig. 11.3** Supraceliac control is obtained by opening the gastrohepatic ligament (**a**), lateral retraction of the stomach and left lobe of the liver, and division of the overlying diaphragmatic crural fibers (**b**). Finger dissection (**c**) is helpful to establish a circumferential plane for clamp placement (**d**) (Reprinted from Lin PH, Chaikof EL. Embryology, anatomy, and surgical exposure of the great abdominal vessels. Surg Clin North Am 2000; 80:417–433, with permission from Elsevier)

or the blunt end of a large retractor. To apply a supraceliac cross-clamp, the gastrohepatic ligament is divided, the left crus of the diaphragm is bluntly dissected, and the aorta is identified at the hiatus (Fig. 11.3). A *key point* is it is easier to identify the aorta if the esophagus has an NGT in it, and often it is *not* easy to clamp this area, particularly in obese patients. If you are uncomfortable with this vascular control technique, then an anterolateral thoracotomy is still an option to obtain proximal control. Always *remember* to reposition the clamp to a lower position when feasible if a supraceliac cross-clamp is in place to limit visceral ischemic time.

#### Specific Zone I Supramesocolic Vascular Injuries

*Aorta* Small injuries to the aorta are debrided and repaired primarily with 3-0 and 4-0 Prolene sutures. If the aorta is significantly damaged, replacing it with a 12–14 mm graft is preferable as there is no vein option for this size. A rifampin-soaked graft may offer some resistance to infection. A simple way to do this is to always keep 1200 mg of rifampin in the OR (two 600 mg tablets that can be crushed on the back table and placed in 50 cc of saline for 10–20 min).

*Celiac Artery and Its Branches* All branches of the celiac artery (left gastric, splenic, and common hepatic) can be ligated. The common hepatic should be ligated proximal to the gastroduodenal artery or repaired if possible.

*SMA/SMV* SMA injuries should be repaired primarily or with an interposition graft. Usually a reversed greater saphenous vein graft is adequate in this situation using 5-0 or 6-0 Prolene suture. Take care that the graft does not kink when the bowel is laid back in anatomic position. The omentum should be placed around the suture line. The pancreas and duodenum are commonly injured structures around this area, and if there is a noted injury, the vein graft should be taken off the infrarenal aorta to avoid the pancreatic injury site that can be prone to leaks. The SMV can be repaired with lateral venorrhaphy, but if complex, it can be ligated. If ligation is performed, then aggressive fluid resuscitation should take place because patients will have mesenteric engorgement and systemic hypovolemia. *Always plan a second-look laparotomy after SMA/SMV repair to evaluate for compromised bowel or graft failure*. In general, a second-look laparotomy is almost always indicated for combat casualties, regardless of the findings at the index operation. Small injuries are commonly missed, and a second look often reveals surprises not recognized in the chaos of index operations in a mass casualty scenario.

### Zone 1 Inframesocolic Injuries

Exposure is via the same exposure for abdominal aneurysm repair. This involves retracting the transverse colon cephalad and the small bowel to the RUQ. The upper extent of the exposure is the left renal vein (see Fig. 11.2). As opposed to the suprarenal aorta, the infrarenal aorta can be ligated and extra-anatomic repair can be performed if there is excessive contamination.

#### Specific Zone I Inframesocolic Vascular Injuries

*Aorta* Exposure is as described above. The same principles apply for the repair or replacement as described in the supramesocolic aorta. Temporary shunting with 24–32 French (8–10 mm) chest tube is often discussed but rarely performed. If you have time to clamp and repair, do it. Remember that if you find one hole, you should always look for a second hole, particularly on the back wall of the vessel.

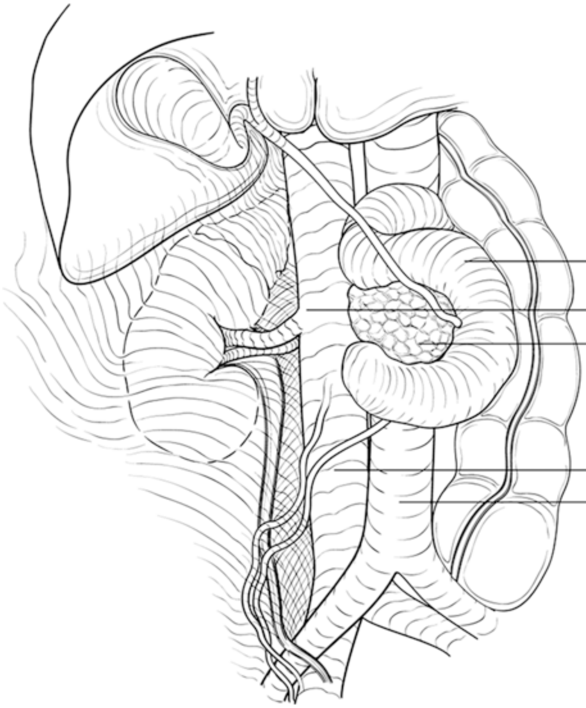


**Fig. 11.4** Right medial visceral rotation achieves full exposure of the duodenum, head of pancreas, infrahepatic vena cava, and right kidney

*IVC* Exposure to the IVC is via a right medial visceral rotation (Cattell-Braasch Maneuver) which involves an extended Kocher maneuver with mobilization of the right colon (Fig. 11.4). For a simple anterior laceration or branch avulsion, a side-biting clamp can obtain control for repair while maintaining luminal flow (Fig. 11.5a). However, this is often initially impossible in a bloody field, and compression with sponge sticks is a great method for control and repair with 3-0 or 4-0 Prolene (see Fig. 11.5b). Remember that just like the bowel, if you have one hole, you should make sure you don't have another hole. Look for a posterior injury (through and through). These are often difficult to mobilize, so extend your anterior venotomy to repair the posterior laceration from the inside (Fig. 11.6). When repair is not straightforward and the patient is unstable, ligation of the infrarenal vena cava CAN be performed. If you ligate the suprarenal IVC, pay close attention to the post-op renal function as it may deteriorate (it often will not). The lower extremities should be wrapped and elevated; reconstruction can be performed at a later time. Ligation of the suprarenal IVC is associated with a high mortality, but it is preferable to extended attempts at repair in an unstable patient.

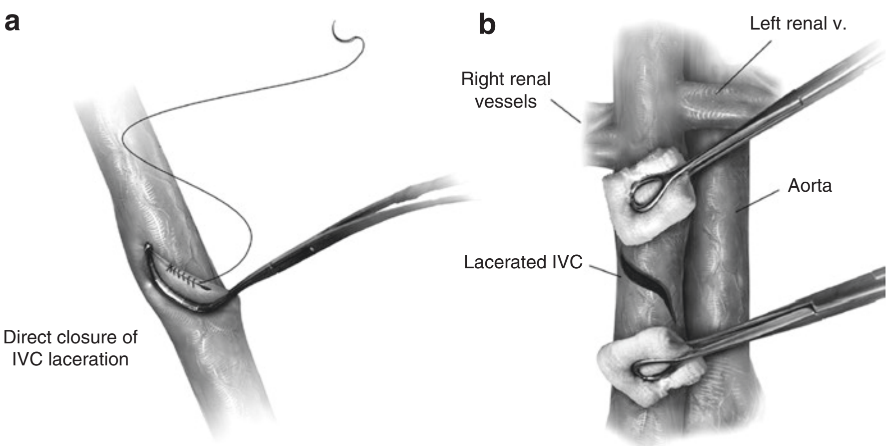


**Fig. 11.5** Control and repair of an anterior vena cava laceration can be accomplished with a side-biting clamp and a running suture repair (**a**) or with two sponge sticks providing proximal and distal compression (**b**) (Modified from Cook PR, Dilley RB. The Inferior Vena Cava and Iliac Veins: Management of Operative Injuries, Obstruction, and the Palma Procedure. Operative Techniques in General Surgery 2008; 10:154–163, with permission from Elsevier)

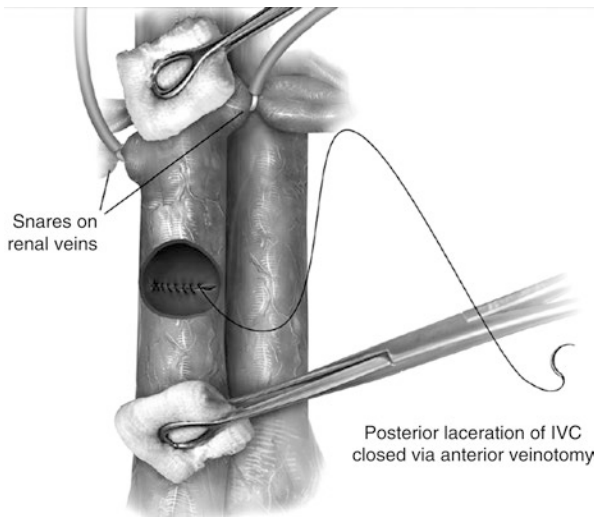


**Fig. 11.6** Repair of a posterior vena cava laceration through an anterior venotomy and sponge stick control (Modified from Cook PR, Dilley RB. The Inferior Vena Cava and Iliac Veins: Management of Operative Injuries, Obstruction, and the Palma Procedure. Operative Techniques in General Surgery 2008; 10:154–163, with permission from Elsevier)

## Zone 2 Vascular Injuries

Patients with zone 2 hematomas from blunt trauma that are expanding and pulsatile should be explored; leave stable hematomas alone. The hard and fast rule taught in residency is that ALL zone 2 hematomas from penetrating trauma should be explored. This is a good general principle, but there are some specific situations where you may be better off leaving them alone even if the mechanism is penetrating. If the hematoma is clearly lateral to the renal hilum and is non-expanding, then this is either a soft tissue injury or a renal parenchymal injury. There is no reason to treat these differently than blunt injuries, and exploring them will only increase your chances of stirring up bleeding and possibly having to do a nephrectomy. For the majority of zone II penetrating hematomas that DO require operative exploration, they are best approached via right or left medial visceral rotation as described above (also see Chap. 10 on renal injuries). Lateral arteriorrhaphy of the renal artery can be performed with 5-0 and 6-0 Prolene. Interposition saphenous vein grafting can be employed in stable situations. With regard to the renal veins, if the right renal vein must be ligated, nephrectomy is usually required since there is no collateral drainage. The left renal vein can be safely ligated distally (close to the vena cava) as long as the adrenal, lumbar, and gonadal veins are intact to provide collateral drainage for the left kidney.

## Zone 3 Vascular Injuries

Associated injury of the bowel and urogenital structures often accompanies injuries to the pelvic (iliac) vessels, complicating your decisions regarding repair. Exposure of the more distal vessels is often difficult, particularly for the vein injuries since they are located deep to the arteries (Fig. 11.7). In blunt trauma, hematomas should not be opened except for the caveats listed above. The focus in combat trauma is on penetrating injuries in the pelvis. With arterial trauma, if there is no complete transection, these injuries can be associated with massive blood loss. Conversely, completely transected vessels tend to spasm and retract and, especially in hypotensive patients, can be identified and clamped. Exposure of the distal aorta and iliac vessels is obtained as shown in Fig. 11.8. Remember that a good first move may be to clamp the distal aorta and/or vena cava, and then proceed with iliac exploration. Ligation of the internal iliac arteries is tolerated as there are extensive collateral pathways, but it is preferable to not ligate both iliac arteries. Conversely, ligation of the common iliac and/or external iliac artery is associated with a high rate of limb loss; therefore, repair or shunting of these injuries should always be attempted. Lateral arteriorrhaphy should be utilized for small injuries to the iliac arteries, whereas interposition grafting can be performed for larger injuries using an 8 mm rifampin-soaked Dacron graft. A significant proximal injury or avulsion can be reimplanted at a lower level after some mobilization (Fig. 11.9). If you do not have vascular graft material or have massive contamination, then another option for an external iliac artery injury is an internal iliac to external iliac transposition procedure (Fig. 11.10).

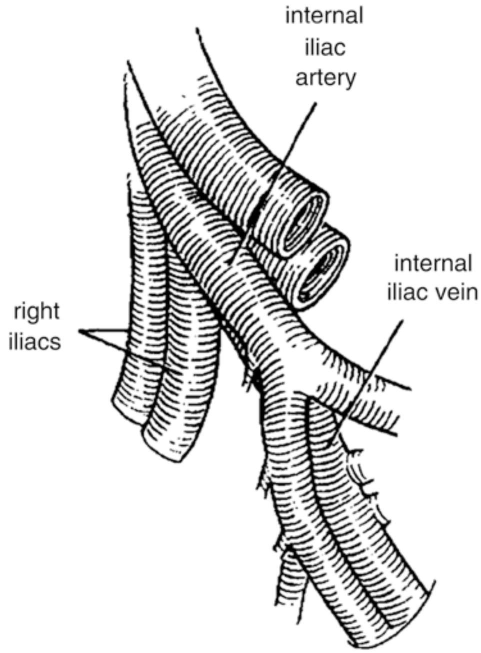


**Fig. 11.7** Anatomic relationship of the iliac arteries and veins; note the location of the veins deep to the arteries (Reproduced from Lee JT, Bongard FS. Iliac vessel injuries. Surg Clin North Am 2002; 82:21–48, with permission from Elsevier)

Debride and completely divide the injured external iliac artery after ligating the proximal end, then divide the internal iliac artery and transpose the proximal end to the distal end or side of the injured external iliac to restore flow to the leg. Shunts can and should be utilized if the patient is in extremis. In the case of massive contamination and an unstable patient, the ends of the iliac can be ligated, living tissue placed over the stumps (omentum, etc.), and femoral to femoral bypass performed once the patient is stable. If the iliac veins suffer simple injuries, they can be repaired primarily with 3-0 and 4-0 Prolene sutures. For longitudinal injuries to the vein, using the index finger and the middle finger for venous control and sewing in a running style is an efficient method for repair. If the iliac veins need to be ligated, elevation and wrapping of the affected ipsilateral extremity should be performed and you should consider fasciotomy. If you have a combined arterial and vein injury, fasciotomy of the affected calf should routinely be performed.

One of the most vexing problems is the penetrating pelvic injury to the sacral plexus. Most of the time, obtaining control in this region is difficult and packing is performed. In the majority of these injuries, there is concomitant sigmoid or rectal injury, and dividing the rectum below the injury and mobilizing the rectal stump in the retrorectal plane allow for improved visualization and packing of this area. If there are large bleeding veins visualized in that area, figure of eight sutures or U-stitch control with pledgeted 4-0 Prolene sutures is an effective measure of control. Even though the veins in the area are the problem, obtaining control of the internal iliac arteries can help slow bleeding in the area, and in dire circumstances, the arteries can be ligated. Complete pelvic vascular exclusion can be obtained by clamping both

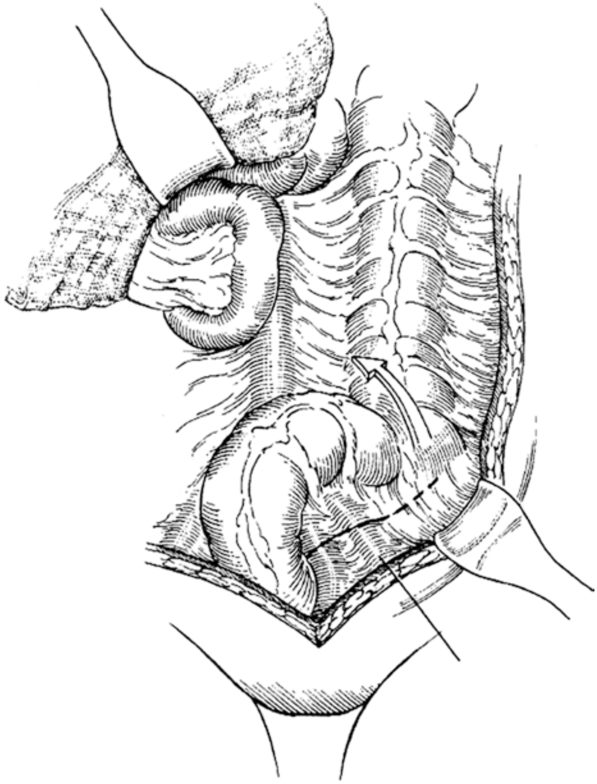

**Fig. 11.8** Exposure of the distal aorta and iliac vessels. The small bowel is retracted to the right upper quadrant, and the lateral attachments of the sigmoid colon are divided (*dotted line*) to obtain distal iliac exposure (Reproduced from Lee JT, Bongard FS. Iliac vessel injuries. Surg Clin North Am 2002; 82:21–48, with permission from Elsevier)

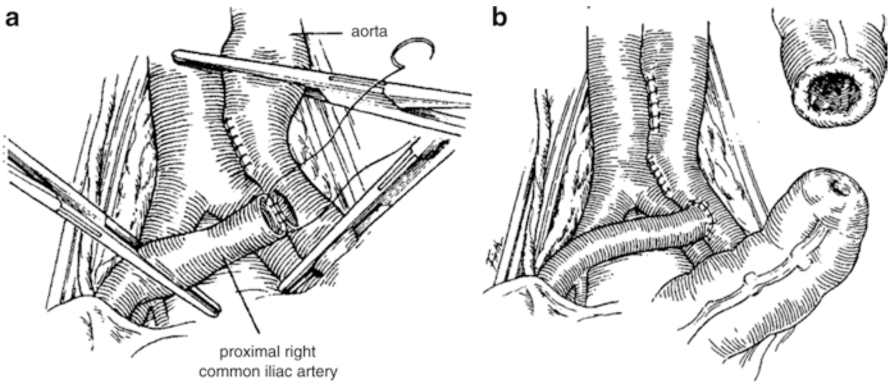


**Fig. 11.9** A proximal common iliac artery injury or avulsion can be repaired by oversewing the defect and creating a new anastomosis more distal on the contralateral common iliac (**a**). This effectively creates a new and lower common iliac bifurcation (**b**) and is particularly useful in avoiding prosthetic in the setting of bowel injury (colostomy shown) or other contamination (Reproduced from Lee JT, Bongard FS. Iliac vessel injuries. Surg Clin North Am 2002; 82:21–48, with permission from Elsevier)

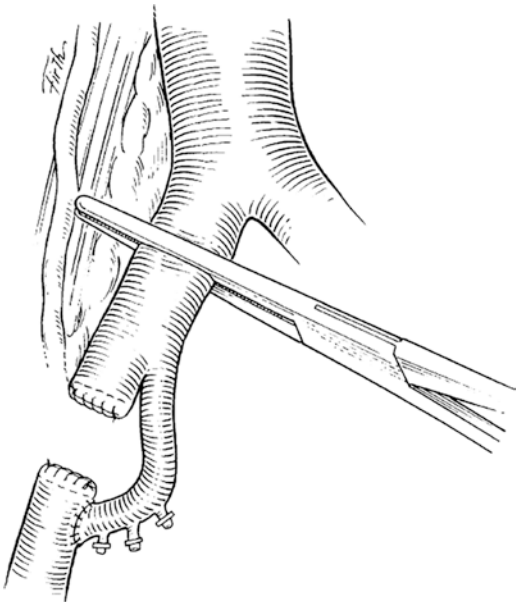

**Fig. 11.10** Transposition of the internal iliac artery to the external iliac artery to restore extremity flow after an injury to the proximal external iliac artery (Reproduced from Lee JT, Bongard FS. Iliac vessel injuries. Surg Clin North Am 2002; 82:21–48, with permission from Elsevier)

common iliac arteries and veins. Combined with pelvic packing, this approach may be effective to finally obtain control of this difficult problem. Another option that has been used successfully in several cases of massive pelvic hemorrhage has been the application of an advanced topical hemostatic dressing, such as Combat Gauze®. This can be left in place and removed at a subsequent exploration in 24–48 h.

### Damage Control in Abdominal Vascular Trauma

All major vascular injuries to the abdomen should have a planned second-look procedure. Temporary closure can be performed via numerous techniques. As stated above, certain arteries can be ligated with impunity (the celiac trunk and its branches and the internal iliac artery), while others must be repaired or bypassed (SMA, common and external iliac artery). Intraluminal shunts can be placed with a plan for a second-look procedure and repair. The warning should always be if the patient is stable (and there are no other patients in dire need of your attention) for repair, *then do it* now. Placing a shunt is not without risks, especially intra-abdominal shunts. These can lead to exsanguination if dislodged during movement and may have severe sequelae if they occlude prior to definitive repair.

## The Massive Pelvic Disruption

Many of you may be familiar with the difficulties encountered when managing a patient with a severe pelvic fracture and associated bleeding. In general, the civilian algorithm for this is to not operate and to use adjuncts such as external fixation, pelvic binding, and angiographic embolization to control hemorrhage. In the combat setting, you will likely not have the option of angiographic embolization to control the hemorrhage, and an orthopedic surgeon is likely not available to apply an external fixator. You must control the hemorrhage in the old-fashioned way: with suture. There are several key points to remember if you are in this scenario:

1. If the patient is unstable, the abdomen should already be open to rule out intraperitoneal hemorrhage.
2. Throwing lap sponges on top of a large pelvic hematoma does not provide tamponade – you must violate your instincts and open it.
3. Widely open the pelvic hematoma, and THEN pack the pelvis with laparotomy pads to soak up blood to visualize what is bleeding and individually ligate bleeders.
4. If the patient remains unstable, ligate the internal iliac artery on the more injured side.
5. If they are still unstable, ligate the contralateral one.

## Final Thoughts

We all know the surgeon who claims to have saved a patient by placing a Foley catheter somewhere other than the bladder. The anecdotal "trick" can work once in a while, but nothing beats sound standard operative exposure and control. The exception is if one is facile with intraluminal occlusion balloons and placing of long sheaths in the aorta and iliacs to control the major vessels remotely. However, what may be true at a Level I trauma center in the United States is likely not the same scenario you will face in a combat hospital. Be aggressive. Do not be afraid to operate. Dying patients belong in the operating room. If you are confused, just start opening body cavities until you find the bleeding.

## Civilian Translation of Military Experience and Lessons Learned

David V. Feliciano

**Key Similarities**

- Penetrating trauma predominates as the mechanism for major abdominal vascular injury in both civilian and military settings.
- The primary initial modality of treatment of major abdominal vascular injuries is operative in almost all settings and circumstances.
- Damage control techniques and "second-look" operations are liberally utilized in both civilian and military settings.

**Key Differences**

- Access to resources such as computed tomography and endovascular techniques may not be available in the combat environment; this usually does not affect the initial primary surgical approach, but may impact secondary diagnostic and therapeutic maneuvers.
- The rare stable patient with a contained major abdominal vascular injury may have more options for treatment in civilian settings.
- There may be more options for treatment of major hemorrhage associated with pelvic fractures in civilian environments, including rapid external fixation and angioembolization.
- Drs. Singh and King reviewed the anatomy, vascular exposures, and options for repair, shunting, and/or ligation of injured abdominal vessels in a condensed, but comprehensive, way. This brief commentary will reemphasize their critical points and suggest some alternate approaches.

## Prep and Drape

Having a prep and drape from the chin to the bilateral toenails allows access to intrathoracic structures and to the greater saphenous vein in either the groin or at the ankle. Also, pulses can be assessed immediately after repair of the common or external iliac artery.

## Cross-Clamping of the Supraceliac Abdominal Aorta When a Hematoma Is Present in the Supramesocolic Area

By placing a finger or Kelly clamp inside the muscle fibers of the aortic hiatus of the diaphragm at the 2 o'clock position, the fibers can be divided with the electrocautery. Further exposure of the distal descending thoracic aorta (without overlying celiac ganglia or lymphatics in the way) can be obtained by continuing to divide the posterior part of the left hemidiaphragm at the same position.

## Graft from Infrarenal Aorta to Superior Mesenteric Artery (SMA)

Patients with combined pancreatic-proximal SMA injuries will benefit from insertion of a temporary intraluminal shunt at a first "damage control" operation. At the reoperation in a stable patient, the infrarenal aorta and the proximal SMA on the underside of the mesentery are exposed and controlled in proximity to one another. A Doppler flowmeter is helpful in finding the posterior aspect of the SMA as flow through the proximal shunt is diminished as compared to normal arterial inflow. Bypass grafting is accomplished from the right anterolateral aorta to the underside of the SMA using an 8–10 cm reversed autogenous saphenous vein graft excised from an uninjured thigh. The proximal shunt is removed, and both ends of the SMA are closed with 4-0 polypropylene suture and covered with a viable omental pedicle.

## Ligation of the Infrarenal Abdominal Aorta

I have never done this, but understand the possible need in the patient with hypothermia and a severe intraoperative coagulopathy. If the insertion of an interposition graft is chosen instead, a polytetrafluoroethylene graft is avoided (bleeding from needle holes). A woven or albumin-coated Dacron graft should be used in this situation.

## Posterior Hole in Inferior Vena Cava (IVC)

Performing a repair of a posterior perforation of the IVC through an extended anterior bullet or shrapnel venotomy results in an hourglass narrowing. With proximal and distal vascular control using DeBakey aortic clamps, the IVC is rolled toward the aorta. Lumbar veins near the perforation on the right side of the spine are clipped to decrease backflow into the area of injury. A meticulous repair with 4-0 or 5-0 polypropylene suture is then performed with the other advantage that no suture knots are in the lumen of the IVC.

## Ligation of the Infrarenal Inferior Vena Cava (IVC), Common Iliac Vein (CIV), or External Iliac Vein (EIV)

Ligation of these major veins decreases arterial inflow at the capillary level which affects the arteriovenous gradients in the myofascial compartments of the lower extremities. Significant postoperative elevation of the injured extremity or both extremities further adversely affects this arteriovenous gradient. These two factors contribute to an increased risk of a below knee or thigh compartment syndrome. Therefore, it is worthwhile to measure the compartment pressures in the anterior and deep posterior myofascial compartments below the knee before completing the first trauma laparotomy (or after ligation of the femoral or popliteal vein in a lower extremity). A compartment pressure in the 30–35 mm range is likely to worsen with postoperative elevation of the extremity as noted above. Depending on the level of the patient's "physiologic exhaustion," unilateral or bilateral below knee 2-incision 4-compartment fasciotomies should be performed (20 min with attending surgeon and fellow or senior resident) at the first operation. If this is not performed, serial measurements of below knee and thigh anterior compartment pressures should be performed in the intensive care unit.

## Ligation of the Suprarenal Inferior Vena Cava (SIVC)

Shunting after a complex injury of the SIVC is awkward because of the size of the vessel and proximity of the orifices of the renal veins. Therefore, ligation is occasionally performed. While some patients and their kidneys survive this maneuver, every effort should be made to return the patient to the operating room in 4–6 h. A large externally supported polytetrafluoroethylene (PTFE) interposition graft is then inserted using 4-0 or 5-0 PTFE sutures.

## Complex Repair of the Common (CIA) or External Iliac Artery (EIA) in the Presence of Enteric or Colonic Contamination

With an end-to-end repair or insertion of an interposition graft into the CIA or EIA in the presence of enteric or fecal contamination, there is an increased risk of an anastomotic blowout (end-to-end or plastic graft) or dissolution of the graft (saphenous vein) in the postoperative period. Proximal and distal ligation around the arterial injury and insertion of an extra-anatomic crossover femoro-femoral PTFE graft immediately or within 4–6 h is an option, but few trauma vascular surgeons choose this. If the complex arterial repair is performed in situ, the greater omentum should be mobilized off the transverse colon. The vascularized pedicle of the omentum is then wrapped around the entire area of repair of the vessel like a gauze wrap around an extremity.

## Bleeding from Presacral Veins

The defect in a bleeding sacral vein can often be visualized if two suction devices are available. The time-honored insertion of a tack using an orthopedic hammer into or on either side of the defect is one option, but can rarely be performed in the deep posterior part of the narrow male pelvis. Another option is to cut off a 2 cm piece of greater omentum and suture this devascularized tissue using 3-0 or 4-0 polypropylene sutures into the periosteum of the sacrum on either side of the venous injury.

# 12 To Close or Not to Close: Managing the Open Abdomen

Amy Vertrees, Craig D. Shriver, and Ali Salim

**Deployment Experience**

| | |
|---|---|
| *Amy Vertrees* | Surgeon, 745th FST, FOB Jalalabad, OEF/Afghanistan, 2011 |
| | Chief Medical Officer, 28th FSE, OEF/Afghanistan, 2013 |
| | Surgeon, 10th CSH, Erbil FST, OIR/Iraq 2016 |

*As long as the abdomen is open, you control it. Once closed it controls you.*

Unknown

No matter what your previous experience or surgical practice has been, you will extensively use and be exposed to damage control abdominal surgery and the open abdomen in combat or disaster surgery. If you are looking for level I, evidence-based medicine on how to approach and manage these patients, you are out of luck. You may have seen multiple different techniques of temporary abdominal closure and approaches to achieving definitive abdominal closure, many of which claim to be the optimal approach. Like most things in surgery, there is more than one way to achieve an excellent outcome for your patient. The critical factors are to develop a thorough understanding of the basic principles and pitfalls of open abdominal management, as well as your local capabilities and limitations. This chapter outlines a

A. Vertrees (✉)
Walter Reed National Military Medical Center, Department of Surgery, Bethesda, MD, USA
e-mail: amy.e.vertrees.mil@mail.mil

C.D. Shriver
Murtha Cancer Center, Walter Reed National Military Medical Center, Bethesda, MD, USA

A. Salim
Trauma, Burns and Surgical Critical Care, Brigham and Women's Hospital,
Department of Surgery, Boston, MA, USA



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general approach to the open abdomen based on years of experience with combat casualties in the Iraq and Afghanistan conflicts. The basic principles outlined here are universal, but the details and techniques can and should be adapted or adjusted based on your individual situation and the realities on the ground.

**Bottom Line Up Front (BLUF) Box**

1. Closure of the abdomen begins on the day of injury: avoid fluid overload and control sepsis.
2. Leave the abdomen open to save time needed for closure, allow for second looks, and prevent abdominal compartment syndrome.
3. Create a temporary abdominal closure kit ahead of time to ensure that all of the supplies, especially the adaptors needed for suction, are readily available.
4. Return to the operating room based on patient physiology and not an arbitrary time.
5. Temporary closures should control heat loss and fluid shifts and contain and PROTECT viscera.
6. Close the abdomen if you can. When in doubt, leave the abdomen open.
7. Beware of the warning signs of abdominal compartment syndrome: drop in urine output, abdominal distention, and increased ventilator requirements.
8. Continue to reverse factors causing open abdomen: control contamination and sepsis, judicious use of fluids, and improve ventilator status.
9. Avoid further loss of abdominal domain – use adjuncts to prevent fascial retraction.
10. The primary factor in success or failure of obtaining fascial closure is YOU – be aggressive and aim for closure within 5–7 days of injury.
11. Avoid planned ventral hernia and the associated high rate of fistulae.

## Why Leave the Abdomen Open?

The abdomen is left open in specific circumstances: as part of a damage control strategy, planned second-look operations, and prevention of abdominal compartment syndrome. However, in the combat setting the open abdomen will be used much more liberally for several additional reasons. In general, combat injuries can be more severe, often multi-system, and resources and personnel may be limited. CT scans ("truth machines") are not available in far-forward locations. Multiple fragment wounds or blast injuries have a higher potential for missed injuries or progression of injury that can be identified at a second-look operation. Limited time, limited supplies, and multiple casualties waiting for an operation will often mandate rapid temporary closure even in situations where you might otherwise perform a definitive closure. And don't forget to consider the evacuation process – you cannot monitor your patients for missed injuries or the development of catastrophic abdominal complications or compartment syndrome if they are on a helicopter or airplane.

Damage control surgery is required for the seriously injured patient, when it is critical to get in and get out and avoid the lethal triad of metabolic acidosis, coagulopathy, and hypothermia. Rapid initial surgeries have specific goals: control of hemorrhage by ligating, repairing or shunting injured vessels, and/or packing of solid organ or pelvic injuries and control of contamination by identifying injuries to bowel and repairing, diverting, or stapling ends without any attempt at anastomosis. By accomplishing only what is absolutely necessary, the patient can be taken to the ICU to continue resuscitation and prepare the patient for more definitive operations when they are more stable. The abdomen is closed temporarily with dressings detailed below, but whipstitch skin closure only or penetrating towel clamps can also be used if that is all that is available.

Packing is an essential component of damage control if bleeding from solid organ or venous injury is present. The abdomen is packed, temporary closure is achieved, and the patient is stabilized prior to further treatment of the injuries. Packing must provide enough pressure to tamponade bleeding, but care must be taken to not compress the inferior vena cava and decrease venous return to the heart. Hypovolemia is often present in this scenario, exacerbating the problem. If a patient cannot be stabilized after packing, reassess the packing and temporary closure. Although time is a critical factor in these patients, do not just assume that a panicked abdominal packing is an adequate damage control procedure. *An extra 10 or 20 min in the OR to assure that you have adequate hemorrhage and contamination control is much preferred to watching your patient bleed out from their abdominal wound in the ICU*. Abdominal compartment syndrome is still possible with vacuum closures and other temporary closures and may prompt an early return to the operating room or a bedside laparotomy in the ICU.

The abdomen should always be left open if a second look is planned. This is especially useful if the second look will be done by another surgeon at a higher level of care. Clearly dead bowel should be resected; however, it is not always obvious if bowel cannot be saved. If there is a question of bowel viability at the initial surgery, an extensive resection of potentially viable bowel should be avoided and a second look should be planned. Bowel viability may improve with continued resuscitation, and prevention of extensive resection is necessary to avoid short gut syndrome. Anastomoses in a patient with potential for deterioration are risky and so are often better served by delay until a subsequent return to the OR. An ostomy could be avoided if the patient remains stable after the initial operation, and an ostomy can be formed at the second look if the situation for an anastomosis is not ideal. A failed anastomosis that is not immediately recognized can lead to overwhelming sepsis requiring significant fluid resuscitation and virtually guarantee an open abdomen that is difficult to close.

It is critical to identify abdominal compartment syndrome (ACS) and predict patients who may develop this syndrome. Unfortunately, we have no absolute measures for predicting which casualties will go on to develop ACS. Patients that are already acidotic, hypothermic, and coagulopathic are at the highest risk for ACS and should be left open. Other high risk factors are patients receiving massive transfusion or large volume resuscitation, large thermal injuries, high grade liver injuries, and mesenteric vascular injuries. The abdominal domain is limited, and excessive visceral or retroperitoneal edema, blood, gas, ascites, or stool can cause systemic life-threatening problems. Abdominal compartment syndrome can occur in patients without intra-abdominal injuries (secondary ACS) in cases of substantial bowel or retroperitoneal edema from massive fluid resuscitations or systemic inflammatory responses with capillary leak causing extensive interstitial edema. Clinical signs of ACS include a tight and distended abdomen, hypotension, low urine output, and rising ventilatory peak pressures. This clinical picture should prompt immediate opening or reopening of the abdominal cavity. One exception to this rule is the patient who has a purely secondary ACS, which is usually due to massive volume resuscitation and the buildup of tense abdominal ascites, most commonly seen in injured patients with significant burns. Emergent laparotomy in a significant burn patient has a tremendously high mortality rate. Attempting all other methods of decreasing abdominal pressure is best. A quick bedside ultrasound or diagnostic tap can identify the presence of massive ascites, and these patients may be better managed by large volume paracentesis or placement of a percutaneous drain. Improving ventilation, decreasing fluid overload, improving sedation, and nasogastric or orogastric decompression can help mitigate an elevated abdominal pressure.

Measurements of intra-abdominal pressure are useful for identifying impending or active ACS and are usually achieved by indirect methods. Bladder pressure is most commonly used (Fig. 12.1): the bladder is decompressed with a Foley catheter, 50–200 cc of sterile saline is infused into the catheter, and the catheter is then clamped distal to the area of pressure measurement. A pressure transducer with a needle (like that used for arterial pressure measurements) is used to puncture the hub of the Foley as shown in Fig. 12.1. The transducer should be zeroed at the symphysis pubis with the patient in a supine position and then allow the waveform time to equilibrate. Although bladder pressure is most commonly used, you can measure intra-abdominal pressure via any hollow structure in the abdominal cavity. Alternative methods of indirect measurements include intragastric (NG tube) or inferior vena cava pressure through the femoral vein. If pressure-transducing equipment is not available, see Appendix A for a low-tech bedside method of estimating bladder pressure.

Although every patient may respond differently, organ dysfunction increases with increasing intra-abdominal pressure (IAP), and a value of >25 mmHg has been suggested as a target for decompression. Reopening and re-exploration is recommended for anyone with a pressure above 35 mmHg. One pitfall you have to take into consideration is that these pressure cutoffs generally apply to normotensive patients. *Abdominal compartment syndrome can occur with bladder pressures of less than 20 in patients with hypotension!* Think of the abdominal cavity like the cranial vault – the perfusion pressure will be a function of the mean arterial pressure (MAP) minus the abdominal compartment pressure. Therefore, if the MAP is already low, then even an abdominal pressure of 15 mmHg can result in a perfusion pressure that is inadequate. Remember that abdominal compartment syndrome is a *clinical diagnosis* – no single test is absolutely necessary for the diagnosis and treatment of ACS. A patient with a tight abdomen and who is difficult to ventilate should have consideration given to opening the abdomen. When in doubt, open a closed abdomen or leave the abdomen open.

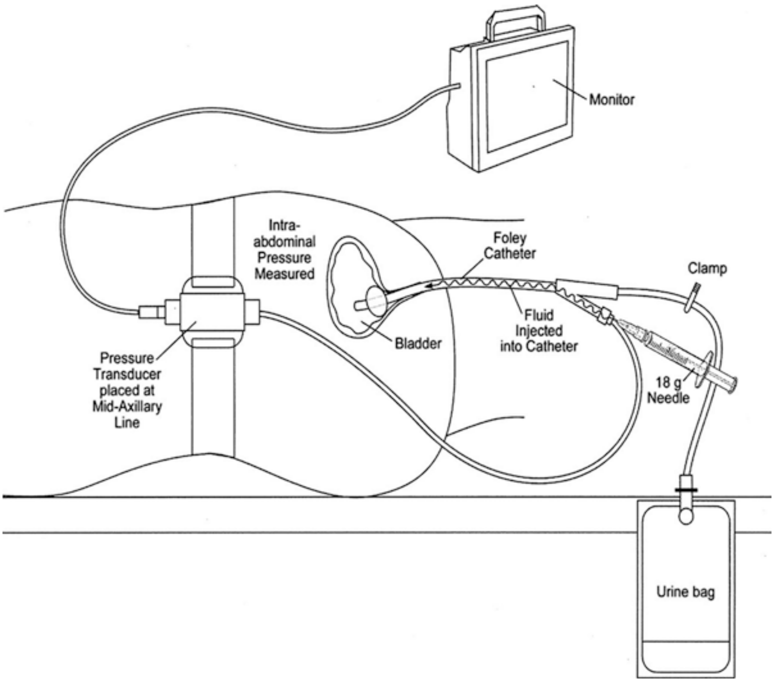


**Fig. 12.1** Demonstration of bladder pressure measurement (Reprinted from *Journal of the American College of Cardiology*, 51(3), Wilfried Mullens, Zuheir Abrahams, Hadi N. Skouri, Gary S. Francis, David O. Taylor, Randall C. Starling, et al., Elevated Intra-Abdominal Pressure in Acute Decompensated Heart Failure A Potential Contributor to Worsening Renal Function?, 300–306, Copyright 2008, with permission from Elsevier)

## How to Temporarily Close the Open Abdomen

Intra-abdominal contents must be protected from desiccation and from insensible losses. Temporary closures have been used to achieve this goal, and many different types of closure have been described. The most common method of temporary closure involves using any type of plastic occlusive barrier such as large sterile irrigation bags or Steri-Drape® (3 M®, St. Paul, MN) plastic sheeting with small slits cut in the plastic to allow egress of fluid. A sterile X-ray cassette cover will also work very well – use a scalpel to make multiple small slits in the plastic to allow fluid to flow into the vacuum component. This sheeting is then tucked under the fascia down to the paracolic gutters (Fig. 12.2), ensuring that all exposed bowel is covered and protected from direct contact with any sponge material. Laparotomy sponges or operative towels are then placed over the plastic barrier, with drains within or on top of the sponges. An occlusive dressing like Ioban® (3 M®, St. Paul, MN) is then used to seal the wound. Fluid egress is achieved with large tubes (often nasogastric tubes with the air vent portion of the sump drain tied into a knot, chest tubes, or 2 JP drains) placed on top of the towels or gauze and underneath the occlusive dressing

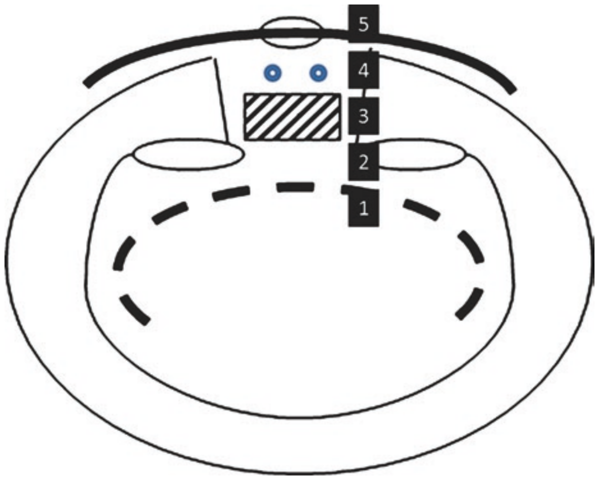


**Fig. 12.2** Plastic draping tucked underneath the fascia to the paracolic gutters (*1*). Mesh to fascial edges for serial closure and prevention of retraction (*2*). Towels, lap sponges, or KCI® V.A.C. sponges (*3*). JP, NGT, or chest tube drains (*4*). Ioban®- or KCI®-adherent dressing (*5*)

with attachment to continuous wall suction. It is important to create a "mesentery" with the Ioban® around the tube used to prevent leaks and pressure on the skin (Fig. 12.3a, b). Adaptors are needed to attach the closure to suction, and it is important to identify which adaptors will be needed ahead of time.

An excellent option that is now commercially available is the temporary abdominal closure kits or "Abdominal Wound-Vac" (V.A.C.® dressing, Kinetic Concepts, Inc.). This all-in-one sterile prepackaged kit provides a polyurethane foam dressing sandwiched in between perforated plastic sheeting, large oval vacuum sponges, adhesive drapes, and an adhesive pad with suction tubing. The sponges can be secured to the skin edges with several staples, or alternatively the skin can be sutured closed (fully or partially) over the top of the sponges. The suction tubing is then connected to a self-contained vacuum device which can provide varying levels of continuous or intermittent suction and fluid collection. It has been our experience that the use of negative pressure systems for temporary abdominal closure greatly improves the ease of postoperative nursing and wound care and also improves the rates of early primary fascial closure.

The method of closure used is not as important as following the basic principles of visceral coverage and protection, fluid and contamination control, maintenance of abdominal domain, prevention of fascial retraction, and prevention of compartment syndrome. You should develop an agreed upon method of temporary abdominal closure with your group of colleagues and have all materials prepackaged and readily available to minimize operative delays. If you develop a well-considered standard algorithm for temporary abdominal closure, open abdomen management, and abdominal closure, then you will see improved results, decreased complications, and improved fascial closure rates.

**Fig. 12.3** Demonstration of temporary abdominal closures. (**a**) Irrigation bag, gauze, and JP drains shown after Ioban® removed. (**b**) Operative blue towel over a chest tube and covered with Ioban dressing. A mesentery is formed over the Ioban® to prevent leaks. (**c**) Abdominal wound vacuum closure with skin edges sutured partially closed over vacuum sponge to maintain tension and prevent retraction

## Serial Abdominal Closure

Successful final closure involves planning ahead. Reversal of causative factors, prevention of fascial retraction, and avoidance of the visceral block adhering to the abdominal wall are the most important considerations. Reversal of causative factors

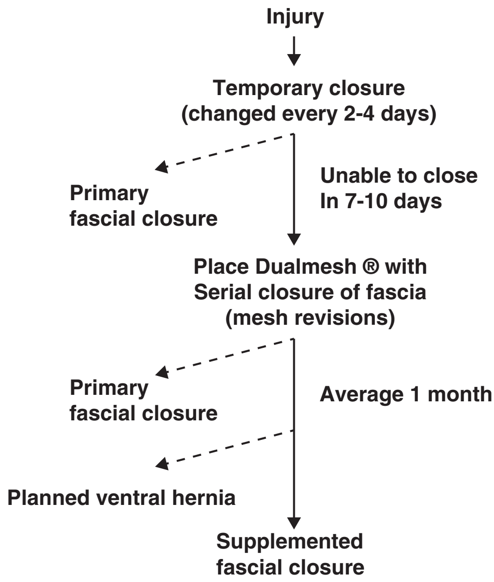


**Fig. 12.4** Timeline for abdominal closure

includes judicious use of fluids (strategies and end points of resuscitation are covered in another chapter), controlling contamination, preventing and treating sepsis, and improving ventilator status to prevent visceral edema from high positive end-expiratory pressure (PEEP). Figure 12.4 demonstrates an algorithm outlining the approach and timeline for closure of the open abdomen. Ideally, primary closure should be achieved within 7–10 days and should be accomplished in the majority of open abdomens (70–90%). If you are not able to achieve primary closure within this time period, prevention of fascial retraction and serial closure should be initiated.

Prevention of fascial retraction involves some method of adherence of the fascia to hold on to the edges as the inevitable retraction occurs. We have frequently used mesh as a serial closure device (Fig. 12.5a–d). Goretex Dualmesh® is sewn to the fascial edges to contain the abdominal contents and prevent fascial retraction. A wound vacuum dressing is placed over the mesh. The wound vacuum sponges are changed every 2–4 days, and the mesh is lifted to determine if abdominal domain can be reclaimed. This is often once or twice a week, with a couple of centimeters trimmed off the middle of the mesh each time and reapproximated with Prolene® or PDS® suture. Serial closure techniques that provide traction to the fascial edges may result in macerated fascial edges that need to be debrided to allow proper healing and avoid hernia recurrence. Our previous closures have required supplemental material to finally close the abdomen once serial closure is complete and the Dualmesh® prosthesis has been removed. Of note is the fact that the Dualmesh® is ALWAYS temporary and never should be left as the definitive closure material. It is contaminated (by definition) and must be explanted once it completes its jobs as a temporary abdominal containment material and “bridge” to abdominal closure.

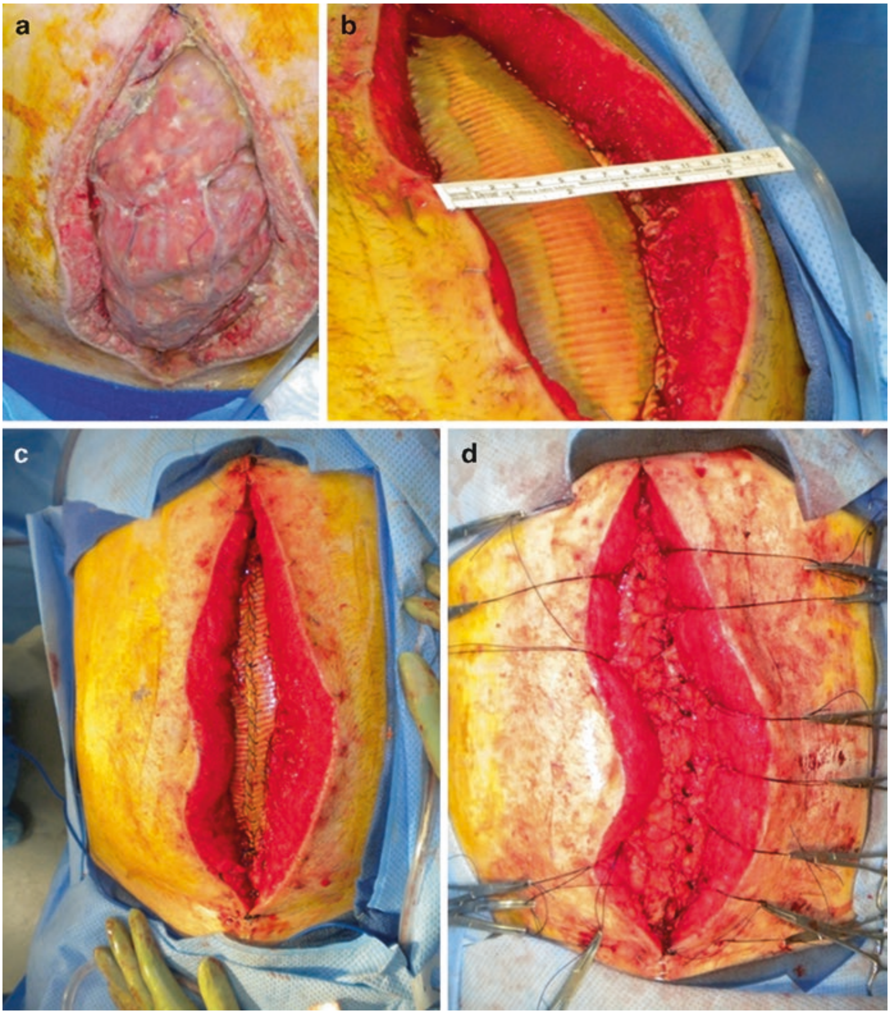

**Fig. 12.5** (**a**) Open abdomen. (**b**) Dualmesh® sewn to fascial edges. (**c**) Mesh revision of Dualmesh®. (**d**) Dualmesh® removed and fascia primarily closed. A FlexHD® underlay was placed in this patient

We modified our published technique with placement of a 10–10 plastic drape (Steri-Drape® from 3M®, St. Paul, MN) beneath the Dualmesh® from paracolic to paracolic gutter, which prevents adherence of the abdominal wall to the visceral block. This allows more movement of the abdominal wall and increases the possibility of primary closure. It also allows access to the underside of the fascia for underlay mesh if desired. The drape is replaced at each mesh revision, taking care to avoid injury to the visceral block. Tension on the skin and subcutaneous tissue is important to allow final skin closure. Negative pressure from wound vacuum placement is usually sufficient, but the dressing should be slightly smaller than the wound rather than crammed into the space. Vessel loops can be stapled to the edges of the skin in a Jacob's ladder pattern. If the fascia cannot be pulled together, having enough skin and subcutaneous tissue for closure will provide more protection and decrease entero-atmospheric fistula formation.

Inability to place mesh or failures of serial closure has required planned ventral hernia (PVH). In this technique, if there is no granulation tissue, vicryl mesh is sewn to the fascial edges. If there is adequate skin and subcutaneous tissue that can be mobilized to cover the wound, then primary skin closure can be performed over multiple subcutaneous closed-suction drains. If there is inadequate native abdominal skin, then coverage must be provided by other means. Once an adequate granulation bed has formed over the vicryl mesh, a split-thickness skin graft is placed over the granulation tissue and viscera. This results in a large hernia that can be repaired in 6–12 months. This method of closure is associated with a high rate of enterocutaneous fistulae. We seek to avoid PVH at all costs, and in our published experience and long-term follow-up, this method should be and is unnecessary in wounded warriors. The techniques described in this chapter and our publications that avoid PVH are the standard now.

## Complex Abdominal Wall Reconstruction: Component Separation

Fascial reapproximation with native tissue and avoidance of the use of prosthetic mesh is the ideal goal of open abdomen management. However, if there is a large fascial gap that cannot come together without undue tension after the abdominal domain has been reclaimed, then the traditional answer has been placement of a mesh bridge. Suboptimal results of mesh closure have renewed interest in using the layers of the abdominal wall to optimize closure. Understanding the layers of the abdominal wall and how they can be manipulated is necessary to understand popular techniques of component separation (Figs. 12.6 and 12.7). Complete component separation in some surgeon's hands can theoretically bridge gaps up to 20 cm but is associated with significant re-herniation rates. A more reasonable expectation for this technique is to bridge gaps of 5–15 cm. There are several options for component separation (see Fig. 12.6). A preoperative CT scan will identify the layers available and help decide which option is best.

Traditional component separation involves identifying the anterior rectus sheath and raising lateral skin flaps circumferentially until you can identify the lateral rectus border and the insertion of the external oblique aponeurosis. The external oblique aponeurosis is then divided longitudinally from the costal margin to the inguinal ligament. You should see a flimsy layer of fat and wispy connective tissue below the aponeurosis – if you see muscle, then you are too far medial or lateral. Grasp and elevate the cut edge of the aponeurosis laterally while retracting the rectus muscle medially. This exposes the connective tissue layer deep to the aponeurosis which can be divided all the way out to the midaxillary line. If this does not provide enough mobilization for fascial closure, then the rectus muscle can be rolled anteriorly allowing longitudinal division of the posterior rectus sheath. This will provide an

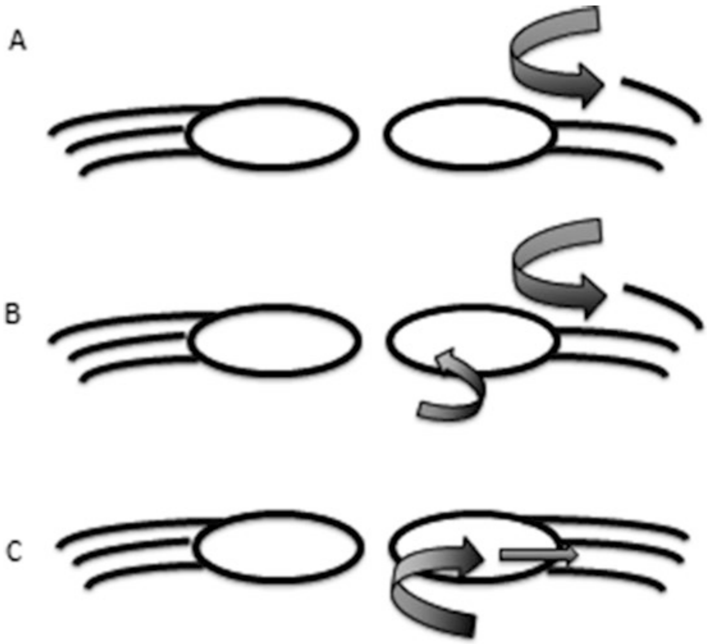


**Fig. 12.6** Variations in component separation technique. (**a**) Traditional component separation releasing the external oblique aponeurosis. (**b**) Release of the external oblique aponeurosis and the posterior rectus sheath. (**c**) Release of the transverse abdominis muscle (TAR)

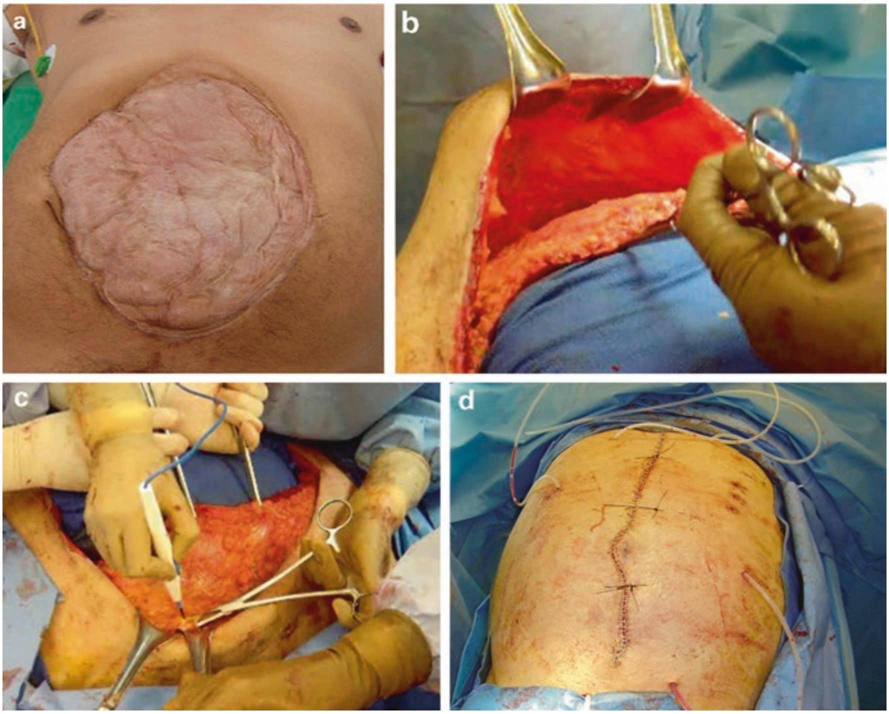


**Fig. 12.7** Component separation procedure following damage control laparotomy. (**a**) Large ventral hernia with skin graft on bowel. (**b**) Skin flaps are raised circumferentially over anterior rectus sheath and external oblique aponeurosis. (**c**) Division of the external oblique aponeurosis as it inserts into the lateral rectus sheath. (**d**) Excess skin is resected and closed primarily over drains

additional 2–3 cm on each side. The fascial edges can now be approximated primarily. *Do not ignore perforating arteries during flap creation.* Control them with suture if needed. "Blowing through" the space with electrocautery will cause suboptimal sealing and retraction into the muscle wall, only to rebleed on the ward.

Posterior component separation with transversus abdominis muscle release (TAR) has gained popularity recently. The posterior rectus sheath is identified and followed laterally. The transverse abdominis muscle is identified and released, moving laterally as noted above. Care must be taken to avoid injury to the nerves; otherwise a pseudo-hernia will develop as the muscle loses innervation. This closure avoids anterior flaps, and mesh can be placed just above the transversus abdominis muscle to decrease recurrence but minimize mesh exposure and complication.

## Supplementing Closure with Mesh

Regardless of the method of closure, use of mesh will reduce hernia rates. There are many choices for supplemental closure materials, with individualized benefits and complications. The location of the mesh placement is also important. Plastic mesh (polypropylene, Goretex®) is associated with increased adhesions, fistulae, and infections. They are best used in a non-contaminated field with interposed tissue such as peritoneum or omentum to decrease wound complications. Biologic mesh (Alloderm®, Surgisis®, FlexHD®) became rapidly popular for their advertised strength and ability to withstand infection or contamination. However, these materials have a high failure rate (>50%) when used as a fascial bridge or when subjected to exposure and desiccation in open wounds or with vacuum closure with an "expensive hernia sac" as a result. However, they may be the only good option in a contaminated field to provide temporary closure and protection. Biologic mesh over the abdominal contents might reduce underlying bowel injury and decrease enterocutaneous fistula. Biologic mesh is prohibitively expensive and might not be available for that reason.

Mesh can be placed in an onlay, interposition, underlay, or retrorectus position (Fig. 12.8). Hernia rates are decreased substantially with mesh overlap of 4–6 cm, so interposition mesh is the least ideal. Onlay mesh requires anterior skin flaps, so is ideal when there are already flaps made (for example, in traditional component separation), and the posterior aspect of the abdomen is not easily accessible with

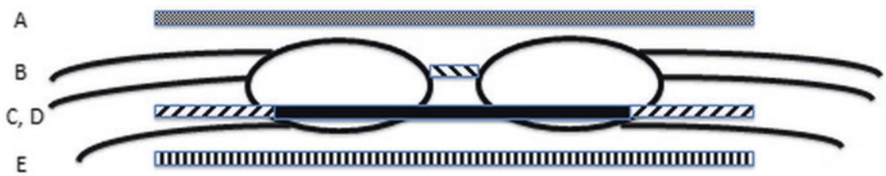


**Fig. 12.8** Mesh placement related to the layers of the abdominal wall. (**a**) Onlay above the anterior fascia. (**b**) Interposition mesh with mesh attached to the linea alba. (**c**) Retrorectus mesh with mesh placed behind the rectus muscle. (**d**) Extension of retrorectus mesh with transversus abdominis muscle release. (**e**) Underlay mesh placed into the abdominal cavity

adherence of the visceral block to the underside of the fascia. Underlay mesh allows necessary overlap but places the mesh adjacent to the abdominal contents, increasing the possibility of adhesion and fistula formation. Retrorectus mesh placement allows overlap of the midline but allows placement behind the rectus muscle, so the mesh is not in contact with the abdominal contents or the subcutaneous space. The latter mesh placement can be easily combined with TAR component separation.

## Specific Pitfalls and How to Avoid Them

Specific pitfalls in open abdomen management include closing an abdomen that should remain open, not recognizing the need to reexplore or adjust dressings, enterocutaneous fistula formation, allowing retraction of fascia or adherence of the visceral block to the underlying abdominal wall, not reversing causative factors, and leaving packs in the abdomen. All of these can be avoided or minimized with a standard and careful team approach to these patients.

Abdominal compartment syndrome (ACS) must be either prevented or treated promptly when recognized. Temporary closures will not prevent the need to reexplore if a surgical treatment is necessary, and ACS still occurs with temporary packing. One of the most common causes of ACS in the patient with an open abdomen from trauma is recurrent intra-abdominal hemorrhage. This should be rapidly recognized by a dropping hematocrit, hemodynamic changes, and bloody output from the abdominal wound. This should prompt immediate re-exploration which should be performed in the operating room. *Do not attempt an exploration for bleeding at the bedside!* If it is suspected that the temporary closure is simply too tight, then the vacuum suction can be released, any skin closure should be opened, or the dressing can be removed and replaced under no tension. Alternatively, if the fascia was not fully opened at the initial operation, then extension of the incision may be needed. Chemical paralysis of the patient, particularly if there is any obvious agitation or increased muscle tone, can often improve the situation or temporize until definitive intervention can be accomplished.

Enterocutaneous fistula is a miserable complication in the open abdomen patient, and prevention is the best strategy. Usually any type of primary repair of these fistulae is doomed to failure, and your goal should be to achieve adequate control and drainage. To prevent this complication, optimize nutrition, close the abdomen as soon as possible, and protect the underlying bowel at all times. If a fistula develops, try to convert it to an enterocutaneous fistula by achieving adequate drainage well off of the midline. If you are unable to do this, then you are left with the very difficult problem of an entero-atmospheric fistula draining directly into your open abdominal wound. This is an entirely different and more difficult entity, since it will continuously soil the abdominal cavity, wound, and fascial edges. The lack of surrounding skin precludes the placement of an ostomy appliance or other device to easily control the effluent. Your goal now should be to mature the fistula and surrounding tissue to a point where an ostomy appliance can be applied while also protecting the remaining exposed bowel. If the skin can be closed above and below

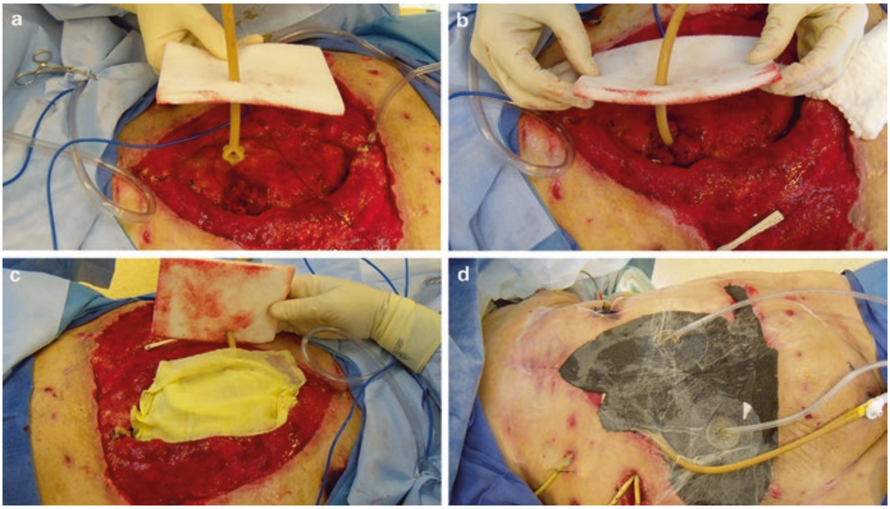

**Fig. 12.9** Wound vacuum and Malecot drain management of an open abdomen with enterocutaneous fistula. (**a**) 20 French Malecot drain is brought through a hole in a *white wound vacuum sponge*. (**b**) The fistula is intubated with the drain and sponge is cut to fit the defect. (**c**) A layer of nonadhesive dressing (Xeroform shown) is applied between the vacuum sponge and exposed viscera. (**d**) Completed dressing with standard *black vacuum sponges*

the fistula, then it can be converted to a "floating ostomy" directly in the midline wound. If not, then placement of a wound vacuum sponge with a defect cut out directly over the fistula will allow drainage and placement of an ostomy appliance while also protecting and maturing the surrounding tissue. Alternatively, the fistula(e) can be intubated with a drainage tube (Malecot catheter) which is brought through the wound vacuum sponge (Fig. 12.9).

Loss of the abdominal domain is associated with retraction of fascia, so use supplemental material if necessary to prevent retraction. If you maintain some degree of tension on the skin by partial or complete closure over the vacuum sponges, you will prevent some degree of fascial retraction. The visceral block will adhere to the underlying abdominal wall and decrease your chances of primary closure, so ensure that plastic sheeting goes all the way down to the paracolic gutter. This will also provide an access to the fascia for supplemental underlay of mesh. Finally, always remember to double-check the entire abdominal cavity for retained packs and get an X-ray before final closure; the sponge count is always unreliable in damage control surgery.

## Final Points

Damage control surgery is an excellent tool in seriously injured patients. Open abdomen management is required for many of these patients. If there is a doubt about visceral edema, contamination, or need for second looks, then plan for the worst-case scenario and leave the abdomen open. This is especially true if there will be a discontinuity of care providers in the evacuation chain. Eventually, the abdomen should be closed within several weeks of the primary injury. Keep the end goal in mind and set yourself up for a successful closure by protecting the viscera, preventing fascial retraction and adherence of viscera to the abdominal wall, and controlling factors contributing to the loss of abdominal domain. There are many techniques available to assist with abdominal closure. Serial abdominal closure allows reclaiming the abdominal domain over time. Primary fascial closure is the ideal goal of open abdomen management. If primary closure is not possible, component separation methods and mesh supplementation are options with downfalls to all of the approaches. Above all else, when in doubt, leave the abdomen open!

## Civilian Translation of Military Experience and Lessons Learned

Ali Salim

**Key Similarities**

- Goals of damage control surgery similar in civilian and military practice
- Technique for temporary coverage and progressive closure of the abdomen similar in civilian and military practice

**Key Differences**

- Indications for damage control are more expansive in the military experience and include the need to consider evacuation process.
- Planned ventral hernia repair uncommon in military practice.

Due in large part to lessons learned from our military colleagues, advances in trauma care have resulted in improved survival of many severely injured patients. As noted in the current chapter, these advances include "damage control surgery" or "abbreviated laparotomy" with abdominal packing and recognition of abdominal compartment syndrome. As part of damage control surgery, and for the treatment of the abdominal compartment syndrome, the abdomen is frequently left open. Damage control has been extended to the management of life-threatening intra-abdominal bleeding and severe intra-abdominal sepsis, resulting in an increased prevalence of the open abdomen among emergency surgery cases. Although the numbers of "open abdomens" are decreasing due to changes in resuscitation and transfusion practices, it still represents a complex and challenging surgical complication. Despite these difficulties, the civilian management of the open abdomen is very similar to the military experience.

## Damage Control

Overall, about 10–15% of all laparotomies for trauma are managed with damage control techniques. Traditionally, damage control has been advocated for patients "in extremis" (those with exhaustion of physiological reserves and imminent irreversible shock and death), but with initiation of damage control earlier – before the patient becomes coagulopathic and "in extremis" – outcomes are improved. Although the indications are not as expansive as in the military (we do not have to worry about an evacuation process for our patients), we will also employ damage control for patients with bleeding from difficult anatomical areas, some complex injuries not amenable to easy surgical control, and for temporary stabilization before transfer to higher-level care. We have learned from our military colleagues that damage control should be considered early, before the patient reaches the "*extremis*" stage, taking into account the available resources, nature of the injuries, experience of the surgeon, clinical condition of the patient, and any comorbid conditions. Following damage control, the fascia or the skin should never be closed, as this would surely lead to intra-abdominal hypertension. However, the abdomen can be closed temporarily using one of the available materials and techniques. Important steps for the management of the open abdomen include temporary coverage that protects the viscera and allows serial access to the peritoneum, medial retraction of the fascia, progressive closure of the fascia, and, finally, definitive fascial closure during the initial hospitalization or in a delayed fashion as a planned ventral hernia repair.

## Temporary Coverage

A wide variety of techniques have been described for temporary abdominal coverage. The vacuum pack technique is well described by the authors. It utilizes available equipment and is inexpensive. For this reason, even in civilian practice, the vacuum pack is occasionally used. Increasingly, one of the commercially available temporary abdominal closure kits utilizing negative pressure therapy is utilized. We favor the use of the ABThera® (KCI, San Antonio, Texas) wound vacuum device. The ideal coverage should be readily available, rapidly applied, allow repeat access to the abdomen, prevent loss of domain, preserve the fascia, and facilitate primary fascial closure. By utilizing constant negative pressure, both the vacuum pack and commercially available "wound V.A.C.™" fulfill all the necessary criteria mentioned above.

## Progressive Closure

The ultimate goal with any open abdomen is to achieve primary fascial closure. This often occurs during a second operation. When the abdomen is not amenable to primary closure because of continued bowel edema or bleeding, several techniques have been described for progressive closure. The commercially available "wound V.A.C.™" applies constant medial tension on the fascial edges, presumably prevents fascial retraction, and facilitates primary fascial closure. Using this technique, primary fascial closure can be obtained in nearly 90% of open abdomens. Although the likelihood of achieving primary fascial closure decreases after 9 days of open abdominal management, the use of the abdominal "wound V.A.C.™" has allowed successful closure up to 49 days post injury.

The Wittmann Patch is a commercially available device that has also been employed for progressive closure to achieve primary fascial closure. It is used in a similar fashion as described with the Goretex Dualmesh®. This Velcro-type device is sewn into the fascia and allows for progressive fascial approximation. Unfortunately, there is a paucity of data regarding its use.

## Definitive Closure

In civilian practice, there is a small subset of patients where primary fascial closure is not possible. For this group, a number of techniques have been described with varying degrees of success. Primary closure with a nonabsorbable prosthetic mesh (polyprolene, polypropylene, polytetrafluoroethylene) or nonabsorbable biological prosthesis (human and porcine acellular dermal matrix) has had fairly good results. However, no long-term results exist for the use of the biologics. Although uncommon in the military experience, closure with absorbable mesh or skin graft as a planned ventral hernia and later repair at 6–12 months either using nonabsorbable prosthetic mesh or a component fascial separation technique have both been very well described with excellent results.

## Final Points

The open abdomen has become the standard of care in damage control procedures, the management of intra-abdominal hypertension, and in severe intra-abdominal sepsis. This approach has saved many lives but has also created new problems, such as severe fluid and protein loss, nutritional problems, entero-atmospheric fistulae, fascial retraction with loss of abdominal domain, and development of massive incisional hernias. Early definitive closure is the cornerstone in preventing or reducing the risk of these complications. The introduction of new techniques and materials for temporary and subsequent definitive abdominal closure has improved outcomes in this group of patients.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Damage control resuscitation.
2. Management of war wounds.

## Suggested Reading

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# Dismounted Complex Blast Injury Management

# 13

Travis M. Polk, Matthew J. Martin, and Matthew J. Eckert

**Deployment Experience**

| | |
|---|---|
| *Travis M. Polk* | Surgeon/Officer In Charge, Combined Joint Special Operations Task Force Forward Surgical Team, Tarin Kowt, Uruzgan Province, Afghanistan, 2009–2010 |
| | Chief of Trauma, NATO Role 3 Multinational Medical Unit, Kandahar, Afghanistan, 2013–2014 |
| *Matthew J. Martin* | Chief of Surgery, 47th Combat Support Hospital, Tikrit, Iraq, 2005–2006 |
| | Chief, General Surgery and Trauma, 28th Combat Support Hospital, Baghdad, Iraq, 2007–2008 |
| | Commander, 655th Forward Surgical Team, FOB Ghazni, Afghanistan, 2010 |
| | Chief of Surgery, 758th Forward Surgical Team, FOB Farah, Afghanistan, 2013 |

T.M. Polk
Naval Medical Center Portsmouth, Department of General Surgery, Portsmouth, VA, USA

M.J. Martin
Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA

M.J. Eckert (✉)
Uniformed Services University, Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA
e-mail: matthew.j.eckert.mil@mail.mil


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*Matthew J. Eckert* Trauma Surgeon, Camp Bastion Role 3 Hospital, Helmand, Afghanistan, 2012–2013

USSOCOM Surgical Support, Iraq, 2014–2015

USSOCOM Surgical Support, Horn of Africa, 2015

USSOCOM Surgical Support, Iraq, 2016

**BLUF Box (Bottom Line Up Front)**

1. Know the typical injuries and patterns that characterize the "dismounted complex blast injury": extremity amputations, pelvic/perineal trauma, penetrating truncal wounds, spine/pelvis fractures, and almost *always* large-volume hemorrhage.
2. Start resuscitation immediately with either a 1:1:1 strategy or using whole blood. (A good rule of thumb to start with is four units of PRBCs with matching plasma and platelets for each amputated or mangled extremity.)
3. Nearly exsanguinated patients tend to arrest during rapid sequence intubation. Start refilling the tank beforehand, and delay intubation until you are in the OR if possible.
4. Get immediate extremity hemorrhage control with adequate tourniquets, but do not be distracted by these injuries.
5. Most of these patients belong in the operating room immediately and do not need an immediate "pan-scan."
6. Assume that every patient has a life-threatening truncal or extremity vascular injury until you prove otherwise.
7. Once the patient is stabilized, and all life-threatening wounds treated, CT scanning is useful for detection of occult injury since patients may be covered with hundreds of wounds of varying size.
8. Surgical care requires efficiency and teamwork; prep everything, and utilize multiple teams and surgeons working simultaneously rather than in sequence.
9. Communicate *everything* to the next echelon. These patients are incredibly complex and require coordinated care along the entire continuum.

## Introduction

Explosive injury represents three-quarters of woundings and over half of the deaths on today's battlefield. While severe injuries still occur to those traveling mounted on vehicles, advancements in vehicle armor and personal protective equipment have led to a substantial improvement in the survivability of these incidents. On the other

**Fig. 13.1** Preoperative photo of patient with complex dismounted blast injury notable for mangled or amputated extremities, perineal/scrotal wounds, and multiple truncal fragment wounds

hand, the dismounted complex blast injury (DCBI) has become the signature injury pattern of the conflicts in Iraq and Afghanistan. Since 2009, these injuries dramatically increased among both dismounted coalition forces and civilian in Afghanistan due to increasing numbers of high-energy improvised explosive devices (IED) partially buried or disguised in the landscape. The uniquely devastating injury pattern that has resulted includes multiple traumatic amputations of the lower and upper extremities, as well as complex penetrating and blast-effect injuries of the pelvic and abdominal cavities, severe pelvic fractures, spine fractures, and injuries of the internal and external genitalia (Fig. 13.1). Frequently, these injuries also include varying severity of traumatic brain injury. Unfortunately, despite continuing efforts, the highly lethal DCBI cluster has a mortality rate as high as 73%.

Although IED injury has become a hallmark of modern battlefield trauma, events such as the Boston Marathon bombing and attacks in Madrid, Paris, and Brussels have also raised recent awareness of the increasing threat to civilian settings. While the devices deployed against troops and vehicles are typically high-yield explosives, IEDs can come in almost any shape, size, and explosive yield. Smaller yield devices are a particular problem among civilian populations since they can be easily hidden or attached to common objects and triggered when they are picked up—and some are even purposefully made to look like toys. Among civilian children and adults who encounter these devices, a common pattern is significant facial and neck injuries as well as one upper extremity traumatic amputation consistent with their bending over to inspect the object in the landscape when it detonates (Fig. 13.2), whereas coalition forces frequently lose the nondominant upper extremity due to its forward location in the "low-ready" weapons carry position. Table 13.1 illustrates the wide spectrum of blast injury effects.

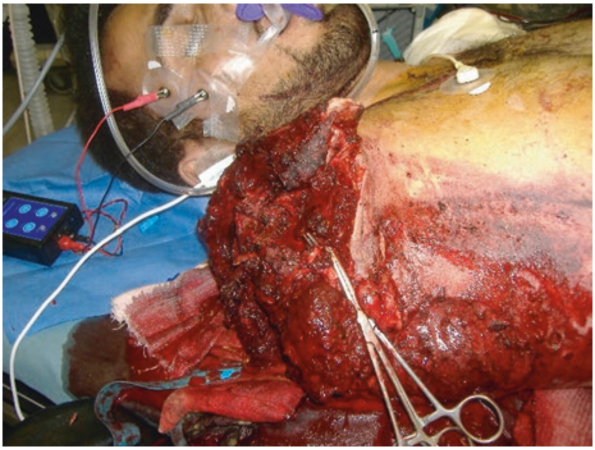

**Fig. 13.2** Patient with right arm amputation at shoulder from picking up a low-yield IED

**Table 13.1** Spectrum of blast-related trauma

| Phase of blast injury | Mechanism of injury | Typical injuries |
|---|---|---|
| Primary | Overpressurized wave/blunt | Barotrauma—ears/lung, TBI |
| Secondary | Penetrating | Projectile injury |
| Tertiary | Blunt | Fractures, crush, amputation |
| Primary/quaternary | Burn/other | Thermal burn, inhalation injury, exacerbation of comorbid disease |

Adapted from *Surgery During Natural Disasters, Combat, Terrorist Attacks, and Crisis Situations*, Dismounted complex blast injury, 2016, Galante J, Rodriguez C. With permission of Springer

## Prehospital Care

Details of prehospital care for this type of patient have been provided in the previous chapters. The main emphasis is on hemorrhage control, with additional adjuncts of pain control, administration of antibiotics, and rapid preparation for transport to a Role 2 or 3 facility.

Incorporating the principles of "permissive hypotension" resuscitation and damage control resuscitation for patients sustaining severe hemorrhage in the field, the DCBI patient receives minimal crystalloid resuscitation prior to surgical control of hemorrhage to avoid the exacerbation of hemorrhage and coagulopathy frequently encountered in this population. Thus, *early resuscitation goals are the minimal infusion of crystalloid fluids to achieve mentation and a palpable radial pulse and early initiation of blood and plasma transfusion.*

## Initial Resuscitation

Upon arrival to surgically capable treatment facilities, initial management remains consistent with the "CABC" mantra. Hasty field tourniquets are assessed and replaced with more effective pneumatic tourniquets. Initial resuscitation is begun immediately following massive transfusion protocol guidelines of a 1:1:1 ratio of packed red blood cell to plasma to platelets or the use of low titer group O whole blood. Due to peripheral venous access site limitations from the extent of injury and to allow for easy use of a rapid transfusion device, large-bore central venous access above the diaphragm is rapidly obtained, usually at the subclavian site since the cervical spine should be protected in these patients; however, initial standard peripheral intravenous access may be adequate to begin resuscitation until movement to the operating room (OR). If peripheral or central venous access is difficult to obtain, intraosseous access is obtained. Since use of the commonly utilized tibial or humeral locations may be limited by injury, a sternal intraosseous line (IO) is a reliable and effective initial conduit for administration of drugs, fluids, and blood products. Care must be taken to use an appropriately sized needle to avoid passing through the sternum into the mediastinum.

As resuscitation progresses, blood product administration is guided by the patient's hemodynamic status as well as standard coagulation parameters (PT/INR), hemoglobin/hematocrit, and arterial or venous blood gases. Measurement of base deficit upon arrival and serially throughout the resuscitation remains one of the easiest and most useful resuscitation markers.

There is now an increasing body of experience and evidence with using either thromboelastography (TEG) or rotational thromboelastometry (ROTEM) to assess clotting function, clot strength, and platelet contribution and to identify any evidence of significant hyperfibrinolysis. The goal of these TEG/ROTEM protocols is to rapidly identify or even prevent the development of the acute coagulopathy of traumatic shock that is seen among severely injured patients and associated with significant mortality and morbidity (Fig. 13.3). Recent evidence suggests that the

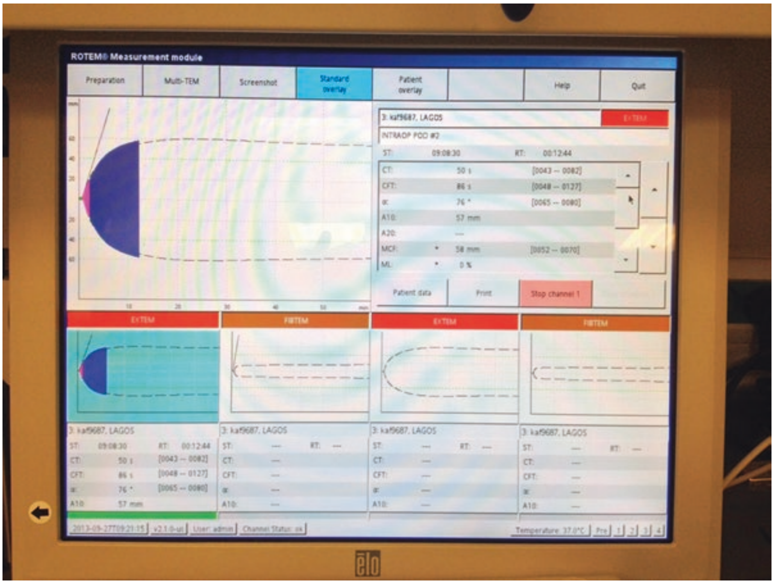


**Fig. 13.3** Rotational thromboelastometry (ROTEM) viewing screen in the operating room at a Role 3 in Afghanistan. ROTEM may be utilized to target massive transfusion requirement and correct coagulopathy

early (within 3 h of injury) administration of the antifibrinolytic agent tranexamic acid (TXA) is associated with improved morbidity and mortality in the setting of severe injury and major hemorrhage. TXA is now a part of the Joint Theater Trauma System guidelines for the treatment of life-threatening bleeding in massive transfusion situations and should be considered to all patients with large-volume bleeding or to those at risk of major bleeding. In many cases, TXA administration is now started in the prehospital setting due to TCCC guidelines.

Rapid sequence intubation must not be undertaken in a cavalier manner in the DCBI patient. Due to near exsanguination, these patients initially have little reserve and may be unable to undergo the procedure without initial resuscitation. Medication dosages should be decreased, and the team must be prepared for potential hemodynamic collapse and arrest. If able to ventilate and oxygenate the patient temporarily, you should strongly consider waiting on endotracheal intubation until after a brief period of volume expansion with blood products.

DCBI by definition includes severe multisystem trauma and requires expeditious but thorough ongoing evaluation before and during surgery. The initial sequence of evaluation and management will vary depending on your facility's location, capabilities, and available personnel and resources, but should always follow principles of damage control (Fig. 13.4). Unstable patients should proceed directly to the operating room for exploration and control of major hemorrhage, while stable patients may tolerate further resuscitation and imaging to assist in operative planning. *For the patient* in extremis*, take caution when making even short delays to do things like place a central line or intubate the patient—these can be done in the OR while simultaneously initiating surgical exploration.* Resuscitative surgical care requires efficiency and teamwork; utilize multiple teams and surgeons working simultaneously rather than in sequence (Fig. 13.5).

## Imaging

Enhanced focused assessment with sonography for trauma (eFAST) is useful for detecting hemothorax, pneumothorax, hemoperitoneum, and hemopericardium. All patients should be evaluated with ultrasound, but don't be misled. If your eFAST exam shows free fluid in the abdomen, trust this result and operate immediately; however, if the ultrasound is negative, then trust your clinical exam and your gut feeling—if they say operate, do it.

Limited plain film radiography performed early in the resuscitation will help to identify injuries and is a critical adjunct to evaluation, triage, and operative planning in these highly labile patients. All patients should get chest and pelvic films with the inclusion of abdominal and extremity films if needed to rapidly identify fractures or foreign bodies. In unstable patients, torso imaging should take priority, while extremity films can be completed as needed in the OR after hemorrhage control. *Don't wait to view all the images before moving to the OR—start resuscitating the patient and operating and let the images catch up to you.*

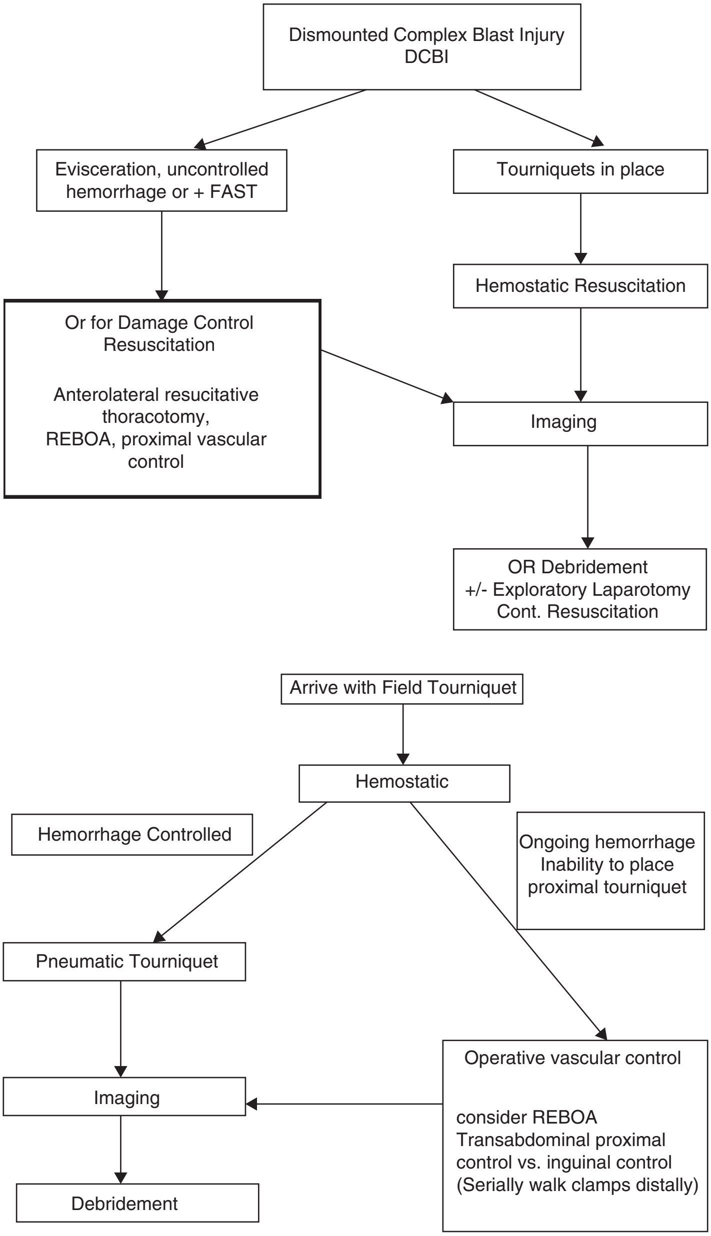


**Fig. 13.4** Algorithm for evaluation and management of DCBI. General approach (**a**) and management with tourniquets from the field (**b**) (Adapted from *Surgery During Natural Disasters, Combat, Terrorist Attacks, and Crisis Situations*, Dismounted complex blast injury, 2016, Galante J, Rodriguez C. With permission of Springer)

**Fig. 13.5** Multiple surgeons and teams are shown operating in this triple amputee DCBI patient. Two general surgeons are performing an exploratory laparotomy for proximal iliac control and abdominal damage control, while two orthopedic surgeons address debridement and hemostasis of the bilateral transfemoral amputations. A fourth surgeon is seen to the right debriding an upper extremity amputation under pneumatic tourniquet control (Reproduced from *Front Line Extremity and Orthopaedic Surgery*, Combat pelvic injuries and hip dislocations, 2014, Gaines R, Mamczak CN. With permission of Springer)

In patients who are clearly hemodynamically stable or those who have had initial hemorrhage control and operative intervention, further assessment with contrast-enhanced CT imaging that includes the head, neck, chest, abdomen, pelvis, and spine should be performed. These procedures will assist in identification of occult or missed injuries as well as guide further operative planning. When the patient's wounds are too numerous to count, assessment for occult vascular injury becomes difficult as trajectory is impossible to determine. Palpable pulses and extremity comparison indices are useful, but sometimes difficult to assess in the shocked polytrauma patient that is missing portions of multiple limbs; therefore, CT angiography or even on table angiography in the operating room is beneficial for detection of occult vascular injury.

## Hemorrhage Control

Your immediate priority upon arrival to the operating suite is control of hemorrhage. Extremity injuries including amputations should be reassessed and immediately controlled with tourniquets if not already performed. Frequently, the initial tourniquets that were placed while hypotensive will prove inadequate as the hemodynamic situation improves. However, tourniquet control is not always possible due to the high level of transfemoral amputations, injuries in the junctional region, or associated hemorrhage from open pelvic/perineal wounds.

While use of a junctional tourniquet or wound packing may help temporize the profound hemorrhage, proximal control must usually be obtained via laparotomy. *You should gain rapid transabdominal control of the infrarenal aorta and then work your way distal to first control each common iliac artery and ultimately isolate the bilateral internal and external iliac vessels.* Rummel tourniquets or "Potts" (double looped) vessel loops are very effective for this purpose since they are less traumatic than vascular clamps and can also be left in place if required during an operative pause for imaging or resuscitation You should attempt to avoid permanent ligation of the internal iliac artery since it can result in significant posterior muscle ischemia and necrosis; however, this remains an important tool in your armamentarium in the setting of uncontrollable pelvic hemorrhage. Alternatively, in some cases for high thigh lesions, a generous groin incision with division of the inguinal ligament may allow proximal control of the external iliac vessels. While proximal control of the iliac vessels can also be obtained in the retroperitoneal plane via a kidney transplant-style approach, avoid the temptation to get fancy. Leave this approach to elective vascular and spinal surgery, and go the speed and extensile opportunity of a laparotomy. If you have the requisite comfort and skill, resuscitative balloon occlusion of the aorta (REBOA) in the infrarenal Zone 3 may also be used in this situation. In profoundly labile or moribund patients, left anterolateral resuscitative thoracotomy or Zone 1 REBOA (above the diaphragm) may even be necessary to assist in resuscitation or control more proximal injuries.

Patients with severe pelvic fractures should be temporarily stabilized with a pelvic binder followed by external fixation if available. In the absence of immediate interventional angiography capability, preperitoneal pelvic packing should be considered. To perform this procedure, make a low midline incision over the pubic symphysis. Carefully separate the rectus muscles and gain access to the pre-vesicular space of Retzius. Using blunt dissection, open this space into the pelvis and remove any clot with your hand. Place up to five laparotomy packs on each side tightly into the preperitoneal space, and then close the incision in the anterior rectus fascia. If laparotomy is required, care should be taken to limit the lower extent of the midline celiotomy incision to prevent inadvertent entry into the preperitoneal space and loss of tamponade. If there is continued bleeding, or if preperitoneal packing is not possible due to complete disruption of this space, then ligation of one or both internal iliac arteries can be performed. We would recommend placing a clip across the vessel, which can then be removed at the next take-back operation if the bleeding has stopped or can be left on permanently if needed.

## Abdominal Injuries

The need for abdominal exploration is based upon imaging findings, obvious signs of penetrating injury, peritoneal signs, or physiologic instability without another identified source. In many forward facilities, there are no CT scanners available, and all decision making is based on clinical exam, laboratory results, plain x-rays, and ultrasound. A FAST exam that is positive for free abdominal fluid should prompt abdominal exploration in this setting, regardless of the current hemodynamics.

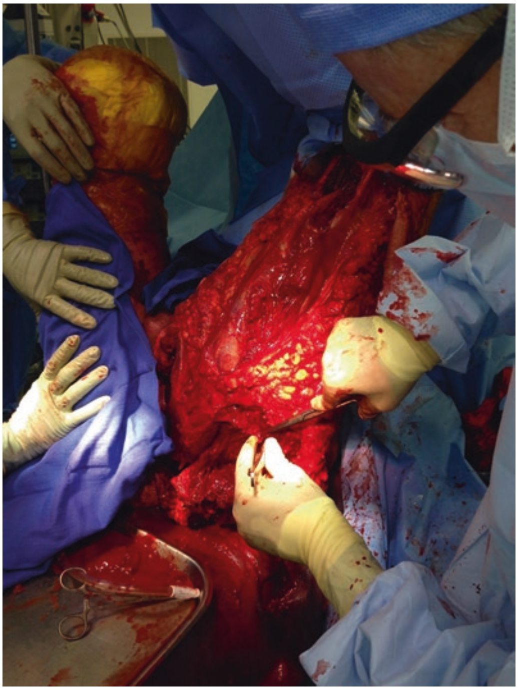

**Fig. 13.6** Massive posterior degloving with injury to the anal sphincter, rectum, and scrotum. This patient was treated with a diverting colostomy. There is a contralateral transfemoral amputation

Digital rectal examination should be performed to evaluate sphincter tone and the presence of blood. If injury is suspected, rigid proctoscopy is indicated to assess anorectal injury. Fecal diversion at the initial or subsequent operations should also be performed in the setting of major perineal trauma, open pelvic fractures, or extensive soft tissue wounds that will be affected by the fecal stream (Fig. 13.6). If there is any doubt, don't try to be fancy; just perform the colostomy. We have known since World War II that this is effective, and recent quality-of-life studies in DCBI patients have failed to demonstrate a difference between those with and without colostomy. Principles of damage control surgery (immediate control of life-threatening hemorrhage and enteric spillage) as well as debridement of obvious contamination and devitalized tissues should guide the initial operation. At the initial operation, bowel injuries may occasionally be primarily repaired; however, the bowel is usually resected with staplers and left in discontinuity since the zone of injury frequently worsens over time in these patients. A more rapid alternative to bowel resection at the time of initial operation in a very unstable patient is to simply ligate and exclude bowel injuries with umbilical tape passed around the intestine proximal and distal to the injury.

The abdomen is typically left open to facilitate timely re-exploration and avoid development of abdominal compartment syndrome. Crystalloid fluids should be limited with a focus upon balanced blood product transfusion ratios to decrease pulmonary morbidity and facilitate early weaning from mechanical ventilation and abdominal closure.

## Thoracic Injuries

Thoracic exploration may also be required more frequently than with civilian trauma. When the chest tube that you placed demonstrates a large-volume hemothorax upon initial placement or continues to drain blood, you should explore the chest via anterolateral thoracotomy. This will allow you access to almost all critical structures and still give you the opportunity to access the mediastinum or abdomen when you find the blood is coming from a pericardial hole or through the diaphragm with a missed thoracoabdominal injury. Avoid the temptation to turn the patient and try to perform a posterolateral approach—the invariable result is that you will always find that you are in the wrong place with the patient in the wrong position.

Use caution when trusting your pericardial FAST windows completely. Like the abdomen, if the FAST is positive, do the sternotomy; however, if it is negative, consider the possibility of a false negative from body habitus, poor visualization due to subcutaneous emphysema, or decompression of blood from the pericardium into the pleural space. If there is a concerning wound with a hemothorax or if the FAST window is questionable, perform a diagnostic pericardial window via either a subxiphoid or transdiaphragmatic approach. If the pericardium contains blood, do the sternotomy, find the injury, and repair it.

## Vascular Injuries

Previously applied tourniquets should be released in a controlled fashion to facilitate identification and control of bleeding structures in the extremity. Major vessel injuries need to be appropriately ligated or repaired as indicated. The use of a temporary intravascular shunt is an excellent alternative in the damage control setting. This can be done rapidly, restores flow, and defers formal repair until the patient is stabilized and adequately resuscitated; however, use caution if you are considering a more ambitious vascular reconstruction during the index damage control operation—it always takes longer and bleeds more than you expect.

## Pelvic Fractures

Severe pelvic fractures are present in 40% of DCBI patients with bilateral transfemoral amputations (Fig. 13.7). Major pelvic hemorrhage may result from these fractures, and you should consider preperitoneal packing. Pelvic binding, external fixation, and preperitoneal pelvic packing all help to reduce the pelvic volume and control hemorrhage. These fractures should be initially stabilized with a pelvic binder followed by external fixation. In unstable patients, pelvic binders may be trimmed to facilitate vascular access in the inguinal regions, exploratory laparotomy, or preperitoneal packing. Additionally, external fixation can be performed with the binder in place by cutting access holes over the iliac crest. Depending upon the extent of combined anterior diastasis and posterior sacroiliac disruption,

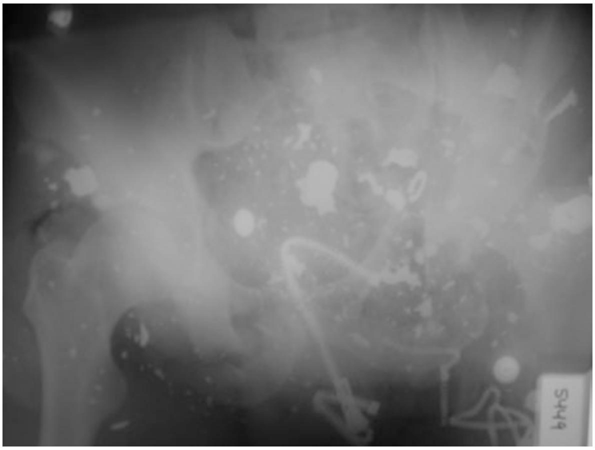

**Fig. 13.7** Radiograph demonstrating severe open-book pelvic fractures in a DCBI patient with three traumatic amputations (Reproduced from *Front Line Extremity and Orthopaedic Surgery*, Combat pelvic injuries and hip dislocations, 2014, Gaines R, Mamczak CN. With permission of Springer)

rotational and vertical stabilization and closure of the pelvis with external fixation may be difficult to maintain. In these cases, leaving the binder in place along with the external fixator, selective use of traction, use of a double frame external fixator, or early placement of percutaneous sacroiliac screws may be required.

## Genitourinary Injuries

Complex blast injuries frequently result in abdominopelvic, perineal, and genital trauma. Nearly 90% of those with bilateral transfemoral amputations have associated genitourinary injuries. The presence of blood at the urethral meatus, ballottable prostate, or severe perineal bruising suggests potential urethral injury. Retrograde urethrogram may be helpful to define the injury, but a single gentle attempt at placement of a transurethral Foley catheter by an experienced provider is reasonable. If unsuccessful, suprapubic bladder decompression may be required. The presence of gross hematuria suggests bladder injury. Bladder injury management should be guided by cystogram results and managed in a similar fashion to civilian injuries with conservative Foley drainage of contained extraperitoneal leaks. Intraperitoneal or uncontained extraperitoneal injuries are repaired operatively with two layers of absorbable suture along with catheter drainage. Vaginal examination is performed with any pelvic fracture to exclude an open fracture or in the setting of any vaginal bleeding or injury to the vulva or perineum.

Injuries to the male external and internal genitalia are frequently encountered, and a high index of suspicion must be maintained. Any evidence of scrotal hematoma or penetrating scrotal injury should mandate bilateral exploration. Mild bruising may be evaluated with testicular ultrasound, but with a low threshold for operation for any abnormal findings. Upon scrotal exploration, orchiectomy is always a procedure of last resort. In the case of testicular rupture, gentle irrigation and debridement of non-viable seminiferous tubules should be performed and the tunica albuginea closed.


**Fig. 13.8** External genital trauma. (**a**) There is significant injury to the glans penis, and the transected corpus cavernosum is evident. The proximal urethral opening is visible at the base of the wound. A left-sided orchiectomy was performed while the right testicle was repaired. (**b**) Penetrating scrotal injury with large hematoma and ecchymosis. (**c**) In this photo, the nonviable tubules should be debrided and the tunica albuginea repaired with absorbable suture, thereby avoiding orchiectomy (Reproduced with permission from Eastridge B et al. Damage Control Surgery. In: Savitsky E, Eastridge B. (eds.). Combat Casualty Care: Lessons Learned from OIF and OEF. Borden Institute, Office of the Surgeon General, United States Army, 2012)

Lacerations to the tunica albuginea, urethra, or corpus cavernosum of the penis should be repaired with interrupted absorbable suture (Fig. 13.8). The scrotum is closed over Penrose drains, or a negative-pressure dressing may be applied if there is significant skin loss. This approach is preferred to subcutaneous thigh pockets as it avoids undue traction on the vas deferens which can lead to tubule contraction and loss of viable sperm.

## Soft Tissue Management

Traumatic amputation sites are frequently heavily contaminated and should be copiously irrigated with several liters of isotonic fluid (Fig. 13.9). High-volume/low-pressure irrigation with gravity-fed irrigation or bulb suction syringe is preferable to pressurized pulse irrigation devices due to a concern that these devices may cause further tissue damage and drive contaminants deeper into the viable tissue. Foreign bodies, dirt, and debris are often driven by the blast along fascial planes well away from the initial entry sites, and these wounds should be thoroughly explored and debrided with separation of intramuscular fascial planes. This will require several subsequent rounds of operative debridement until closure can be safely considered.

While the initial priority is adequate debridement of all devitalized tissues, the surgeon must also be cognizant of future reconstructive and functional needs. Functional areas such as the face, neck, hands, and genitalia should be treated with more frequent and judicious debridement. If necessary, amputations should be initially performed at the zone of greatest injury with care to preserve any potentially viable soft tissue even as an asymmetric flap. External fixation or splinting of fractures proximal to the zone of maximal soft tissue injury rather than further amputation to the fracture should be considered to preserve residual limb length. When in doubt, defer amputation of a mangled extremity to a subsequent procedure following reassessment by a multidisciplinary team. Definitive procedures are highly discouraged at the initial operation, and these wounds should NEVER be closed in this setting.

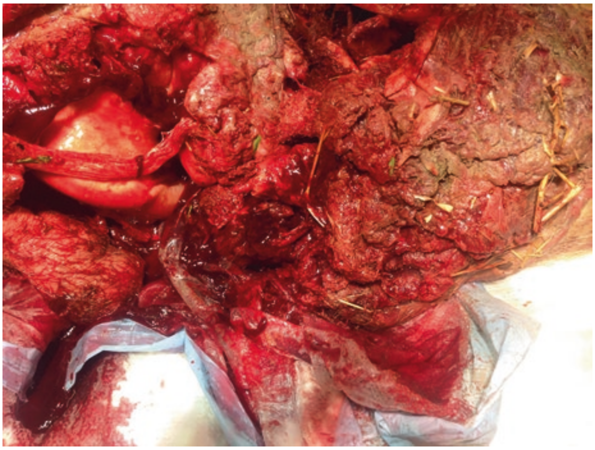

**Fig. 13.9** Profound contamination of wounds with dirt, plant matter, and other debris commonly seen in DCBI

The care of complex blast injury patients can require extensive resources and staff efforts. These seriously injured patients will undergo serial operative examinations with careful evaluation of evolving tissue necrosis and viability prior to definitive wound management. Recurrent tissue necrosis may signal the development of the highly lethal complication of invasive fungal infection (IFI) and should prompt aggressive surgical and antimicrobial therapy.

All DCBI patients should be treated empirically with 24–72 h of empiric antibiotic coverage. The use of a first-generation cephalosporin such as cefazolin (or clindamycin, if allergic to penicillin) is usually adequate; coverage is broadened to include metronidazole or more extensive gram-negative coverage in the presence of intra-abdominal contamination, open pelvic fracture, or perineal wounds.

Patients at increased risk for IFI include dismounted blast injury, traumatic above-knee amputation, and supermassive blood transfusion of >20 units of red blood cells given in the first 24 h following injury. These patients should receive topical antifungal/antimicrobial treatment with dilute Dakin's dressings (0.025% sodium hypochlorite solution (50 mL full strength [0.5%] Dakin's in 950 mL sterile water)). If recurrent necrosis concerning for IFI occurs, tissue cultures should be obtained to assess for *Mucor* and *Aspergillus*. Systemic antifungal therapy is initiated with both liposomal amphotericin B and voriconazole. Antimicrobial therapy with broad-spectrum gram-positive and gram-negative coverage should also be given due to the high incidence of bacterial coinfection.

Utilization of negative-pressure wound dressings may facilitate wound management and cleanliness and aid healing (Fig. 13.10). Due to the size of the wounds, creativity is often required, and commercial devices may not always be available. Improvised negative-pressure dressings can be adapted with gauze, drains, and adhesive plastic drapes, such as Ioban (3 M).

Wound irrigation with cycled negative-pressure wound therapy (5 min dwell each hour) using a dilute Dakin's solution is also effective for at-risk wounds.

## Subsequent Care

Given the frequency of operative interventions often required as well as time spent in the intensive care unit, comprehensive critical care management should focus on preventing further complications and facilitating wound healing. This should include maintaining normal body temperature, early initiation of enteral nutritional support as appropriate, multimodal pain management strategies, aggressive weaning from mechanical ventilation, and limiting the duration of prophylactic antibiotic therapies.

While the exact incidence of venous thromboembolic events (VTE) in the DCBI population is not clear, it is likely very high. Recent data from combat casualties suggests that approximately 10% will develop early VTE, while 22% will develop one prior to ultimate discharge. Additionally, recent evidence has suggested that approximately 9% of severely wounded will have primary pulmonary thrombi noted on CT imaging of the chest within hours of wounding. Therefore, once


**Fig. 13.10** Complex dismounted blast injury patient shown at the time of initial operation (**a**) and then at the first take-back operation for additional washout and debridement (**b**). Note the multiple extremity amputations, abdominal wounds, and perineal injury with open scrotum. Following several washout and debridements, improvised negative-pressure dressings are applied to clean wounds (**c**)

surgical hemostasis and coagulopathy is corrected, pharmacologic prophylaxis is indicated with twice daily low molecular weight heparin. In patients that cannot tolerate early pharmacologic VTE prophylaxis, strongly consider the placement of a removable vena cava filter.

## Final Thoughts

Whether in the forward deployed environment or in the civilian rural or austere setting, these severely injured patients will receive care at multiple facilities as they are transferred from the austere environment to higher levels of care ending with a

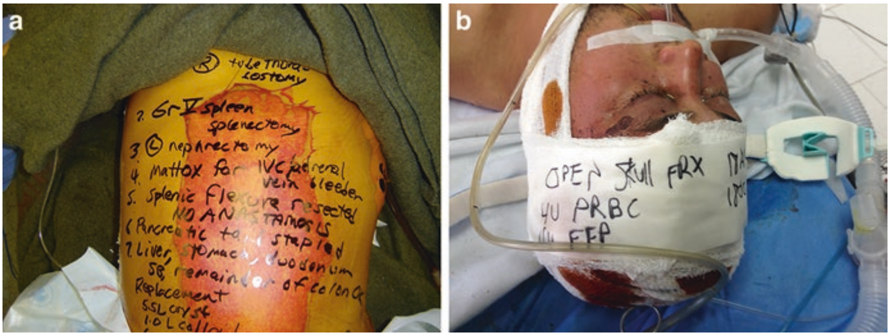


**Fig. 13.11** Patients who underwent damage control procedures at a far forward military medical treatment facility, including (**a**) damage control laparotomy and (**b**) washout and debridement of an open skull fracture with brain injury. Key information about the procedures performed, blood products given, and time/date of dressing changes conveyed by simply writing on dressings or bandages

major tertiary care and trauma center. This requires a concerted effort by all key players along this "chain of life" to coordinate seamless care for these incredibly complex and difficult to manage patients. Adequate communication between levels of care is arguably the most important factor in ensuring that there are no lapses or missed opportunities that could result in significant patient harm and long-term adverse outcomes. This is difficult in any environment, but particularly in the middle of a combat zone where communication lines may be unreliable and computer and Internet access are similarly sparse and without a universal tracking and electronic medical record system. We have found that in these circumstances it is often the simplest solutions that work the best. This includes clearly documenting what was done at your facility, what operations were performed and what the major injuries were, what resuscitation/fluids/meds have been administered, and the time/date of the last surgical exploration or washout/debridement. Arguably the best solution for this has been to document directly on the patient by writing on dressings or bandages with a permanent marker to clearly communicate key information to the providers at the next level who will be receiving the patient (Fig. 13.11). This has greatly facilitated the coordination of care and helped avoid many unnecessary repeat operations or procedures.

The dismounted complex blast injury patient represents a truly challenging multisystem trauma phenomenon that has great relevance in both the military and civilian settings. Rapid evaluation and initiation of damage control resuscitation are key components of the initial care, followed by operative intervention without undue delay to control hemorrhage, remove contamination, debride devitalized tissue, and restore perfusion as needed. These patients are best served with multidisciplinary involvement including general and trauma surgery, critical care, and orthopedic and often vascular and urologic surgical expertise, but frequently, the initial operation is performed by a small surgical team in an austere location. Definitive surgical repairs should be avoided during the initial operation, and the principles of damage control surgery and resuscitation dramatically improve the outcome of these cases.

Despite the horrific presentations of these severely injured patients and the requirement for coordinated care across multiple continents, high survival and functional outcomes are achievable for those that arrive alive to medical treatment facilities. This can only be obtained with meticulous care and a multidisciplinary approach.

Lastly, the unfortunate fact is that DCBI patients rarely present singly due to the mechanism of injury. Often these patients will be injured with others and present as part of mass casualty scenario. While the care of just one of these patients is highly complex and resource intensive, the care of multiple severely injured patients arriving simultaneously or in short succession can create chaos in even the well-staffed facility. Success in these situations can only be achieved through deliberate personal and team preparation, constant maintenance of situational awareness, and steadfast focus on damage control priorities.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Amputation.
2. Catastrophic care.
3. Damage control resuscitation.
4. High bilateral amputations and dismounted complex blast injury.

# Thoracic Approaches and Incisions

# 14

Jeffrey A. Bailey, Philip S. Mullenix, and Jared L. Antevil

**Deployment Experience**

| | |
|---|---|
| *Jeffrey A. Bailey* | Chief of Trauma ("Trauma Czar"), 332nd Expeditionary Medical Group, Air Force Theater Hospital, Balad Air Base, Iraq, 2006, 2007–2008 |
| | Director, US Central Command Joint Theater Trauma System, Operation Enduring Freedom, Afghanistan, and Operation New Dawn, Iraq, 2010–11 |
| | Director, US Central Command Joint Theater Trauma System, Operation Enduring Freedom Afghanistan, 2013 |
| *Philip S. Mullenix* | Special Operations Surgeon, undisclosed locations, in support of Operation Enduring Freedom, 2013–2014 |
| | Special Operations Surgeon, undisclosed locations, in support of Operation Enduring Freedom, 2013 |
| | Special Operations Surgeon, undisclosed locations, in support of Operation Enduring Freedom, 2012–2013 |
| | Cardiothoracic & General Surgeon, 10th CSH Task Force, Senior Medical Officer, Herat, Afghanistan, 2011–2012 |

J.A. Bailey
Uniformed Services University, Walter Reed National Military Medical Center, Directorate of Surgery, Bethesda, MD, USA

P.S. Mullenix (✉)
Cardiothoracic Surgery, Walter Reed National Military Medical Center, Department of Surgery, Bethesda, MD, USA
e-mail: philip.s.mullenix.mil@mail.mil

J.L. Antevil
Walter Reed National Military Medical Center, Navy Specialty Leader for Cardiothoracic Surgery, Department of Surgery, Division of Cardiothoracic Surgery, Bethesda, MD, USA



M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_14

Cardiothoracic & General Surgeon, 31st CSH Task Force, Theater-wide Consultant for Cardiothoracic Surgery, Baghdad & Al Kut, Iraq, 2009–2010

*Jared L. Antevil* Cardiothoracic & General Surgeon, Task Force MedSouth, Afghanistan, 2010–2011

Medical Officer for Marine Expeditionary Unit Service Support Group 13, USMC aboard USS Duluth, amphibious assault ship, Western Pacific Deployment, 2000–2001

*"It's all in the game yo, all in the game."*

Omar Little, The Wire, Season 1, Episode 13

**BLUF Box (Bottom Line Up Front)**

1. We are not here to cure cancer or treat angina – this is war surgery.
2. Principles of Special Operations also apply to war surgery: simplicity, speed, rehearsal, repetition, and purpose are what you need to overcome the frictions of war.
3. Always prep the patient for the maximum.
4. Often the correct approach to chest trauma is a laparotomy and chest tube(s).
5. It's not called paranoia when the patient *actually is* bleeding in some other compartment.
6. Don't be afraid to extend your incision or make a hole somewhere else.
7. If your patient is dying, the ipsilateral anterolateral thoracotomy is your friend.
8. For inadequate exposure after anterolateral thoracotomy or suspected right pleural space hemorrhage = clamshell.
9. For box wounds without pleural hemorrhage = sternotomy.
10. Left subclavian injuries suck.
11. For suspected proximal left subclavian arterial injury, start with a high left anterior thoracotomy.
12. You probably need a good reason to ever do a posterolateral thoracotomy in a fresh combat trauma patient.

## This Is War

No one is going to thank you for making fewer or smaller incisions on a corpse: leave your handbook of minimally invasive keyhole surgery at home – this is no boutique affair. And we are not here to cure cancer or treat structural heart disease. You will find that stuff in a handbook of *elective* cardiothoracic surgery. That's for the specialized and circulatory-supported surgeons who are regularly entering the chest back home. This is a place where a general surgeon is the only hope a patient has to survive a thoracic wound. That hope is vested in *you*. Fortunately, it's also where an experienced general surgeon is likely to know a lot about the priorities and pitfalls of thoracic surgery for trauma. Out here the chest is in YOUR WHEELHOUSE. But the rub is that even among seasoned general surgeons, there is limited (though highly intense) *individual* experience. It's a difficult area to build a wealth of experience in, given that less than half of penetrating chest wounds even require a thoracic operation. In those that do require surgery however, the stakes couldn't be higher. Death, with scythe in hand, will hover over you in the OR and stalk your patient long after you have placed the last staple in the incision (or incisions) you have made.

## Rules of Engagement

This chapter is not about when to dive into the chest. It's not even really about what to do when you get there. These topics are well covered elsewhere in this book. It's about how to begin and adapt an operation based on knowledge and skills YOU BRING to the situation you face. Utility for exposure and control of the thoracic vessels and organs IN YOUR HANDS is the single most important factor in choosing an incision and keeping your options open. Be ready to cut based on limited information; you don't have the luxury of waiting for an extensive secondary survey and adjunctive data. Also, be ready to modify or abandon your initial incision based on what you do – or maybe even more likely – *do not find*. The utility of the incision you choose (the extent of exposure and control it provides) is inversely proportional to the amount of preoperative information – especially imaging – you have available.

## The Principles of Special Operations Apply

With penetrating injury to the torso in a combat zone, hemorrhage is generally multi-cavitary, non-compressible, and exsanguinating. This means your patient is bleeding to death two or three times faster and in more places than they do back home. They are also colder, probably got to you later, and – look around – you don't have all the cool stuff and great help like you do back at the big house. Multiple fragment wounds or a single bullet can create audible torrential misery in several compartments at once. You know from your training that this is happening in one or more of five contiguous areas: right chest, left chest, mediastinum, peritoneum, and retroperitoneum. Therefore, like a special operator taking down a house, you must clear each of these "rooms" by any means necessary. Generally, that's your eyes, ears, hands, and brain, and if you are lucky, a bedside FAST and portable CXR. Fortunately, the principles of Special Operations *do* apply. A simple plan, repeatedly and realistically rehearsed and executed with speed and purpose AS A

TEAM, is what you are after. This, combined with your best emulation of Carl von Clausewitz' moral factors of courage, intellect, boldness, and perseverance, and you will dominate the frictions of war.[1]

## Always Prep the Patient for the Maximum

You are dealing with multi-cavitary wounding and multifocal exsanguination until proven otherwise. Accordingly, your best approach to positioning the patient is supine with arms out and prepped from chin to knees and chest to elbows, circumferential where possible and down to the table everywhere else (obviously making appropriate modifications for missing limbs, maxillary/facial trauma, back wounds, etc.). This provides *you* the best opportunity to extend the incision, make new ones, harvest conduit, and gain junctional access and gives YOUR TEAM a straightforward, reproducible approach for every patient you bring back. With a few prep sticks, a groin towel, and two split sheets, you can prep anybody for anything. Leverage the principles of simplicity and repetition. Drill it with your crew and get a picture up on the wall. One less thing to worry about = more time for you to think.

## Laparotomy and Chest Tubes

A good plan to always have in the back of your mind is what to do if your patient suddenly crumps from a hemodynamic standpoint somewhere along your little trauma train. The expeditious deployment of bilateral chest tubes and a crash laparotomy with pericardial window through the anterior diaphragm immediately provide you with the bleeding status of all major compartments and, importantly, position you to actually do something about it. You can move to sternotomy if the window is positive, particularly if you think you might have an anterior cardiac or great vessel wound, and the pleural output is reassuring or to anterolateral thoracotomy if you see blood pouring into one of the pleurovacs on either side.

A second situation to consider is the ipsilateral penetrating chest wound with instability that worries you for unmitigated thoracoabdominal mischief going on under the diaphragm. This scenario is not uncommon and often initially best approached with chest tube and laparotomy, with options for pericardial window or thoracotomy from there depending on what is coming out of the chest tube and what you are finding in the belly. At the end of the day, you may find laparotomy and a chest tube were all you needed to definitively manage what at first appeared to be a primary chest problem. And this is particularly true on the right side, where there is no big ventricle to injure and a more likely source of bleeding is the liver. Right chest tube and laparotomy in these patients, at least statistically speaking, are a good place to start.

[1] Note: You are deployed so you have a lot of time to kill (you can only sleep, work out, and eat DFAC chow so many hours in a day). Why not use some of it and read Vice Adm. McRaven's fantastic *Spec Ops: Case Studies in Special Operations Warfare: Theory and Practice*; or if you are truly bored, skim a bit of Book III of *On War* – Ol' Dead Carl thought a lot about this stuff long before you did.

## Be Paranoid About the Other Compartments

Once you have made a decision, and committed up front to the belly or one of the chest compartments, always assume the patient is bleeding to death from somewhere else until proven otherwise. If the initial compartment appears uninjured, or if you have found and fixed a problem and the patient is still not responding to resuscitation, obviously you know you need to look elsewhere fast. Your patient may also be trying to die from bleeding across the diaphragm, up in the pericardial sac, or over in the contralateral pleura. Be on the lookout for hypotension that is not getting better despite seemingly good moves on your part in whatever compartment you are presently in. You must find out why your patient is still "tree-topping" before it's too late. Keep COMMO lines open across the drape with your anesthesia partner. Do they look even more frightened and anxious than they usually do? Is the patient not responding to your great surgery and all the blood products? Are the central pressures now up and you are missing tamponade? Is the diaphragm in your face and filling up your thoracotomy workspace because the belly is actually full of blood? Did the airway pressures just spike or the $SaO_2$ just tank because you have a chest cavity full of blood, or now there's a lung down under tension? The signs can be subtle, and it pays to be crazy anal-retentive in this matter. They may call you paranoid, but sometimes the patient really is bleeding to death from several places at one time, and YOU are the patient's last line of defense.

## Make Your Incision Bigger or Make a Hole Somewhere Else

As you can see ad nauseam from this discussion, the quandary of what incision to make first in trauma chest surgery is almost a cliché in books like this. That's because it's hard, and you are going to get it wrong a good bit of the time. But once you *are* engaged, trying to understand the mechanical situations at play in the various compartments can be informative. Chest tube output is helpful if it is positive, but don't assume that the compartment is controlled if not much is coming out and you are still having a problem. Tubes kink, get fissured or clogged up with blood and tissue debris, and can even end up in a love handle or the axillae and never make it in the chest in the first place. Even positive chest tube output can be misleading. Abdominal blood can be pouring into the chest through a hole in the diaphragm and right out your tube. Now you know you need to move rapidly from wherever you are to the belly, and deal with the problem directly. The pericardial sac can also fool you – tamponade can be fluid-responsive for a while and develop over time. So if you are in the belly or an ipsilateral chest, and things still aren't right, have a low threshold to open the pericardium and control the space.

Basically, now's the time to bury the ego, resist the flail, and be prepared to just make your hole a lot bigger, make an incision somewhere else, or both. Recognize that a laparotomy readily extends to sternotomy and vice versa. Anterior thoracotomy can become a clamshell. Lateral neck incision flows right into sternotomy and vice versa if you need to chase combined injuries up into the neck or down into the

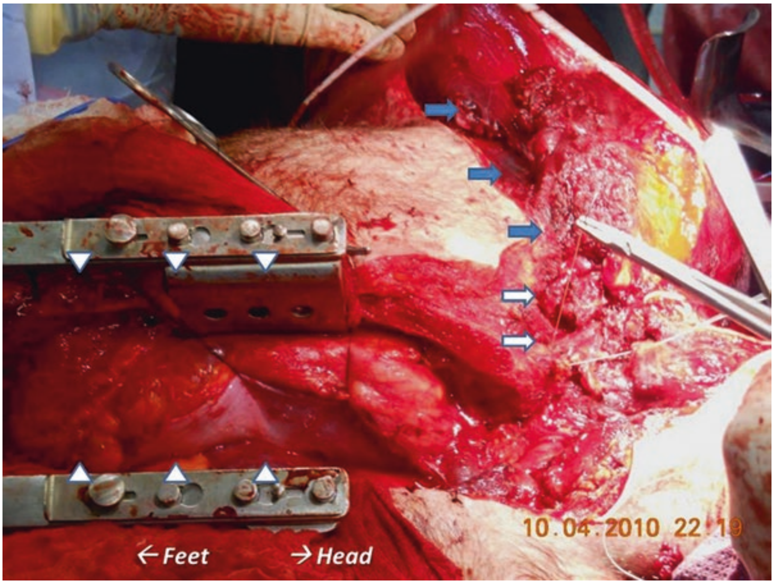


**Fig. 14.1** Be flexible and extend your incision where necessary. Patient with complex multiple fragment wound injuries to right subclavian artery and vein and right brachial artery. An initial median sternotomy (*open arrowheads*) was performed for proximal control of the innominate artery. The sternotomy was extended to a right clavicular incision, and the clavicle was partially removed to allow for direct repair of the subclavian vascular injury (*white arrows*). Extending the incision onto the right arm (*blue arrows*) allowed for both distal control for the subclavian arterial injury and for direct repair of the right brachial artery

mediastinum. Sternotomy to anterior thoracotomy can also make sense, particularly on the left side depending on the situation. Sternotomy also can be transitioned out to right or left clavicular exposure as need be (Fig. 14.1). Laparotomy can even be hockey-sticked up into the left chest across the diaphragm for exposure of the descending aorta. Don't let some anatomical barrier come between you and saving your patient. Exploiting these relationships and responding to new information dynamically by extending your incision or making a new one is a good thing, not a referendum on where you started and what you got wrong. War surgery is a process, not a procedure. Embrace it and move on.

## Anterolateral Thoracotomy Is Your Friend

If your combat trauma patient has just arrested, or is about to arrest from a potentially reversible cause, the left anterolateral (resuscitative) thoracotomy is your "go-to" weapon of mass destruction. It's maximally invasive, resource intensive, and can put your team at risk, and the probability of success in any given case is not exactly a "confidence builder." This deal is a direct action mission emphasizing the principles of surprise, speed, audacity, and purpose that can accordingly cause some collateral damage in the process. But if you think you need to address life-threatening intrathoracic bleeding, reverse tamponade, do open massage, deal with massive air embolus, or clamp the aorta to improve cerebral perfusion or gain some proximal control – and you have the resources and no major competing priorities elsewhere – you probably need to pull the trigger. Main reasons to hold fire here are patients with blunt trauma with arrest before arrival and no signs of life (came in dead, stayed dead) and during resource-intensive MASCAL events where your precious personnel capital, blood products, table time, bed space, and adjunctive technologies are best directed at more survivable casualties.

This eventuality is definitely one you *can* prepare for and LIKELY WILL experience during the course of your deployment. Make sure you got all the supplies (it's not much really) packaged up in several places in the trauma bay and the OR stored for easy access and checked regularly to make sure they don't need a re-up. A full-up kit might include:

- Scalpel #10
- Curved Mayos
- Finochietto rib spreaders (need at least two!)
- Ferris-Smith or large rat tooth forceps
- Metzenbaums long
- DeBakey aortic clamp
- DeBakey forceps long
- Satinsky clamp large
- Satinsky clamp small
- Needle driver long
- Several tonsils
- Lebsche and mallet
- 3–0 and 4–0 Prolenes double-armed
- PTFE pledgets for above
- 3–0 Ethibonds
- 2–0 silk ties
- Pack of lap pads
- Paddles

Get this stuff together, mock it up, designate roles, and drill this with your team regularly. Make sure to emphasize with everybody how much risk there is associated with this in terms of iatrogenic injuries and exposures from all the hands, eyes, sharp objects, and body fluids flying around. Take this seriously. Drill it and then drill it some more. It is unlikely you will save a large number of folks you try this on, but there *is* a real possibility you will injure or infect your teammate in the process if you and your crew are not working together.

Your goal here, basically, is to try to convert a dead person into a really sick person. Key objectives are to identify and release tamponade, control major bleeding in the left chest, do open cardiac massage, and cross-clamp the descending aorta. Moves available from there include separate right anterolateral thoracotomy (if the mediastinum has been cleared), and you think you are dealing with a life-threatening right chest problem or extension to clamshell if you have been dealt an anterior cardiac or proximal great vessel injury. Leverage your potential for success where possible by starting with an intubated patient who has good access (ideally both above and below the heart) and is getting a proper blood product resuscitation. You will also be glad you got a gastric tube down to have the stomach decompressed (and to aid in palpation of the esophagus to minimize the chances of injuring it during temporary aortic clamping) and a right chest tube in place so you can have some idea what's happening on the other side. You need good suction, and generally it takes two to make one. Make sure you and everybody around have on some eye protection, gown, and gloves (mainly for one's own protection rather than some sterility benefit for the patient). Obviously, if you recognize that arrest is imminent when the patient hits the trauma bay (or know from the 9-line beforehand), taking the patient directly to the OR and doing everything there makes a bad situation a whole lot less challenging to deal with effectively.

If you know ahead of time that you are receiving a casualty in extremis (or with imminent arrest), now is the time to mobilize whatever blood product resources you have on hand. There is no patient undergoing resuscitative thoracotomy who will NOT need massive transfusion to survive. If you have been savvy enough to have your "walking blood bank" up and running, you will find that nothing on Earth soothes the savage beast of coagulopathic bleeding like fresh whole blood.

Decisiveness and timing are key when it comes to a resuscitative thoracotomy. Resist the urge to "see how the patient does" with additional resuscitation. When you are faced with an indication for this operation (witnessed or recent arrest in a viable patient with penetrating injury), just do it. When the dust settles, it is not likely you will be criticizing yourself (or be questioned by your team or your patient's comrades) for being "too aggressive." As long as you appropriately manage the risks to your crew, and wisely utilize your critical resources, performing resuscitative thoracotomy when indicated for a patient who ultimately does not survive is NOT a failure. It provides you (and your team) with experience that may very well save the next patient and the reassurance that in the face of mortal injury, you gave the patient every possible shot at going home to their family alive.

## Conduct of Operation

1. Get everybody out of the way except the ideally one (or zero) person predesignated to help you. If you don't have an airway or good access yet, obviously you need to keep people on that but out of the way as much as possible. Take your Velcro headlamp out of your pocket and put it on.
2. If you can, stuff a bump or a rolled towel under the left chest to rotate it forward so you get a wide exposure, and don't end up trying to operate with the edge of the table in your way.
3. Stop the chest compressions, and keep them off until you can do them directly at the heart. This minimizes movement, makes your exposure and getting stuff done in there easier, and prevents somebody else from getting hurt.

4. You are shooting for the fourth or fifth interspace but no time to count them out. Cut from the nipple down to the table in a curvilinear fashion up along the arc of the ribs best you can tell. The angle is steeper the skinnier and taller your patient is. You should pass right through the chest tube hole if it was put in the correct place. Err on the high side if you are unsure where to go. High, wide, handsome.
5. After you are through the soft tissues, grab some heavy Mayos, place them half in and half out of the chest, and divide the intercostals and whatever else is left by sliding the scissors along the superior aspect of the rib. Asking your anesthesia colleague to hold the vent for a second here might get the lung out of the way long enough to keep you from injuring it as you make this move. Do your best to get as BIG an incision as you can, and divide EVERYTHING in the chest wall that might be holding you up.
6. You are probably going to bag the mammary artery up near the sternum at some point in all this, so keep in mind that if the patient lives, you will need to make sure that is clipped or otherwise controlled before you get out of there.
7. Place the rib spreader, handle downward leaving open your clamshell option, and crank it open. Then optimize your workspace best you can quickly and crank it open some more. Remember the rib spaces are wider near the sternum compared to near the back, so try to use this to your advantage in getting the retractor in and setting up a good view.
8. Evacuate any clot and pack the lung up and out of the way, and take the inferior pulmonary ligament bluntly up from the diaphragm to the inferior pulmonary vein without causing more damage the best you can. Lung bleeding? Deal with it directly with stapled non-anatomic resection, etc., as described elsewhere in this book. You think big air embolus? Clamp the hilum, aspirate air from the ventricle best you can, and pray.
9. Whether or not it looks like there is blood in the pericardium, open it completely from the inlet to the diaphragm well above the hilum to avoid the phrenic. The pericardium can be hard to grab, particularly if it is full of blood, so for this you probably need some rat tooth forceps and a pair of scissors. Evacuate any clot and deliver the heart. Hole in the heart? Deal with it directly as described elsewhere in this book.
10. If there is no organized cardiac activity, start open CPR with your good two handed technique. If you have v-fib or pulseless v-tach and internal paddles are available, try shocking the patient (20–30 joules). Remember the heart doesn't have a real chance of coming back until the patient has some semblance of a physiologic pH, temperature, and enough blood volume return to fill the ventricle without cavitation. Now also maybe the time to try your intracardiac epinephrine, $Ca^{2+}$, vasopressin, $Mg^{2+}$, or other assorted voodoo. You have gone this far, give your damage control resuscitation time to work, and don't give up on the open massage until you are sure they are dead.
11. If you think (or know) the problem is abdominal exsanguination, focus on clamping the descending aorta right after you get in and pack the lung up. Remember, this is likely a young person with no blood pressure, so be prepared that the aorta will be smaller and more flaccid than you imagined. Start by

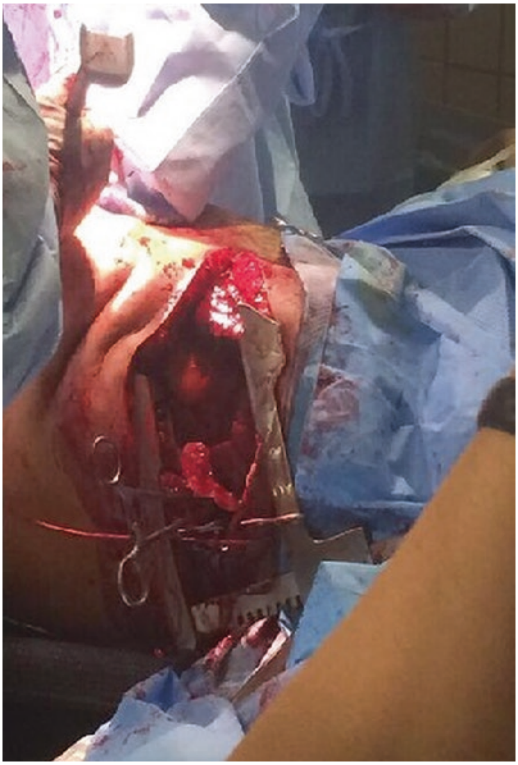

**Fig. 14.2** Left anterolateral thoracotomy

sweeping up the arc of the vertebral body laterally and posteriorly up toward the middle, and you will find it. Try to get as low as you can near the diaphragm without making things too hard and the angles too awkward. Key maneuver to get the clamp across safely is to make sure you open up the parietal pleura both in front of and behind the aorta. Spread your scissors to open the pleura in front of and behind the aorta just enough to accept the vascular clamp – this is no time to add to the misery by avulsing an intercostal artery (hole in the aorta!). And if you were able to get the OG or NG down beforehand, this will help you from damaging the esophagus in all of this as well.

12. After you get the clamp on and you think it is good, drive on with resuscitation of the patient, and deal with the abdominal problem immediately (Fig. 14.2). You have about half an hour maximum for a miracle to happen. Get the clamp off as soon as you can. If you assess the abdominal injury and feel like you can move the clamp down into the abdomen, or get control some other way and take the clamp off altogether, do it (ideally opening it and leaving it in place so you can re-clamp as needed). All the better in terms of neurologic injury and evil humor washout syndrome you are going to be dealing with later if the patient lives.
13. Get to the OR, hopefully you are there already.

## For Inadequate Exposure After Anterolateral Thoracotomy or Suspected Right Pleural Space Hemorrhage = Clamshell

The bilateral thoracosternotomy (or "clamshell" incision) is the most versatile incision in chest surgery. It does introduce some pretty significant potential morbidity in the way of pain and healing, but a dead patient has never thanked their surgeon for keeping the incision small. Clamshell is rarely going to be your first move. Generally, this is an extension from left anterolateral thoracotomy, when you (1) suspect right pleural space bleeding (based on right chest tube output or mechanism of injury) or (2) simply do not have adequate exposure to temporize or repair an injury. In particular, management of anything other than the most straightforward penetrating cardiac injury or proximal great vessel (SVC, ascending aorta, main pulmonary artery) injury will almost always necessitate more exposure than that allowed by an anterolateral thoracotomy. These injuries are best exposed via median sternotomy, but if you have already committed to an initial left thoracotomy, the circumstances of the patient's presentation have made clamshell the more logical next maneuver. Even if you are able to temporize such an injury in the trauma bay via left thoracotomy, you should plan on extending to a clamshell in the OR for definitive repair. This is because with these injuries there is no such thing as "proximal control," and you are never more than a minute away from mortal exsanguination. Exposure, therefore, is priority one, two, and three.

## Conduct of Operation

1. Generally, you already have the left resuscitative thoracotomy. So now you need to make the right-sided thoracotomy incision. From a left anterolateral thoracotomy, it is generally easiest to make a mirror image right anterolateral thoracotomy prior to sternal division, but depending on circumstances, if you think you need to be a bit higher or lower on the right, you can take it a rib space above or below as need be.
2. Divide the intervening sternum with a Lebsche knife, Gigli saw, or heavy shears ("ugly but effective"). You will be transecting both internal mammary vascular pedicles, so you will need to address them later after resuscitation (these vessels don't bleed much in a hypotensive or arrested patient).
3. After you divide the sternum, electrocauterize the periosteal sternal edges (and apply bone wax if you have it), and then use scissors or cautery to release the sternum from the anterior pericardium (a key maneuver for adequate exposure). There is nothing to worry about injuring with this step – just cut or use electrocautery until you see the shiny/whitish pericardium and you are able to elevate the proximal sternum adequately without undue tension.
4. Finally, place a second rib spreader in the right thoracotomy incision and go to work (Figs. 14.3 and 14.4).

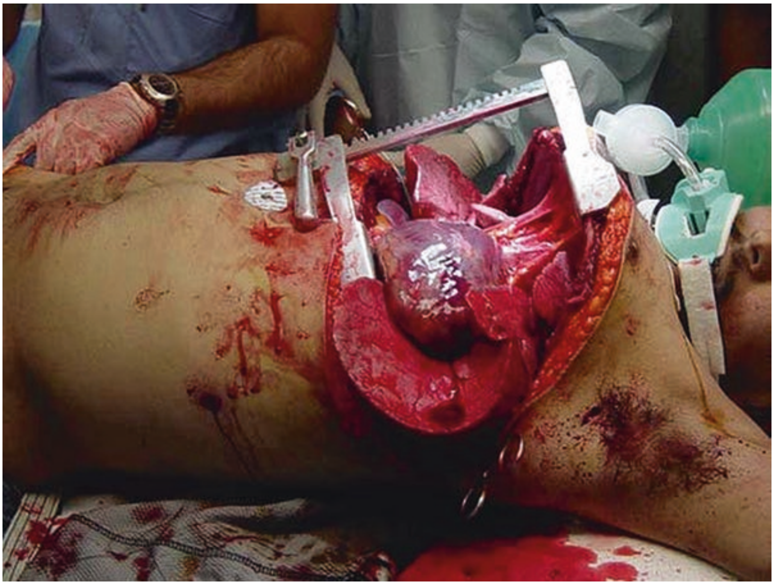

**Fig. 14.3** Clamshellthoracotomy viewed from left

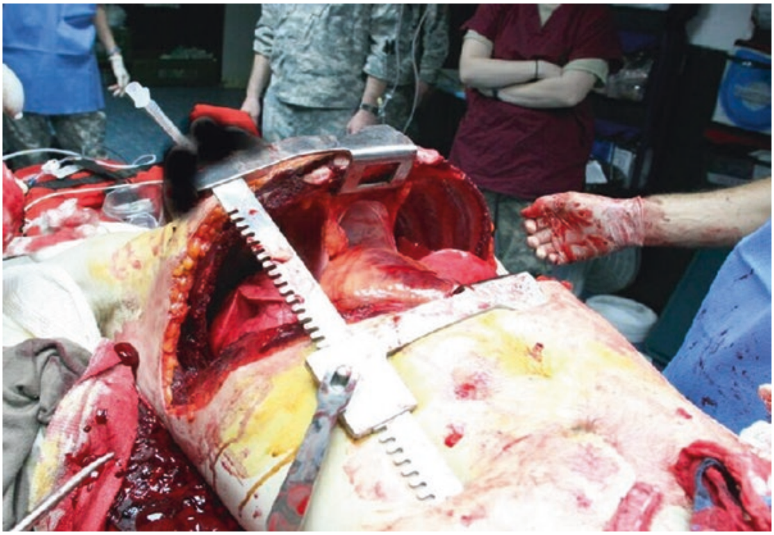

**Fig. 14.4** Exposure available with clamshell thoracotomy

## For Box Wounds Without Pleural Hemorrhage = Sternotomy

In the unstable patient, or with obvious pleural hemorrhage, you need a really good reason not to always start with an anterolateral thoracotomy. But all things being equal, if you are pretty sure you have an anterior cardiac or great or arch vessel injury and associated mediastinal hematoma, sternotomy gets you right at the problem (whether or not you want to be there when you do is another question). The median sternotomy gets you the heart, ascending aorta and proximal to mid arch, base of the innominate, proximal right subclavian, proximal left carotid, as well as sundry other vascular structures including the innominate vein, SVC, main PA, and proximal branches. Notably missing from this list is the left subclavian artery, and distal arch and descending aorta. It also provides some access to the pulmonary hilar structures and to a lesser extent the lungs. It is versatile in that it can be extended into a neck exploration incision if you are after carotid or jugular injury or out over the clavicle in a move on the proximal upper extremity vessels. You can combine the clavicular and sternotomy incisions with an anterolateral thoracotomy and maximally expose this area and create a trap door. The trap door is aggressive and can be a morbid deal recovery-wise but will provide access to the subclavian artery and its branches including the proximal vertebral, the internal mammary, and the axillary arteries. As discussed previously, the sternotomy also rolls easily into a midline laparotomy. The disadvantage to this incision is that it provides suboptimal access to the lungs, particularly the left lower lobe, and provides no exposure to the posterior mediastinal structures, particularly the descending aorta.

A sternotomy can seem like an intimidating incision if you are a general surgeon who has not done one in years (or decades). Just remember – it is just another incision. Unless the patient has had prior heart surgery (fortunately not too common in the warfighter population), you can’t screw this up too bad. Worst case scenario is that you end up way off the midline and you (or more likely the next guy up to chain) will have to put some extra work into the closure. But you are in the lifesaving business here – if you need to do a sternotomy, just get a knife and go to work. You probably won’t have a sternal saw, but if you do, great. More likely you will be packing your trusty Lebsche knife and mallet, so get it out and get the feel of it beforehand, and watch some YouTube videos and learn how to use it.

## Conduct of Operation

1. Perform skin incision from the suprasternal notch down to just below the xiphoid, divide the soft tissue down the middle, and then use your forefinger above and below to bluntly develop the space above and behind the suprasternal notch and the xiphoid process so that you will be able to get the saw or the Lebsche in, through, and out of the sternum. Use your thumb and forefinger of your nondominant hand to provide your own countertraction on the skin as you

cut – the laparotomy trick of you and your assistant pulling against each other to find the linea alba works great, but trying that on the sternum just pulls you off the midline to the side of whichever one of you whose adrenaline is pumping more.

2. Before you start pounding the mallet or firing up the saw, have your anesthesia partner hold the vent (or disconnect) for a second so the lungs fall away from the middle, and allow the right ventricle to drop down a bit while you are dividing the bone. If you do have a saw, make sure the blade isn't in backwards, and test fire it first to make sure it is going to work. And when you do start cutting, get the saw going just before you get into the bone, because it won't get up to speed if it starts under resistance.
3. Do whatever you can to best gain the midline on the bone, and make adjustments while you are hammering or sawing. Divide the sternum completely. It will be bloody, and bone wax is helpful here for the marrow if you have it, as well as setting your electrocautery on "kill" for the coagulation setting (50+) to deal with the periosteum, chest wall muscle, soft tissue venous hosers, or any other non-vital collateral victims in your way.
4. Get in the retractor. Putting the retractor crossbar at the top versus the bottom is a style point, but there is usually less tension at the bottom (and keep it out of the way of the patient's neck if you need to extend the incision toward the head). If you are encountering a lot of tension when you spread the retractor blades, it probably means you need to extend the skin/fascial incision caudally.
5. Place lap pads or towels under the blades on either side to help control nuisance oozing from the marrow and soft tissues (which in a coagulopathic patient can sometimes make it hard to sort things out in the sternal well).
6. Once the retractor is in, you will see mediastinal fat and thymus remnant. Again, make sure the electrocautery is up to 50 or so, and divide all the fat down to the shiny whitish pericardium, from the level of the diaphragm up to the innominate vein. The innominate vein (typically located under the top third of the manubrium) is the only thing you can hurt between the back of the sternum and the front of the pericardium. But if you electrocauterize into it, you will be sorry (and will probably start to lose control of your operation), so take your time dividing the thymus fat up top.
7. If you are preparing to open the pericardium for an underlying mediastinal hematoma, make sure you have everything ready to control the situation as you are about to unroof it.
8. Once the pericardium is exposed, make a small rent in it with an electrocautery or knife, and then open the rest in the midline over your finger. Start by going caudally, teeing off the pericardium along the diaphragm on both sides. Superiorly you should open it up all the way to the pericardial reflection along the front of the ascending aorta.
9. Place stay sutures ("pericardials") along the edge of either side of the pericardium, which should be snapped to the drapes or skin outside the incision under a fair bit

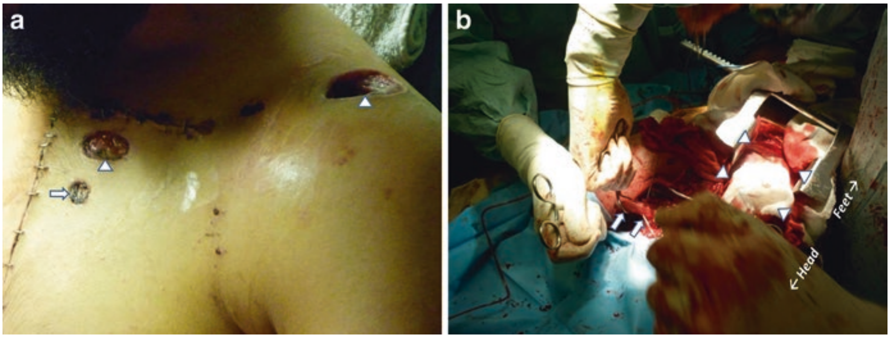


**Fig. 14.5** (**a**) Left subclavian venous injury. Patient with tangential gunshot wound (*arrowheads*) causing left subclavian venous injury and second gunshot wound to left anterior chest (*arrow*). (**b**) Left subclavian venous injury. After median sternotomy (*arrowheads*) revealed no great vessel injury, the incision was extended across the left clavicle, which was removed (*arrows*) to allow for subclavian vein repair

of tension. Usually 2–3 on either side will do the trick, and any suture (3–0 or bigger) will work fine. Pericardials are critical for exposure – they will keep the ventilating lungs out of your field and will help retract the heart/great vessels closer to you. If there is bleeding from within the pericardium during this step, you cannot let it distract you from opening the pericardium completely and placing pericardial stays, as without these key maneuvers for exposure, you will be chasing your tail when trying to negotiate the primary problem.

10. You are now looking at the heart and the great vessels. Fix the problem. A gentle finger over the hole is a good place to start.

## Left Subclavian Injuries Suck

Not a lot of great options here if you have a bad one. But if the patient is unstable and bleeding to death and the usual Foley balloon in the hole tricks are not going to work, you will need to do something here. Mid or distal left subclavian, think about a left anterolateral thoracotomy and getting initial control with a sponge stick or something up there while your partner dives down above or through the clavicle from the front. As described above if you are already working from a sternotomy position, extensions to clavicular exposure or full trap door are logical options (Fig. 14.5a, b). Yes, this is a bad problem. But you don't make 'em, you just take 'em. One way or another, get down through there, and get it solved – remember the clavicle is just a bone, so divide it, and do what you have to do to get control of the situation. Proximal left subclavian is even more challenging. The key thing to understand here is that unlike the other two arch vessels, you generally can't get to the proximal left subclavian from sternotomy – starting with a high left anterior thoracotomy is your best shot.

## For Suspected Proximal Left Subclavian Arterial Injury, Start with a High Left Anterior Thoracotomy

There are few worse places to have an arterial injury in the chest than the proximal left subclavian artery, which lies at the end of a deep and dark hole from any surgical approach. If you suspect this injury, diving right in using a supraclavicular or transclavicular approach will probably not end well for you or the patient. Instead, begin by achieving proximal control via a high left anterior thoracotomy.

## Conduct of Operation

1. Palpate the "sternal angle" along the middle of the upper sternum, which is the universally present transverse ridge at the junction between the manubrium and sternal body. This marks the location of the second rib. An anterior thoracotomy for proximal left subclavian control can be approached through the second or third interspace (i.e., above the third rib or above the fourth rib). Going through the former interspace places you more directly over the subclavian, but at the expense of less ability to spread the ribs. A generous anterior third intercostal space thoracotomy is probably a safe bet, so march down one rib (and change) from the sternal angle, and make a skin incision (parallel to the clavicle) from one fingerbreadth off of the sternum medially to the anterior or midaxillary line laterally. If you are not comfortable feeling the sternal angle, a safe skin incision is simply midway between the clavicle and the nipple (in a male), parallel to the clavicle. If you make the incision in this approximate location (without counting ribs), then utilize the interspace that presents itself at the base of your incision, and you will probably be OK.
2. Divide the fatty tissue down to the pectoralis major fascia and muscle, then open the pectoralis (using cautery or sharp technique), and electrocauterize through the remaining flimsy fibrovascular tissues down to the top of the fourth rib. Next, cauterize along the top of the rib on a broad front. Once you are through most of the intercostal muscle, it is generally safer to pop through the pleura bluntly (with a Kelly clamp) instead of motoring through the pleura (and into the adjacent lung) with cautery.
3. After you enter the pleural space, use a plastic suction tip, and hug the inner chest wall, or use a moist lap pad to pack the lung out of the way, so you can safely divide the rest of the intercostal muscle off the top of the fourth rib for the extent of your skin incision (using cautery). As you approach the medial-most extent of this intercostal incision, you will need to mind the internal mammary artery (and veins). Unlike the scenario of a resuscitative thoracotomy, it is best not to transect these vessels here (one more thing to worry about bleeding). You can avoid the mammary by stopping the intercostal incision about two fingerbreadths lateral to the edge of the sternum. If you do get into the mammary vessels, don't panic – just clip or tie them.

4. Next, place a rib spreader into the wound, with the crossbar medial to keep it out of the way of your clavicular incision. If at this point you are not able to get enough exposure to see and safely encircle the proximal left subclavian artery (after packing the lung away inferiorly with a moist lap pad and opening the pleura overlying the aortic arch), there are several options to allow for better exposure. The first and fastest is to carry your incision further laterally to allow greater rib spreading. If this doesn't work, then divide the fourth costal cartilage about 2 cm lateral the sternum (using a knife is probably easiest, although you can also use cautery or a heavy scissor). This will "release" the fourth rib and allow for better exposure in your workspace. Finally, if all else fails, the sternum can be divided transversely across the midline (after controlling/dividing the internal mammary vessels) using a Lebsche knife or other available means.
5. Once you have adequate visualization (keeping in mind that "adequate" may not be "good"), you can encircle and control the base of the left subclavian artery before making your supraclavicular (or trans-clavicular) incision to reach the proximal subclavian artery directly.

## The "Trapdoor" Incision

Often mentioned but rarely used, the trapdoor combines a partial (or complete) median sternotomy with a clavicular (or neck) incision at the top of the sternotomy and an ipsilateral thoracotomy incision at the bottom of the sternotomy. This would almost never represent your initial plan of attack. The trapdoor is useful when you are facing combined penetrating cervical and mediastinal injuries or a bad subclavian injury, and after sternotomy and clavicular incision (for right-sided injuries), or after a left anterior thoracotomy and clavicular incision (for left-sided injuries), you still can't obtain adequate exposure or are facing declining hemodynamics. In one of these scenarios, by completing a trapdoor, you probably have a better shot at keeping the patient alive. No new incisional techniques here – just add a sternotomy or anterior thoracotomy and see what you need to see.

## Think Twice Before You Start with a Posterolateral Thoracotomy

The posterolateral thoracotomy is great exposure for the esophagus, posterior hilum, mediastinal structures, chest wall, and stem to stern descending thoracic aorta. It is certainly optimal for non-emergent stuff after the patient has survived damage control procedures days before, and perhaps now you are dealing with evacuation of loculated effusion, retained hemothorax, a space problem, or debriding soft tissue damage or resecting devitalized lung. The trouble with this approach is that it boxes you in to essentially just the ipsilateral chest and mediastinum with minimal access to ongoing mischief elsewhere – a major liability at a time when you need to maximize flexibility and multi-compartmental access. And remember, to see anything, you generally need the lung down on that side, and that means double-lumen tube or bronchial blocker. Without this, in addition to the billowing lung in your way, blood and debris from the bad side can freely flow down into the good lung (bronchi are just tubes, and if you are operating on a bleeding chest, do you really want to risk drowning the patient in his own blood and secretions?). Finally, since you will be positioning the patient on their side and perhaps even breaking the table in the middle, you need to have high confidence in your thoracic spine clearance; generally, this is not something you can count on the minute the patient hits your trauma bay door. So best reserve the posterolateral thoracotomy for the patient who has already survived original damage control and has a known unilateral injury complex requiring only a thoracic operation.

All that said, if you do find yourself in a position to need to do a posterolateral thoracotomy (likely for a stable patient at one of the higher echelons of care), here are the basics:

## Conduct of Operation

1. If you have a beanbag, get this on the OR table before the patient is placed there. If you don't have access to a beanbag (more likely), you can use large IV bags wrapped in towels as anterior and posterior "bolsters," placed in front of and behind the patient after they are in lateral position (placed between the chest and the OR table, in front of and behind the patient). The goal is to have a physically stable patient who will not be displaced from the table in the middle of your operation (a patient falling off of the table is unacceptable and avoidable, even downrange).
2. After the breathing tube (a double-lumen type if your anesthesia partner has the sophistication and resources available to place one) is secured well, the patient is lifted straight up in the air, moved away from the planned operative side, and placed in the lateral decubitus position. This generally takes several people to do safely – one to control the head and mind the breathing tube, one or two more to lift and position the patient, and one to manage the legs. Once the patient is in the decubitus position, if you have a bed that can "break," you will want to do this now, with the patient positioned to have the break of the table at the level of the anterior superior iliac spine/iliac crest. Breaking the bed will create a larger interspace for you to work in but is not an absolute necessity for a posterolateral thoracotomy. Next, get a pillow placed between the legs (with the "down leg" bent and the "up leg" straight), and make sure the patient's legs and hips should be taped securely to the bed. The "down arm" should be placed on an arm board straight at the elbow but flexed slightly at the shoulder (so it is up and out of your way), and the "up arm" can be placed in a flexed position at the elbow on a pillow or folded blankets (like a freestyle swimmer – hand below the wrist below the elbow below the shoulder). But no need to obsess too much about arm position here – if the arms are out of your way and their position looks relatively natural, without excessive torque on the patient's joints, it will work.

3. After a wide prep and draping, mark out a skin incision. Start with a posterior mark, midway between the medial border of the scapula (where you can palpate the scapula's bony "spine") and the vertebrae. Make a second mark one fingerbreadth below the inferior-most tip of the scapula, then mark out between these two dots in a gentle curve to delineate the posterior aspect of your incision. Anteriorly, simply create a gentle curve in a cephalad direction parallel to the ribs, marking all the way to the sternum.
4. Make a generous skin incision, carry it down to latissimus muscle (the first muscle you will encounter), and then electrocauterize all the way through the latissimus (slowly, with electrocautery on at least 50, to ensure you get all the pesky muscle bleeders). Deep and anterior to the latissimus, you will encounter the serratus muscle, which should be divided partially (opening it up as much as needed to get to the chest wall for the extent of the incision). In peacetime surgery, one or both of these muscles are generally preserved for a thoracotomy, but you can leave the sexy, "muscle-sparing" boutique thoracotomies for your colleagues back in CONUS who have the luxury of nearly infinite resources and a warm and cozy bed to crawl into at night (and no threat of mortar fire). Once you get through the latissimus and serratus, all that is left between you and the ribs are some fascia and fatty tissue which you can quickly divide with a electrocautery. As you work deep to the latissimus posteriorly, stop when you encounter the longitudinal paraspinal fascia.
5. Next place a large, handheld retractor under the scapula and have an assistant forcefully lift the scapula off of the chest wall, allowing you to insert a hand under the scapula and bluntly dissect as high as you can go. This will mobilize the scapula off the chest wall to relieve incisional tension, and for an "elective" thoracotomy, this maneuver would allow you to "count the ribs" to plan your thoracotomy level. In reality, unless you have significant thoracic surgical experience, this can be tricky. The bottom line is that the tip of the scapula generally overlies the sixth rib. For most chest surgery, your goal should be a fifth intercostal space entry. So if you are not able to figure out the rib-counting exercise, just plan on entering the chest right above the level of the tip of the scapula (this will get you in into the chest at a level close enough for most government work).
6. After you have determined your interspace for attack, electrocauterize along the top of the rib on a broad front until you are through most of the intercostal muscle, then pop through the pleura while having the anesthesia provider hold (or better yet temporarily disconnect) the vent to allow the lung to fall away from the chest wall. After you enter the pleural space, you can either use a plastic suction tip hugging the inner chest wall or use a moist lap pad in the chest to push the lung away, allowing you to divide the rest of the intercostal muscle off the top of the lower rib, stopping posteriorly when you reach the transverse process and stopping anteriorly well before you reach the sternum (and before reaching the internal mammary vessels, located one fingerbreadth off of the sternal border). The more intercostal muscle you take down off the rib, the more you will be able to spread the ribs (and the better your exposure).

7. Next, encircle the lower rib at the posterior aspect of your incision (as far posteriorly as you can comfortably reach) using a fine-tipped right angle, hugging the rib to try to avoid injuring the intercostal bundle. Then use a rib shear to divide the rib at this level. If you get into the intercostal vessels during this step, no worries – just turn up the electrocautery and nuke 'em. After dividing the rib, you can resect a small portion of the remaining rib if you choose (to prevent the remaining ends of the free rib from rubbing against one another when the patient moves around after surgery), but this is not a necessity. After dividing the rib, electrocauterize the periosteal edges of the remaining rib, and place your rib spreader. If you don't have a rib shear, you can create a (relatively) controlled fracture of the lower rib by simply placing a rib spreader and gradually increasing the spread until you hear an audible (and esthetically unpleasant but technically effective) pop indicative of a rib fracture. Either dividing the lower rib under vision or creating a controlled fracture will have the same desired effect of allowing you to spread the ribs far enough apart to be able to fit a hand comfortably into the pleural space. If you can't fit your hand in (or even worse can get it in, but can't get it back out), you either need a bigger incision, more rib spreading, or a different profession (maybe orthopedics).
8. If you find yourself too high or too low to do what you need to do once you get in there, don't be afraid to move up or down two ribs ("bunk bed" thoracotomies), all through the same skin/soft tissue incision. You need to optimize your workspace, and if you have to make two intercostal incisions to get it done that just is what it is.
9. At this point, you are ready to go to work – you will need a good headlight and a long electrocautery tip. If you don't have these resources at your facility, you probably chose the wrong incision for your echelon of care.

## The Bottom Line

Don't confuse war surgery with elective thoracic practice. You need simple, purposeful, reproducible, feasible, and fast solutions set in your mind for the various scenarios. Do as much of your thinking beforehand as possible during all the downtimes, so you can rehearse them with your team repeatedly until rote. When the patient hits the door, always prep them for the maximum, and BE FLEXIBLE after you make your initial move. Think about the compartments – where is the bleeding happening now? Be paranoid about the other compartments until you clear them one way or another, and remember that the other compartment may not even be in the chest but in the belly. Never be afraid to extend your incision or make a hole somewhere else. For box wounds without pleural hemorrhage, think about a sternotomy. Remember that you probably need a good reason to ever do a posterolateral thoracotomy in a fresh combat trauma patient. And know that sometimes, there is a left subclavian artery hosing and it might be a bad day. Embrace it and do the right thing. No matter what the situation is, remember that YOU HAVE WITHIN YOU the courage, intellect, audacity, perseverance, and proper training, and YOU WILL save your patient. And if all else fails, left anterolateral thoracotomy is a good place to start.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Damage control resuscitation.
2. Management of war wounds.

# Lung Injuries in Combat

# 15

Matthew J. Martin, Michael S. Meyer, and Riyad Karmy-Jones

**Deployment Experience**

| | |
|---|---|
| *Matthew J. Martin* | Chief of Surgery, 47th Combat Support Hospital, Tikrit, Iraq, 2005–2006 |
| | Chief, General Surgery and Trauma, Theater Consultant-General Surgery, 28th Combat Support Hospital, Baghdad, Iraq, 2007–2008 |
| | Commander, 655th Forward Surgical Team, FOB Ghazni, Afghanistan, 2010 |
| | Chief of Surgery, 758th Forward Surgical Team, FOB Farah, Afghanistan, 2013 |
| *Michael S. Meyer* | Chief of Surgery, 249th General Hospital, Bagram, Afghanistan, 2005 |
| | Chief, General and Thoracic Surgery, Theater Consultant-Thoracic Surgery, 86th Combat Support Hospital, Baghdad, Iraq, 2008 |

*In massive insults to the organism, treat the patient for the insult, without waiting for the response to the insult.*

Mark Ravitch (1910–1989)

M.J. Martin (✉)
Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA
e-mail: traumadoc22@gmail.com

M.S. Meyer
Surgery Uniformed Services University of the Health Sciences, Pulse Heart Institute, Multicare Cardiothoracic Surgeons, Multicare Tacoma General Hospital, Tacoma, WA, USA

R. Karmy-Jones
Legacy Emanuel Hospital, Trauma Department, Portland, OR, USA



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This chapter is based on two universal truths in combat trauma: (1) You WILL be faced with severe thoracic injuries that require quick decisions and operative intervention, and (2) most of you are not fellowship-trained cardiothoracic surgeons and will not have one immediately available. You may be given the advice that "damage control in the chest is just like damage control in the abdomen" – don't be lulled into complacency. Losing the comfort level and deep understanding of anatomic relationships that you have in the abdomen makes combat chest surgery an entirely different and often unforgiving adventure. There are two things you can do to set yourself up for success in thoracic trauma – Prepare and Practice. Prepare by reviewing any anatomy text or surgical atlas to get familiar with the critical structures and relationships as well as basic operative techniques. Practice by either scrubbing in to elective thoracic cases if you can, or by reviewing common thoracic injury scenarios and how you will handle them. Do not forget the most basic lesson of the soldier – **"you will fight as you train."**

**BLUF Box (Bottom Line Up Front)**

1. Blast mechanisms often create a deadly combination of blunt lung injury (contusion) and penetrating parenchymal damage.
2. Simple chest tube drainage has a much higher failure rate than in civilian lung injuries – be prepared to operate!
3. Damage control surgery and temporary closure is not only for the abdomen – use it.
4. You do not need a CT scan to diagnose most chest injuries or to determine if an operation is needed.
5. Lateral decubitus positioning and double lumen endotracheal tubes are time-consuming luxuries that most bleeding patients can't afford.
6. The only VATS in combat trauma is Very Aggressive Thoracic Surgery.
7. Avoid retained hemothoraces by doing it right the first time – this means in the OR.
8. Pulmonary tractotomy is a great technique – and you will almost never use it. Most operative combat lung injuries will require anatomic or nonanatomic resection.
9. Review your thoracic anatomy and surgical techniques – consulting cardiothoracic surgery is usually not an option.
10. Don't forget about air embolus – it can kill your patient faster than hemorrhage.

## Surgical Approach ("You Can't Get There from Here")

The previous chapter describes in detail how you should approach chest injuries in combat trauma and the choice of incisions. The main point that cannot be repeated often enough is that you should almost always be approaching these injuries through an anterolateral thoracotomy or median sternotomy, with the patient supine.

Inexperienced trauma surgeons use “elective” surgical approaches aimed at maximizing ease and exposure at the expense of flexibility and options. A good combat surgeon will accept less-than-perfect (although always adequate) exposure to maintain the maximal amount of flexibility and options. If you break this basic rule, then you will inevitably end up with the patient in a lateral decubitus position when you realize that the bleeding is actually coming from the abdomen, the mediastinum, or the other side of the chest. You can do everything you need to do through an anterolateral thoracotomy – just make sure your incision is long enough, and you have adequate self-retaining retraction. Rapid entry into the chest can be obtained with one or two aggressive swipes of the scalpel through skin, fat, and muscle followed by wide opening of the remaining intercostal muscle fibers and pleura using heavy scissors. The best and most underutilized maneuver to improve exposure is to extend your skin incision medially for 5–10 cm onto the opposite chest and divide the sternum. Now that you’re there, establish your priorities and get to work.

## Damage Control Principles in the Chest (This Ain’t the Abdomen)

Just like a combat trauma laparotomy, a damage control approach should be your default when operating on major traumatic lung injuries in the combat setting. Do what needs to be done immediately and what the patient will tolerate, and then get out to finish the fight another day. But that is where the similarities to abdominal damage control end. In the abdomen the only *immediately* life-threatening concern you need to focus on is controlling hemorrhage. This is usually not the case in the chest. Tension pneumothorax, cardiac tamponade, arrhythmias, refractory hypoxia or hypercarbia, and the dreaded air embolus are all quick and silent killers that need to be on your mind and rapidly addressed or prevented. Close coordination with your anesthesia provider in these cases is of the utmost importance, particularly in the setting of lung injury. Do not waste time trying to get a double lumen endotracheal tube or bronchial blocker in perfect position before starting the operation – you will usually lose much more than you gain, and it can wait until you have bleeding controlled. Some simple manipulations of the tidal volume and respiratory rate or positioning of the endotracheal tube (i.e., advanced to right mainstem) can make your life a whole lot easier and get the inflated lungs out of your way. An additional useful maneuver is to have the anesthesia provider disconnect the patient from the ventilator after full exhalation, compress the deflated lung with packs and a hand-held or self-retaining retractor, and then reinitiate mechanical ventilation. This will give you almost the equivalent of single-lung ventilation.

Just like in the abdomen, hemorrhage control is goal number one. Packing is not the first maneuver, particularly when the chest is full of blood! Rapidly scoop out the clot with your hands, and then use some dry lap pads and suction to remove the remainder of the pooled fluid. Now assess the hemorrhage and determine if the bleeding can be easily controlled with manual compression or clamping – if so, proceed with definitive control. If you have large volume hemorrhage or bleeding from multiple sites then go ahead and pack the cavity, make sure your anesthesia provider is catching up and ready for more bleeding, and then begin pack removal and hemorrhage control. If the volume of bleeding is too great to allow for packing to assist in visualization, use your fingers as a clamp to occlude the main pulmonary artery and vein at the hilum while an assistant works on using sponges and a sucker to clear out the blood. If no assistant is available a large vascular clamp can replace your fingers to accomplish the same goal. At this point you can gradually release the hilar vessels to better localize the bleeding source. A kidney pedicle clamp is commonly available in the field and can be used, although a larger, more gently curved, and less traumatic clamp (if available) is a better choice. Adequate exposure, retraction, and packing of the lung, and strong suction are your best allies for localizing the bleeding and obtaining control.

In addition to hemorrhage, you must also consider and address the several other quick killers listed above. Opening the chest has removed the possibility of any tension physiology on that side, but don't forget about the contralateral chest. Be liberal about putting in a chest tube on the other side to rule out significant bleeding or pneumothorax. If you are using a median sternotomy, you can incise both pleura and open them widely with your fingers. If you are faced with life-threatening hypoxia or hypercarbia, then quickly look for a potentially treatable source such as a massive air leak from lung parenchyma or an injury to the proximal airways. Maximize ventilation of the normal lung by advancing the endotracheal tube to mainstem the opposite airway, placement of a bronchial blocker, or a double lumen tube. All of these take some time, so try to control the air leak by clamping the lung or airway proximal to the site of injury. This may entail clamping the entire lung hilum for a very proximal injury, even using your fingers as a clamp initially as described above. Alternatively, if you have good exposure and visualization, you can rapidly suture the injury and return later for definitive repair. For proximal airway injuries, use absorbable suture such as PDS or Maxon in case your rapid repair turns out to a durable one.

Don't forget about air embolism! It is a relatively common and often unrecognized killer in patients with a large pulmonary laceration who have the potential for air entry into the pulmonary venous system. There are several things you can do to minimize the chance of an air embolus: rapid control and compression of the injured lung segment, proximal pulmonary hilar clamping, low-pressure ventilation until the injury is controlled, and submerging the injured area under saline. If your patient experiences sudden cardiac decompensation with no other obvious source, then air embolism should be assumed, and you can follow the management principles outlined in the next section.

Performing a damage control closure of the thoracic cavity can be more complicated than the abdomen. Simply packing the cavity and closing is usually not an option, particularly when there is bilateral lung injury and the patient won't tolerate complete compression of one lung. Other factors you must consider are creating a tension pneumothorax or tamponade by closing the cavity without adequate drainage, and maintaining some degree of normal respiratory or chest wall mechanics. In any chest closure, you must leave adequate large-bore chest tube drainage. In general, nothing less than two 32F tubes is adequate after a trauma thoracotomy, especially if transport out of theater is in the patient's near future. My preferred temporary closure is using a large monofilament suture incorporating muscle, fascia, and skin in an en masse running and locked closure. This will create a tight closure and control bleeding from the wound margins better than a skin-only closure. Rapid skin-only closure can also be performed with a running suture, staples, or towel clips. Alternatively, the wound can be closed without suture by manually holding the wound edges together and applying a large Ioban dressing. Ioban is also useful in a complex incision that doesn't come together adequately, and there is concern for air leak. Don't forget bleeding from your incision! The chest wall musculature, intercostals vessels, and internal mammary arteries will all bleed significantly if not properly assessed and controlled before leaving the OR.

## Pneumothorax

Pneumothoraces are relatively common and Hemothoraxin combat trauma, although the isolated pneumothorax without an associated hemothorax or other significant chest injury is much less common than in civilian trauma. Physical exam diagnosis is often difficult, particularly in the noisy and chaotic trauma bay. You should familiarize yourself with the simple and highly reliable technique for ultrasound diagnosis of a pneumothorax (see Chap. 6) as you may not have x-ray immediately available. You will see many patients arrive with needle catheters placed in the field – these are often placed unnecessarily and frequently never actually penetrate into the thoracic cavity. You are not automatically obligated to place a chest tube – assess the patient and if their pulmonary status is stable, remove the needle and do your ultrasound or chest x-ray. If there is associated blood, then a large-bore chest tube placed in the standard fashion (posteriorly to the apex) is appropriate. If it is an isolated pneumothorax then you are often better off placing a smaller tube in a more anterior position and guiding it along the anterior chest wall to the apex.

Hemothorax in combat injuries should raise your concern for associated severe intrathoracic injuries, continued bleeding, and the possible need for an operation. While the majority of civilian hemothoraces can be managed with tube thoracostomy only, we have found that to be much less successful in the combat setting. Always remember the limitations of your surroundings – the trauma bay in any forward deployed facility is a highly contaminated, crowded, and unsterile environment that is not optimized for procedures. You will also not have VATS available to easily manage problems like a retained hemothorax or empyema. If your patient has a significant hemothorax that requires chest tube drainage, then the best place to do that is in the controlled and more sterile environment of the operating room. Prep and drape the entire chest so you are ready to convert to an open thoracotomy or sternotomy if needed. If you make your chest tube incision slightly larger than usual (2–3 cm is fine), you can pass a large suction catheter (Poole suction) into the chest to thoroughly evacuate the blood and perform large volume irrigation prior to placement of the chest tube. Then a large-bore chest tube can be easily placed and secured, and the patient transferred to either the ward/ICU, or evacuated to the next echelon of care.

## Lung Parenchymal Injuries

Injury to the lung parenchyma will be the most common problem you will face when operating in the chest. Fortunately, it is usually not difficult to quickly identify the exact area of injury and to gain at least temporary control of bleeding. The injured area will typically demonstrate continuous low-volume bleeding and will likely also have a visible or audible air leak. The first instruments you should be sticking into the chest to control bleeding should always be your hands. Simple bimanual pressure on the injured area is usually sufficient to control bleeding and will also improve handling by compressing air out of the lung tissue. It may also be helpful to have the anesthesia provider lower the tidal volumes or advance the endotracheal tube to mainstem the opposite bronchus to facilitate exposure. Even with both lungs being fully ventilated, you can collapse the ipsilateral lung by applying gradual and continuous pressure during exhalation with laparotomy pads and then maintain the exposure with a self-retaining retractor or with an assistant maintaining compression of the deflated lung.

Normal lung tissue is relatively fragile, so injured lung tissue is extremely easy to tear or disrupt with improper or overly aggressive handling. Use only your hands initially to expose the lung and compress the area of hemorrhage. Grasping and retracting the lung is aided by using a small lap pad or gauze for traction, but do not pull the tissue perpendicular to the injury as this will enlarge the parenchymal disruption and worsen the air leak. Duval lung clamps are available in the field and can be a useful adjunct when manipulating the lung. Additionally, using Duval lung clamps to temporarily oppose injured lung tissue can control the air leaks initially and free your hands to continue exploring the chest and deal with more urgent matters.

After you have adequately controlled hemorrhage and assessed parenchymal injuries, you must decide on the most expedient and complete method to control air leaks while at the same time preserving lung tissue (Fig. 15.1). Young, healthy soldiers

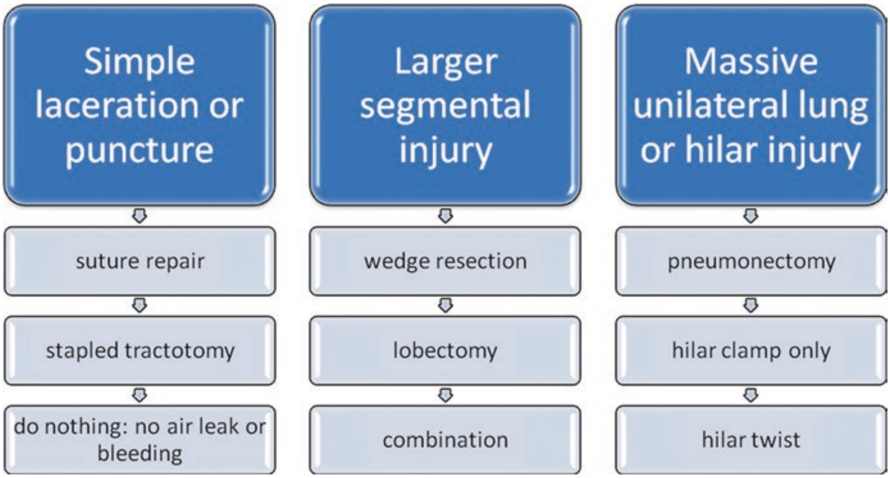



**Fig. 15.1** Diagram outlining operative management strategies to consider based on the type and degree of lung injury

will tolerate a significant amount of lung tissue loss, so do not be worried about large stapled wedge resections. The choice of staple load will depend on the thickness of the tissue to be divided; however, staples with a depth of 3.5–3.8 mm in a linear stapler (this translates into a blue or gold Ethicon GIA load) are good choices that work in all situations. For missile wounds through the lung tissue, a stapled tractotomy (Fig. 15.2) may be an adequate method to initially control air leaks as well as get to the source of bleeding. One arm of the stapler is placed through the missile tract, and the lung above the tract is divided. You may need more than one load to accomplish the above goals. Inspect the opened missile tract and ligate large vessels and air leaks with suture as needed. Pneumonorraphy, or oversewing of the entrance and exit wounds, should be avoided. You may not have an appropriate stapler or staple loads, so an alternative is to use clamps to secure and divide the tract (Fig. 15.3), and then oversew each side of the divided lung parenchyma.

Do not expect a stapled tractotomy and a couple of stitches to be the answer for most combat-type injuries. Unlike civilian low-velocity penetrating injuries, a

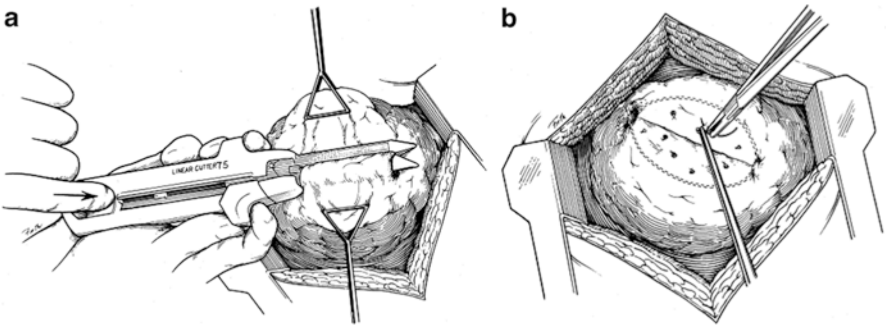



**Fig. 15.2** Stapled tractotomy for a penetrating through and through lung injury. A linear stapler is passed through the defect and fired (**a**), opening the tract and exposing the underlying injured lung tissue. Direct suture repair of bleeding and parenchymal disruption can then be performed (**b**) (Reprinted from Asensio JA, Demetriades D, Berne JD, Velmahos G, Cornwell EE 3rd, Murray J, et al. Stapled pulmonary tractotomy: a rapid way to control hemorrhage in penetrating pulmonary injuries. J Am Coll Surg 1997;185:486–487, with permission from Elsevier)

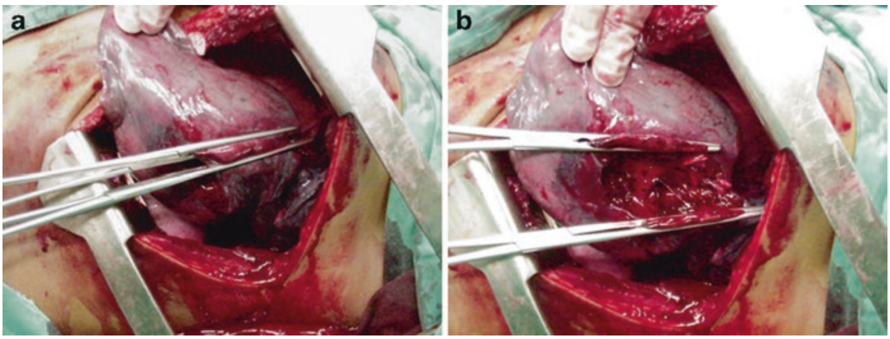



**Fig. 15.3** Pulmonary tractotomy performed with large noncrushing clamps placed through the defect (**a**) and then sharp division of the tract to expose the underlying injured lung (**b**)

high-velocity missile or multiple fragments will deform or devascularize the tissue so severely that a tractotomy is not a good or even possible option. For most peripheral injuries, the damaged lung can be wedged out with a stapler. Manually compress the area to be resected during exhalation to flatten it for placement of a linear stapler. Do not buttress the staple line with suture as you will likely make things worse. Some residual air leak is acceptable and expected. However, if a significant amount of tidal volume is being lost during ventilation, there is a tremendous observable air leak in the operative field, or the chest tubes placed are not adequately draining the pleural space as evidenced by a persistent pneumothorax on a postoperative chest x-ray, additional lung resection may be necessary. In the operating room, place water (sterile water works best; saline is okay) in the chest to try to localize the majority of the remaining air leak. A large volume air leak that can be isolated to a particular lobe that cannot tolerate more staples will likely need a formal lobectomy. Do not leave your patient with a massive bronchopleural fistula in the name of preserving an already damaged lobe – he will be much better off with a little less lung than with ongoing air leaks and contamination.

When operating in a controlled environment, lobectomy is a precise and deliberate operation that can be challenging. Without a solid idea of normal anatomy and the major variations that can be seen from one side to the other, a trauma lobectomy can quickly become a frustrating operation. While a thorough anatomical review is beyond the scope of this chapter, there are several points that will help you successfully complete the case. As a general rule, when approaching the pulmonary arteries, be gentle as this artery does not have the same characteristics of arteries in the systemic circulation due to the low pressure of the pulmonary arterial circulation. They tear easily, they do not hold suture well, and have a tendency to dissect when handled roughly. The pulmonary artery branch vessels are especially fragile and can be transected by suture that is snugged down too tightly in the heat of battle. If you decide to individually suture ligate the branches of the pulmonary artery, be sure to use stick ties in addition to your ligatures. If a pulmonary artery is bleeding after being tied or stapled, avoid the urge to continue placing ligatures or stick ties. Remember this is a low-pressure system, so Surgicel or a similar topical hemostatic agent should be placed with a sponge over the area of concern initially; this type of bleeding almost always stops without further intervention as long as there is no major coagulopathy present. The pulmonary veins are much more forgiving and will tolerate some manipulation. When possible, use linear staplers with a vascular load for all pulmonary arteries and veins; it is a quick and reproducible technique. If space seems limited in the chest for using standard linear staplers, consider using an endoscopic linear stapler if available. They can be placed through chest tube sized holes to allow for a better angle of approach to vascular structures.

## The Pulmonary Hilum: Tread Lightly

Hilar anatomy is very predictable and constant between the two thoracic spaces (Fig. 15.4), while lobar and segmental anatomy is highly variable. As you look into the chest while standing at the patient's injured side, which will likely be through an

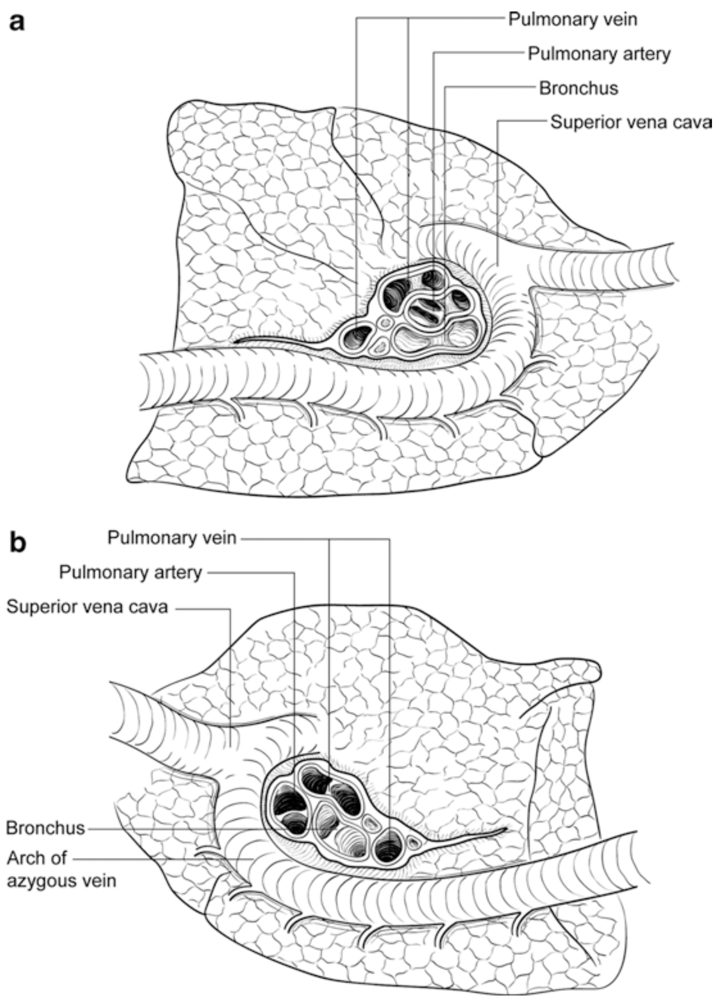



**Fig. 15.4** Diagram of the pulmonary hilar anatomy for the *left* (**a**) and *right* (**b**) lung as seen from an anterolateral thoracotomy approach

anterolateral thoracotomy, reflect the lung posterior and laterally (toward yourself) so that branches of the pulmonary vein can been seen. They are usually overlying the pulmonary artery and usually must be divided first. This relationship is especially critical when removing the upper lobe as these two structures may be so closely associated, and it will be difficult to distinguish them in a bloody field. The bronchus will be slightly deep to the pulmonary artery from this aspect. While this is great exposure for a pneumonectomy, additional manipulation of the lung superiorly and inferiorly will allow exposure of vascular structures to the individual lobe. As the lung is mobilized, retraction of the lobe needing resection anteriorly (away from you) will facilitate the dissection.

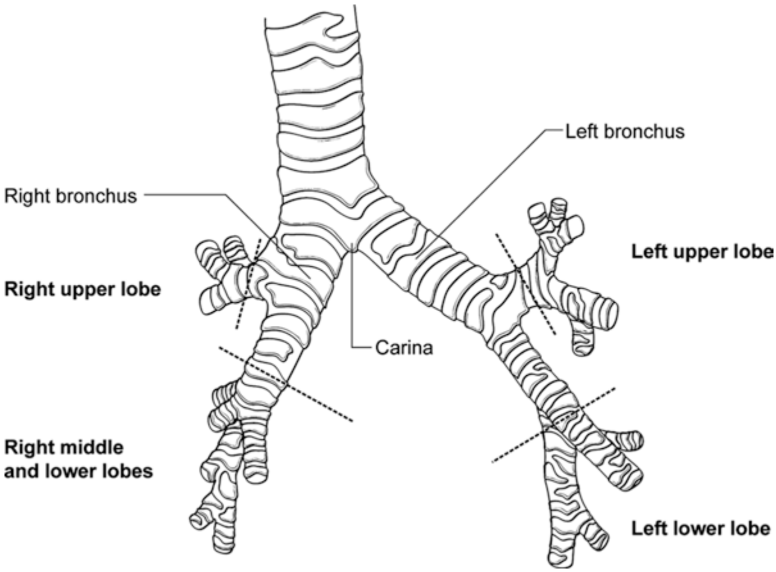



**Fig. 15.5** Diagram of the basic bronchial anatomy with dotted lines indicating the line of bronchial division for a formal lobectomy

A good place to start with any lobectomy is with division of the inferior pulmonary ligament and incision of the pleura surrounding the lobe to be removed; both of these maneuvers allow for better lung mobilization. Identifying the pulmonary artery deep in the major fissure is the easiest method to begin identification of pulmonary artery branches. Umbilical tapes and Rummel tourniquets are handy to have in order to isolate arterial branches you are not initially certain about or as a way to help guide the anvil of a stapling device. An umbilical tape is also useful when completing a fissure. After using a combination of your fingers and a kidney pedicle clamp to determine where the fissure should be completed, pass an umbilical tape through the space you created to guide the anvil of your stapler. Exposure and identification of key structures is aided by alternating your exposure dissection between an anterior and posterior approach – once the anterior dissection is done or cannot proceed any further safely, flip the lung away from you and approach the lobar hilum from the posterior side. An understanding of the basic bronchial anatomy is particularly critical for identification and control of the correct bronchial structures (Fig. 15.5).

When operating on the right side, do not go through a great effort to spare the middle lobe, especially when removing the upper lobe as they share venous drainage from the superior pulmonary vein and the minor (or horizontal) fissure is usually incomplete. The middle lobe is easier to preserve when removing the lower lobe as the major (or oblique) fissure is often well formed. As the pulmonary artery is exposed in the major fissure, look for a posterior ascending arterial branch to the posterior segment of the upper lobe. This will need to be divided in addition to the branches of the superior pulmonary trunk when removing the upper lobe. When the lower lobe is being resected, care must be taken to preserve this branch as it is easy to inadvertently divide when completing the major fissure. An additional technique to assist in exposing structures for procedures on the right upper lobe is to divide the azygous vein.

As on the left side, be aware of pulmonary artery branches supplying the upper lobe, as the main artery travels through the interlobar fissure. Specifically, there may be one or two lingular branches as well as a smaller artery to the posterior subsegment of the anterior segment of the upper lobe. These three vessels may also exist as a common trunk. Vessels to the lower lobe should take off from the pulmonary artery directly opposite from the lingular branches. At times, the bronchus to the superior segment of the lower lobe must be divided separately. If you have a large air leak after a left lower lobectomy, look for this portion of the bronchus to ensure it is secured.

## Pulmonary Hilar Control

As with all pulmonary injuries that present to the surgeon with a field of frothing blood, it is imperative to gain immediate control of hemorrhage with techniques described above and elsewhere in this book. If you have adequately controlled bleeding and air leaks from the lobes and you are still having difficulty, look centrally. You will be faced with deciding if the injury is vascular, tracheobronchial, or both. There is an oft-stated fallacy that you have to divide the inferior pulmonary ligament to allow for access to the hilum. This is simply not true and not required for initial hilar control. You can gain immediate and rapid hilar control with your hand without any mobilization – simply retract the lung laterally and encircle the hilar structures which are tethering the lung to the mediastinum with one hand (Fig. 15.6). This will gain time for you to do a little mobilization and switch out your hand for a vascular clamp. Incise the inferior pulmonary ligament for 2–3 cm to allow full retraction of the inferior lobe, but beware that further division will lead into the inferior pulmonary vein. You can now pass a large straight or slightly angled vascular clamp across the proximal hilum and clamp tight enough to compress both the bronchus and the vessels. Formal pneumonectomy can then be completed immediately, or at a later time if needed. An alternative technique that has been described is the "hilar twist," which is accomplished by dividing the inferior pulmonary ligament and then rotating the lung to twist the hilum and cut off pulmonary blood flow (Fig. 15.7). The lung is secured in the twisted position by placing packs superiorly and inferiorly, and then a damage control closure can be performed. While this can achieve initial hilar control, I would strongly recommend against using this technique to provide long-term hilar occlusion, as it is less secure and could easily "untwist" with disastrous consequences.

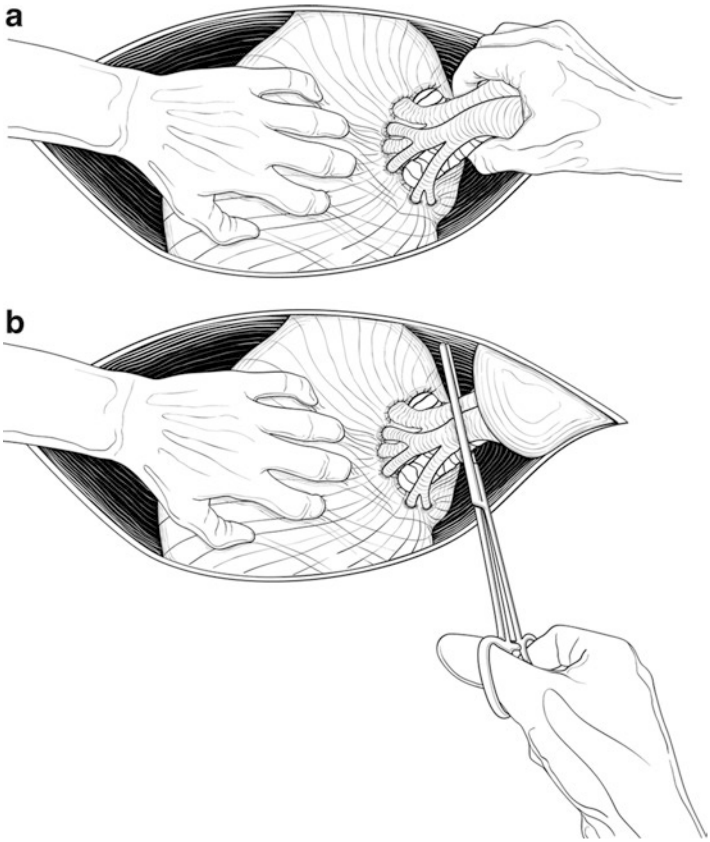



**Fig. 15.6** Approach for obtaining manual control of the pulmonary hilum (*panel a*), followed by placement of a vascular clamp (*panel b*) if necessary

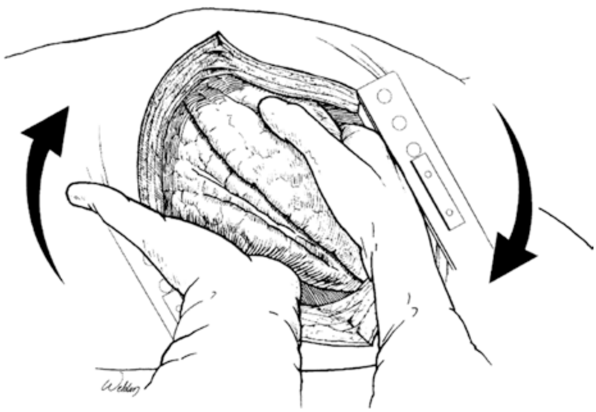


**Fig. 15.7** Hilar twist maneuver for control of pulmonary hemorrhage. The inferior pulmonary ligament is released and the lung is then twisted clockwise 180° (Reprinted from Wilson A, Wall MJ Jr., Maxson R, Mattox K. The pulmonary hilum twist as a thoracic damage control procedure. Am J Surg 2003;186:49–52, with permission from Elsevier)

## Pneumonectomy (It Is Not a Dirty Word)

A pneumonectomy in the trauma setting carries a high associated morbidity and mortality, due to both the physiologic impact of the procedure as well as the severity of injuries. The key to a successful outcome in this scenario is making the decision early and performing the procedure rapidly and in concert with your anesthesia provider. Too often, the pneumonectomy is performed as a "last-ditch" measure after an hour or two of failed attempts at lung salvage. Typical indications for a pneumonectomy will be massive multilobar injury, complex hilar injuries, or any significant injury that will require complex reconstruction in an unstable patient.

The only reason not to do a stapled pneumonectomy in the trauma setting is that you don't have a stapler available. Simple en masse ligation of the hilar structures should never be attempted – you will not be able to adequately compress the vascular structures due to the rigidity of the bronchus. This may be immediately obvious or may manifest as sudden exsanguinating hemorrhage once the patient is better resuscitated and the blood pressure increases. There are several techniques to be aware of to perform an expedient trauma pneumonectomy. If you can gain control of the hilum with a large clamp or your hand, a stapled pneumonectomy is very simple and fast (Fig. 15.8). Pass a large TA stapler (at least 60 mm, possibly a 90 mm) through the space you created to encompass all vascular and bronchial structures. If you can safely pass a second stapler to create a doubled stapled pneumonectomy, this may make for a better long-term result. Make sure you cross the "blood-brain barrier" and communicate with the anesthesia providers at the head of the table! When you clamp the hilum you will not only take one lung out of duty, you will create massive right heart afterload which is often not well tolerated. We would recommend starting a dobutamine infusion with hilar clamping to improve right heart contractility and decrease the pulmonary artery pressures, and have additional vasopressors ready to go as needed. The patient will also likely require continued volume support as well as a high fraction of inspired oxygen and careful ventilatory management to avoid undue barotrauma to the remaining lung.

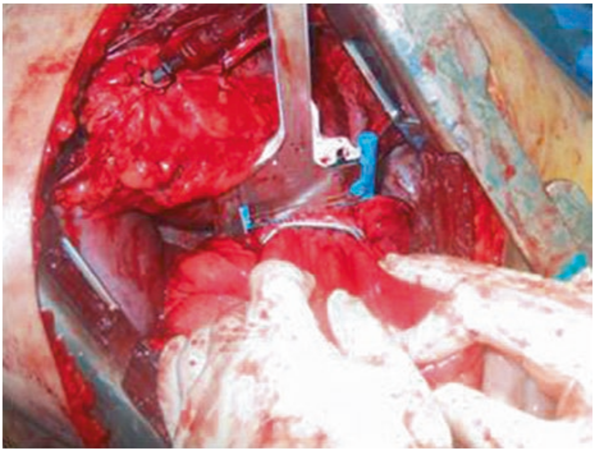
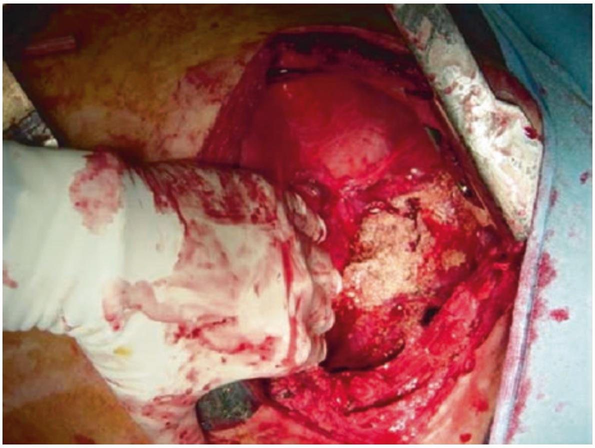


**Fig. 15.8** A trauma pneumonectomy can be rapidly performed by en masse stapling of the hilar structures once control has been obtained. One or two staple lines are applied and the hilum is then sharply divided

**Fig. 15.9** Damage control thoracotomy with application of QuikClot topical hemostatic granules to diffusely bleeding area of lung and chest wall



A large chest tube should be placed after pneumonectomy and placed to water seal, not suction. You want to ensure the mediastinum is balanced; if you find the mediastinal shift to the operated side is great enough to cause hemodynamic instability, introduce air into the empty pleural space, and check your results with a chest x-ray. If you are unsure pneumonectomy is necessary and can get the patient out of the OR without this, pack the chest as necessary, perform a temporary closure, and plan to bring the patient back when better resuscitated. If a pneumonectomy is still indicated, a more controlled operation can be planned with deliberate dissection of the hilar structures, better securing of the bronchus, and less chance of injuring surrounding structures such as the phrenic and vagus nerves and esophagus. In several cases of ongoing lung hemorrhage that could not be easily controlled in a far-forward setting, topical hemostatic agents or dressings have been used along with packing to control bleeding and get the patient to the ICU or to a higher level of care. Fig. 15.9 shows a granular hemostatic (QuikClot powder) which was applied by a forward surgical team (FST) and achieved complete hemostasis until the patient reached a level III facility. The currently approved combat hemostatic dressing that is now widely available is Combat Gauze, and this can be used in any body cavity for packing bleeding injuries. This dressing is simply a standard gauze-roll (coated with kaolin to help clot form) so it can be packed anywhere just like any gauze dressing. Quick thinking and using all of the tools at your disposal will save lives in thoracic trauma.

## Air Embolism

As mentioned above, air embolism is a quick and often unrecognized killer in the setting of major bronchial disruption with associated pulmonary vein injury. It can occur in both penetrating and blunt trauma, which includes blast injury. The best chance for survival is early control of the source of the air. A high index of suspicion

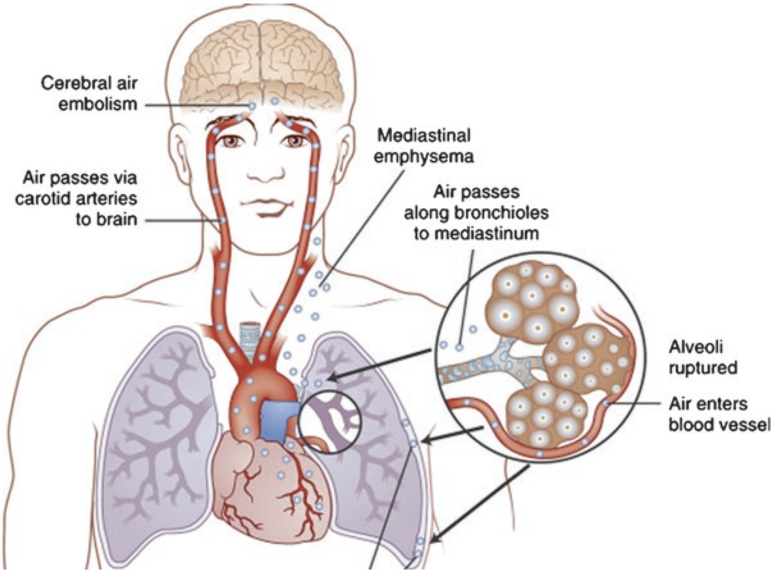



**Fig. 15.10** Air embolism to coronary and cerebral circulation can occur with traumatic disruption of alveoli and pulmonary veins resulting in air entry into left ventricle via pulmonary venous return (This figure was published in Wilderness Medicine, 5th Edition, Auerbach P. (ed.), Diving Medicine, p. 70–77, Copyright Elsevier 2007)

is critical as associated injuries in the multitrauma patient may have similar symptoms, which includes profound hypotension and sudden cardiac arrest. Remember that air entrained into the injured pulmonary veins will enter the left side of the heart, not the right. This makes it a very different entity than the usual air embolism seen with inadvertent air injected into a peripheral or central vein. A large amount of air can be tolerated on the right side, but an extremely small volume of air on the left side can be deadly. This is due to the impact of air bubbles entering the coronary arteries (as little as 0.5 ml into the left anterior descending artery) resulting in acute occlusion and cardiac arrest. Larger amounts of air may also cause significant neurologic injury if it reaches the cerebral circulation (Fig. 15.10).

The most critical point in management has been mentioned: control the air leak as quickly as possible by placing clamps across the injured lung parenchyma. If this is unsuccessful, clamp the hilum as expeditiously as possible. If there are no clamps immediately available, use your hands to compress the lung tissue or compress the hilum. You can also fill the chest with saline while awaiting the tools you need. Simultaneously, the anesthesia provider should be lowering the tidal volumes or airway pressures, attempting to exclude the injured lung by advancing the endotracheal tube to the uninjured side, placing the patient in steep head-down position, and starting pressors and fluid to maintain blood pressure. As the surgeon, you must tell the anesthesia provider to do these maneuvers. At this point you will likely be resuscitating an arrested heart. If the left chest is already opened, clamp the descending aorta to help with hypotension and also help to flush the air through the arterial system. This should only be attempted if the air leak is controlled or you risk disseminating air to the rest of the organ systems. Additionally, open the pericardium and perform the most important intervention, which is open cardiac massage to provide perfusion but also to pump the air bubbles through the and out of the coronary arteries. You can also attempt to needle aspirate the left ventricle if there is not an immediate return of organized cardiac activity. If you have the right chest opened, divide the sternum, complete a clamshell incision, and proceed with the above maneuvers. The only option at this point is to continue to support the patient with open cardiac massage, defibrillation with paddles applied directly to the heart, and intracardiac pressors as needed. If you are successful in supporting the patient through this, consider leaving your clamps on the lung tissue in place, removing the aortic cross clamp, and temporarily closing the patient before undertaking a major pulmonary resection.

## Evacuation

The medical evacuation process is covered in more detail elsewhere in this book. For the patient with a major lung injury, you can expect significant challenges in the postoperative hemodynamic and ventilatory management. You most likely will not have access to any advanced support modalities such as cardiopulmonary bypass, high-frequency ventilation, or inhaled nitric oxide. When you max out your standard ventilator settings and have 100% inspired oxygen running, you have nowhere to go and no room for any further deterioration. You must make evacuation arrangements for these high-risk patients as early and rapidly as possible. You may have a very narrow window of stability during which they could tolerate a transport ventilator to get them to a higher level facility with access to these salvage modalities. An alternative developed during the conflicts in Iraq and Afghanistan was the Acute Lung Rescue Team (ALeRT), based at Landstuhl Regional Medical Center. This group was staffed and resourced to bring advanced ventilatory modalities and a critical-care transport team to the combat theater to evacuate patients who would otherwise not survive standard medical evacuation. The ALeRT team included the capability for providing extracorporeal membrane oxygenation (ECMO) during transport, which was utilized to salvage a soldier after an emergent pneumonectomy in Afghanistan. Consult them as early as possible to avoid any delays in assembling or transporting the team where they are needed.

## Final Points

Pulmonary injuries require the surgeon to operate outside their usual comfort zone on an injury pattern that can cause the rapid demise of the patient if not quickly addressed. There is no time to spare when addressing these injuries so be prepared prior to seeing one. Know what clamps, chest tubes, and staplers are available immediately upon your arrival at a new duty station, combat support hospital, or FST, and replace or order what you think is appropriate. Fast thinking during these cases and control of your environment to include addressing the actions of the anesthesia provider will save lives. Do not delay your saving of the patient with one more IV or another attempt at a bronchial blocker. You do not need a lung to be deflated in order to fix it. Remember that the heart and lungs are like Siamese twins: what affects one organ will affect the other. Expect that the necessary and rapid control of bleeding from the hilum may put your patient in right heart failure and be prepared to handle such situations postoperatively. Your best tool to gaining initial control is your hands, so don't forget to use them.

## Civilian Translation of Military Experience and Lessons Learned

Riyad Karmy-Jones

**Key Similarities**

- Lung preservation approaches including tractotomy and wedge are preferred.
- In unstable patients, single lumen endotracheal tubes are optimal.
- Retained hemothoraces should be drained early.

**Key Differences**

- Minimally invasive approaches with lung isolation are more common.
- Pneumothoraces are more commonly observed.
- There is a plethora of techniques (e.g., ECMO), imaging (e.g., CT), and specialty help (e.g., cardiothoracic surgeons, echo-capable anesthesiologists) available which facilitates care, which in turn permits more complex interventions.

I am sure that every commentary will begin by noting that the civilian (nonzone of conflict) experience differs in having more resources (people, equipment, pharmacology, consultants), time, less-devastating injuries, and the ability to stabilize and transfer with reproducible reliability. That being said, a shotgun blast at close range or massive chest wall injury with underlying lung destruction can pose the same issues, and the general approach described by the authors are equally applicable in the civilian setting.

The thrust of this chapter involves patients who require immediate surgery, and in the majority of cases, VATS and posterolateral thoracotomy are equally inadvisable in the civilian world as they are in the zone of conflict. One exception could be the removal of impaled objects in a hemodynamically stable patient. Knives, pick-axes, etc., have been removed under VATS guidance using posterolateral positioning and double lumen tubes with excellent results. Because there is more “time” and “stability” in civilian practice, there is more ability to use posterolateral and minimally invasive approaches than in the military setting.

The authors give a thorough description of the relevant anatomy. As most approaches will be “from the front,” a brief review is warranted. On the right, the key identifying landmark is the azygous. The azygous wraps over the mainstem bronchus. Just inferior to it is origin of the upper lobe bronchus, whose anterior margin marks the apical branch of the right pulmonary artery. On the left, the midpoint of the underside of the aortic arch marks the superior border of the main left pulmonary artery. Just inferior to that is the superior border of the left upper lobe pulmonary vein. At this junction, there are generally the first two branches of the left pulmonary artery. Downward traction in this area should be relatively gentle as the apical most branch tears easily (hence the nickname the “widow maker”). Thus, if rushed, identifying these areas will lead the surgeon to the critical points in each hemithorax.

There are some technical points that the authors bring out that should be highlighted. In terms of airway management, in an unstable patient, most centers utilize single lumen tubes. The ease and availability of endobronchial blockers makes this a rapid and useful tool as opposed to the military setting. In general, the left lung is isolated with the blocker, the right by advancing the endotracheal tube into the left mainstem.

Median sternotomy offers excellent exposure particularly for anterior penetrating injuries (between midclavicular lines). However, I agree that a dedicated clamshell offers the maximum flexibility. Generally, this starts with an anterolateral thoracotomy. We teach and preach that the first anterolateral incision be made on the side where the majority of the bleeding is or is suspected to be. We (many disagree) de-emphasize performing anterolateral thoracotomy for “cross clamping the aorta.” It is possible to massage the heart from the right and cross clamping the aorta for intrathoracic trauma has not been shown to be beneficial except in the setting of air embolism. It is important to curve the incision as one goes medial, aiming for a midpoint between the sternomanubrial junction and xiphoid. If the sternum is divided, after bluntly pulling down the mediastinal pleura, virtually all areas of the chest can be exposed. A common error is to make the anterolateral incision straight, crossing the sternum at the xiphoid level, which limits the exposure when converting to a clamshell. If the patient is in arrest or very hypotensive, one does not need to individually ligate the internal mammary arteries. Once pressure is restored, they will bleed and can then be easily ligated.

The description of damage control techniques exactly fits the civilian environment. It is very hard to “pack” the chest. Sponges can be placed over raw lung, and topical sealants can be temporizing. Thoracic compartment syndrome is a real entity, often declaring itself at the end of surgery when trying to close the chest or simply removing the rib spreader results in sudden cardiac and/or ventilator compromise. In a damage control setting, closing the mass of skin and muscle is the best option as described. If the chest cannot be closed, or even if the retractor needs to be left in place, the use of sponges (with or without negative pressure) and Ioban (with chest tubes) is effective.

The authors appropriately stress the importance of early hilar control. In the setting of massive pulmonary hemorrhage, survival has been independently linked to the time it takes to control the hilum. The simplest approach is hand compression. If it is possible to divide the inferior ligament, this makes clamping or using a hilar snare easier. If not, bringing the largest, least atraumatic clamp possible down on the hilum from superior aspect allows clamping of the mainstem bronchus, pulmonary artery, and, to a varying degree, the superior pulmonary vein. Civilian practice has moved away from performing the "hilar twist," but in a military setting, if this is required it is perfectly understandable.

As the authors note, the civilian experience permits many more options for managing pneumothorax and/or retained hemothorax. CT imaging allows precise definition of the size and location of the air/blood. Many centers now use smaller catheters to drain these collections. VATS is much more available. In a mass casualty or austere setting, it is much harder to follow and reexamine patients, making definitive treatment the safer approach. In addition, uncertain transfer and potentially long air transport in nonpressurized aircraft generally dictate that pneumothoraces that are "watched" in the civilian world be managed with chest tubes. Retained hemothoraces are better evacuated, especially if a chest tube has been placed. A hemothorax that is visible on plain chest radiograph after tube placement has a greater than 25% chance of developing into an empyema. The "nonrib spreading" approach described is applicable in the civilian setting as well, although we often avail ourselves of VATS technology. Of note, "pleuroscopy" (using a mediastinoscope or sigmoidoscope) can be performed on a ventilated patient without lung isolation and is a useful adjunct.

The authors' description of managing parenchymal and central injuries applies equally to the civilian setting. Do not oversew through and through injuries as the lung tends to continue bleeding, leading to a cycle of dense central parenchymal hematoma, airway bleeding, and sepsis. Tractotomy is an excellent option for exposing central airway and vascular injuries; although in the civilian setting we have the luxury of using stapler reinforcement (e.g., bovine pericardial strips). In young patients, the fissures are often complete or nearly so. Gentle incision or separation with a suction tip (the PA runs in the major fissure) can often permit the affected lobe to be swung up in a pedicle and mass stapling can be utilized (nonanatomic stapled lobectomy). If performing a stapled lobectomy or pneumonectomy, first fire the stapler (or twice if possible as the authors describe) THEN cut the lung or lobe out. If you do not fire before cutting, the bronchi will keep the stapler edges apart just enough for the vessels to slide out. Ideally, after stapled pneumonectomy, the stump should be covered with viable tissue (especially the right mainstem) to reduce the risk of bronchopleural fistula. The authors rightly comment on the acute right heart strain that can occur, and of course civilian centers have a number of adjuncts available (such as ECMO) to support the patients. However, the key is early hilar control and minimize crystalloid resuscitation. In general, after any pneumonectomy, the patient should not be positioned with the affected side down.

Rapid options for temporizing can include filling the chest with bags of saline to be removed at later washout. In the civilian setting, we have the option of using silicone breast implants which are probably not part of the military armamentarium.

Air embolism is a problem in the civilian setting as well, except that we have tools such a transesophageal echo to help diagnose it, CT head to look for causes of focal neurologic changes, and hyperbaric oxygen to treat it. Otherwise, the authors describe a universally appropriate approach.

The authors mention primary blast injury. Ironically, because in the civilian world the explosions have “less force,” there may be a higher incidence of primary blast injury than in the military setting. In the zone of conflict, the blast is usually lethal. History is important. If the explosion (whether due to “benign” reasons like fuel tanks or “malignant” reasons like improvised explosive devices) has occurred in an enclosed space (e.g., a bus or room) the risk of primary blast lung injury is increased. Because civilians are not wearing protective head gear, evidence of ear injury will suggest that they were subjected to a blast wave. If there is evidence of a primary blast lung injury, ideally general anesthesia should be avoided for 24–48 h to avoid the risk of air embolism. Regional anesthetic techniques are more available in civilian settings (e.g., epidural for extremity fixation). Civilians are more often injured by secondary, tertiary, or quaternary effects (such a fragments piercing the chest).

In summary, the techniques described are equally applicable in the civilian setting, just not needed as often. Up to a third of pneumothoraces are now watched; many hemothoraces are drained by smaller bore pigtail tubes; minimally invasive approaches are more often utilized in stable patients; patients can be easily temporized and transferred to higher levels of care; and there are a wide array of specialty and advanced support techniques readily available. However, in the critical patient, the approaches described should be emulated.

# 16 Diagnosis and Management of Penetrating Cardiac Injury

Daniel G. Cuadrado and Kenji Inaba

**Deployment Experience**

| | |
|---|---|
| *Daniel G. Cuadrado* | Camp Bastion, Helmand Provence, Afghanistan, 2013<br>USSOCOM surgical support, Bagram, Afghanistan, 2014<br>USSOCOM surgical support, Horn of Africa, 2015<br>USSOCOM surgical support, Northern Africa 2016 |

*"Have no fear of perfection – you'll never reach it."*

Salvador Dali (1904–1989)

**Bottom Line Up Front (BLUF) Box**

1. Management of these injuries can be intimidating, complex, and resource consuming. But remember devastating cardiac or great vessel injuries do not make it to the trauma bay alive.
2. Have a high index of suspicion for penetrating cardiac injury (PCI) in patients with penetrating neck, truncal, or upper abdominal injury.

(continued)

D.G. Cuadrado, MD (✉)
General and Thoracic Surgery, Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA
e-mail: daniel.g.cuadrado.mil@mail.mil

K. Inaba, MD, FACS, FRCSC
Anesthesia and Emergency Medicine, LAC+USC Medical Center, Department of Surgery, Los Angeles, CA, USA
e-mail: kinaba@surgery.usc.edu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(continued)

3. Pericardial tamponade must be promptly recognized and treated. Patients with isolated cardiac injuries and tamponade have the highest survival rate with emergency department thoracotomy (EDT).
4. A positive eFAST exam for pericardial fluid with hemodynamic instability must be further evaluated surgically.
5. Be prepared for rapid chest entry during induction and intubation, with knife in hand.
6. The surgical approach depends on equipment, experience, and suspected injuries. The clamshell thoracotomy is the workhorse incision with excellent exposure and more effective use of a surgical assistant. Sacrificing exposure to spare the sternum makes no sense.
7. In patients in cardiac arrest on chest entry, be prepared to deal with ventricular fibrillation after opening the pericardium and clamping the aorta. In the absence of internal paddles, Zoll pads attached to Duval clamps are a field-expedient method.
8. Partial occluding clamps are an excellent tool for managing injuries to the atrium, atrial appendage, and superior and inferior vena cava.
9. The pericardium is "nature's pledget"; use it for all cardiac repairs and as needed on the great vessels.
10. Cardiac injuries are best managed through big incisions, with big pledgets, on big suture needles, with big bites of tissue.

## Introduction

During the wars in Iraq and Afghanistan, thoracic injuries accounted for 10% of combat casualties with truncal hemorrhage reported as the main cause of preventable death in 47–67% of cases. The mechanisms for cardiac injury in the civilian trauma environment are typically from stab wounds and low-velocity gunshot wounds. These also exist in the combat environment, along with the additional threat from improvised explosive devices (IEDs) and high-velocity weapons. Recent terrorist attacks in Paris and the United States show that these injuries are possible on large scale in the civilian environment. These patients present on a spectrum from benign in appearance to lifeless, occasionally with rapid progression. Evaluation for these injuries must be rapid and diligent, with immediate treatment before the development of pericardial tamponade.

## Evaluation for Suspected PCI

Patients presenting with penetrating injuries of the neck, trunk, or upper abdomen should be suspected of having a PCI until proven otherwise. There should seldom be a diagnostic dilemma in the evaluation of a suspected PCI. For the hemodynamically unstable or arrested patient, the EDT is both diagnostic and therapeutic.

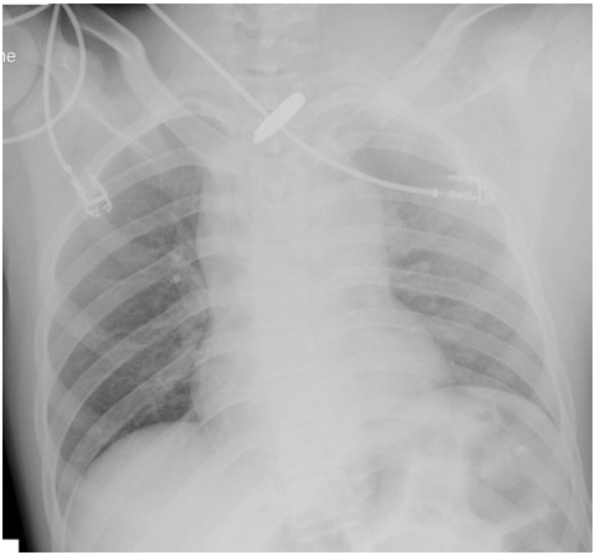

**Fig. 16.1** Chest X-rays from combat GSW to the left shoulder. Patient presented tachycardiac to the 130s with an SBP 92. After positive eFAST, he was taken to the OR for exploration

Patients who present hemodynamically stable must be exposed, rolled, and examined for other areas of injury. An AP chest radiograph may increase the suspicion for PCI with widening of the mediastinum or the presence of fragments over the cardiac silhouette (Fig. 16.1).

The Extended Focused Assessment with Sonography for Trauma (eFAST) exam is a rapid and sensitive method to identify intrapericardial fluid. During the Paris attacks of November 2015, FAST was utilized as an initial screen for unstable casualties. In patients with a negative FAST, a CT scan can be performed for further evaluation after normalization of hemodynamics with resuscitation. However, a CT scan is unnecessary for confirmation of a positive FAST, and a patient with a suspected PCI does not belong in the Department of Radiology.

The presence of pericardial fluid on FAST or CT scan must be explored with subxiphoid pericardial window or transdiaphragmatic pericardial window during laparotomy. In these cases, it is imperative for the surgeon to be ready in the operating room during the induction of anesthesia. The initiation of positive pressure ventilation along with the loss of sympathetic tone can lead to cardiac arrest. As the situation allows, the chest should be prepared, and the surgeon should be gowned and gloved.

Patients who lose vital signs en route and present without signs of life should undergo immediate intubation and a left anterolateral thoracotomy (resuscitative thoracotomy) (Fig. 16.2). This left side is the first side of chest entry regardless of the side of injury. The incision is carried from just below and medial to the nipple down the table. The chest is entered in the fifth intercostal space, and the inferior pulmonary ligament is released. The goals of a resuscitative thoracotomy are (1) release of left-sided tension pneumothorax, (2) opening of the pericardium for release of tamponade, (3) cross clamping of the descending aorta, and (4) identification and treatment of injuries. If pericardial tamponade is identified, a clamshell thoracotomy should always be performed to facilitate repair (Fig. 16.3).


**Fig. 16.2** Same patient was taken to the OR for exploration; he was prepped awake with surgeon scrubbed at the bedside. The patient lost vitals on induction necessitating rapid sternal entry

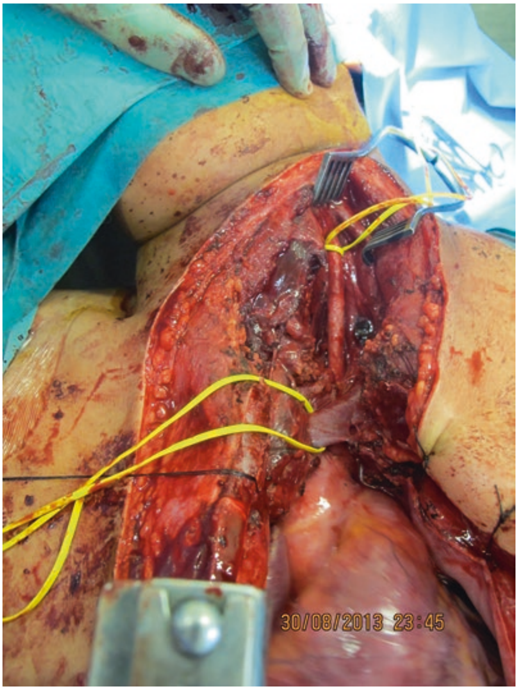


**Fig. 16.3** On exploration, pericardial tamponade was released with a laceration of the innominate vein identified and repaired. The incision was carried up to the left neck to expose the carotid artery given the proximity to the carotid sheath. Patient was discharged ambulatory and neurologically intact on POD#5

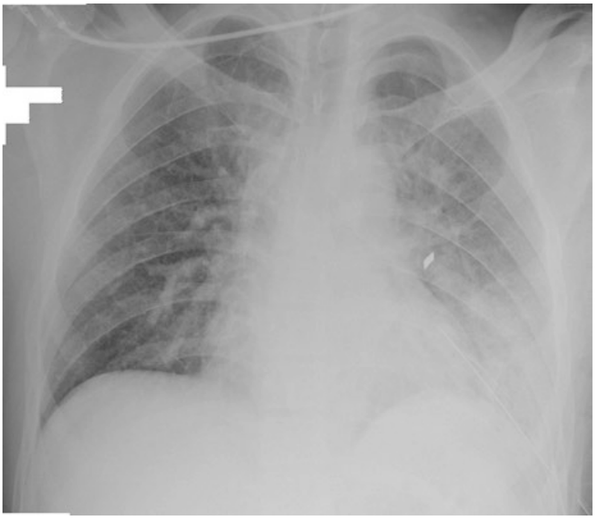

**Fig. 16.4** A 25-year-old Afghan soldier who presented following a dismounted IED with multiple 2–3 mm lacerations over the left chest. Presented in extremis with weak carotid pulse that improved with four units of PRBC and four units of plasma. Patient was taken direct to OR following a positive eFAST for pericardial fluid

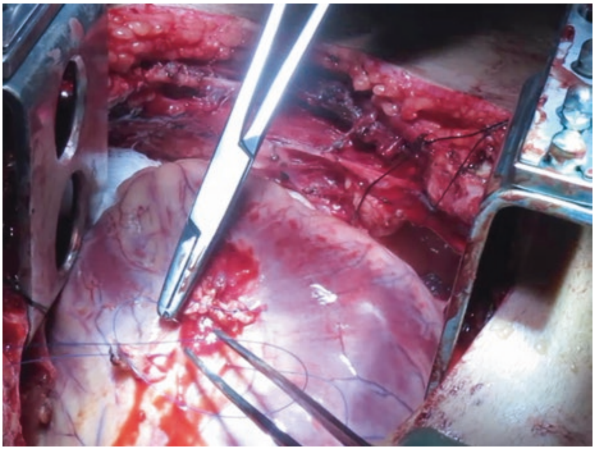

**Fig. 16.5** Following median sternotomy, the pericardium was opened with removal of a large anterior clot. A 1 cm full-thickness right ventricular laceration was identified and controlled with an index finger. Moistened laparotomy pads were placed underneath the left ventricle, and 2 cm pericardial pledgets were fashioned. Cardiorrhaphy was performed with 3-0 Prolene on a double-armed/double-loaded MH needle. Large bite of right ventricle facilitated hemostatic repair

Unstable patients, with a positive pericardial FAST who respond or have a transient response to blood product resuscitation, can be taken immediately to the operating room for definitive management with median sternotomy. Incisions can be extended from the sternotomy as needed once the tamponade has been released and the injury repaired. Again, nonresponders should undergo a resuscitative thoracotomy in the trauma bay.

In cases with penetrating chest trauma where tamponade physiology is evident clinically or by ultrasound examination, the patient should proceed immediately to median sternotomy for cardiac repair (Figs. 16.4, 16.5, and 16.6), again keeping in mind the risk of cardiac arrest on induction of general anesthesia.

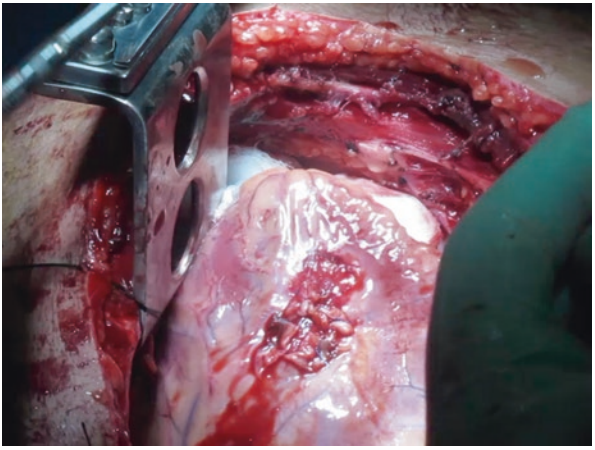

**Fig. 16.6** Completed repair of right ventricular laceration. Note the large pericardial pledgets. Patient was discharged ambulatory and neurologically intact on POD#7

For situations in which there is a suspected PCI in the setting of abdominal hemorrhage, a transdiaphragmatic pericardial window can be performed. Standard indications include (1) the presence of pericardial fluid on FAST exam, (2) missiles or fragments in the vicinity of the heart on X-ray or CT scan, (3) suspicious trajectory (i.e., trans-mediastinal), and (4) sudden hemodynamic deterioration without another obvious cause. The diaphragm is easy to repair; never hesitate to open it if there is suspicion of intrathoracic pathology.

Patients who presented hemodynamically stable with positive pericardial fluid represent a high-risk group. The benefit of additional diagnostic imaging studies such as CT scan or plain films must be weighed against the real threat of cardiovascular collapse from tamponade. There should be a low threshold to perform a pericardial window to rule out PCI. When in doubt, be aggressive and vigilant.

## Techniques in the Diagnosis and Management of PCI

These techniques should be employed in the operating room under general anesthesia with the patient prepped and draped from above the chin to below the knees bilaterally. The operative field created provides you access for pericardial window, median sternotomy, laparotomy, neck and thoracic inlet exploration, and exposure of the femoral vessels and saphenous vein as needed.

## Pericardial Window

A pericardial window is a diagnostic procedure to confirm the presence of hemopericardium. The setup for the procedure should include a sternal saw or Lebsche knife and a full trauma prep. A midline incision is created centered over the xiphoid process for 2–3 cm in either direction. The incision is carried either sharply or with electrocautery down to the linea alba which is incised inferiorly to expose the xiphoid process. The xiphoid process is then dissected inferiorly and laterally, grasped with a Kocher clamp, and divided with a curved Mayo scissor. A finger can then be passed bluntly substernally through the foramen of Morgagni. The pericardium can then be palpated deep to the sternum and cleared bluntly with a lap sponge. The pericardium is then grasped with two Allis clamps and opened sharply with Mayo scissors with the incision carried inferiorly. Take care not to open the pericardium initially with cautery to avoid conducting on the heart. Cautery can be used once the pericardium is opened for hemostasis along the pericardial edges. Any pericardial fluid is evacuated along with residual clot. The presence of hemopericardium mandates a median sternotomy. Serous fluid can be managed with a small JP or Blake drain (7 Fr or 10 Fr) in the pericardial space through a separate stab incision through the rectus abdominis fascia and skin. The fascial defect and skin are closed with suture of your choice. Secure the drain to the skin with a nylon or silk suture 2-0 or larger and place the drain to bulb suction. Even in cases of a negative pericardial window, a pericardial drain should be placed in case there is bleeding along the pericardial edge.

When opening the pericardium during resuscitative thoracotomy, incise the pericardium longitudinally 2–3 cm anterior and parallel to the phrenic nerve. Extend the incision inferiorly and open further as needed to deliver the heart, identify PCI, and perform defibrillation or internal compressions. Hemopericardium, if present, should be followed by immediate conversion to a clamshell incision to identify and repair the source.

A transdiaphragmatic pericardial window is similar to the subxiphoid approach. The left lobe of the liver can be retracted to the right to facilitate exposure. Retract the stomach and esophagus inferiorly, and identify the midportion of the diaphragm "by projecting an imaginary line from the xiphoid to the esophagus posteriorly." Grasp the diaphragm with Allis clamps and incise the diaphragm vertically 3–4 cm. You will then view the pericardium, and you should incise it similarly. If there is no hemopericardium, close the diaphragm incision with interrupted suture (2-0 Prolene). If you encounter hemopericardium, median sternotomy is indicated.

## Median Sternotomy

Start with a midline incision from the sternal notch to the tip of the xiphoid process (or connect with the incision you made for the subxiphoid pericardial window). Divide the subcutaneous fat with cautery to the level of the pectoralis major fascia. Palpate the sternal notch and use cautery to divide the sternoclavicular ligament in the midline until you can hook your index finger around the sternal notch, palpating the posterior manubrium. Next identify by palpation the second intercostal space bilaterally and mark the midline of the sternum with cautery at that point. Use cautery to divide the tissue in the midline from the sternal notch to the second ICS. Divide the fascia over the midline xiphoid until you can hook your index finger to palpate the posterior sternum inferiorly. Use cautery to divide the tissue in the midline from the second ICS to the xiphoid. Use the battery-powered sternotomy saw or Lebsche knife to divide the sternum in the midline following the cautery line

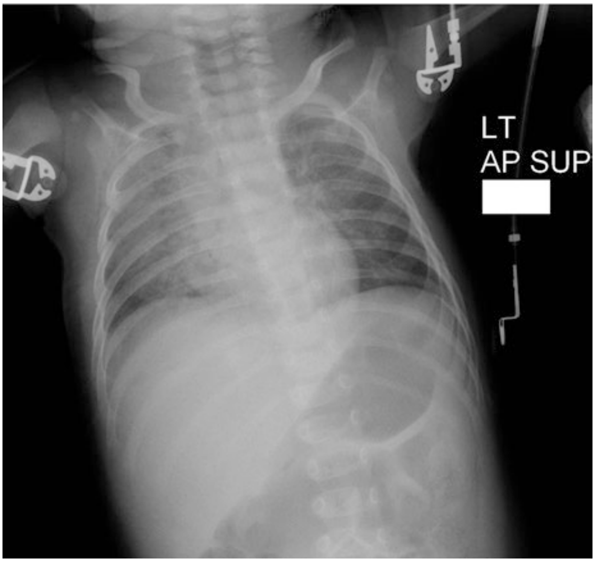


**Fig. 16.7** Chest X-ray of a 2-month-old female that presented following a GSW to the chest. Presented hypotensive with transient response to PRBC infusion. eFAST nondiagnostic. CT scan (not shown) demonstrated extravasation from the right subclavian vein with a large anterior chest hematoma. Taken directly to the OR for median sternotomy

you create taking care to remain in the midline to prevent sternal complications and mediastinitis. In babies and small children, the sternum can be divided with curved Mayo scissors or standard suture scissors. Stop bleeding from the edges of the anterior and posterior tables of the sternum with cautery. Cautery will not stop marrow bleeding, so use a topical hemostatic agent. Vancomycin powder (1 g) mixed with 2 cc of water will create a paste which can be hemostatic (Vanc paste). Bone wax may be available, but some evidence suggests that it increases the risk of mediastinitis and sternal nonunion. Once the periosteal edges and marrow have been addressed, the sternal retractor is placed with care not to open the retractor too widely, and place stretch on the brachial plexus. The pericardium is then opened and the operation proceeds (Figs. 16.7, 16.8, and 16.9).

Before closing the sternotomy, place at least one mediastinal closed suction drain to monitor for bleeding and prevent tamponade. Bring it out through the upper abdominal fascia without violating the peritoneum. If the pleural space is violated, then place a 24 Fr chest tube or 19 Fr Blake drain into the pleural space. These chest tubes may be brought out near the midline next to the mediastinal drain. Close the sternotomy with interrupted stainless steel wire – for adults use #5 or larger. I prefer #7 wires. Three wires *through* the manubrium and four *around* the body of the sternum (through interspaces) should suffice. Take care not to plunge through the posterior table into the right ventricle. Having your assistant lift up on the sternum with a rake or Army-Navy retractor helps to prevent this complication. The wire sites should be closely inspected for hemostasis prior to chest closure. Close the fascia, deep dermis, and subcuticular layers with running absorbable suture (2-0 Vicryl for fascia, 3-0 Vicryl for deep dermis, and 4-0 Monocryl for subcuticular) unless wound contamination or other considerations such as substantial soft tissue loss dictate otherwise.

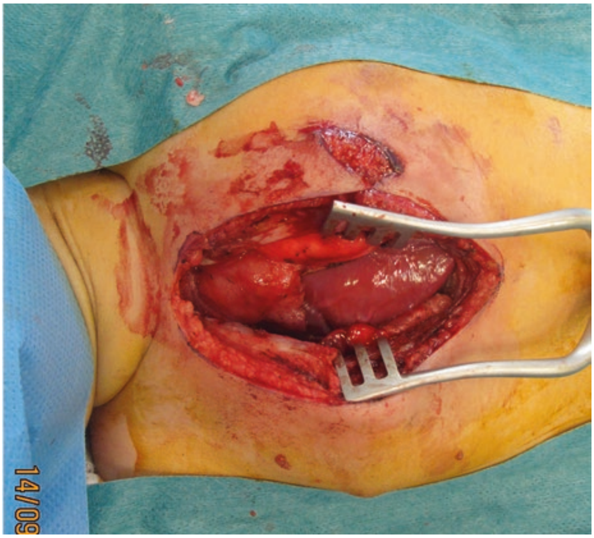


**Fig. 16.8** On entry into the chest, a large thymic hematoma was encountered. The thymus was resected, and a laceration to the innominate vein was identified and repaired with 7-0 Prolene. Hemodynamics improved markedly after lifting the enlarged thymic hematoma off the pericardium

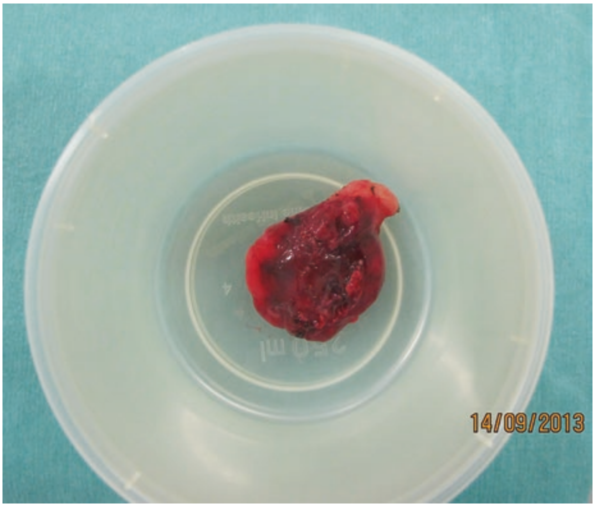


**Fig. 16.9** Thymic hematoma following excision. The hematoma created a tamponade effect by direct compression of the right atrium and ventricle. Patient did well postoperatively and was discharged to her family on POD#3

## Pericardial Well

Creating a pericardial well increases exposure for you to identify and repair PCI. After positioning the sternotomy retractor and opening it five to seven clicks, use cautery to divide the mediastinal fat overlying the pericardium. Use cautery or a 15 blade to incise the pericardium. When incising the pericardium, it is best to grasp the pericardium with Debakey forceps or Allis clamps, lifting the pericardium away from the right ventricle. This may not be possible with a tense pericardium, but a suture can be placed to assist in this situation with upward traction. Once the pericardiotomy is large enough, insert a plastic sucker tip or a finger to protect the myocardium as you use cautery to extend the pericardial incision inferiorly toward the diaphragm. Use cautery to create a T-incision at this level. To the right, you will palpate a dimple in the pericardium, and your T-incision should stop there. To the left, the T-incision should be toward the ventricular apex as far as you can visualize, again using your finger to protect the underlying myocardium. Superiorly you will need to divide thymic fat up to the innominate vein to expose the underlying pericardium. Use clips or ligatures when you divide the veins in the thymic fat because they drain directly into the innominate vein and can become a source of significant blood loss. There is usually no need to skeletonize the innominate vein, but do identify and avoid it. Extend the pericardial incision superiorly over the midline of the ascending aorta and stop where the pericardium attaches to the aorta. Use 0 silk sutures to suspend the pericardium at the level of the ascending aorta, the right atrial appendage, and the inferior T-incision, bilaterally (six total, three in each side). Secure the sutures to the skin or around the sternotomy retractor (see Fig. 16.4). When you spread the retractor further (to 10–12 clicks), the pericardial sutures will open and lift the pericardium providing necessary exposure.

The pericardium should not be closed under any circumstance. Pericardial fat may be reapproximated; however, closure of the pericardium creates a potential risk for tamponade. Particularly if the patient's wounds are multiple and extensive and the patient has received large volumes of fluid resuscitation and blood transfusions, pericardial closure could put pressure on the right ventricle.

## Identifying Penetrating Cardiac Injury

A detailed examination of the intrapericardial contents must be performed to evaluate for injury. Bleeding and hematoma are clear signs of injury. Active bleeding may be difficult to identify if the injury is located posteriorly. Ensure you have tested and ready internal defibrillator paddles on the field and notify the anesthesia provider before manipulating the heart. In the far forward or austere environment, I have used Zoll pads connected to Duval clamps with successful defibrillation in a traumatically injured US soldier (Fig. 16.10). Volume loading, judicious pressors, rotation of the patient to the right for lateral wall exposure, and Trendelenburg position can help to minimize the decrease in blood pressure that cardiac manipulation produces. Moistened laparotomy pads placed behind the left ventricle deliver the heart into the operative field while maintaining ventricular geometry.

The right atrium, right ventricle, ascending aorta, main pulmonary artery (PA), and venae cavae are readily inspected with little or no manipulation. The left atrial appendage can be visualized just to the left and posterior to the main PA. To inspect the more posterior right atrium and right pulmonary veins, have the anesthesia provider hold ventilations briefly as you push the right pericardium toward the right pleural space with your suction and your assistant gently retracts the right atrium to the left. To inspect the anterolateral, inferior, and posterior left ventricle, as well as

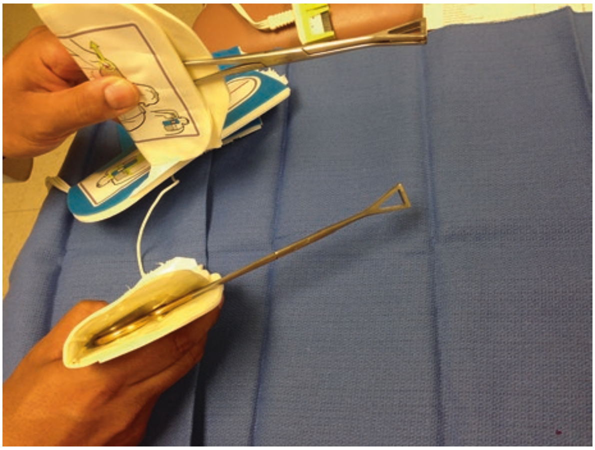

**Fig. 16.10** Technique for internal defibrillation in the absence of internal paddles. Zoll pads were connected to Duval clamps with a clamp placed above and below the heart. Defibrillation was accomplished with a single shock at 30 J

the left pulmonary veins and the left atrium, gently lift the cardiac apex out of the pericardial space using a dry laparotomy pad for traction. Inspect these areas briefly if hypotension and dysrhythmias occur. You can place one or multiple folded, warm, moist laparotomy pads posterior to the left ventricle to facilitate exposure of the left anterior descending coronary artery and the anterior left ventricle and apex. This is usually tolerated well hemodynamically.

## Repairing Penetrating Cardiac Injury

Unless there is obvious massive hemorrhage originating elsewhere in the pericardium, injuries should be repaired as they are encountered. Bleeding should be controlled temporarily, if possible, using digital pressure, while repair is planned. While you are planning with digital control, it is the ideal time to create and prepare pericardial pledgets. Some injuries are easily accessed, but others require you to lift the cardiac apex to expose the injury. Moist laparotomy pads placed under the heart can help facilitate this exposure as can deep pericardial sutures. In these instances, it is easiest for you to suture in concert with the cardiac rhythm with your dominant hand while holding position with your non-dominant hand. Attempting to suture with your assistant retracting the heart is usually more difficult. When the suture is complete, maintain exposure with your non-dominant hand and have your assistant tie the suture. Under extreme circumstances, I have administered adenosine (6 mg) for a temporary cardiac standstill to place a crucial suture. This must be clearly communicated and coordinated with anesthesia due to the hemodynamic consequences of such a maneuver.

Atrial injuries may be located in a position, such as the right or left atrial appendage or right atrial free wall, where a partial occluding vascular clamp may be applied to maintain hemostasis while repair is accomplished. Care must be taken to avoid occluding the right coronary artery with the clamp. Vigorous retraction on the clamp can cause tears to form in the thin-walled atrial tissue, making repair more challenging. Repair of atrial lacerations may be completed with running double-armed 4-0 Prolene suture on an SH needle. Interrupted U stitches of pledgeted 4-0 Prolene may also be used. Pledgets should be used anytime you are repairing great vessel or external cardiac injury, and all ventricular lacerations should be repaired using pledgets. Both Teflon felt and autologous pericardium work well.

Ventricular lacerations should be repaired with interrupted U stitches of pledgeted 3-0 Prolene on an MH needle or a similar large needle. Individual pledgets may be used, but 1–2 cm strips of autologous pericardium 1 cm in width running the length of the repair are also useful. The needle should enter one side of the laceration and exit the other side in one pass. Each needle is passed across the laceration and then placed through the free pledget. The suture is tied taking care not to tear the myocardium. The anterior right ventricle is particularly thin and prone to tearing as you tie the suture, extending the laceration sometimes beyond repair. Take care to not inadvertently ligate a coronary artery in the laceration repair.

Some atrial and ventricular injuries may not be actively bleeding when identified. Small epicardial and intramural hematomas need not be unroofed or repaired. Topical hemostatic patches, such as the Evarrest, can be considered; however, a pericardial drain should be left to identify hemorrhage and prevent tamponade. If you have identified a full-thickness laceration or cannot rule out a full-thickness injury, then perform the repairs as described.

In the setting of massive, audible bleeding, visualization may be impossible. Under these circumstances, you may use inflow occlusion to temporarily suspend venous return to the heart, allowing visualization of the wound edges and expeditious placement of U stitches of pledgeted 3-0 or 4-0 Prolene suture on an SH needle (see Fig. 16.9). First obtain circumferential control of the superior vena cava (SVC) by dividing the adventitial tissue to the left and right of the SVC and anterior to the right main pulmonary artery. Use a renal pedicle clamp to secure a moistened umbilical tape around the SVC and pass the tape through a Rummel tourniquet made from a 12 or 16 Fr red rubber catheter. Also obtain circumferential control of the inferior vena cava (IVC), bluntly dissecting by spreading with Metzenbaum scissors perpendicular to the IVC at its junction with the right atrium. You may feel more comfortable encircling the IVC with your left thumb and index finger, bluntly dissecting the tissue posterior to the IVC. Pass a renal pedicle clamp posterior to the IVC within the pericardium to secure a moistened umbilical tape around the IVC, and pass the tape through a Rummel tourniquet. Have suture loaded and ready to use when you occlude the SVC and IVC by cinching the umbilical tapes in the Rummel tourniquets. The patient's systemic blood pressure will decrease to nothing, and ventricular fibrillation may result. You may repeat the process several times, allowing recovery between iterations, until the PCI repair is completed or visualization no longer requires inflow occlusion. This requires careful orchestration with anesthesia.

Lacerations of major coronary arteries should be repaired if possible, but ligation may be the only option when the necessary equipment for coronary artery bypass is not available. Smaller coronary artery branches and coronary veins that are bleeding should be ligated with 4-0 or 5-0 Prolene suture on an RB-1 or SH needle. If a PCI is located adjacent to an intact coronary artery, repair the injury with pledgeted U stitches of 3-0 or 4-0 Prolene suture on an SH needle. The needles should pass *under* the coronary artery, and the pledgets should be on either side of the vessel, so flow in the vessel is not compromised.

## Intracardiac Injury

As a trauma surgeon managing penetrating cardiac wounds, you must be as cognizant of the possible "hidden" injuries as you are of the dramatic and obvious myocardial injury. These will mainly consist of injuries to the valves resulting in incompetency and injuries to the septum resulting in a primarily unidirectional (left to right) shunt or a retained intracardiac foreign body. Thankfully, the majority of these injuries that survive to the operating room will be well tolerated and compensated and not require any emergent intervention. However, major valvular incompetency (from the injury or from the repair) can result in significant hemodynamic changes and atrial or ventricular dilation that can be life-threatening. Have a high index of suspicion in all patients with cardiac wounds and use whatever means you have available to make an early diagnosis. With the widespread use of ultrasound in even the far forward setting, you should have the ability to do a basic transthoracic or even a transesophageal echocardiogram. In combination with your physical exam and hemodynamic assessment, you should be able to identify the presence of an intracardiac injury and begin medical therapy (i.e., afterload reduction, inotropes, etc.). In the combat setting, you will not have access to the equipment or support that you need to do complex open heart surgery, so evacuate or transfer the patient as soon as is practical.

## Summary

Surgeons of all backgrounds who are deployed to a combat setting should prepare for the challenge of penetrating cardiac injuries. When presenting in the combat setting, these injuries are a major drain of both personnel and resources. The time to think about repair options and techniques is not while you have your finger on the hole. Basic surgical techniques for repair can be performed during pre-deployment training and should be requested for those not comfortable. Basic procedures such as pericardial window, EDT, clamshell thoracotomy, and median sternotomy must be tools in the armamentarium of every surgeon who will be primarily managing these patients. The rarity of these injuries makes it a prime target for simulation and live tissue training. Hemodynamic compromise and cardiac arrest can progress rapidly, so evaluation of other less life-threatening injuries may need to be delayed. The decision to proceed to the OR for suspected PCI should be the default. When in doubt, be aggressive.

**Key Similarities**

- Primary diagnostic modality is ultrasound, with high sensitivity and specificity for clinically significant injuries.
- Arresting patients require immediate resuscitative thoracotomy and repair; this is a high-yield indication for this intervention.
- For non-arresting patients, the goal of the index operation is immediate sternotomy and wall closure.

**Key Differences**

- Mechanism is different, with stab wounds being the predominate cause in the civilian sector.
- Body armor changes the topography of stab wound location for combat wounds.
- Lack of follow-up for injured host nationals may compromise the ability to diagnose concomitant septal or valvular injuries.

In his very well-executed chapter on penetrating cardiac injuries, Dr. Cuadrado provides a practical summary of the essential management points that can make a difference between survival and death in these highly time-sensitive injuries. While the majority of management principles remain the same whether this injury is sustained on the battlefield or on the streets of Los Angeles, there are a few key differences that will be described in this commentary. The demographics of penetrating cardiac injury differ significantly between the military and civilian settings, even at large urban trauma centers. There is a higher proportion of stab wounds in the civilian sector, especially in those that survive to hospital, and a lack of blast projectile injury. In addition, the topography of cardiac injuries seen in the combat setting is affected by the use of body armor, which would decrease the incidence of the typical anterior chest wall stab wound seen commonly here in the United States.

Five presentation categories were described. At our center, patients are generally categorized into three groups: those that are stable, unstable, or arresting. From a practical management standpoint, this can be further simplified into just two groups: those who present in arrest or near arrest and those that have vital signs. Arresting patients should undergo a resuscitative thoracotomy. Penetrating cardiac injury is a very high-yield indication for resuscitative thoracotomy with high survival rates, especially for stab wounds which can reach double-digit percentages. Based on recent data, some civilian centers have begun utilizing cardiac ultrasound, using the absence of cardiac movement or fluid to cease resuscitative efforts due to the near universal fatality of patients without one of these findings. In general however, if a resuscitative thoracotomy is to be performed, patients with a penetrating cardiac injury are a solid indication for doing so. For non-arresting patients, whether unstable or stable, as pointed out in the chapter, ultrasound is the optimal first step.

As emphasized by the author, wounds outside the “cardiac box” can easily traverse the mediastinal structures and cause a cardiac injury. With minimal cost, time and radiation burden constraining its use, and a near perfect sensitivity and high specificity, ultrasound should therefore be performed immediately on all patients at risk. CT was mentioned in the chapter; however, we do not utilize this in our diagnostic algorithm. If the ultrasound is negative, it is highly unlikely that there is a clinically significant injury. If positive, with its high specificity, we would proceed directly to the OR for sternotomy without the need for confirmatory imaging. All equivocal studies are worked up with repeat formal transthoracic echocardiography or, if the patient was proceeding to the OR for a concurrent laparotomy or neck injury, a pericardial window. One pitfall to consider is the patient presenting with a large hemothorax or ongoing chest tube output and a negative ultrasound. This can be caused by a large pericardial opening that cannot collect the blood draining from the heart which manifests as a falsely negative ultrasound.

To clarify the approach to thoracoabdominal injuries, the cardiac injury is more time sensitive than the abdominal injuries. If fluid is seen in both the abdominal cavity and around the heart and only one team is available to operate, the median sternotomy should be performed immediately and the cardiac injury repaired before the patient arrests and becomes unsalvageable. I would also agree with all of the indications listed for a pericardial window; however, any clearly positive finding of fluid visualized in the pericardium should result in a sternotomy. In general with the widespread availability of point-of-care ultrasound, the need for a pericardial window has decreased dramatically. If required, one technical point that should be emphasized in the description of the window relates to the initial entry into the pericardium. This is the critical part of the procedure. The pericardium should be grasped as described and all trickle-down blood stopped. Entry is easiest using a single, fully committed cut with scissors. We avoid the use of electrocautery to mitigate the risk of collateral injury to the underlying heart. At the moment of entry, the pericardial fluid should be visualized, looking for any blood. Blood trickling into the field or multiple small insufficient cuts may lead to a suboptimal examination of the pericardial fluid.

Intraoperatively, as described, close inspection of all aspects of the heart including the posterior circumference is critical. Close communication with the anesthesia team is key prior to any intraoperative cardiac manipulation. The placement of laparotomy pads posterior to the LV as described is an excellent technique. For the actual repair of injury, while I would agree that there is no contraindication to the use of pledgets, we do not routinely advocate for their use in all ventricular injuries. The majority of injuries repaired do not require pledgets, especially if there is no tissue loss which is the case for virtually all stab wounds. In the combat setting with destructive injuries requiring more tension to reconstruct, pledgets may be more helpful. The choice of needle as pointed out by the author is also very important. A classic pitfall is to select a small needle which makes the repair very difficult. Our trauma residents all carry two 2-0 Prolene sutures on a 37 mm ½ circle (V-26/MH) needle in their pockets to repair cardiac injuries during a resuscitative thoracotomy on call.

For non-bleeding injuries, we agree that if a full-thickness injury cannot be excluded, the safest option is to repair the injury. It is true that as described by the author, small hematomas likely can be managed by placement of a drain alone. In fact, the South African experience has demonstrated that in the civilian setting where patients can be closely watched and immediately intervened upon, subxiphoid window proven hemopericardium in presumed "sealed" cardiac injuries is effective and safe with a shorter ICU and hospital stay.

The technique of inflow occlusion for repair of large injuries is well described and makes me want to try it. However, in the civilian setting, most destructive injuries not amenable to control by digital compression by the operator and requiring inflow occlusion would likely already have died from tamponade or, if the pericardial rent was large, exsanguination prior to executing such a maneuver.

The goal of the index operation for both the civilian and military surgeon remains the same: rapid closure of the external cardiac wounds. As described, it is not uncommon to find postoperative valvular or septal defects that require further intervention, and as such, we routinely perform postoperative ultrasound. While this standard also applies to injured coalition forces who can be transferred to a higher level of care after their index operation, this follow-up may not be an option for injured host nationals.

For both military and civilian surgeons caring for injured patients, the rapid diagnosis and repair of a cardiac injury is a technically straightforward and potentially high-yield procedure that should be in the skillset of every general surgeon. This chapter serves as an excellent summary of the critical decision nodes, management principles, and pitfalls, and should require reading for any surgeon taking trauma call.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Emergent resuscitative thoracotomy.
2. Civilian translation of military experience and lessons learned.
3. Kenji Inaba.

# Thoracic Vascular Injuries: Operative Management in "Enemy" Territory

# 17

Joseph J. DuBose, Timothy K. Williams,
and Benjamin Starnes

**Deployment Experience**

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|---|---|
| *Joseph J. DuBose* | Trauma Surgeon, Operation Iraqi Freedom, 332nd EMDOS, Balad, Iraq 1999 |
| | Trauma Surgeon, Operation Enduring Freedom, Role 3 MMU, Kandahar, Afghanistan, 2010 |
| | Trauma Surgeon, Operation Enduring Freedom, Bagram AB Role 3 AFTH, Bagram, Afghanistan, 2011–2012 |
| | Trauma and Vascular Surgeon, USSOCOM Surgical Support, 2016 |
| *Benjamin W. Starnes* | Operation Noble Anvil, Task Force Hawk, Kosovo, 1999 |
| | Vascular Surgeon, Operation Iraqi Freedom, Kirkuk, Iraq, 2003 |
| | Vascular Surgeon, Operation Iraqi Freedom, Kirkuk, Iraq, 2004 |

J.J. DuBose, MD, Lt Col, USAF, MC (✉)
Uniformed Services University of the Health Sciences, Davis, CA, USA
e-mail: jjd3c@yahoo.com

T.K. Williams, MD
David Grant Medical Center, Heart, Lung and Vascular Center, Travis AFB, CA, USA
e-mail: timothy.williams.72@us.af.mil

B. Starnes, MD
University of Washington, Department of Surgery, Seattle, WA, USA
e-mail: starnes@uw.edu


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**BLUF Box (Bottom Line Up Front)**

1. All penetrating thoracic wounds should be assumed to have hit the heart or a big blood vessel until proven otherwise.
2. If you have hard signs of a vascular injury, then the place you need to be is the operating room, not the CT scanner.
3. The battle is won by choosing the correct incision and knowing where to get proximal control. The rest is easy.
4. Don't go diving into hematomas until you are prepared and your anesthesia team is ready for massive blood loss.
5. Ligate and divide the innominate vein to access the proximal great vessels.
6. Know what you can safely ligate. Almost all veins and the subclavian arteries can typically be safely ligated without serious sequelae – exceptions in the chest are the IVC and SVC.
7. Open vascular surgery techniques are still required – and continue to be the mainstay in combat and disaster surgery.
8. Ensure you have adequate suture and vascular grafts *before* you need them.
9. If you have endovascular capability, use it! It can provide easy vascular control for your operative repair or help you avoid a difficult and bloody operation altogether.

## Introduction

One of the features that distinguish a great surgeon from a good surgeon is the ability to remain calm under pressure, strongly direct a team of providers, and stay focused on the mission at hand. Thoracic vascular injuries can make for good theater and subsequent tall tales when there is a successful outcome, but nowhere is it more critical to be in the "great surgeon" mindset than with the management of these unforgiving injuries. "Control" is the operative term. Despite the divergence of vascular and general surgery in the civilian sector, every combat trauma surgeon needs to have the basic vascular surgery knowledge and skillset to manage these injuries. Consultation with a vascular surgeon or transfer may not be an option.

*Rule number one* When preparing to open a chest, whether in the emergency department or operating room, check your own pulse first. Slow your respirations and heart rate and get to work. Your movements must be methodical and controlled. There can be no gross or uncontrolled maneuvers, and you must keep other excitable assistants or "ham-handed" surgeons out of the way. Speak directly and with confidence to your team members. You will get one shot at saving this life. Move the gawkers out of the way and finish the operation. You are not a hero just because you can open a chest. It's what you do *after* you open the chest that counts.

## Wounding Patterns and Physiology on the Modern Battlefield

Military surgeons are routinely trained in nonmilitary environments and, as such, may be unprepared for life on the battlefield. Howard Champion in 2003 described six unique considerations with regard to acute resuscitation in a combat setting: (1) the high energy and lethality of wounding agents; (2) multiple causes of wounding; (3) preponderance of penetrating injury; (4) persistence of threat in tactical settings; (5) austere, resource-constrained environment; and (6) delayed access to definitive care.

The majority (~75%) of survivable chest wounds on the battlefield can be managed with simple tube thoracostomy. Greater than 90% of vascular injuries can be diagnosed based on the history and physical exam findings alone. Hard signs suggesting a vascular injury include pulsatile bleeding, expanding hematoma, palpable thrill, audible bruit, and evidence of ischemia as indicated by pulselessness, pain, pallor, paresthesia, and paralysis in an affected upper or lower extremity or stroke when dealing with injury to the great vessels. Soft signs of vascular injury include a history of moderate hemorrhage at the scene of injury, injury in proximity to a named vessel, decreased but present pulse, non-expanding hematoma, and associated peripheral neurologic deficit. Hard signs do not require a lot of workup – in general they belong in the operating room ASAP!

Classic wounding patterns that should cause one to suspect major thoracic vascular trauma include the presence of hemorrhagic shock, jugular venous distension suggesting SVC syndrome or cardiac tamponade, an expanding hematoma at the base of the neck, or a discrepancy in pulse exam between each upper extremity or between the upper and lower extremities. The trajectory of the penetrating wound should also lend clues to the nature of the injury. Bullets can take somewhat unpredictable courses or ricochet off of bony structures, but they can't defy the laws of physics. For single projectile wounds, knowing the entrance and exit site greatly assists you in focusing your evaluation on the area at risk. For stable patients with no obvious indication for surgery, CT scan with IV contrast is an excellent tool for evaluating critical structures and also for reconstructing the trajectory of the missile or the location of multiple fragments. It is particularly useful for proven or suspected trans-mediastinal wounds.

## Preoperative Management

A classic primary survey should commence immediately in the emergency department (ED) simultaneously with attempts at resuscitation. In the presence of suspected massive thoracic vascular injury, venous access should be established if possible in the lower extremities or at least in the upper extremity that seems least likely to be involved with the injury.

If the casualty needs to be transferred to a higher echelon of care, for example, from a forward surgical team to a combat support hospital, chest tubes should be placed prior to rotary-wing transfer. These patients are essentially inaccessible during transport in a modern evacuation helicopter, and placement of a chest tube en route can be extremely difficult. If there is concern for exsanguination from chest tube placement, the thoracotomy should have already been initiated, and your decision to transfer was incorrect. The patient described won't survive transport and needs your expertise now.

If the patient rapidly decompensates in the ED with suspected thoracic vascular injury or if you witness cardiovascular collapse, a resuscitative anterolateral thoracotomy through the fourth or fifth interspace is required. Upon entering the chest, the location of the injury should be identified. Inspect the heart. If the pericardium is tense, you need to incise the pericardium sharply and longitudinally anterior to the phrenic nerve. Deliver the heart out of the pericardium, and begin compressions against the sternum with the palm of your hand if needed. Be gentle!

If there is a lot of blood in the left chest and the patient's heart appears empty, incise the parietal pleura over the aorta to be able to get a clamp fully across the aorta to the spine, and clamp with an atraumatic clamp. Remember that you are now on a clock so mark the time in your head. You have just less than 30 min to release that clamp, and the more time that passes by, the more risk this patient has of dying from uncontrolled coagulopathy, liver failure, or reperfusion injury. If you get the patient back, continue your resuscitation but get the patient to a place where you can conduct a formal operation.

## Patient Preparation

Patients with suspected thoracic vascular injuries should be prepared for operation with standard surgical approaches in mind and with additional preparations allowing for access of more proximal vascular control. In addition, preparation should be made for recovery of an adequate vein for a reconstructive conduit from an uninvolved extremity. Hence, patients with suspected thoracic vascular injuries should have the entire chest and neck prepped into the field to allow for rapid performance of median sternotomy or thoracotomy, as well as preparation of one or both of the lower extremities to allow for recovery of the greater saphenous vein for conduit. In the chest, the first goal is to stop the bleeding and then perform a definitive repair. If suture won't fix the problem, a large prosthetic graft or bovine pericardial patch will. It is rare to use saphenous vein for reconstruction in the chest with the exception of elective aortocoronary bypass. We prefer to stock 18 × 9 mm collagen-coated knitted and bifurcated Dacron grafts. The tubes are long enough to repair any aortic injury, and the limbs come in handy and are a perfect size for any great vessel reconstruction that is required. When you arrive at your facility, immediately inspect your current stock and supply level of vascular grafts. The time to discover what you have available (if anything) is not in the middle of one of these cases.

## What Incision Do I Make? The Choice of Incision Is a Crucial Decision

There are several surgical approaches to the thorax, each with key advantages and disadvantages for emergent trauma applications. The surgeon should be familiar with all of them, and the clinical situation should determine the choice of incision. Hemodynamically unstable patients may not tolerate lateral positioning for traditional posterolateral thoracotomy incisions more commonly used for elective thoracic surgery. Compounding the difficulty, the decision for incision may be based upon only a portable chest radiograph, chest tube output, wounding patterns, and mechanism of injury. In emergent scenarios, the surgeon will likely have limited knowledge of potential mediastinal involvement, the projectile's path, or additional cavitary involvement. With penetrating thoracic trauma, there is also the possibility of injury to adjacent body regions, such as the abdomen and neck to consider. Therefore, the chosen initial thoracic incision must prove versatile in accommodating flexibility to provide exposure to rapidly and effectively treat subsequently identified injuries.

In the stable patient, additional imaging in the form of CT may prove very useful. Armed with better understanding of the location and nature of injury, a better decision regarding optimal therapy can be formulated. In the modern endovascular age, this information may also facilitate the effective utilization of less-invasive adjuncts either alone or in support of open surgical means.

Commonly employed open operative approaches include anterolateral thoracotomy, posterolateral thoracotomy, and even bilateral thoracotomy (or "clamshell thoracotomy") and median sternotomy. Each has its own potential benefits and associated limitations.

## The Anterolateral Thoracotomy

The left anterolateral approach – or "the trauma surgeon's handshake with the patient in extremis" – is perhaps the most expedient thoracic incision. It affords immediate control of the distal thoracic aorta and ready control of the proximal left subclavian artery origin at the apex of the thoracic cavity on the left. The heart can also be readily accessed from this incision, allowing evacuation of hemopericardium and effective cardiac compressions or even direct cardiac repair in select situations.

External landmarks are the most reliable expedient means of identifying optimal incision orientation. The incision is initiated just below the nipple in males and extends from the lateral aspect of the sternum along the curvature of the rib into the axilla. By extending the ipsilateral arm and placing a bump to elevate the thorax approximately 20 degrees, the incision can be carried optimally posteriorly – a maneuver that will improve posterior exposure. If required, this incision can be extended across the midline into a "clamshell thoracotomy." The main disadvantage of the anterolateral approach is exposure of posterior thoracic structures. The posterolateral thoracotomy allows better exposure of the hemithorax, especially the posterior structures, and is the standard incision for most elective thorax operations. The posterolateral incision, however, lacks of versatility and has limited usefulness in the emergent setting. It may, however, prove the preferred approach in more stable patients that require exposure and treatment of intrathoracic tracheoesophageal injuries.

## Clamshell Thoracotomy

The previously described “clamshell thoracotomy” extension of the anterolateral thoracotomy across the sternum is a maneuver that affords excellent exposure to both pleural spaces, the anterior mediastinum, and nearly the full complement of thoracic vascular structures. The incision is a mirror of the anterolateral thoracotomy but on the right side. The sternum can be divided using a Lebsche knife or trauma shears to connect the two incisions.

In practice, if no imaging is available to guide incision selection in a patient in extremis, the author instructs another capable member of the team to place a right thoracostomy tube simultaneous to left anterolateral thoracotomy. If blood is identified upon right thoracostomy tube placement, then the left anterolateral incision is immediately extended to a “clamshell” incision. Other very experienced authors advocate routine “clamshell” thoracotomy for all patients in extremis who have the potential for significant thoracic injury.

Extension of the “clamshell” incision into a midline laparotomy can be accomplished via a “T” extension onto the abdominal wall. There is limited ability, however, to extend into the neck with this particular incision. As a result, separate neck incisions along the sternocleidomastoid are typically utilized when required.

## Median Sternotomy

Median sternotomy is a commonly utilized incision of elective cardiac surgery and is very effective in facilitating excellent access to the heart, proximal great vessels, and anterior mediastinum (Fig. 17.1). This particular incision is also versatile – and can be extended as an abdominal, periclavicular, or neck incision. Division of the sternum along its long axis can, however, take more time than the “clamshell” exposure variant of mediastinal exposure.

An additional extension of the median sternotomy includes the “trap door” approach, whereby an anterolateral thoracotomy is combined with a median sternotomy (most commonly on the left) to facilitate improved exposure to the proximal course of thoracic vessels. In practice, this incision is rarely utilized, however, as similar exposure can be obtained with the combination of a median sternotomy and a periclavicular incision.

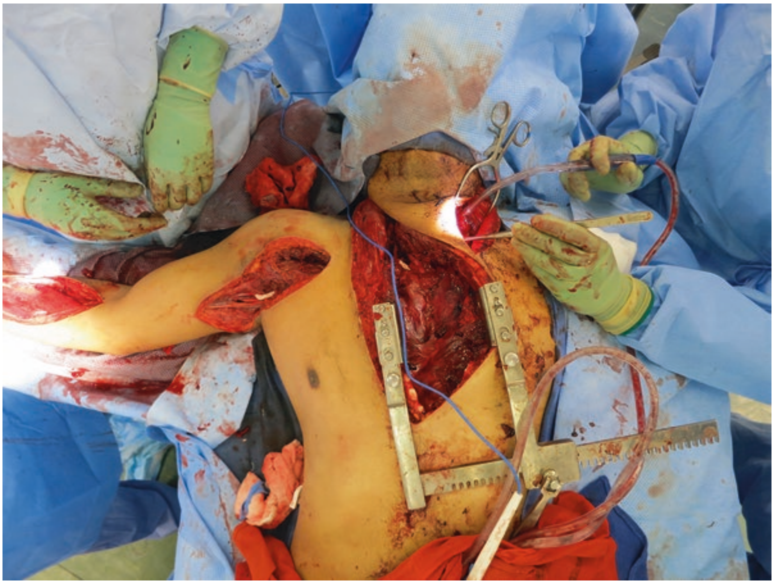

**Fig. 17.1** Median sternotomy with extension into bilateral cervical and right transclavicular incision

## Periclavicular Incisions (Supraclavicular, Infraclavicular, and Transclavicular)

The clavicle effectively guards the mid-subclavian artery from expedient surgical exposure bilaterally. Exposure of this region may also afford control of the proximal vertebral arteries should they require it. Options for improved exposure of this area include incisions above, through, or below the clavicle.

Infraclavicular incisions are limited by their ability to afford wide exposure without significant division of the pectoralis major but can prove effective in rapidly facilitating vascular control of junctional hemorrhage of either proximal arm. To facilitate this control, an incision is made approximately one fingerbreadth below the middle of the clavicle. The pectoralis major fibers are identified and splint, exposing the underlying pectoralis minor. This muscle is then encircled and divided, exposing the distal subclavian/proximal axillary artery for clamping and control.

Supraclavicular access of the subclavian artery can be achieved by making an incision approximately one fingerbreadth above the clavicle, centered on the medial (or clavicular) head of the sternocleidomastoid (SCM) muscle. This medial head of the SCM is then divided, revealing the jugular vein medially and the anterior scalene directly under the medial SCM head. Overlying this muscle, traveling from lateral to medial (unlike most nerves that travel medial to lateral in surgical fields) is the phrenic nerve. This nerve is preserved and the anterior scalene is divided. This reveals the underlying subclavian artery, which can be effectively controlled.

**Table 17.1** Ideal incisions for various thoracic vascular injuries

| Injured vascular structure | Exposure |
|---|---|
| Unknown | Left anterolateral thoracotomy ± clamshell |
| Ascending aorta | Median sternotomy |
| Transverse aortic arch | Median sternotomy |
| Innominate artery | Median sternotomy |
| Right subclavian artery | Median sternotomy or right supraclavicular if distal |
| Proximal left common carotid artery | Median sternotomy |
| Left subclavian artery | Left anterolateral thoracotomy or left supraclavicular if distal |
| Descending thoracic aorta | Left posterolateral thoracotomy |
| Superior vena cava | Median sternotomy |
| Suprahepatic inferior vena cava | Right thoracoabdominal with splitting of the diaphragm |

The transclavicular approach affords perhaps the widest and most effective exposure of the subclavian artery. This is accomplished by an incision directly over the clavicle. The ligaments of the clavicular head can then be divided using a scalpel or scissors, but these attachments are notoriously dense and problematic. Obtaining circumferential control of the midclavicle and dividing it with a Gigli saw may facilitate a more expedient and effective exposure. Subsequent reflection of the clavicle affords excellent exposure of the subclavian vein and artery as well as the proximal common carotid (particularly on the right side) (Table 17.1).

## Principles of Repair for Specific Injuries

Upon exposure, the first goal is to get control of the bleeding. This often requires just simple digital control. Unfortunately, on the battlefield, holes in arteries can be bigger than one's digit so this is not always possible. If the injury is easily controlled with the tip of an index finger, this is where a calm approach will save the day. First, *slow down*. If you now have control of the injury, communicate with your anesthesia colleagues and allow them to catch up. If the patient is hypertensive, ask them to lower his blood pressure to below 90 systolic. *Wait for your pitch*. Once the conditions are right, you can start to repair this large vessel by sewing under the tip of your finger with a 3-0 Prolene and slowly advancing your finger backward over the injury. Take large bites and use pledgets if needed on the first stitch. Before you know it, the injury will be repaired. Remember that shunting or even ligation (with or without later reconstruction) is an option for most thoracic vessels.

## Ascending Aorta

These injuries are usually fatal at the scene but, if small, can be survivable. The previous paragraph describes such an approach to this injury. Remember that the ratio of elastin to collagen in the proximal aorta is much higher. This means that the aorta in this region is more expansile but can tear very easily. Remember to use pledgets and take large bites. A DeBakey-Bahnson clamp can be useful to side-bite the ascending aorta in order to get control while maintaining forward flow.

## Proximal Great Vessels

When approaching these vessels through a median sternotomy, it is extremely important to get proximal control first. This means *not* diving into a hematoma in the superior mediastinum but opening the pericardium and marching up the ascending aorta. It is important to divide the left innominate vein between ligatures to expose this region. As stated previously, it is ok to clamp the base of the innominate for repair of an innominate artery injury. Likewise, it is ok to clamp the base of a left common carotid injury. It is deadly to clamp both simultaneously. For elective situations, clamping both of these vessels would require the use of deep, hypothermic circulatory arrest, and this won't be available to you on the front line. You will have to do your best to individually repair these injuries. An alternative is to stage the repair by first sewing a 9 mm Dacron conduit to the ascending aorta and bypassing individually to the innominate artery and then going after the left common carotid injury with either suture repair or bypass depending on the circumstances.

Proximal left subclavian injuries are among the most challenging to handle due to their location. The ideal exposure for these injuries is a left posterolateral thoracotomy which is not a standard exploratory incision for trauma; you will usually be working from a sternotomy to anterior thoracotomy. Don't waste time and blood loss struggling to expose and repair the injury from these incision. Just reach your hand (or a sponge stick) up to the apex and compress the area of hemorrhage – this will stop the bleeding. You can now decide on how best to approach the injury. Adding an infraclavicular incision to your median sternotomy with dislocation of the sternoclavicular joint will provide adequate exposure. If you are in anterior thoracotomy position, you can hold pressure while repositioning the patient to lateral decubitus. If the patient is doing poorly or you have other injuries to deal with, ligate the artery; this will usually be well tolerated and if needed can be repaired or bypassed later.

## Descending Thoracic Aorta

These are the most fun to repair and usually require only a suture repair or patch angioplasty for fragment wounds. For larger penetrating wounds, blast wounds, or blunt aortic tears, you will usually need to perform a formal interposition graft (18 mm Dacron). Remember that you have limited time to clamp this vessel (<30 min of hepatic and mesenteric ischemia), and if your clamp time exceeds this, you should consider removing the clamp intermittently (while controlling the injury with a fingertip) in order to give the liver a "drink" of the good kind of blood. You will need to accept the moderate blood loss that will be associated with this maneuver. A left posterolateral thoracotomy is ideal, but you may often need to do it through an emergent anterolateral thoracotomy. Good exposure and retraction of the heart and lung anteromedially is critical. Although the injuring mechanisms in combat are most commonly from projectiles, you may see blunt aortic injuries from ground or helicopter vehicular crashes. These are no different than their civilian counterparts, with the exception that you will not have the immediate option of cardiopulmonary bypass. Remember that these are rarely emergent and can initially be managed with strict heart rate and blood pressure control. Approach them via a left posterolateral thoracotomy with single lung ventilation. The critical point is obtaining adequate proximal control, as the injury is typically just distal to (or involving) the takeoff of the left subclavian artery. Gain control of the left subclavian artery before you attempt control of the proximal aorta, and be prepared to clamp the aorta proximal to the subclavian takeoff if needed.

## Superior Vena Cava/Inferior Vena Cava

These injuries are best approached through a median sternotomy and for more extensive injuries involving the suprahepatic inferior vena cava, extending along the right costal margin and splitting the right hemidiaphragm. Suprahepatic IVC injuries are incredibly lethal and even in the best of experienced hands carry a very high mortality rate. Careful control should be obtained, preferably with a side-biting vascular clamp to maintain blood flow to the right atrium. An alternative method of control is by placement of an atriocaval shunt as described in Chap. 8. This is also usually facilitated by widely opening the pericardium and safely tracing them from the intrapericardial portion at the junction with the right atrium and then proceeding distally. Repair involves lateral venorrhaphy or patch angioplasty with 3-0 Prolene. You should try to avoid ligating either of these two veins at all costs due to the significant impact on venous pressure/edema and the decreased venous return to the heart.

## Azygos Vein

Although not thought of as a major vascular structure in the chest, injury to the azygos vein can be associated with a huge blood loss. The object of the game is to isolate and ligate this vessel. This often requires placement of sponge sticks proximal and distal to the injury through a right thoracotomy followed by ligation. Use a large Prolene suture and drive the needle along the spine to encircle and ligate the vein.

## Pulmonary Arteries

A useful method for control of these injuries is to place a large vascular clamp (DeBakey AG Aortic Clamp) across the pulmonary hilum until the injury can be identified and repaired. In the unstable patient with a complex injury to the pulmonary hilum, you are often better off performing a rapid stapled pneumonectomy.

## Use of Heparin

Following major combat injury, systemic heparinization (50–75 U/kg IV) is best reserved for use in *stable* patients in whom vascular control of the injury has been quickly established, estimated prehospital blood loss is relatively low, and ongoing bleeding sources are minimal. Unstable patients with diffuse hemorrhage from bone fragments, torn muscle, and additional injuries, and patients who are already hypothermic and coagulopathic, should not get systemic anticoagulation. Alternatively, local administration of heparinized saline solution directly into the injured vessel prior to repair may aid in preventing thrombotic complications. The decision to anticoagulate is left to the discretion of the operating surgeon, who must be in close contact with the anesthesia providers in order to fully understand the patient's clinical status. In general, aortic injuries that can be repaired with a side-biting clamp or digital control don't require supplemental heparin due to the high flow in these vessels. If you find your repair is clotting and there is no technical defect, then you should proceed with systemic anticoagulation.

## Shunts

For a variety of reasons, intravascular shunts may have a more limited role in the management of thoracic vascular injuries compared to peripheral counterparts. Size of the vessel encountered, proximal/distal exposure challenges, and short vessel distances or tortuosity contribute to these challenges. Additionally, temporary clamping of any of the great vessels individually is usually well tolerated due to collateral circulation – although clamping of both the innominate and left common carotid should be avoided at all costs due to the extreme risk of stroke. Shunts may be extremely useful, however, in the far-forward setting if you don't have the time, resources, and expertise to perform any type of vascular repair, and maintaining forward flow is crucial.

If used appropriately, temporary intraluminal shunts allow for rapid restoration of blood flow to an ischemic limb or to the brain, while other procedures to include wound debridement, external fixation of fractures, or more lifesaving procedures such as trauma laparotomy or thoracotomy can be accomplished. Shunts may be easily and rapidly placed after proximal vascular control with either a pneumatic tourniquet or vascular clamp and secured in place with Rummel tourniquets or simple silk ties to prevent dislodgement. After placement, patency should be confirmed with intraoperative Doppler of the shunt and distal flow. I recommend the specific use of Sundt shunts as their design minimizes risk of dislodgement when appropriately inserted. The Sundt shunt is lined with an inner coil to prevent kinking or collapse. There is one small area within the shunt of discontinuous coils which should be used for clamping if needed. Clamping the shunt in any other location will crush the coil and occlude the shunt. In a pinch, any sterile hollow tube with adequate flow characteristics can be used as a shunt. For smaller vessels, a nasogastric tube has frequently been used, and for larger vessels, an appropriately sized chest tube may be utilized.

## Surgical Technique

As with all vascular operations, there are several important elements for success. Key among these is careful handling of tissue, use of magnification loupes, adequate lighting, and use of fine instruments with fine, monofilament suture. These requirements are not always met on the battlefield, and the operating surgeon can be faced with challenging circumstances beyond his/her control.

After exposure, injured vessels should be carefully debrided back to normal and healthy appearing tissue. Inflow and back bleeding should then be assessed. If there is no back bleeding, gentle thrombectomy with appropriate-sized Fogarty embolectomy catheters should be performed. The use of a standard pulmonary artery catheter may be useful in this scenario if no standard catheters are available. Minimal manipulation of intima is imperative to prevent vessel thrombosis in the early postoperative setting. After adequate debridement, the vessels should be flushed with a heparinized saline solution both proximally and distally. A tension-free (but nonredundant) repair should then ensue. With combined injuries, arterial repair should precede venous repair except when venous repair requires little effort. The decision to repair venous injuries as apposed to ligation depends of the stability of the patient and demands to treat other injuries. Ligation of venous injuries is usually preferred in the chest unless dealing with the IVC or SVC.

## Conduits

Key to the success of vascular repair in the combat setting is appropriate use of available conduit for reconstruction. It is widely held that the best alternative conduit for reconstruction is autologous saphenous vein. The saphenous vein is the workhorse for vascular surgeons and can be used in multiple locations, but in the chest where the vascular structures are large, the utility of saphenous vein conduit diminishes. It is important to remember the concept of directional flow within veins and thus reverse or turn around the saphenous vein prior to using it as a conduit for revascularization. The saphenous vein may also be used as patch material and has been described to be refashioned in the form of panel or spiral grafts for reconstruction of larger vessels. It is my opinion that spiral grafts and panel grafts should be avoided in the management of thoracic vascular injuries due to the excessive time required to create them. If used, the saphenous vein should always be recovered from an uninvolved lower extremity. Jugular veins are a suitable alternative for larger vessels, particularly if you are already in the neck.

Prosthetic conduits, when used to repair or replace blood vessels in the chest, should be made of Dacron and coated with collagen to aid in hemostasis. As stated before, the author uses 18 × 9 mm bifurcated Dacron grafts as the diameters of both the main body of the graft and the limbs can be used to replace anything in the chest. Another useful patch material is either bovine pericardium or the patients' own pericardium. Don't hesitate to use prosthetic in the setting of esophageal injury with soilage. An infected graft can be dealt with later after saving the patient's life.

## Closure of Incisions

A few comments should be made on closure of thoracotomy and sternotomy wounds after trauma. Remember to appropriately drain these wounds. These are large body cavities that can accumulate a lot of fluid and blood and impair ventilation and oxygenation, not to mention cardiac contractility. For thoracotomy wounds, leave behind large (36 Fr) angled and straight chest tubes – two per hemithorax. For sternotomy wounds, don't hesitate to leave the chest open, especially if it has been a long operation and the patient has received a massive resuscitation. We typically use a plastic bovie holder wedged between the edges of the sternum followed by a sterile hand towel and iodine-impregnated adhesive drapes for the "damage control" sternotomy closure. All sternotomy wounds should be drained with 36 Fr straight mediastinal drains or Blake drains.

## Endovascular Procedures

Although endovascular technology has arguably been the greatest advancement in vascular surgery in recent history, it has also resulted in a loss of basic vascular surgical skills among both staff and trainees. Remember that during the initial phases of any conflict, you may be operating with whatever instruments and equipments you can carry. Chances are you will not have access to a portable C-arm, a power injector, or the necessary equipment to perform endovascular procedures on the front line. However, as the combat operations mature and consolidate, your facility may become capable of performing advanced endovascular procedures. If you have access to this, consider yourself blessed. The endovascular revolution has dramatically changed the mortality for major thoracic vascular injuries. The ability to remotely place a clamp in the form of an occlusion balloon prior to resuscitation and repair is a huge advantage. Basic required equipment for endovascular surgery is listed at the bottom of Table 17.2.

With regard to endovascular treatment of vascular trauma, a few specific injuries deserve to be mentioned:

### Blunt Aortic Injury (BAI)

This injury is usually associated with rapid deceleration and blunt force trauma. Please remember that if the patient has hypotension or profound anemia, it is almost never associated with the BAI, and one should seek out other causes for these phenomena. If BAI cuts loose into the left hemithorax, call the morgue, not the OR. These injuries can often be managed semi-electively with aortic stent grafting. Endovascular expertise is a requisite. The left subclavian artery can be covered with impunity to achieve adequate proximal seal. An example of pre- and post-op images of BAI is pictured in Fig. 17.2.

**Table 17.2** Required equipment for the management of vascular injuries in the field

| | |
|---|---|
| Vascular surgical instruments | All × 2 or more |
| Gerald forceps 7 and 9 in. | Ryder needle drivers 5, 7, and 9 in. |
| Castroviejo needle drivers 7 in. | Diethrich Bulldog clamps 1.75 in. angled |
| Wiley hypogastric clamps 7 in. × 6.5 cm | Satinsky-DeBakey clamps 9.75 in. |
| Profunda clamps 5.5 in. | Cooley pediatric vascular clamp 6.5 in. |
| Adson-Beckman retractor 12.5 in. hinged | Fogarty embolectomy catheters 3 and 5 Fr |
| Jansen mastoid retractor 4.5 in. | Potts-Smith scissors 7.5 × 45 degrees |
| DeBakey aortic clamp | DeBakey-Bahnson aortic clamp |
| *Supplies* | |
| 3-0 Prolene suture – 36 in. (90 cm) SH | 6-0 Prolene suture – 30 in. (75 cm) RB-2 |
| Umbilical tapes | Silastic vessel loops (small and large) |
| Rummel tourniquets | Sundt and Argyle shunts – 10, 12, 14 Fr |
| Teflon or felt pledgets | 19 g butterfly needles |
| Three-way stopcock | 30 cc syringes |
| 18 × 9 bifurcated Dacron grafts | Ringed PTFE grafts – 6 and 8 mm |
| 9 MHz handheld Doppler | Plastic titest needle |
| Sternal retractor | Finochietto retractor |
| Lebsche knife | |
| *Pharmacopia* | |
| Heparin 1000 U/ml, 10 ml vials | Papaverine 30 mg/ml, 10 ml vials |
| 25% mannitol 12.5 g/50 ml, 50 ml vials | Alteplase 2 mg vials |
| Ultravist contrast – 100 cc vial | Fibrin sealant (Flowseal) |
| Thrombin – 1000 U/ml, 20 ml vial | Recombinant factor VII |
| Gelfoam | Heparin saline mix – 10 U/cc normal saline |
| *Miscellaneous* | |
| Headlight – Zipka | Magnification loupes |
| *Endovascular supplies* | |
| Access needle | Lunderquist DC wire – 300 cm (COOK)[a] |
| 11 Fr sheath | 140 cm CODA aortic balloon (COOK)[a] |
| 100 cm marking pigtail catheter | Trilobed snare |
| 100 cm JB-1 5 Fr selective catheter | Viabahn[a] stent graft 7 mm and 8 mm × 5 cm |
| Bentson Starter wire – 180 cm | Thoracic stent graft (Medtronic)[a] |
| Angled Glidewire – 260 cm | 22 mm × 11 cm Talent |
| Ultravist contrast | 24 mm × 11 cm Talent |

[a]COOK Incorporated (Bloomington, IN), Medtronic (Santa Rosa, CA), W.L. Gore (Flagstaff, AZ)

## Axillo-subclavian Injuries

The management of these injuries in the past was associated with massive and lengthy operations. Today, in modern civilian trauma centers or even mature combat trauma facilities, these injuries can be managed in less than 30 min with an endovascular technique. Once identified, our approach is to expose the brachial artery at the antecubital crease on the side of the injury and place an 11 Fr sheath retrograde. Under fluoroscopic guidance, a wire is advanced across the injury, and a catheter is advanced over the wire proximal to the injury. A contrast injection is performed and the extent

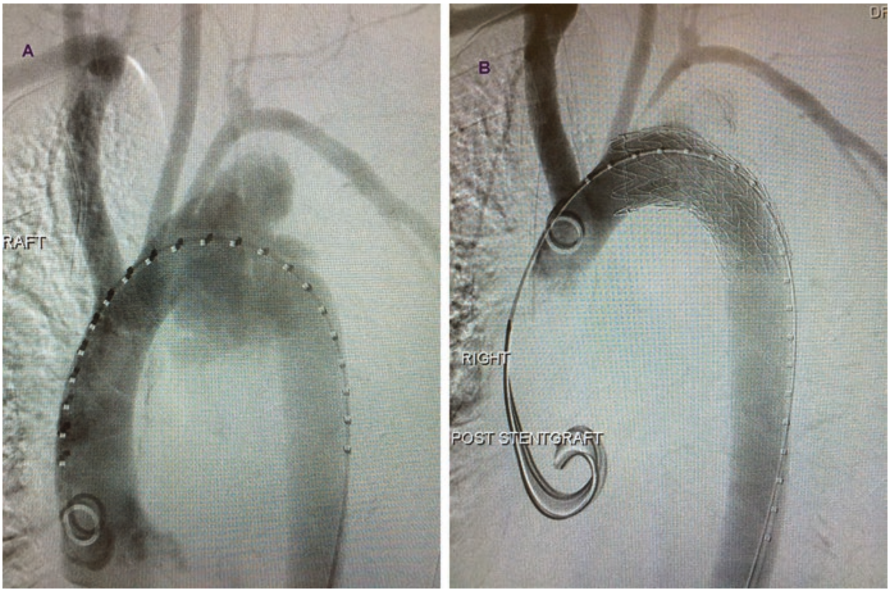


**Fig. 17.2** CT scan reconstruction showing a typical blunt thoracic aortic injury with pseudoaneurysm formation (**a**) and the same vessel after placement of a thoracic endograft (**b**)

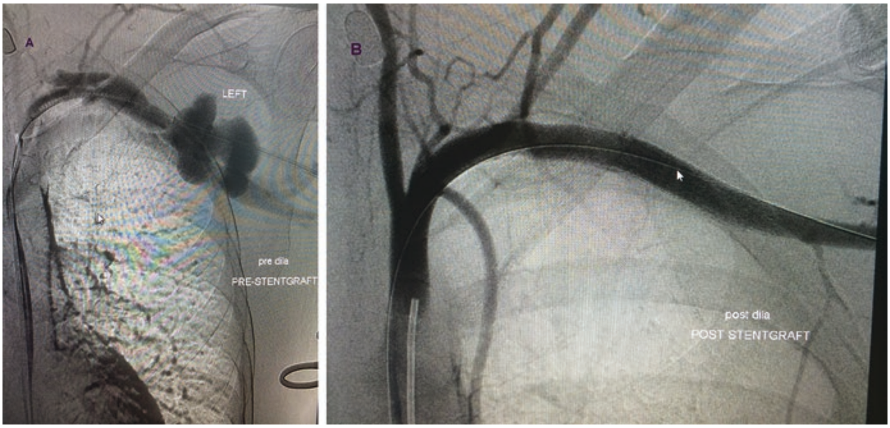


**Fig. 17.3** Angiography demonstrating significant disruption of distal subclavian artery before (**a**) and after (**b**) repair with an endograft

of the injury identified. The injury can then easily be repaired with either a 7 or 8 mm covered self-expanding stent graft (Viabahn; W.L. Gore, Flagstaff, AZ). If the artery is completely transected, the wire will wander out into nonanatomic places. At that point, femoral access can be achieved and the ipsilateral subclavian vessel selected in the arch of the aorta. A trilobed snare can be advanced across the injury and the wire snared and pulled through the body creating a brachio-femoral wire. The stent graft can now be easily advanced across this transection and repaired (Fig. 17.3).

## Required Equipment

Table 17.2 offers a list of suggested supplementary instruments and supplies for the performance of all basic vascular surgical procedures on the modern battlefield. All of these supplies fit easily into a single duffel bag or standard-sized storage chest and are eminently transportable. This list has been compiled by the author over a period of 7 years and three combat deployments. It has proven useful to graduating residents and newly indoctrinated war surgeons. Access to portable X-ray and C-arm fluoroscopy is highly variable depending on the echelon of care and associated embedded capabilities. Most forward surgical team and similar type units will not have this capability, but the majority of combat support hospitals will.

In the FST, space is often limited, and the availability of instruments to the surgeons can be limited. The author suggests placing individual instruments into “peel packs” and hanging them on the operating room wall for ease of visibility and rapid acquisition and use. Your operative team may not be familiar with vascular instruments, techniques, or supplies. Conduct *realistic* rehearsals for major vascular cases where you ask the scrub tech and circulator for all the instruments and supplies that you would normally need. Train your people well, and they will work wonders for you.

## Summary

Using a calm and methodical approach, a majority of thoracic vascular injuries can be approached safely and repaired quickly. Choosing the right incision is half of the battle, and quickly obtaining vascular control without creating further injury gets you almost all of the way home. An understanding of the anatomy and different bailout techniques outlined here is critical. You have all of the prerequisites at your disposal to fix these injuries – just do it! Good luck.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Emergent resuscitative thoracotomy.
2. Vascular injury.

# Chest Wall and Diaphragm Injury

# 18

Alec C. Beekley, Matthew D. Tadlock, and William B. Long

**Deployment Experience**

| | |
|---|---|
| *Alec C. Beekley* | Staff Surgeon, 102nd Forward Surgical Team, Kandahar Airfield, Afghanistan, 2002–2003 |
| | Chief of Surgery, 912th Forward Surgical Team, Al Musayyib, Iraq, 2004 |
| | Staff Surgeon, 31st Combat Support Hospital, Baghdad, Iraq, 2004 |
| | Director, Deployed Combat Casualty Research Team, 28th Combat Support Hospital, Baghdad, Iraq, 2007 |
| *Matthew D. Tadlock* | Humanitarian Surgery, USNS *Mercy* (TAH-19), Micronesia & Papua New Guinea, Pacific Partnership 2008 |
| | Ships Surgeon, USS CARL VINSON (CVN-70), WESTPAC 2011–2012 |
| | Role 2 Officer In Charge, Charlie Surgical Company, Native Fury 2016, CENTCOM AOR |
| | Director of Health Services, 1st Medical Battalion, 1st Marine Logistics Group, 1st Marine Expeditionary Force, Camp Pendleton, 2014–2016 |

*"It seems that there will always be a surgery of war. This will contribute as much to progress as war itself."*

Harvey Graham, 1939

A.C. Beekley
Thomas Jefferson University Hospitals, Paoli Hospital, The Lankenau Hospital, Division of Acute Care Surgery, Division of Bariatric Surgery, Philadelphia, PA, USA

M.D. Tadlock (✉)
Department of Surgery, Naval Hospital Camp Pendleton, Camp Pendleton, CA, USA
e-mail: matthewtadlockmd@gmail.com

W.B. Long
Legacy Emanuel Hospital, Trauma Department, Portland, OR, USA


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**BLUF Box (Bottom Line Up Front)**

1. The majority of chest wall injuries can be temporized with damage-control techniques; complex reconstructive maneuvers should be avoided in the acute phase.
2. Chest wall injury with open pneumothorax is seen much more frequently in the combat setting than civilian settings; be prepared for it.
3. Casualties with open pneumothorax and difficulty breathing need intubation, not monkeying around with an occlusive dressing or chest tube.
4. Significant chest wall injury is associated with significant intrathoracic injuries.
5. The best image to find diaphragmatic injuries is the one that hits your retina through an open incision.
6. Nonoperative management of penetrating thoracoabdominal combat wounds leads to worry, wasted time, complications, and usually operations at the next levels of care.
7. Rib fracture fixation is best left for a higher level of care (Role 4) and is not an immediate priority; if appropriate, it may be considered selectively in Role 3 only if the appropriate equipment and expertise are available as this is not the place to be trying out new procedures one has never performed or has minimal experience in.
8. If there is any concern for pleural contamination, do not put your patients at risk for infection and osteomyelitis by instrumenting fractured ribs.
9. When rib fixation is performed, to decrease the risk of postoperative infectious complications, the original chest tube should be removed, the site cleaned and excluded from the operative field, and a new chest tube placed away from the original insertion site.
10. Irrigate the pleural cavity through the diaphragmatic defect and place a chest tube in good position prior to closing it.
11. Early, rapid, and temporary closure of a large diaphragmatic tear can help you identify which body cavity is the source of ongoing bleeding.
12. Patients with diaphragmatic injuries identified at the time of laparotomy should get a chest tube on the affected side; patients with a diaphragmatic injury identified at the time of thoracotomy should get a laparotomy.
13. Local national pediatric combat trauma will happen; prepare for it prior to deployment.

**Fig. 18.1** Patient injured in bomb attack with a large posterior chest wall defect and open pneumothorax

## Chest Wall Injuries

Despite improvements in body armor, chest wall injuries are still common enough in combat settings that the surgeon must have more than passing familiarity with the management of them. The injuries can range from simple rib fractures, which every general surgeon has dealt with multiple times by the end of residency, to massive tissue and rib loss with eviscerated and injured lung, scapula or shoulder girdle involvement, hemorrhage, and open pneumothorax (Fig. 18.1). The vast majority of chest wall injuries can be temporized with damage control measures until other pressing injuries and physiologic needs can be addressed and stabilized. The reconstruction of chest wall defects from tissue loss can and should be delayed until the patient is evacuated to a higher level of care, or at least until hemorrhage is well controlled, the patient resuscitated, and contamination/infection cleared up.

## Open Pneumothorax

At the beginning of the movie *Platoon*, a newly arrived soldier is shown dying of a "sucking chest wound" after being shot in a firefight. Despite the medics' frantic application of occlusive dressings to a large left chest wound, the soldier's strangled gasps rapidly subside as he dies. This wound is almost never seen in civilian trauma settings but will be seen fairly frequently in combat settings. It can present in stable patients and pose primarily a wound closure challenge, or it can present in unstable

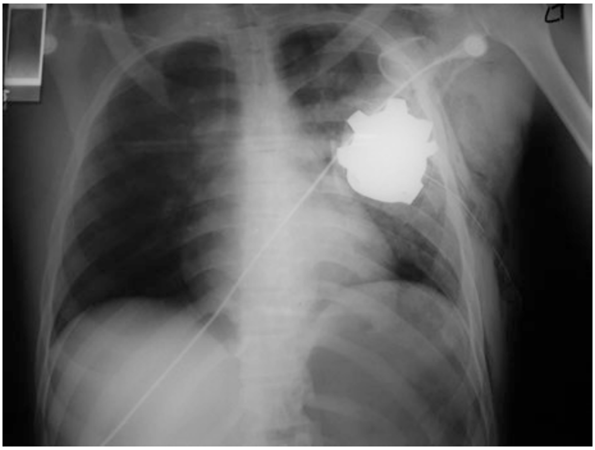

**Fig. 18.2** Patient who presented with a chest wall wound and on X-ray was found to have an unexploded rocket-propelled grenade in his chest wall

patients who are suffering from hemorrhage, hypoxia, and profound shock. Casualties with open pneumothorax have a hole in their chest wall that has less resistance to airflow than their native airways. Although textbooks talk about a hole "2/3 the diameter of the trachea" – which is somewhat cumbersome to measure at the bedside – a good rule of thumb is that if you can see directly into the chest through the hole, it is usually big enough to cause open pneumothorax.

The deployed surgeon should remember two things about open pneumothorax: first, if the soldier has not bled to death into his chest, he will die from asphyxia unless treated; and second, when something creates a hole in the chest wall big enough to cause an open pneumothorax, it usually means something big went tumbling through the chest itself. The "big" objects can include high-velocity bullets or fragments, large lower velocity fragments, rocks, pieces of equipment, and even live ordnance. Be prepared for surprises on chest X-ray (Fig. 18.2). Operation may be necessary simply to remove large fragments and contamination. In hopefully rare cases, live rockets or grenades may need to be removed in a bunker with an explosive ordnance disposal team at hand, as was done by at least one author of this book.

Treatment priorities remain the same as for all casualties. Although classically listed under "B" in the Advanced Trauma Life Support (ATLS) "ABCDE" algorithm, open pneumothorax is technically an airway problem – with each of the patient's inspirations, air flows through the hole in the chest wall and into the pleural space rather than through the patient's airways and into the lungs. Hence, a full-blown open pneumothorax can kill a patient nearly as fast as an airway obstruction. The airway may need to be rapidly secured, particularly if the patient is struggling to breathe and hypoxic. Do not fiddle around placing three-sided occlusive dressings, finding the right-sized plastic material to create a seal, or trying to tape the dressing or Asherman chest seal on a bloody chest in the hope of avoiding intubation. Once the patient is on positive pressure, the airflow resistance differential between that patient's airways and the chest wall injury is eliminated and the airflow problem fixed. Time can then be taken to more completely assess the casualty, place dressings and chest tubes, and obtain a chest X-ray. The chest wall defect can be covered with an occlusive dressing and a separate chest tube placed to suction.

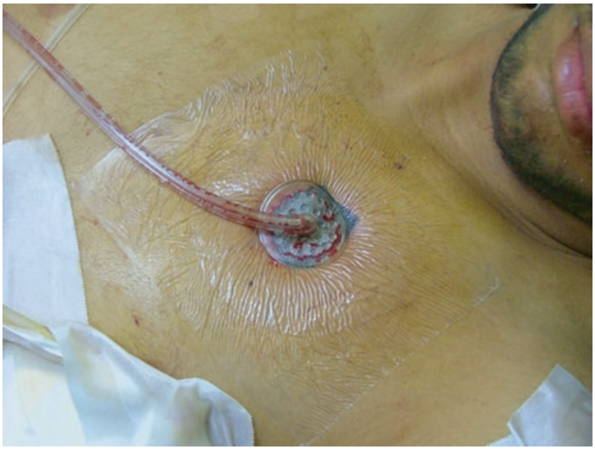

**Fig. 18.3** Use of a negative pressure wound vacuum device to achieve an airtight seal and promote faster healing of an open pneumothorax

The decision to explore the *pleural cavity* can then be based on chest tube output and findings on chest X-ray, as is discussed in the chest injury section. Chest CT scan is rarely needed in the acute setting to make this decision. At a minimum, surgeons should explore the *chest wall defect* to debride devitalized tissue, bone, fragments, clothing, and other wound contaminates and to ensure that intercostal vessels and chest wall muscular bleeders are tied off.

After the casualty's hemorrhage and contamination have been treated, the inevitable question arises – "what the heck do I do with this big hole in the chest?" When in doubt, keep it simple. A blue towel sandwiched between two Ioban drapes makes a fairly sturdy, nonstick dressing that can be placed between the lung and the chest wall defect. Gauze packing into the defect followed by another Ioban dressing will suffice as a sealed, temporary dressing. With medical bleeding, it may also be necessary to pack the pleural space. Intrathoracic packing with laparotomy pads is safe, if necessary, and will not impair hemodynamics or ventilation. Be sure at least one well-placed, functioning chest tube is present. Alternatively, for selected injuries negative pressure wound therapy can be applied directly to the wound (Fig. 18.3). Nonadherent white sponge, when available, can be used against the lung, although sterile petrolatum gauze can also be used between lung and black sponge. Again, at least one chest tube should be in place. With this technique, sealing of the lung to completely close the pleural cavity from the wound can be affected, usually in just 3–5 days of negative pressure therapy.

In either case, evacuation of the patient to a higher level of care is possible with this temporary chest wall closure. Once the patient is stable, small defects can undergo delayed primary closure in layers based on the quality of tissue present and absence of contamination. Usually, enough chest wall musculature is present to mobilize for a relatively tension-free flap closure over the defect. Larger defects may require a synthetic or bioprosthetic patch or pedicled myocutaneous flap – these interventions should generally be reserved for higher levels of care, but you may have to perform these procedures at your forward facility for local national patients.

**Fig. 18.4** Thoracic flail segment as a result of blunt force transmitted by a high-velocity round deflected by the strike plate of body armor

## Flail Chest

Although this is classically considered an injury of blunt trauma, many of the mechanisms in modern combat can cause significant chest wall disruption with the classic resultant flail chest segment and underlying pulmonary contusion. Unlike the typical civilian low-velocity missile wounds, combat mechanisms such as high-velocity missiles, rocket-propelled grenades, or explosive devices can all disrupt enough of the chest wall to cause flail. Modern body armor can often turn what would normally be a fatal penetrating chest wound into more of a blunt-type flail segment (Fig. 18.4). While there may not be significant external chest wall trauma, behind armor blunt trauma can result in significant injury underneath. Remember that while it may be associated with significant pain the primary problem is usually not the flail segment; it is the underlying lung injury and pulmonary contusion. The diagnosis is usually readily apparent from close examination of the wound and chest X-ray. Remember that you will not see the typical "paradoxical" motion of the flail segment if the patient is on positive pressure ventilation.

Treat these similar to their civilian counterparts, but be aware that the likelihood of severe associated intrathoracic injury requiring intervention will be much higher. A chest tube should almost always be placed on the affected side, and early intubation is better than an emergent intubation when the patient tires. Do not put one of these patients on an evacuation vehicle without being sure that their airway is intact and secured. Simultaneously begin administration of pain control agents. An epidural is preferred if you have the expertise and equipment available. Most of these flail segments will stabilize with time, but there is now a growing experience with rib-fixation techniques for refractory injuries or severely displaced fractures.

## Operative Rib Fracture Fixation

Operative reduction and internal fixation of traumatic rib fractures is commonly performed at civilian trauma centers but there are no universally agreed up indications. Commonly accepted civilian indications include severe unilateral chest wall deformity, flail chest in patients requiring intubation and patients requiring a thoracotomy for other reasons. However, in patients with flail chest AND significant underlying parenchymal injury and pulmonary contusions, there is likely no role for operative fixation as it will not result in earlier extubation. Other described potential but controversial indications include acute respiratory insufficiency (i.e., hypoxia, hypercarbia, and uncontrolled secretions) and uncontrolled pain despite optimal medical management and pain control techniques. Definite contraindications include bacteremia, active chest wall or pleural space infection or pleural contamination from enteric contents through diaphragm injuries or from significant environmental contamination at the time of injury. Role 2 is only designed for damage control surgery and rib fixation should not be performed in this setting. Rib fracture fixation should generally be reserved for the Role 4 setting; however, with the appropriate expertise and equipment it may be considered in Role 3. If commercial rib fixation hardware is not available in Role 3, fixation has been described in the setting of an open thoracotomy with anterior plates and screws from generic facial or hand fixation sets. Wire fixation of rib fractures has also been described but these repairs can be unstable and cause further rib fractures.

Exposure is usually dependent on fracture location and which ribs are fractured. Further, all rib fractures do not need to be stabilized. In general, it is not necessary to fixate ribs 1–3 and ribs 10–12 due to difficulty of exposure (ribs 1–3) or fixation is unlikely to improve pain and pulmonary mechanics (ribs 1–3, 10–12). Depending on the fracture pattern, standard thoracotomy incisions or a longitudinal incision centered over several ribs with contiguous rib fractures. You must be familiar with anatomy and avoid injury to chest wall nerves including the long thoracic nerve. General principles of exposure and fixation include:

1. Avoid dividing muscles and use muscle splitting techniques as much as possible.
2. Fixation must be bicortical.
3. The plates used must be flush with the rib being stabilized.
4. Place plates on the superior portion of the rib to avoid injury to the neurovascular bundle.
5. Be careful not to fixate a fracture segment to the wrong rib!

**Rib fracture fixation should not be performed in Role 3 (or anywhere else) without the appropriate expertise or equipment; this is not the place to try out new procedures one has never performed or has minimal experience in!** Regardless of level of care, rib fixation and instrumentation should not be done acutely in combat trauma. Remember, all wounds sustained in combat, particularly those from explosive ordnance or improvised explosive devices are contaminated with bacteria due to dirt, contaminated clothes, and projectile fragments. If there is any concern for pleural contamination, do not put your patients at risk for empyema, chest wall infection, or osteomyelitis. When rib fixation is performed, to decrease the risk of postoperative infection and osteomyelitis, the original chest tube placed at the time of injury should be removed, the site cleaned, and to the best extent possible excluded from the operative field. Then a new tube thoracostomy tube should be placed at a new sterile site away from the original chest tube site.

## Diaphragmatic Injuries

### Diagnosis

In combat trauma, injuries to the diaphragm are typically found during exploration of either the abdomen or chest – *as they should be.* Extensive work-up with CT scan, MRI, laparoscopy, fluoroscopy, or digital probing of the diaphragm through a chest tube hole are either unavailable or simply have no role in the work-up of penetrating thoracoabdominal trauma from military munitions. The surgeon attempts nonoperative management of these wounds at his peril. Missed bowel injuries, rapid decompensation from delayed hemorrhage, and devastating complications such as biliary-pleural or biliary-bronchial fistulae and herniation of bowel with obstruction or infarction have been the result. The safest course is operative exploration and repair of the injuries found.

As with chest wall injuries, diaphragmatic injuries range in severity from small holes that may heal on their own to massive rents with tissue loss and herniation of abdominal viscera into the chest cavity. The temporary cavitation effect caused by high-velocity rounds can cause large diaphragmatic holes and blow a large amount of stomach or bowel contents across both peritoneal and pleural cavities. The best diagnostic tools the surgeon has to determine the extent of the diaphragmatic wounds are his or her hands (gently retracting the upper abdominal organs) and eyes (inspecting the diaphragm). **Inspect both hemi-diaphragms at every exploratory laparotomy!** You would be surprised how many times no one looks and feels up there.

### Treatment

Fancy, complicated repairs of small and moderate lacerations, involving interrupted horizontal mattress sutures with pledgets on each side, are unnecessary and time-consuming. Simple, full-thickness running stitches which incorporate the parietal peritoneum and a full-thickness bite of diaphragmatic muscle usually suffice (Fig. 18.5). An alternative for more compulsive surgeons is to start a running horizontal mattress stitch, leaving the tail long, then at the “corner” of the wound run a simple baseball stitch back and tie to the initial tail. Heavy, nonabsorbable monofilament sutures are the materials of choice. Superior placement of self-retaining

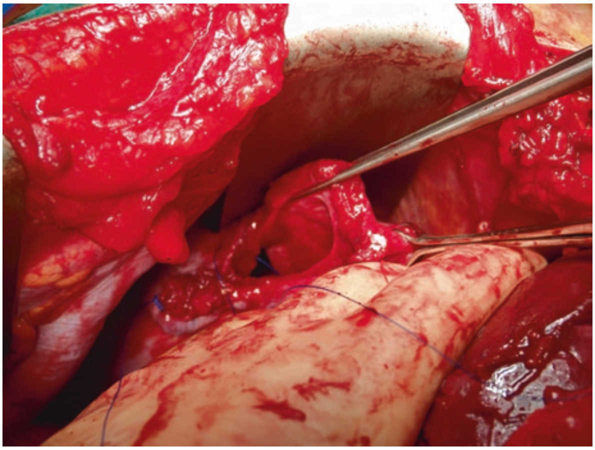

**Fig. 18.5** Penetrating wound to the diaphragm being repaired with a running Prolene suture. Note that the diaphragm is highly mobile and is being lifted up and into the wound providing easy exposure

retractors, "verticalization" of the diaphragm (retracting the costal margins so that the diaphragm is running almost perpendicular to the operating table), and two-handed retraction on liver, spleen, or stomach by the assisting surgeon facilitates exposure and suturing. Remember that the diaphragm is a mobile structure. Do not go down to IT; bring IT up to you (Fig. 18.5). Grab it with long atraumatic graspers on each side of the laceration, and lift it up into the field.

Most of the time, repair of the diaphragmatic injuries can be delayed during the initial operation until hemorrhage and contamination is controlled. Moderate and large diaphragmatic lacerations may allow irrigation of the pleural cavity through the defect prior to closure. An ipsilateral chest tube should always be placed. In patients where obvious foodstuffs or stool have been blown into the chest, subsequent formal thoracotomy for thorough washout of the contaminated pleural cavity may be required. For casualties whose diaphragmatic injuries were discovered at the time of thoracotomy, the surgeon should usually perform a laparotomy to rule out intra-abdominal injury.

While rare, central tendon tears of the pericardial diaphragm can occur, particularly after significant blunt force thoracic trauma from IEDs or explosive ordnance. These injuries should be repaired when identified to prevent subsequent cardiac herniation or superior herniation of colon and intestine, both of which can cause tamponade physiology. Prior to closure, carefully inspect the heart to ensure that there is no injury and no additional tears in the pleural pericardium. When identified, pleural pericardial tears require repair through a thoracotomy to ensure appropriate exposure and avoid phrenic nerve injury. The pericardial space should then be copiously irrigated with warm saline to wash out any potential blood clots or enteric contamination. Be careful not to injure the heart when repairing central tendon defects.

In certain instances, posterior diaphragmatic lacerations allow pooling of blood from the abdomen into the pleural cavity, or allow bleeding from the chest to be pushed into the abdomen with each blow of the ventilator. In the unstable, coagulopathic, multiple injury casualty, this can lead to confusion regarding the source of ongoing bleeding. Is the blood seen welling up from the pleural space coming from the chest, or did it drain up in there from the abdomen? Rapid, temporary closure of the diaphragmatic defect with ipsilateral chest tube placement (if not already done) can rapidly resolve this diagnostic dilemma. In some cases, bleeding lumbar veins or arteries or vertebral body fractures may turn out to be the culprit. In other cases, the blood coming from the chest tube which was originally thought to be from the liver is now discovered to be coming from the lung or heart.

Massive diaphragmatic tears with herniation of abdominal viscera into the chest can confuse FAST (Focussed Assesment with Songraphy in Trauma) exam results, but are usually associated with shock or physical findings of such significance that the decision to go to the OR is not difficult. Attempts to definitively repair these defects in unstable casualties at the initial operation should be avoided. Again, a sterile blue surgical towel sandwiched between two Ioban drapes and sewn to the remnant of the diaphragm edges may provide a temporary solution until hemorrhage and contamination are controlled. The patient will likely need to remain on positive pressure ventilation. Once the patient is stable, the diaphragm can be definitively repaired or reconstructed. Techniques for repair of large lacerations where the diaphragm is torn from its lateral attachments on the chest wall include primary repair by sewing the diaphragm to the rolled up or contracted rim of lateral diaphragm that is usually still present. If this is not possible, then a more complex repair must be considered. Polytetrafluoroethylene (PTFE) or polypropylene mesh may be used to reconstruct missing diaphragm, but their use is limited in contaminated fields. An excellent option for the avulsed diaphragm is the diaphragmatic transposition procedure (Fig. 18.6). With avulsion injuries and tissue loss, the diaphragm will usually not be long enough to be repaired in its usual position. Take the avulsed lateral border of the diaphragm and transpose it to a new superior position (1–3 rib spaces) using interrupted nonabsorbable sutures through the diaphragm edge and around the rib. More complex repairs involving reconstruction of the chest wall and complex flap closures are best done at a higher level of care.

## Local National Pediatric Combat Trauma

Unfortunately, children of all ages are injured during war, and you may be called on to take care of these patients. The management principles of pediatric chest wall and diaphragm injuries are similar to adults with the caveat that rib fracture fixation should not be performed. Pediatric rib fracture fixation for trauma is not well described in the civilian literature and implanted hardware may alter or inhibit normal chest wall growth and should not be performed. This is particularly true in a local national population with limited to no follow-up. Remember, the table of equipment for a Role 2, regardless of service, does not include the supplies to take care of pediatric patients. Pediatric specific equipment need to be ordered specially prior to deployment and hand carried in. Further, the mechanism for resupply needs to be determined prior to deploying. During Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF), children were victims of blast injury not

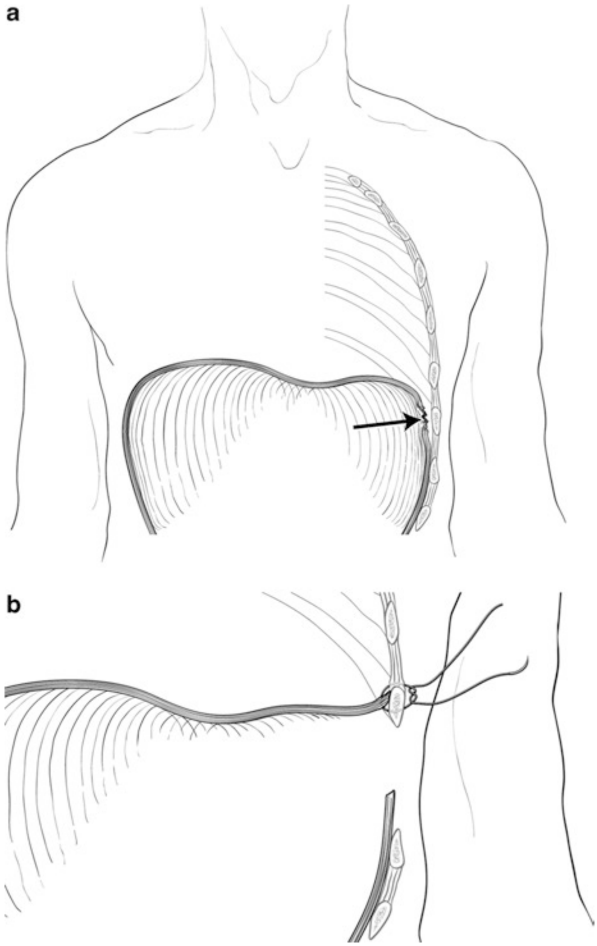


**Fig. 18.6** Transposition of the torn or avulsed diaphragm edge (**a**) to a more superior position with suture pexy to the rib (**b**) will facilitate a tension-free reconstruction to restore proper chest and abdominal domain

infrequently. Other than various skin and soft tissue debridement procedures, the most common procedures performed from ages 0–14 were the placement of chest tubes and vascular access procedures. If deploying with a Role 2, make sure your unit has the ability to intubate, obtain intravenous access, and place chest tubes in pediatric patients of all ages. For babies, if you don't have a pediatric chest tube, a flat 10 French closed suction drain can be used for a pneumothorax; unfortunately, they may frequently become clogged in patients with a hemothorax. For older children, a 12–14 French nasogastric tube can be used to drain the chest temporarily until transferred to a higher level of care. Unfortunately, nasogastric tubes are not good long-term options as they generally do not have enough holes and can also clog. To fashion a makeshift chest drainage system connector you can use a 1 or 3 cc syringe after cutting the flanges off and taking the plunger out. Local national pediatric combat trauma will happen; be ready to take care of these patients.

## Final Points

Chest wall injuries are easily discovered in the trauma bay by physical exam. Diaphragmatic injuries are easily discovered in the OR by direct exam. Neither requires immediate definitive repair, but both need to be addressed at least temporarily during the initial treatment phases and operations. Because of the heavy contamination associated with most combat-related wounds, definitive reconstruction of chest wall defects, particularly with prosthetic devices, should be delayed until the patient is evacuated to higher levels of care or until the patient is stabilized and contamination controlled.

## Civilian Translation of Military Experience and Lessons Learned

William B. Long

**Key Similarities**

- Diaphragm injuries are suspected based on mechanism of injury but can be difficult to confirm without operative exploration.
- Management of open pneumothorax, large traumatic chest wall defects, or impalements in civilian settings follows almost identical management algorithms as in military settings.

**Key Differences**

- Small diaphragmatic defects in stable penetrating trauma patients are much more common in civilian settings, are difficult to diagnosis with standard imaging modalities, and are amenable to laparoscopic and thoracoscopic techniques for diagnosis and management.
- Flail chest or multiple displaced rib fractures after blunt trauma are likely more common in civilian settings, are more likely to be closed fractures, and are therefore more amenable to early surgical rib fixation.
- Resource allocation and the remote locations associated with the military setting pose additional challenges that may require more temporizing with damage control techniques and staged approaches to chest wall and diaphragm injuries.

## Discussion

Dr. Beekley and Dr. Tadlock's chapter on chest wall and diaphragm injury provides an excellent primer on the management of diaphragmatic injuries, chest wall defects, and open pneumothorax, particularly in the setting of combat and injury from explosive or high-velocity weapons. These injuries are frequently obvious in those settings. Chest wall defects resulting in open pneumothorax are often dramatic, and the diaphragmatic injuries are often found incidental to exploration for control of hemorrhage and contamination in the chest and abdomen from these wounding mechanisms. While less common in civilian settings, these injuries are nevertheless encountered on occasion and should be managed by the principles outlined in the chapter.

In civilian settings, blunt trauma predominates and the penetrating injuries are more often caused by low energy/velocity mechanisms (e.g., stab and handgun wounds). Consequently, diaphragm injuries may be more difficult to diagnosis and a high index of suspicion must be maintained based on the mechanism and location(s) of injuries. Despite the wide array of imaging modalities available, small diaphragmatic defects from penetrating thoracoabdominal wounds can easily be missed and result in delayed presentation with diaphragmatic herniation, visceral obstruction, and even strangulation. Fortunately, these injuries are relatively easy to diagnose and repair at initial presentation via minimally invasive surgical techniques (primarily laparoscopy), modalities frequently not available in deployed military settings.

There is also a continually evolving understanding of rib fractures, and there are now multiple hardware sets specifically designed for surgical rib fixation. Many civilian centers have begun to expand the indications for surgical rib fixation beyond flail chest, with the recognition that there are longer term consequences to rib fractures in terms of pain, function, and disability than previously thought. These interventions are still under intensive study and the indications for surgical rib fixation in terms of number and location of rib fractures, objective functional criteria (e.g. VC, FEV1, and incentive spirometry performance), are still a matter of debate. The authors of this chapter are appropriately cautious in recommending that rib fixation be reserved for selected patients only at Role 3 facilities and higher.

Although the authors' chapter is fairly comprehensive, there are a few fine points gained from years of experience that can be added to expand or refine their recommendations. These are added below.

## Chest Wall Defects

Small chest wall defects (<4 cm in diameter) can be covered with an occlusive dressing. There is a theoretical advantage to placing a chest tube through a separate tube thoracostomy site in the chest wall, but the pleural cavity is already contaminated. Why add a new incision in the chest if you don't need to? Put a chest tube in the hole already made by the projectile or object and secure the tube with sutures and wrap the Ioban around it. This chest tube is or others are temporary!

The decision to explore the *pleural cavity* can then be based on chest tube output of a massive air leak or blood, and other findings on chest X-ray, as is discussed in the chest injury section. Chest CT scans are helpful to assess lung damage and whether the lung is ripped, has a large lobar hematoma, a traumatic injury to the thoracic aorta, mediastinal hematoma, pneumopericardium, or unsuspected hemopericardium. Distance and time to the next echelon of care factors into these decisions. Otherwise CT of the chest is rarely needed in the acute setting to make this decision.

Large air leaks can be decreased with bronchial blockers of lobar or segmental bronchi in an emergency to buy time until the patient can be transferred to a higher echelon of care.

Irrigation or pulse lavage of the chest wall and pleural cavity is helpful to decrease contamination.

## Flail Chest

There are many types of flail chest, ranging from sternal flail, parasternal flail, anterolateral flail, lateral flail, and paravertebral flail, each with its own unique challenges for reconstruction. Please make every effort to save large rib fragments (those than can hold two more screws) with attached viable intercostal muscles for later incorporation into a plated rib repair.

## Organ Herniation Through the Chest Wall

Organs that can herniate though intercostal rib fractures include part of a lung, a whole lobe, liver, and spleen, with accompanying injury of a diaphragm. Organs that can herniate though intercostal rib fractures include part of a lung, a whole lobe of a lung, liver, and spleen. Any of these can present with accompanying injury of a diaphragm. Most of the time the skin is intact.

A CT scan of the chest wall with IV contrast helps to make the diagnosis of organ herniation. Unless there is danger of compromise of an organ's blood supply, most organ herniation can be managed initially as a patient with an open chest wound, if the herniated organ is exposed. If not exposed and the organ blood supply is satisfactory, the patient can be referred to a higher echelon of care for definitive care.

## Impalements of the Thorax

Impalements of the chest can happen in both civilian and military combat settings, as patients can fall onto a stake, a metal fence post, Rebar, a tree limb, or a piece of equipment. Patients who survive an impalement can usually make it to the nearest casualty center. The biggest threat to the patient's life is either the patient pulls out the impaling object or somebody else does. This can cause exsanguinating hemorrhage or open pneumothorax. The wound and impaling object are always considered contaminated.

The prehospital care providers need training for extricating the patient from the scene while keeping the impaled object in the patient. This may require tools to cut the impaling object as it enters and or exits from the chest. Then the patient can be transported.

Removal of impaled objects of the thorax should be done in the OR with portable fluoroscopy equipment available. If this is not available, then the surgeon has to decide whether of transport the patient to a higher echelon of care or remove the impaling object with a thoracotomy.

## Traumatic Pericardial Herniation

This rare entity can happen with both high energy blunt trauma, blast type concussion to the chest wall, and theoretically with penetrating injury. The left ventricle and part of the right herniates through the rent in the pericardium, and the pericardium constricts the heart in the atrioventricular groove, producing partial inflow occlusion and marked hypotension. The patient with this entity does not transport well. The patient should undergo a left anterolateral thoracotomy in the partial right lateral decubitus position to expose the left side of the heart. The edges of the pericardial rent are grasped with Allis clamps which are pulled gradually outward and the heart will have a few beats of tachycardia, and then reduces itself. The pericardium can be loosely reapproximated with 3-0 silk sutures and drained with a Blake drain.

## Conclusion

It is incumbent on all trauma surgeons, both civilian and military, to learn the principles in diagnosis and management of these often challenging injuries, as the specter of mass shootings and terror attacks with explosive devices continues to blur the lines between civilian and military trauma.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Management of war wounds.

# Soft Tissue Wounds and Fasciotomies

# 19

Mark W. Bowyer, Peter Rhee, and Joseph J. DuBose

**Deployment Experience**

| | |
|---|---|
| *Mark W. Bowyer* | Chief of Surgery/Trauma Czar, 332nd Air Force Theater Hospital, Balad, Iraq, 2006–2007 |
| *Peter Rhee* | Chief surgeon, Charlie Medical Company, Forward level II facility, Ar Ramadi, Iraq, 2006 |
| *Joseph J. DuBose* | Chief of Surgery/Trauma Czar, 332nd Air Force Theater Hospital, Balad, Iraq, 2009 |
| | Role 3, MMU KAF; Kandahar, Afghanistan 2010 |
| | Bagram Air Base Role 3 Air Force Theater Hospital 2011–2012 |
| | USSOCOM surgical support, Operation Inherent Resolve 2016 |

*The surgeon is not yet born who does not think that he is the one who can close in war a gunshot wound primarily.*

Philip Mitchiner, 1939

M.W. Bowyer (✉)
Uniformed Services University and Walter Reed National Military Medical Center, Department of Surgery, Bethesda, MD, USA
e-mail: mark.bowyer@usuhs.edu

P. Rhee
Grady Health System, Department of Trauma, Atlanta, GA, USA

J.J. DuBose
Uniformed Services University of the Health Sciences, Davis, CA, USA


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**Bottom Line Up Front (BLUF) Box**

1. Maintain situational awareness. Don't get distracted by the wound and miss other life-threatening injuries.
2. Do it in the operating room. Big wounds benefit when you have good lighting, equipment, supplies, and anesthesia, and the operating room has these things.
3. Trust your instincts and your physical exam.
4. Closely examine every wound and the surrounding tissue.
5. Bleeding, contamination control, diagnosis, and reconstruction are the priorities of trauma surgery.
6. Prompt removal of devitalized tissue and debris is imperative to prevent local and systemic problems later.
7. There will be more dirt, debris, and foreign bodies in these wounds than you've ever seen, and it may take several OR sessions to get them clean.
8. Leave all wounds *open* initially. If someone else closed it, *open it*!
9. Pulsatile pressure lavage systems are convenient, but they can hurt soft tissue and may promote rebound bacterial growth. Use simple irrigation.
10. Vacuum therapy and frequent irrigation and debridement are good.
11. Have low index of suspicion for compartment syndrome. If you think about it, you should do a fasciotomy.
12. Complete full fasciotomies can save limbs and lives. There is no role for mini-fasciotomies.
13. Closing wounds primarily is better than skin grafting, and taking patients to the operating room frequently will help achieve that goal.

When trying to describe to other surgeons the difference between the types of soft tissue wounds seen in combat and in peacetime, it is difficult to actually convey the complexity. Imagine the worst injured patient you have ever seen in your civilian practice while deployed to an active battle zone; you may see multiple patients in a single day with wounds that are bad or worse. Even otherwise well-trained trauma surgeons will find themselves initially uncomfortable caring for such injuries. These wounds are devastating, and we rarely see such extensive soft tissue injuries during our training or practice in the USA. The garden variety civilian stab wounds, slash wounds, and handgun injuries are incredibly minor compared to the wounds produced by things like a .50 caliber machine gun, an AK-47 round, or more commonly an improvised explosive device. No amount of reading can completely prepare you for some of these injuries, and you must adopt a different set of rules and strategies to optimize your patient's outcome. Additionally, given that these wounds nearly always involve the extremities, it is essential that the combat surgeon be well versed in recognizing compartment syndromes and performing timely and complete fasciotomies. It is a travesty to have a young solider survive a multitude of potentially life-threatening injuries only to lose a limb or life due to a delayed or improperly performed extremity fasciotomy. The goal of this chapter is to help shorten the learning curve to care for the extensive soft tissue wounds of war and to reinforce the importance of both identifying compartment syndromes and treating them with correctly performed fasciotomies.

When caring for the extensive and complex wounds seen in combat, it is important to stick to basic principles and priorities. There are four principle steps in trauma and combat surgery:

1. Hemorrhage control
2. Contamination control
3. Diagnosis
4. Reconstruction

Whether you are doing a laparotomy or treating soft tissue injuries, the steps and priorities are not any different. The first priority is stopping the bleeding, and if available, bleeding wounds and big wounds should be taken to the operating room immediately. As a general rule of thumb, being in the operating room with wounds is easier on the patient, the hospital staff, and you. You get the best results by doing a good job, and the place to do the best job is in the operating room with proper equipment, lighting, and help.

In the current deployed setting, extensive soft tissue wounds are the norm requiring aggressive management and operative debridement and commonly require fasciotomy to prevent or treat compartment syndrome. While the techniques utilized for performing fasciotomies in theater are similar to that utilized in civilian practice, the indications and specific concerns may differ. It is essential that surgeons tasked with caring for these patients have a detailed understanding of the indications for and the anatomy and landmarks required to perform fasciotomies. Additionally, the austere environment of the deployed setting has afforded us a valuable experience with novel approaches to the subsequent closure of these wounds – experience that we hope to impart to you in this chapter.

## Large Soft Tissue Wounds

The most important aspect of initial treatment of any soft tissue wound is to stick to your ABCs. Though it is important to ensure that an adequate airway is maintained, the vast majority of preventable deaths on the battlefield will be from uncontrolled hemorrhage, and the ABC mantra is adjusted slightly to C-ABC where the initial C refers to control of hemorrhage which should be done simultaneously (if possible) with evaluation and management of the airway. The wounds encountered in this setting are frequently overwhelming in appearance, and you will find that people have a tendency to focus on the wound and not the patient. Avoid the temptation to focus on what may be the most impressive wound of your life and miss other life-threatening issues. Prioritize as you would any trauma patient. If you have ample help and someone else can assess the airway and breathing, then you can address bleeding simultaneously. If you are running the team, then while someone else is trying to control the hemorrhage, you can ensure airway and breathing. While it is important not to miss a problem with an airway, you will save many more lives in combat medical care by controlling hemorrhage from a large soft tissue wound than you will by performing an emergent airway.

Once more pressing casualty issues have been addressed and emergent injuries excluded, attention should then be directed at the soft tissue wound. Bleeding from the wound is the first step. Direct pressure is the preferred method in civilian trauma, but in combat trauma, it is frequently inadequate and also requires a pair of hands that you usually need for other tasks. A well-placed and secured tourniquet is the preferred method for extremity hemorrhage control on the battlefield and in the combat hospital. If the patient arrives without one, put one on in the emergency room. For wounds distal to the elbow or knee, the tourniquet can be removed either in the operating room or in the resuscitation area. If there is uncontrollable arterial bleeding, pressure dressing can be applied, and the tourniquet should be retightened or reinforced with a second proximal tourniquet (Fig. 19.1). For many of the wounds seen in war time, the wounds are not suitable for tourniquets as they are very proximal (Fig. 19.2) and involve junctional areas where the extremities meet the torso. While it might seem tempting to simply irrigate these wounds in the emergency department or resuscitation area, we would advise you to avoid this temptation for all but the very smallest of wounds that do not need to be explored.

The wounds seen in combat must be assumed to be highly contaminated. Dirt and debris will always be present. Metallic fragments from the explosive device itself or surrounding objects may be present, particularly when the victim was in a vehicle that gets blown up. You may often find bone fragments in the wound but no bony fractures – these are fragments from bystanders or from the attacker in suicide bombing-type incidents (aka "bioshrapnel"). Decaying tissues and human or animal feces have also been found in explosive devices employed by insurgents to enhance wound infection rates. Everything imaginable can be found in the wounds (Fig. 19.3). In the least, the projectiles and fragmentation components of modern war wounds represent substantial risk for severe infection. Devitalized tissue, if not adequately debrided, will only fuel these infections and contribute to adverse outcome. One of the recurring lessons learned by newly deployed surgeons is that these wounds will need aggressive debridement, generally more extensive than one might initially expect.

General guidance for initial operative intervention consists of three main components: irrigation, debridement, and leaving wounds open. Antibiotics should be given right away as empiric therapy. The choice of antibiotic should cover gram-negative bacteria (particularly *Acinetobacter*) as they are much more prominent than in civilian trauma practice. We advise wide coverage for gram-positive and gram-negative organisms in your perioperative choice. Next you should then focus on irrigation. While high-pressure pulsatile lavage (HPPL) systems are commonly utilized in civilian practice, it is the current recommendation by the Joint Theater Trauma System Clinical Practice Guidelines (JTTS CPGs) that the employment of these devices be avoided. While these devices make the irrigation process easier,

**Fig. 19.1** Wounds where tourniquets were applied. Panel (**a**) bilateral tourniquets applied at groin, both legs amputated. Panel (**b**) tourniquet not applied due to lack of active blood loss. Panel (**c**) cloth tourniquet applied above wound

there is concern that the use of HPPL is associated with additional trauma to the tissues, creating an environment with a greater abundance of devitalized tissue and setting the stage for more aggressive bacterial regrowth. Several studies have shown higher wound infection and complication rates with pulse lavage compared to standard irrigation. Antibiotic-resistant *Acinetobacter* has also been associated with the HPPL.


**Fig. 19.2** Wounds that tourniquet cannot be effectively applied. Panel (**a**) wound created by rocket-propelled grenade. Panel (**b**) improvised explosive device

These devices are also relatively expensive and may not be available at all medical treatment facilities in the area of conflict. For these reasons, the use of bulb suction or gravity-fed systems should be utilized to provide for high-volume irrigation of all wounds in a more gentle fashion. Normal saline, sterile water, and potable tap water all have similar usefulness, efficacy, and safety for this purpose. How much irrigation to utilize depends on the size of the wound. As bacterial loads in the wound will drop dramatically with increasing volumes of 1, 3, 6, and 9 L of irrigation, we advise (as does the current JTTS CPG on the topic) that the following be utilized as a rule of thumb: 1–3 L for small volume wounds, 4–8 L for moderate wounds, and 9 or more liters for large volume wounds or wounds with evidence of heavy contamination. If the HPPL system is used, it can be made gentler by putting your fingers over the injecting end and to let the fluid fall into the wound. This turns the HPPL into a high-flow low-pressure system. Remember to use warm fluids, as hypothermia can rapidly develop with these large volumes.

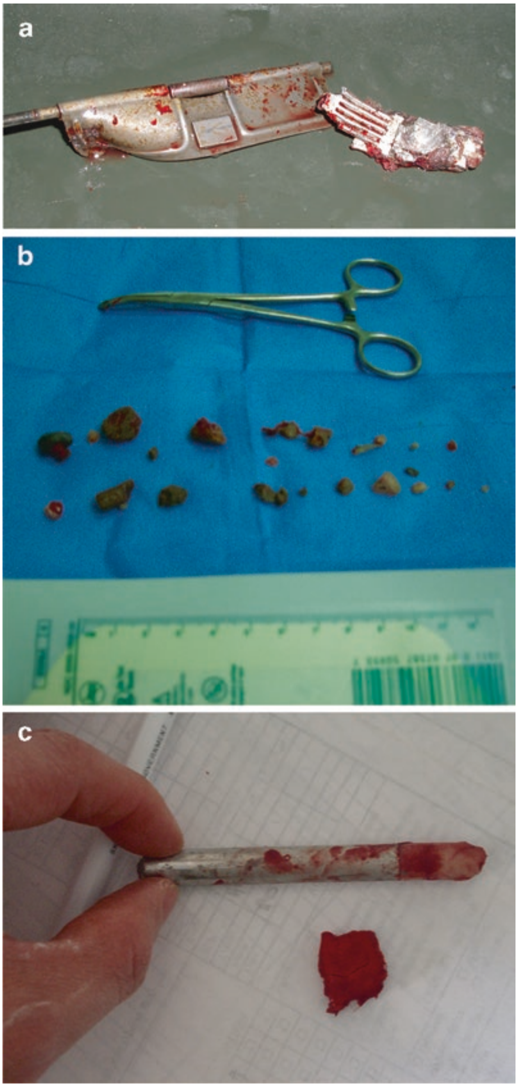


**Fig. 19.3** Foreign objects found in wounds. Panel (**a**) cover of an M4 rifle. Panel (**b**) dirt and rocks in wounds. Panel (**c**) unknown object found in tissue after improvised explosive device

After effective irrigation of the wound has removed all loose debris, you should turn your attention to debridement. Remove all remaining foreign material that is readily visualized or palpated through the wound – do not routinely extend wounds to "chase" a fragment that you might have seen on radiography – it will only create new potential spaces for infection, and you may injure another structure in the process. While the degree of debridement will require you as the operating surgeon to utilize your own judgment, take care to ensure that all devitalized tissue is removed while at the same time attempting to preserve as much soft tissue as possible for reconstruction at a higher level of care or later operations. For the muscle, purple or black tissue that does not move with the electrocautery should be removed, but when in doubt, you can leave it for the next time the wound is debrided if the wound is left open. There is a widely propagated surgical fallacy about the need for massive wide debridement of high-velocity missile wounds. This is based on erroneous assumptions and distortions regarding the size and extent of injury related to the sonic wave and temporary cavity created, with some authors advocating debridement of a cavity 30 times the size of the projectile. *Do not do this*; you will only create significant morbidity and cosmetic defects. This has been refuted by both ballistics data and combat surgical experience. As all of these wounds should be left open after the initial operation, it is reasonable to leave some tissue that you think may survive with the express understanding that this patient should be returned to the operating room for another look and additional debridement within the next 24 h. A common experience downrange was to receive a casualty at the role three who had had a debridement further forward and upon return to the OR find significant devitalized tissue. The initial reaction was to assume that the first operation was inadequate, but subsequent experience proved that some of these wounds (especially blast wounds) are wounds in evolution, in which tissue that looked viable at the initial operation was no longer so on second look. This underscores the need to avoid the temptation of closure at the initial operation, as there remains the strong possibility that the damage to the tissues has not fully declared itself and that additional debridement will be required at subsequent operation.

Dynamic wound vacuum therapy has been revolutionary in the treatment of wounds, and if available, it has been found to be extremely useful. You have to be very careful however that the wound hemostasis is complete as a vessel that reopens can bleed tremendously with the negative suction. For contaminated soft tissue defects, vacuum therapy is ideal. The utilization of vacuum-assisted closure provides for control and clearance of effluent and promotes early wound healing. Additionally, the use of vacuum therapy and other dynamic approaches limits the degree of wound contraction and increases the likelihood of subsequent delayed primary closure of some wounds. For wounds that will not prove amenable to delayed primary closure, vacuum therapy will promote the development of an early granulation bed that may prove amenable to graft coverage in the reconstructive setting. One additional tip is that stretching of the skin and subcutaneous tissue with sutures over the wound vacuum helps later closure without skin grafting. *Your planning for closure should start at the first operation.*

Now that you have completed the initial operation, the patient may be transported to the ICU or ward of your facility for continued resuscitation and postoperative care. The question you must then ask is: “When do I take the patient back for subsequent intervention for this wound?” In general for open wounds, they should be taken back to the operating room approximately 24 h later. Subsequent irrigation and debridement can be done at larger intervals such as 48–72 h, but if the interval is longer, the surprises and disappointments are not worth it. Depending on the length of stay of the patient at your facility and the condition of the wound, some patients may prove amenable to delayed primary wound closure or grafting after just a few operations. You must be mindful, however, that the infection rates in the austere environment of forward care are higher than stateside facilities. For the majority of severe wounds, particularly those involving amputation sites, the wounds should not be closed in theater for casualties that will be evacuating to a higher level of care. For those patients that do not fit into this category, utilize sound judgment to balance appropriately aggressive closure with an appreciation of these infectious risks.

You will also need to coordinate carefully with casualty evacuation personnel to determine the optimal timing of subsequent procedures. Remember that your patient may be in the evacuation chain for 48 h or more until they arrive at a facility and can be returned to the operating room. The way to ensure optimal wound care for medical evacuees is to have a policy that all wounds that require multiple operative sessions are taken to the OR for a final washout and debridement within 8–12 h of transfer. The dressing should also be clearly marked with the date and time of the most recent procedure as you cannot count on medical records to follow the patient.

## Small Multiple Wounds

With war wounds, judgment is critical. Judgment comes from experience, and experience comes from mistakes. Fortunately, you can learn from the mistakes of others rather than repeating these same mistakes on your own. Remember that the mechanism is very important. High-velocity rounds are very different than handgun injuries. For high-velocity rounds, the entry and exit are usually obvious, most commonly with a small entrance wound and a large cavity at the exit site. However, some high-velocity wounds can be seemingly innocuous at the entry and exit sites but have devastating damage to the underlying tissues in between. This should be suspected, and all of these wounds should be operatively explored.

Although many of these injuries will require the soldier to be evacuated from the area, select ones that may be managed locally and the soldier returned to duty. The wound depicted in Fig. 19.4 resulted from a close-range high-velocity round, and when explored, the muscle damage was impressive. This wound was debrided and closed over a penrose drain. Over the next week the drain was advanced out, the wound fully closed, and the patient started on physical therapy on the fourth week of injury. By the sixth week, the patient resumed full duty. This casualty did not have to be transferred out of theater, and the casualty was able to return to duty. He remained out of action and on limited duty for 6 weeks, but he was able to contribute to his unit, and the logistics of evacuating him out and getting a replacement was avoided.

While the big wounds are memorable, the routine far forward is multiple small wounds. These are especially challenging and deceiving. Small fragmentation injuries to the face and neck, arms, legs, and hands are extremely common. For civilians and local military, torso injuries from fragmentation are much more frequent due to the lack of body armor. These "peppering" injuries are difficult to assess, and seemingly innocuous wounds can hide devastating injuries. As an example, two patients were treated at our facility after a suicide bombing. The first patient had fragment


**Fig. 19.4** Close-range high-velocity injury to the left upper arm. Panel (**a**) entry site. Panel (**b**) exit site. Panel (**c**) closed entry site in 2 weeks. Panel (**d**) exit site after irrigation and debridement and closure in 2 weeks. Wound closed over penrose and drain pulled out over 10 days

injuries to his entire body, totaling over 100 small wounds. He was found to have no significant injuries and returned to duty in several days. Another casualty was seen, and although he was in extremis, he had no obvious external injuries. A chest X-ray showed a massive hemothorax and a small pellet in his right chest. On closer inspection, he had a tiny innocuous almost invisible puncture wound in his left chest midaxillary line at the nipple level. The pellet went through his heart and mediastinum. Every patient in an explosive-related incident should get a detailed external inspection and an imaging evaluation for internal injuries, even if their wounds appear small and superficial. If CT scanning is available, this imaging should be considered for all patients with multiple small wounds from blast fragments.

## Fasciotomies

Fasciotomy is among the most commonly performed procedures in present theaters of conflict. Subsequently, the wounds resulting from decompressions of the extremities will be among the most common you will be expected to manage. You will find that blast injuries account for a considerable number of indications for fasciotomy. Blast associated waves, fragmentation, crushing injuries, and resultant extremity fractures and vascular injury may contribute to the development of compartment syndrome of teh extremities. The modern advent of early casualty evacuation by air also introduces an environment in which the signs and symptoms of compartment syndrome are difficult to detect. These conditions frequently mandate the more liberal utilization of prophylactic fasciotomy than in civilian practice.

In our civilian practices, we rarely perform prophylactic fasciotomies. We have the luxury of being able to reliably perform continued and repeat examinations and intervene immediately if needed. You (and your patient) will not have this luxury in combat. For a general rule of thumb, if you suspect a compartment syndrome is present or has a reasonable chance of developing, perform a fasciotomy. Increasing pain remains the most reliable indicator of the need for this intervention, but an exam is not always possible or reliable in patients who are intubated, comatose, or being transferred rapidly across several echelons of care. If you have performed an extremity vascular ligation or repair, routine fasciotomy should be your default. Burn patients also represent a special scenario. For patients with deep circumferential burns of the extremities, the performance of an escharotomy will in most cases avoid the need for subsequent fasciotomy.

Whenever fasciotomy is undertaken, avoid the temptation to perform lesser procedures. Full decompression of the affected compartments is paramount for success. Mini-fasciotomies look cute, but will earn you the disdain of your colleagues at the next echelon who will inevitably have to extend the fasciotomy to adequately decompress the compartments and likely have to debride the resultant dead muscle within the compartment. The practice of fasciotomy in the first few years of the current conflict identified gaps in the readiness of many otherwise well-trained surgeons. As late as 2007, up to 20% of fasciotomies being done in Iraq and Afghanistan were being done incorrectly or in a much delayed fashion with the result of preventable loss of limb and in some cases life. It is a travesty to have an otherwise expertly managed soldier lose a leg or a life because of a failure to recognize the need to perform or adequately perform a fasciotomy. It is incumbent upon all deploying surgeons to have a full understanding of the indications for performing fasciotomies in all of the extremities in combat trauma, as well as the anatomy, landmarks, and essential steps required. Given the relative infrequency of these procedures in both civilian training and practice, we will provide a detailed description of the proper way to perform fasciotomies and the associated pearls and pitfalls.

## Upper Extremity Fasciotomy

Compartment syndrome of the upper arm is less common than the forearm, but should the upper arm require decompression, you can accomplish this through a lateral skin incision from the deltoid insertion to the lateral epicondyle. The upper arm has two compartments, and you should be able to visualize the septum dividing the anterior and posterior compartments through this incision. Make certain to decompress both compartments, while taking care to spare the larger cutaneous nerves and, in particular, the radial nerve which passes through the intermuscular septum from the posterior to anterior compartments just below the fascia.

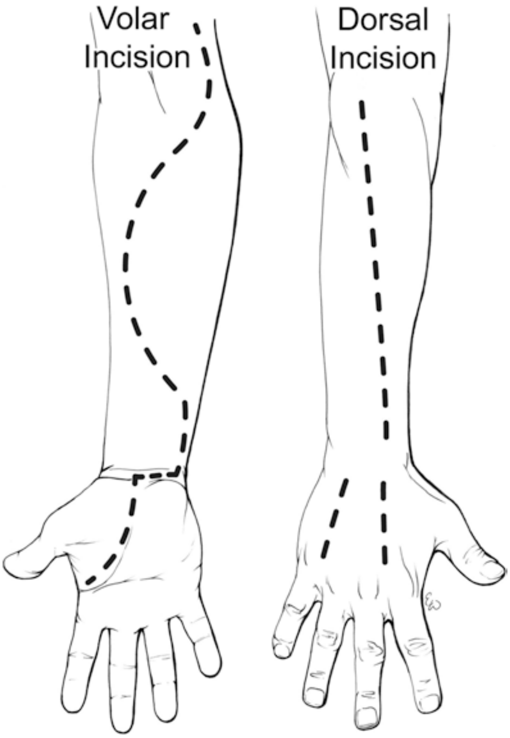


**Fig. 19.5** The volar incision enables decompression of the anterior compartment of the forearm and is carried down onto the hand to release the carpal tunnel. The dorsal incision allows for decompression of the posterior compartment, and the two dorsal hand incisions (if necessary) enable release of the intraosseous compartments

The forearm has three compartments, the mobile wad proximally, the volar (flexor) compartments, and the dorsal (extensor) compartments. The literature contains descriptions of many different skin incisions to open the compartments of the forearm. Most commonly used and described to perform a fasciotomy of the forearm is a curvilinear incision on the volar surface (to release the anterior and volar compartments) which is extended to the hand to release the carpal tunnel (Fig. 19.5). The posterior compartment of the forearm is released through a linear dorsal incision, with two additional incisions on the dorsum of the hand to release the hand (see Fig. 19.5). The rationale for the placement of these incisions is better cosmetic and functional result as well as maintenance of an adequate blood supply to the skin between the two flaps. Additionally, this incision allows for a vascularized skin flap to cover and protect the median nerve and the flexor tendons at the wrist.

When performing fasciotomy of the hand, it is important to completely release the carpal tunnel which extends well onto the palmar surface of the hand. The ligament is distinctively denser than the other tissues of this area, and you will appreciate a distinct haptic feedback ("crunchiness") when cutting it with the scissors. The median nerve is exposed at the wrist and then opened scissors across the transverse carpal ligament above and protecting the nerve (Fig. 19.6a) and then cutting with the scissors until the ligament is completely divided (as evidenced by loss of the "crunch"). The interosseous compartments on the dorsum of the hand must also be decompressed in order to do a complete fasciotomy of the hand. The dorsal incisions are placed between the second and third and the fourth and fifth digits

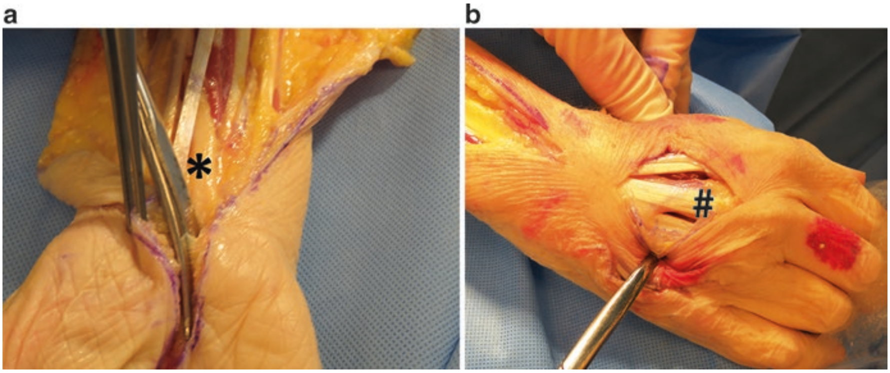


**Fig. 19.6** (**a**) The carpal tunnel is opened by identifying the median nerve (*) and placing the opened scissors above the nerve across the transverse carpal ligament. (**b**) The dorsal incisions on the hand allow for identification of the extensor tendons (#), and using a spreading clamp or scissors, the eight interosseous compartments found on either side of the four extensor tendons are decompressed

exposing the underlying extensor tendons. Through these two incisions, all four of the extensor tendons are located, and a clamp or scissors is used to perforate and spread open each of the total of eight intraosseous compartments found on either side of the tendons (see Fig. 19.6b).

## Lower Extremity Fasciotomy

Compartment syndrome of the thigh is more common in the combat setting than is generally seen in civilian practice. This is likely due to the increased soft tissue damage caused by blast and high-velocity wounding mechanisms. As with other extremity compartments, it is important to understand the anatomy in order to perform a proper fasciotomy. The thigh has three compartments: anterior (quadriceps), medial (adductors), and posterior (hamstrings). The incision for decompression of the thigh extends along the lateral leg from the greater trochanter to the lateral condyle of the femur (Fig. 19.7). After dissection down to the fascia, you must incise the iliotibial band and reflect the vastus lateralis off the intermuscular septum to release the anterior compartment. Then incise the intermuscular septum the length of the incision to release the posterior compartment. Be careful at this point to avoid making the releasing fascial incision too close to the femur, as there are a series of perforating arteries passing through the septum at this location that run posterior to anterior near the bone. The medial adductor compartment is released through a separate incision anteromedially from the groin to just above the knee (see Fig. 19.7). In most cases of civilian thigh trauma, it is sufficient to release just the anterior and posterior compartments through a single lateral incision. In combat casualties, there is a much greater likelihood that the medial compartment will need to be released as well, and you should consider opening both if you are concerned about compartment syndrome of the thigh in a combat casualty.

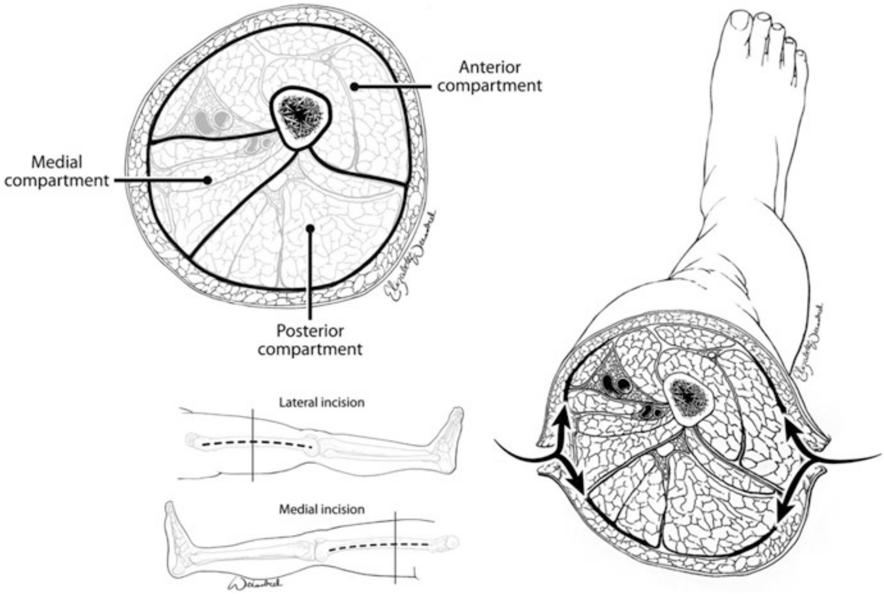


**Fig. 19.7** The three compartments of the thigh are depicted with the incisions used to perform thigh fasciotomy

## Leg Compartment Syndrome and Fasciotomy

The leg (calf) is the most common site for CS requiring fasciotomy. The leg has four major tissue compartments bounded by investing muscle fascia (see Fig. 19.8). It is important to understand the anatomical arrangement of these compartments as well as some key structures within each compartment in order to perform a proper four-compartment fasciotomy. It is not necessary to remember the names of all the muscles in each compartment, but it is useful to remember that the anterior compartment contains the anterior tibial artery and vein and the common peroneal nerve (recently renamed the common fibular nerve); the lateral compartment, the superficial peroneal (recently renamed the superior fibular) nerve (which must not be injured); the superficial posterior compartment, the soleus and gastrocnemius muscles; and the deep posterior compartment, the posterior tibial and peroneal vessels and the tibial nerve.

When dealing with a traumatically injured extremity, there is absolutely no role for getting fancy. The use of a single incision for four-compartment fasciotomy of the lower extremity is mentioned to condemn it. Attempts to make cosmetic incisions should also be condemned, and the mantra should be "bigger is better." Compartment syndrome of the lower extremity dictates *two-incision four-compartment fasciotomy* with *generous* skin incisions.

There are several key features that will enable a successful two-incision four-compartment fasciotomy. The most commonly missed compartments are the anterior

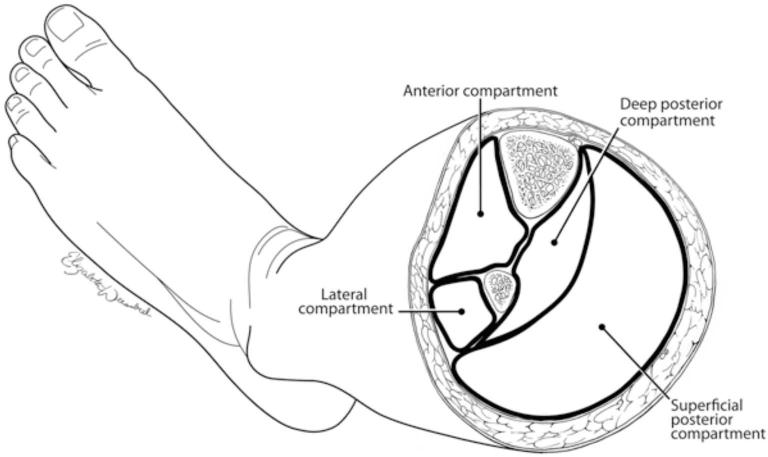


**Fig. 19.8** Cross-sectional anatomy of the midportion of the left lower leg depicting the four compartments that must be released when performing a lower leg fasciotomy

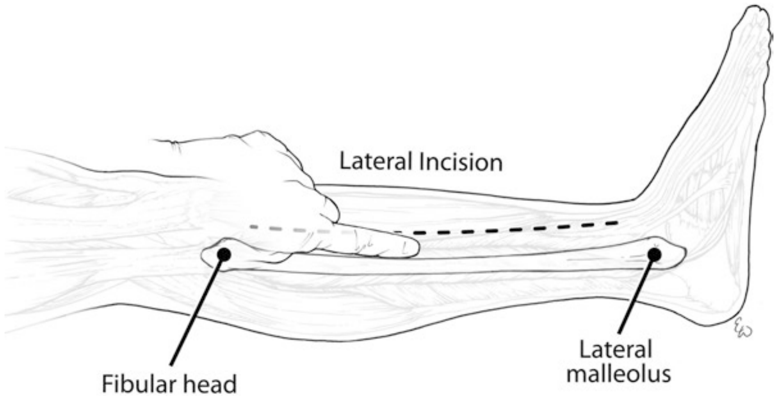


**Fig. 19.9** The fibular head and lateral malleolus are used as reference points to mark the edge of the fibula, and the lateral incision (*dotted line*) is made one finger in front of this (A FINGER IN FRONT OF THE FIBULA). The tibial spine serves as a midpoint reference between the two skin incisions

and the deep posterior. One of the key steps is proper placement of the incisions. As extremities needing fasciotomy are often grossly swollen or deformed, marking the key landmarks will aid in placement of the incisions. The tibial spine serves as a reliable midpoint between the incisions, and the lateral malleolus and fibular head are used to identify the course of the fibula on the lateral portion of the leg (Fig. 19.9). The lateral incision is made just anterior (~1 fingerbreadth) to the line of the fibula, or A FINGER IN FRONT OF THE FIBULA. It is important to stay anterior to the fibula as this minimizes the chance of damaging the superficial peroneal (superior fibular) nerve and helps to correctly identify the intermuscular septum.

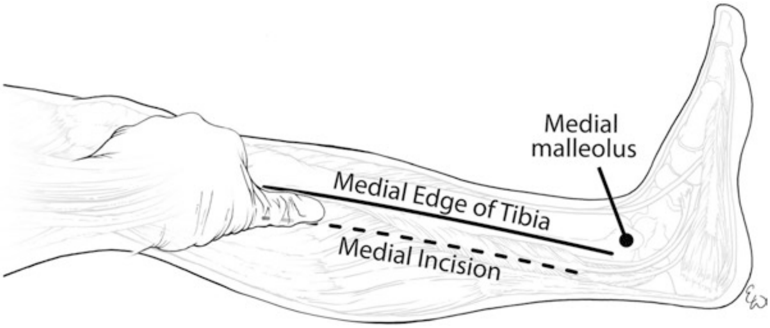


**Fig. 19.10** The medial incision (*dotted line*) is made one thumb breadth below the palpable medial edge of the tibia (*solid line*). A THUMB BEHIND THE TIBIA

The medial incision is made one thumb breadth below the palpable medial edge of the tibia, or A THUMB BELOW THE TIBIA (Fig. 19.10). The extent of the skin incision should be to a point approximately three fingerbreadths below the tibial tuberosity and above the malleolus on either side.

It is very important to mark the incisions on both sides prior to opening them, as the landmarks of the swollen extremity will become rapidly distorted once the incision is made.

## The Lateral Incision of the Lower Leg

The lateral incision (see Fig. 19.9) is made ONE FINGER IN FRONT OF THE FIBULA and should in general extend from three fingerbreadths below the head of the fibula down to three fingerbreadths above the lateral malleolus. The skin and subcutaneous tissue are incised to expose the fascia encasing the lateral and anterior compartments. Care should be taken to avoid the lesser saphenous vein and peroneal (fibular) nerve when making these skin incisions.

Once the skin flap is raised, the intermuscular septum is identified. This is the structure that divides the anterior and lateral compartments. In the swollen or injured extremity, it may be difficult to find the intermuscular septum. In this setting, the septum can be identified by following the perforating vessels down to it (Fig. 19.11a). Classically, the fascia of the lower leg is opened using an "H"-shaped incision. The crosspiece of the "H" using a scalpel will expose both compartments and the septum. The legs of the "H" are made with curved scissors using just the tips which are *turned away* from the septum to avoid injury to the peroneal (fibular) nerves (Figs. 19.11b and 19.12). The fascia should be opened by pushing the partially opened scissor tips in both directions on either side of the septum opening the fascia from the head of the fibula down to the lateral malleolus. Inspection of the septum and identification of the common peroneal (fibular) nerve and/or the anterior tibial vessels confirm entry into the anterior compartment. The skin incision should be closely inspected and extended as needed to ensure that the ends do not serve as a point of constriction.

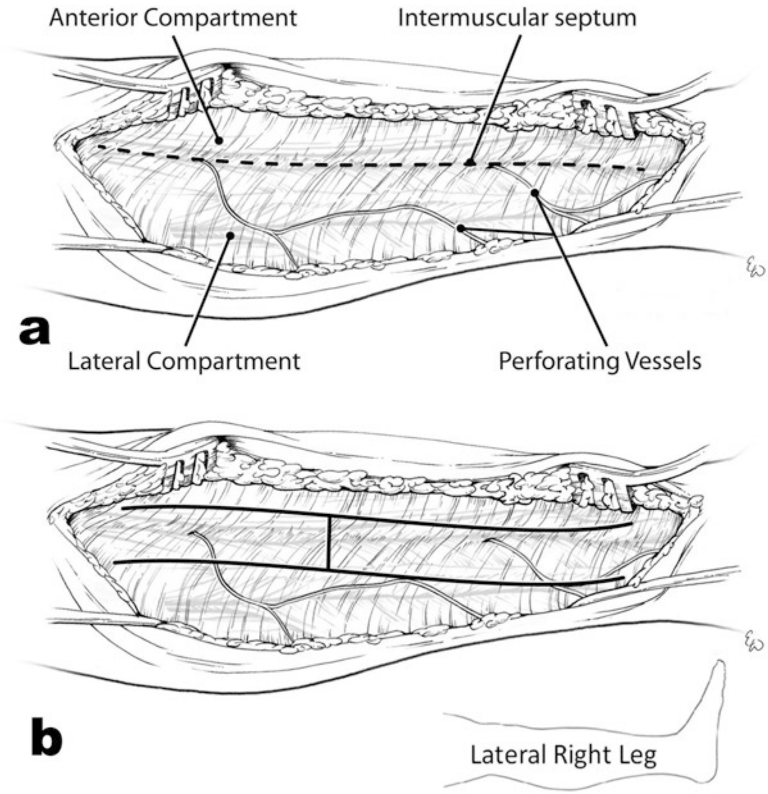


**Fig. 19.11** (**a**) The intermuscular septum separates the anterior and lateral compartments and is where the perforating vessels exit. (**b**) The fascia overlying the anterior and lateral compartments is opened in an "H"-shaped fashion

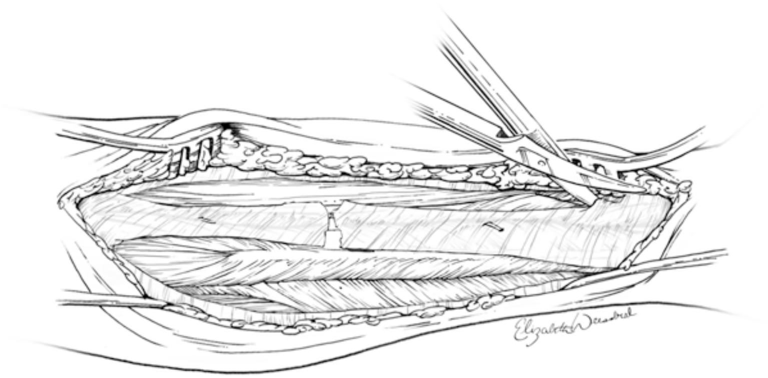

**Fig. 19.12** The fascia overlying the anterior and lateral compartments is opened using scissors in an "H"-shaped fashion with the scissor tips turned away from the septum

## The Medial Incision of the Lower Leg

The medial incision (see Fig. 19.10) is made one fingerbreadth below the palpable medial edge of the tibia (ONE THUMB BEHIND THE TIBIA). When making this incision, it is important to both identify and preserve the greater saphenous vein, as well as ligate any perforators to it. In most individuals, the fascia next encountered will be that which overlies the superficial posterior compartment which contains the soleus and gastrocnemius muscle. Opening this fascia from the tibial tuberosity to the medial malleolus effectively decompresses this compartment (Fig. 19.13). The key to entering the deep posterior compartment is the soleus muscle. The soleus muscle attaches to the medial edge of the tibia, and dissecting these fibers completely free from and exposing the underside of the tibia ensures entry into the deep posterior compartment (Fig. 19.14). Identification of the posterior tibial neurovascular bundle confirms that the compartment has been entered. The muscle in each compartment should be assessed for viability. The viable muscle is pink, contracts when stimulated, and bleeds when cut. Dead muscle should be debrided back to healthy viable tissue. The skin incision is left open and either covered with gauze or a vacuum-assisted wound closure device which has been shown in recent studies to speed up and improve the chances definitive closure of these wounds.

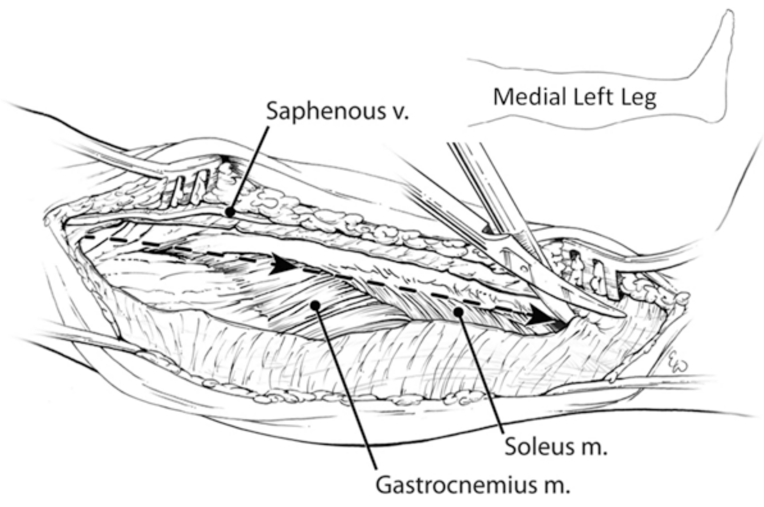


**Fig. 19.13** The medial incision is placed such that the saphenous vein can be identified and preserved, and the fascia is opened to expose the soleus and gastrocnemius muscles in the superficial posterior compartment

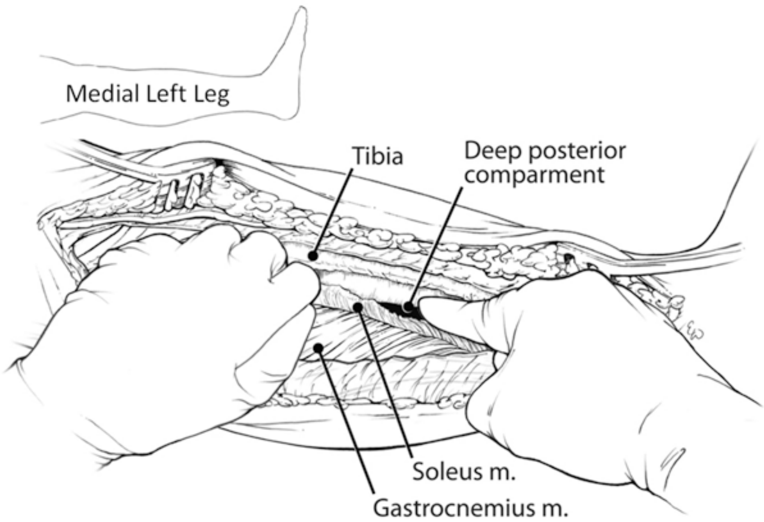


**Fig. 19.14** The soleus muscle is dissected off of the inferior border of the tibia allowing entry into the deep posterior compartment

## Pitfalls Associated with Fasciotomy of the Lower Leg

The major pitfall that should be avoided during lower extremity fasciotomy is failure to open one of the four compartments. The anterior compartment is the one most commonly missed during lower extremity fasciotomy. One of the reasons for missing the anterior compartment stems from making the incision too far posteriorly, either directly over or behind the fibula. When the incision is made in this manner, the septum between the lateral and the superficial compartment may be directly below the incision and is erroneously identified as the septum between the anterior and lateral compartments (Fig. 19.15a). When the lateral incision is made ONE FINGER IN FRONT OF THE FIBULA, the intramuscular septum between the anterior and lateral compartments is found directly below the incision making successful decompression likely (see Fig. 19.15b).

The deep posterior compartment can also be missed, and a thorough understanding of the anatomy is key to ensuring that this does not happen. One potential way to miss the deep posterior compartment is to get into the plane between the gastrocnemius and soleus muscle and believe that the compartment has been released (Fig. 19.16a). Proper decompression of the deep posterior compartment requires that the soleus fibers be separated from their attachment on the underside of the tibia (see Figs. 19.14 and 19.16b).

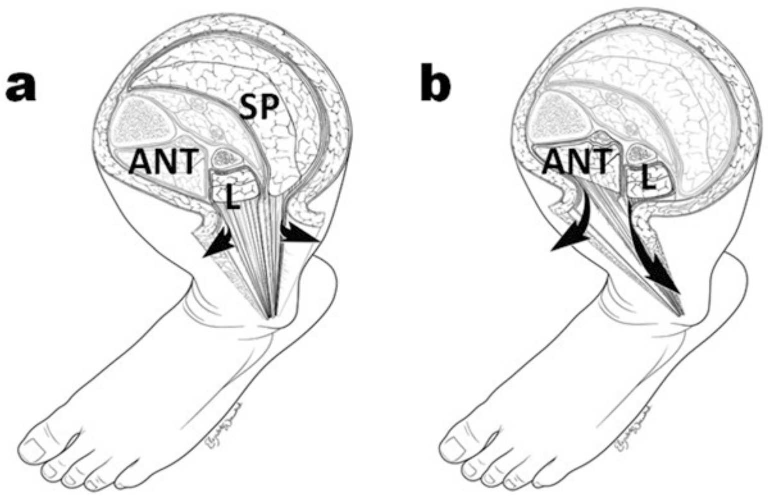


**Fig. 19.15.** As seen on the left (**a**), when the lateral incision is made too far posterior, the septum between the lateral (*L*) and superficial posterior (*SP*) compartments may be mistaken for that between the anterior (*ANT*) and lateral leading to the anterior compartment not being opened. When the lateral incision is made one finger in front of the fibula (**b**), the septum between the anterior and lateral compartments is more readily identified allowing for adequate decompression of both the anterior and lateral compartments

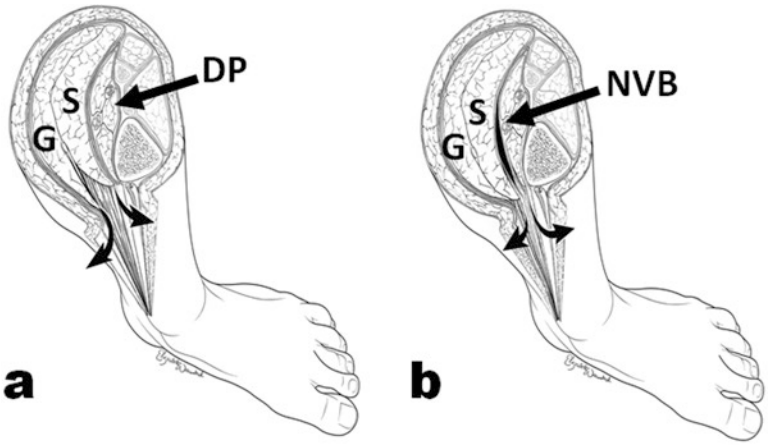


**Fig. 19.16** As seen on the left (**a**), a potential pitfall when doing the medial incision is to develop a plane between the gastrocnemius (*G*) and soleus (*S*) muscles and believing that this represents the plane between the superficial and deep posterior (*DP*) compartment. As seen on the right (**b**), entry into and release of the deep posterior compartment require separating both the gastrocnemius and soleus from the underside of the tibia. Identification of the neurovascular bundle (*NVB*) confirms that the deep posterior compartment has been entered

## How to Manage the Fasciotomy Wound

There are several dynamic ways to address the fasciotomy wound. Vacuum therapy is well tolerated and facilitates control of effluent as the tissues continue to swell. The problem with this approach is that since the dressing changes do not have to be done frequently, there is sometimes a tendency to not take the patient back often. Delay in treating the wounds frequently will result in the skin retracting and making primary closure difficult. This will then ultimately result in split-thickness skin graft. While this is acceptable, delayed closure of the skin will prevent subjecting the patient to taking skin off to cover a wound and is cosmetically preferable. There are many methods and devices available to assist in pulling the skin and subcutaneous tissue together. The main problem is that most approaches only pull on the skin edges. For example, a favored technique is to use a "roman lace" technique where vessel loops are stapled or sewn at the edge of the skin, and then some tension is applied to the open wound. The problem is that this is rarely strong enough to pull the wound closed. If too much tension is applied, then the sutures or staples fall out.

## Pulley Suture: Trick of the Trade

A trick of the trade which is highly effective in closing any type of wound is what we call the "pulley stitch" (Fig. 19.17). Care has to be taken as this suture is so effective that it can create a compartment syndrome from the skin. This technique is cheap as it only uses a heavy monofilament suture and can even be pre-placed loosely at the original operation so that it can be pulled at the bedside.

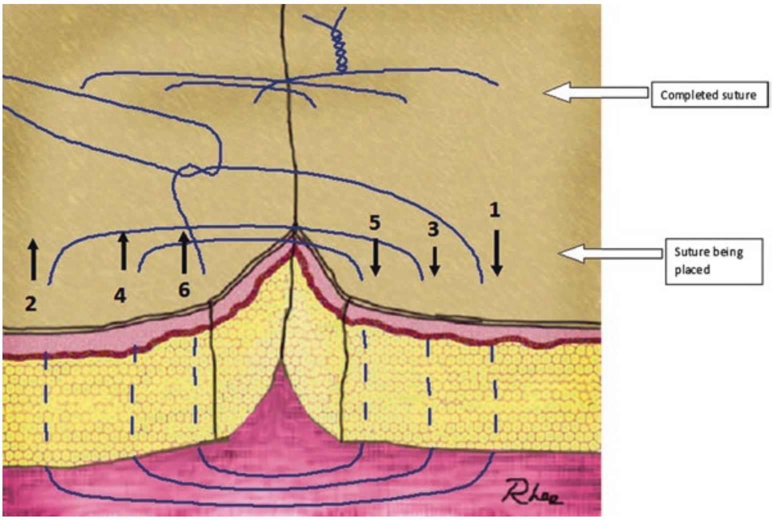


**Fig. 19.17** Pulley suture technique. Large suture is place continuously, 1 FAR, 2 FAR, 3 MIDDLE, 4 MIDDLE, 5 NEAR, 6 NEAR

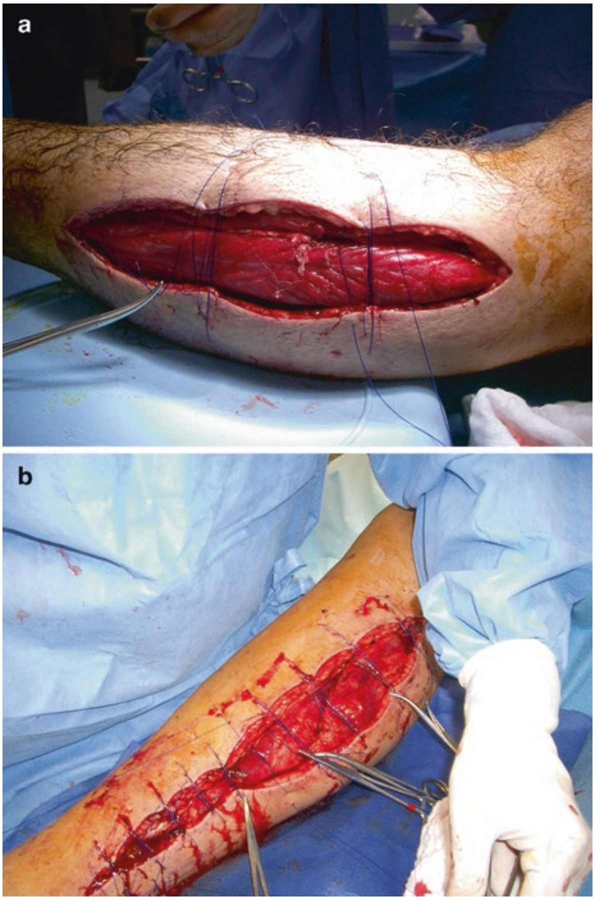


**Fig. 19.18** Panel (**a**) pulley sutures being placed with 2–0 Prolene. Panel (**b**) multiple pulley sutures in place ready to tie

This suture has been used successfully to close fascia, or any tissue. The principle of the suture is that you use one continuous suture to pull an area of tissue evenly as the sliding suture will distribute the tension equally, as opposed to the vertical mattress where all the tension is on the outer suture, and the tissue in between is bunched up. The inner suture only reapproximates the skin edges. The pulley suture will pull tissue far away from the wound while pulling tissue in the middle and at the skin edges as well. The wound can be closed over a small penrose drain if needed. After several pulley sutures have been placed, other simple or running sutures can be placed between or across the pulley suture (Fig. 19.18), or staples can be used. Once the skin has stretched in a day or so, sutures under tension can be cut, and the sutures that were not under tension will take over the burden of the tension. This technique has prevented the need of many reconstructive surgeries including skin grafting (Fig. 19.19). To create a pulley suture, start with a simple interrupted suture taking about 2 cm bites of the skin and subcutaneous tissue. The second pass should mirror the first, except now take the bites about 1 cm from the

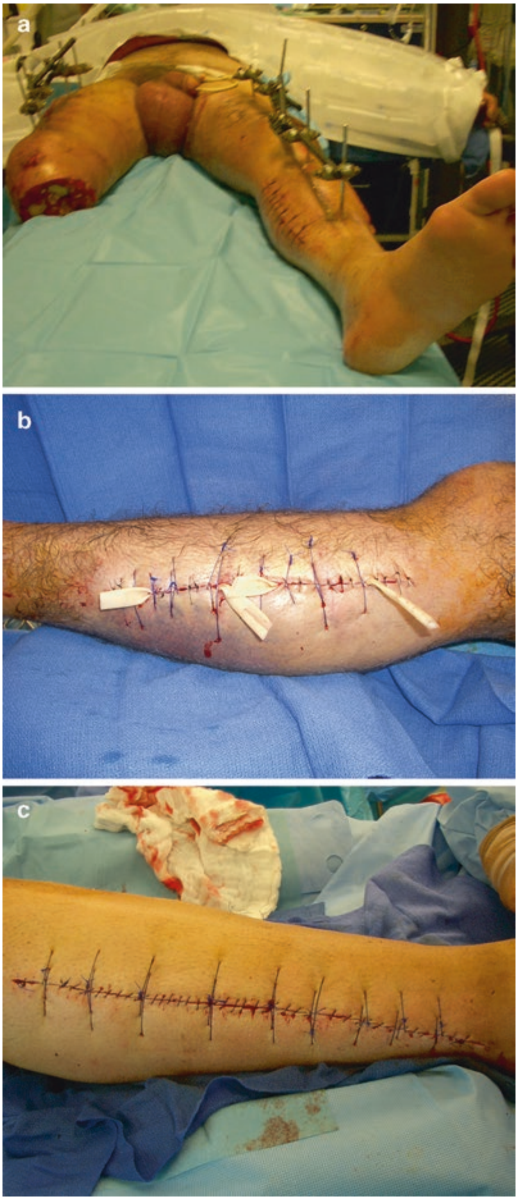


**Fig. 19.19** Examples of definitive combat wound closures. Panel (**a**) fasciotomy wound closed. Panel (**b**) closed over penrose. Panel (**c**) skin edges closed across the pulley sutures

skin edge, in the same line as your first pass. The third pass is again in the same direction, but taking only skin edge to skin edge (2–3 mm). Steady gentle upward traction on the suture ends will now create significant and distributed force to bring the wound together and allow for easy knot tying under no tension. As opposed to the vertical mattress suture which is "far – far – near – near," the pulley suture is "far – far – middle – middle – near – near."

## Final Thoughts

Soft tissue wounds experienced in modern warfare are considerable challenges that you will frequently encounter. Be aggressive about irrigation and debridement – it will serve you well in avoiding the local and systemic effects of what can develop into devastating infection. But do not be aggressive about closing these wounds at the initial operation! This is one of those lessons that seem to be learned the hard way by newly deployed surgeons, over and over again. Remember that your decision-making and technique can set the stage for a successful outcome or a devastating complication, even when dealing with the "simple" soft tissue wound. Additionally, become an expert on learning how to diagnose and treat compartment syndrome. You should be proficient with fasciotomies and look for reasons not to do a fasciotomy on combat casualties with extensive soft tissue wounds of the extremities.

**Acknowledgment** The authors are grateful to Ms. Elizabeth N. Weissbrod, MA, CMI for the excellent illustrations used in this chapter.

## Relevant Joint Theater Trauma System Clinical Practice Guidelines Available at: www.Usaisr.Amedd.Army.Mil/Cpgs.Html

1. Acute extremity compartment syndrome – fasciotomy.
2. Management of war wounds.
3. CCAT negative pressure wound therapy (for patient transport).

# 20 Extremity Fractures and the Mangled Extremity

Brandon R. Horne, R. Judd Robins, and George Velmahos

**Deployment Experience**

| | |
|---|---|
| *R. Judd Robins* | Chief, Orthopedic Surgery, 655th Forward Surgical Team, Ghazni, Afghanistan – Operation Enduring Freedom, 2010 |
| *Brandon R. Horne* | Chief, Orthopedic Surgery, 447th Expeditionary Medical Support Squadron, Baghdad, Iraq, 2006–07<br>Chief, Orthopedic Surgery, Craig Joint Theater Hospital, Bagram, Afghanistan, 2009 |

*In reality there is no way to separate today's surgery and our practice from the experiences of all the surgeons who have preceded us.*

Ira M. Rutkow

B.R. Horne
Wright-Patterson Medical Center, Department of Orthopaedics, Wright-Patterson AFB, Dayton, OH, USA

R.J. Robins (✉)
Uniformed Services University of the Health Sciences, United States Air Force Academy Ambulatory Surgical Center, Department of Orthopaedic Surgery, Sports Medicine Service, USAF Academy, El Paso, CO, USA
e-mail: RobinsRJ@Hotmail.com

G. Velmahos
Emergency Surgery and Surgical Critical Care, Massachusetts General Hospital, Department of Surgery, Boston, MA, USA


M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_20

**BLUF Box (Bottom Line Up Front)**

1. Damage control principles guide orthopaedic treatment in the austere environment.
2. It is required at times to operate on multiple extremities or have multiple surgical teams engaged simultaneously.
3. Application of a tourniquet is the initial treatment of traumatic amputations or mangled extremities.
4. Remove all debris, foreign bodies, and devitalized tissue at the first operation—*Do Not Perform Primary Wound Closure*.
5. When possible, attempts at limb salvage should guide initial surgical treatment for traumatic amputation and mangled limb injuries.
6. Principles of triage and surgical care are life over limb—when a patient is in extremis, therapeutic amputation may be required to preserve life.
7. Know how to apply a basic external fixator—even for non-orthopaedic surgeons.
8. Know the environmental constraints—if no advanced orthopaedic care is locally available, complex limb salvage surgery for a local national is not a viable option. Definitive amputation may be indicated.
9. If there is poor prosthetic support, then a local national patient may be better off with a poorly functioning but intact limb than an amputation.

## Caveats

1. Rough reapproximation of skin as a temporary closure over a drain or hemostatic dressing may help control bleeding/oozing during transport—this act must be documented and communicated.
2. Foot wounds, especially near or in glabrous skin, benefit from immediate closure if clean and appropriately debrided.
3. Cultural differences: if amputation is inevitable but not immediately necessary, consider immediate amputation. In certain cultures (e.g., Afghanistan), despite clear indications, cultural biases will prevent the patients from consenting to amputation to the point of prolonging care (using up critical bed space) or risking their life from infection.

## Initial Assess1ment and Resuscitation

Advanced trauma life support principles guide all facets of care, including traumatic amputations and mangled extremity injuries. It is easy for the medical team to be distracted by major extremity war injuries, but principles of controlling hemorrhage, securing airway and breathing, and ATLS secondary surveys remain the cornerstone of initial treatment. It is important for orthopaedic and limb surgeons to support and direct the priorities of initial trauma care.

To this end, early application of tourniquets for hemorrhage control is a mainstay of wartime trauma care. Limb-threatening injuries due to blast effects can lead to massive hemorrhage and quickly become life-threatening injuries. This can occur through characteristic pulsatile bleeding from an arterial injury or sustained low pressure bleeding from venous sources, injured muscle, and fractures. While civilian trauma care approaches tourniquet use as a treatment of last resort, in the combat setting, tourniquets are applied early and often. Orthopaedic and trauma surgeons can encourage and support the use of tourniquet application by first responders/field medics to help preserve both life and limb.

Initial trauma care for patients with mangled extremities and amputations is to stop the bleeding. A well-applied tourniquet can control hemorrhage immediately. Additionally, the application of topical hemostatic dressings and compression dressings can aid in controlling less profound sources of blood loss. If initial surveys determine hemorrhage cannot be controlled once a tourniquet is released, then surgical control is the only option. Initial resuscitation should include judicial use of blood product replacement. Most patients with traumatic amputation or mangled limbs present with significant loss of blood volume. The typical combat casualty is young and healthy and will have significant reserve but will crash physiologically once they lose a critical amount of blood. Replacement with intravenous fluids most often is inadequate, therefore many times patients require the use of multiple units of packed red blood cells, plasma, platelets (often recommended as a “pack” of 4 units pRBCs, 4 units FFP, and 1 “6 pack” of platelets per mangled/amputated limb), and occasionally whole blood.

For mangled extremities and traumatic amputations, administer tetanus toxoid and a first-generation cephalosporin early in the the patient's resuscitation. Studies from civilian trauma centers support the most important factor in preventing infections in open fractures is time from injury to administration of antibiotics [5]. Surveillance data from the Joint Theater Trauma Registry has demonstrated that administration of additional antibiotics to include aminoglycosides and/or penicillin actually leads to increased infection rates over the ensuing days and weeks of treatment [6]. If the patient is stable for transport, go to the OR. However, trauma bay debridement focused on removing gross contamination, copious amounts of irrigation with sterile saline, and application of a sterile dressing should be accomplished. The use of supplements such as antibiotics and soaps in irrigation solutions has demonstrated increased wound complications and infection rates, so sterile saline is the best solution of choice for irrigation [7]. Do not forget splints if time/situation permits. This can decrease pain and blood loss.

In combat trauma, teams often must operate on multiple sites at the same time. Prep the entire body, including all involved extremities, so that all teams may operate simultaneously. This will save significant time and resources and get the patient to the ICU/recovery in rapid fashion. Before removing field tourniquets, apply a pneumatic tourniquet above the site of injury. If needed, prep the field tourniquet into the sterile field prior to removal to minimize blood loss between the time of tourniquet removal and surgical control. The first operation is damage control: control hemorrhage and debride the wound. A therapeutic amputation may need to be considered at this time for both hemorrhage control and to stabilize the patient in extremis. If required, proceed rapidly and without delay. Use a tourniquet, remove the limb, identify vascular structures, and suture ligate with stout “stick ties.” 0 silk works well. For large vessels, consider double ligature. Tag large nerves for later revision if identified.

## Open Extremity Fractures

The keys to successful management of open fractures are early antibiotics, temporary stabilization, and irrigation and debridement (I&D) of wounds that is repeated until a clean wound bed is established, followed by eventual definitive stabilization and closure. Early fracture stabilization has multiple benefits in physiologically stabilizing the distressed trauma patient. It will significantly decrease fracture-related pain and can often stop bony and soft tissue blood loss. It will decrease the systemic inflammatory response and may provide protection against fat embolization. In addition, the surrounding neurovascular structures will be protected from further injury due to mechanical instability. Appropriate stabilization is absolutely required before mobilization or transportation to another facility.

There is no consensus on timing for open fracture irrigation and debridement, timing on fixation, amount of irrigation to use, or how long to prescribe antibiotics. Common practice that is supported in the literature, based on Joint Theater Trauma System data, is urgent administration of antibiotics (upon arrival in the trauma bay/prior to surgical intervention) and debridement and irrigation of open wounds as soon as possible. Low-pressure, high-flow irrigation with normal saline is the best choice for irrigation.

It is important to take open fractures or potentially open fractures to the OR for debridement and provisional stabilization. There is no practical role for culturing acute fracture wounds. Repeat irrigation and debridement of open fractures every 24–48 h or arranging for that to be done through the evacuation chain is the standard of care. Consider performing an irrigation and debridement on the day of transfer to a higher level of care to accommodate potential delays during transport. Clearly mark the dressing with the date of the last operative debridement so that colleagues who receive the patient will be aware of the last intervention.

Occasionally, it can be difficult to determine whether a fracture is truly open or is closed with a local abrasion. There is a fair amount of disagreement regarding how to treat these. In the combat environment, treat them as open fractures until proven otherwise.

## Nerve and Tendon

It is common to encounter injured nerves and tendons during exploration and debridement of extremity wounds. It may be difficult to distinguish tendon from nerve; inspecting the cut end (after debriding devitalized segments) will help with identification: nerves will be yellow-white and contain multiple round fibers, while tendons will be blue-white and have cross-hatching (like wood). Blast injuries in war trauma typically result in massive wounds with significant contamination and nonviable tissue, so there is little role for immediate primary repair. Tendon repairs can wait until the wound is cleaner, and most combat nerve injuries will be repaired in a delayed fashion. In general, leave hand tendon repairs for someone with specialized training. Tag the ends of the nerve for easy identification later.

Occasionally, one will encounter a very clean and sharp major nerve transection suitable for immediate primary repair with no orthopaedic surgeon or neurosurgeon immediately available. Common examples are median or ulnar nerve transections (often associated with brachial artery injuries). In these cases, align the ends of the nerve properly, sharply debride the ends to a clean edge, and reapproximate the epineurium only using fine Prolene (6–0) or nylon sutures (Fig. 20.1). Ensure adequate tissue coverage of the repair. Splint or stabilize the extremity in some degree of flexion to prevent tension and motion at the repair site. It will take months to determine the success of repair and ultimate degree of return of function.

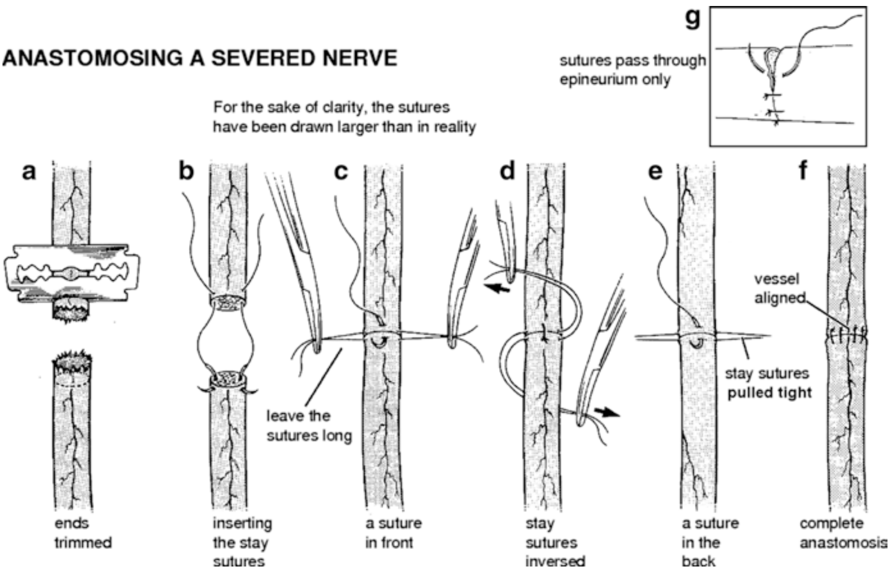


**Fig. 20.1** Technique of epineurial primary nerve repair. The ends of the nerve are sharply debrided (**a**), two stay sutures are placed (**b**), anterior (**c**) and posterior (**d**, **e**) approximating sutures are placed, and the anastomosis is completed with multiple interrupted sutures (**f**). Note that sutures pass through the epineurium only (**g**) (Reprinted with permission from "Injuries to Vessels, Nerves, and Tendons." In: Primary Surgery, Volume 2, German Society for Tropical Surgery, 2008, Fig. 55.8, illustration by Peter Bewes)

## Compartment Syndrome: When to Intervene

Much attention is given to compartment syndrome and fasciotomies when discussing combat trauma, with emphasis focused on never missing a potential or existing compartment syndrome. Some have advocated using a very lowh threshold to perfom fasciotomies, particularly on patients with extremity injury who are being placed into the evacuation chain.

Management of compartment syndrome, even in war trauma, needs to be indicated. Fear of missing a compartment syndrome should not drive a surgeon to perform fasciotomies "just to be safe." Indications for compartment fasciotomies are certainly indicated in patients with tense compartments that are easily noted with palpation and described as noncompressible or "woody hard." Other indications are in alert patients with pain out of proportion and pain with passive stretch, as well as patients with reperfusion of a previously dysvascular limb when intensive care observation is not available. Some discussion has focused on performing prophylactic fasciotomies on patients prior to transfer to higher echelons of care. It should be remembered that lower limb fasciotomies will be associated with a 25% complication rate in regard to sensory function, wound complications, and infection, as well as cause potential need for skin graft, and can complicate definitive fixation options. When hard signs and symptoms are present, there should be no hesitation on the surgeon's part to perform emergent fasciotomies. If transfer time between levels of care is greater than 4 h and patients are at reasonable risk of developing a compartment syndrome in transit, then fasciotomies may be indicated in this situation. However, when short transfer times are available or the capacity to hold a patient for 24 h of observation exists, then close observation and clear communication with the receiving surgeon are likely to be of greater benefit to the patient. See Chap. 19 for detailed review of extremity fasciotomy techniques.

As a final word regarding compartment syndrome, strongly resist the urge to release a missed compartment syndrome. If receiving a patient and time of injury or time of onset of compartment syndrome is unknown, or if it is uncertain that onset occurred less than 8–12 h ago, it is best to not perform fasciotomies. Experience in the Global War on Terror has demonstrated a threefold increase in mortality and twofold increase in amputation rate when fasciotomies are performed on delayed or missed compartment syndromes [8]. Please recognize the chance to intervene to save function has passed, and opening a necrotic compartment will likely harm the patient. In these cases, splint the affected extremity, treat pain, monitor renal function, and ensure appropriate hydration occurs to prevent renal damage from the onset of myoglobinuria.

## Amputation vs. Limb Salvage

The decision to amputate can be agonizing. There are generally two absolute indications for amputations in wartime surgery:

1. Near-complete traumatic amputation with an obvious nonviable distal segment (Fig. 20.2).
2. A patient in extremis and the injured extremity's condition is contributing to their demise.

**Fig. 20.2** Near-complete lower extremity amputation with proximal pneumatic tourniquet. Limb salvage is clearly not possible, and the amputation should be quickly completed and left open

Unfortunately for the combat surgeon, the more common scenarios are not as clear cut. Often, combat surgeons have little experience in complex limb reconstruction for the mangled extremity. Therefore, in forward settings, as long as the patient can be resuscitated, perfusion to the limb can be maintained or restored, every potentially salvageable limb should be preserved. This requires a multidisciplinary approach between general, vascular, and orthopaedic surgeons. This principle especially guides treatment for upper extremities, where the function of a residual limb can far exceed that of a prosthesis. When possible, have a frank discussion with the patient regarding the status of their injuries, and make no promises as to the ultimate success of limb salvage efforts. After the patient has survived their acute injuries and arrived at rear tertiary care centers, the decision to amputate based on reconstructive feasibility and expected functional outcome can be better made with more clear indications in this setting. Contrary to LEAP study data and recommendations regarding the detrimental effects of delayed amputation, for the combat casualty who participates in the decision for "late" amputation, the patient can often be left with the sense that amputation was the best course of treatment and that every effort was made to salvage the limb prior to amputation.

Three points warrant highlighting. First, scoring systems, such as the Mangled Extremity Severity Score (MESS) that is used to evaluate the mangled extremity, do not reliably indicate the need for amputation or predict successful limb salvage in wartime mangled extremity injuries [9]. Treatment decisions should not be made on the basis of such a score alone. Second, when considering amputation, make every effort to consult with available surgical colleagues and determine consensus. Document the reasons for the decision and any feedback provided from surgical consultations. Third, distal sensation of the mangled extremity *should not be considered* in the initial decision to amputate or attempt limb salvage. Early sensory loss of the foot has minimal impact on long-term functional outcome, and acute sensory function is not predictive of long-term sensation, particularly for the patient who has a tourniquet applied or a coexisting vascular injury [10].

When attempting limb salvage, common scenarios include initial rapid stabilization of the limb with external fixation, restoring arterial perfusion with a temporary arterial shunt as required, wound debridement and irrigation, definitive restoration of blood flow as indicated, and management of compartment syndrome and reperfusion injury, followed by definitive closure, many times with the use of flap coverage and skin grafting. Bear in mind the local unit surgical capability and its context within the theater medical plan and most importantly the overall condition and stability of the patient. Do not discount the ability to rapidly transfer a dysvascular limb to a higher echelon that is capable of vascular repair/shunt. This should obviously be considered in light of the transport time/distance, weather, tactical situation, and casualty load.

## Debridement

The initial surgery often provides the best opportunity for debridement as the soft tissues are compliant, and there are no constraints related to protecting previously repaired or reconstructed tissues (Fig. 20.3). It is hard to overstate the extent of dirt, bone, debris, and fragments that can be driven into the soft tissues and along fascial planes by an explosive device (Fig. 20.4a, b). Develop and utilize a methodical

**Fig. 20.3** Traumatic amputation being prepared for initial debridement. Only devitalized tissue should be removed and no attempt made to formalize or close the amputation

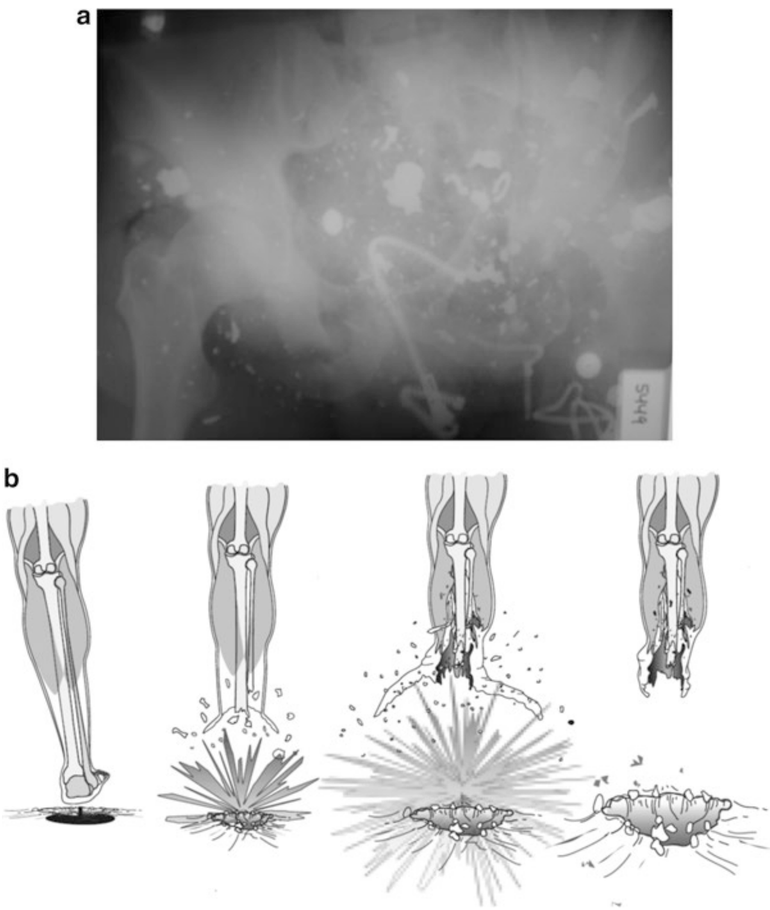


**Fig. 20.4** (**a**) Preoperative x-ray demonstrating the amount and extent of contamination forced into the soft tissues by a typical blast mechanism. (**b**) "Umbrella effect" of blast mechanism commonly found in military personnel on dismounted patrol that encounter the direct effects of a mine (Reprinted from Emergency War Surgery, 3rd Revision, 2004. Compiled by Walter Reed Army Medical Center Borden Institute, US Department of Defense, US Army. The fourth edition is available here: https://bookstore.gpo.gov/products/sku/008-300-00050-0-0)

approach to debridement of wounds in order to maximize efficiency and efficacy. Start with removing gross contamination; this can be done in the trauma bay and also immediately prior to the surgical prep. After sterile preparation and draping, inspect the wound and become familiar with the gross anatomy of the injury; develop a plan to extend traumatic wounds that will allow exposure of the zones of injury. Start with debridement of the nonviable skin and subcutaneous tissues. Avoid raising skin flaps alone—preserve the perforating blood supply to the skin when possible. Scissors work well for this step. They are quick and leave a clean edge, and there is less risk of injuring a surgical assistant in the hectic surgical environment. Next, extend traumatic fascial defects, being mindful of underlying peripheral nervous and vascular anatomy, to allow inspection of the underlying muscle as deeply embedded fragments that can burn deep tissues despite an innocuous superficial appearance. Accessible fragments and other ballistic material should be removed, although every piece of metal does not need to be taken out if the trauma of exploration exceeds the benefit of foreign body removal. Carefully inspect and remove contaminated bone that no longer has soft tissue attachments. At times, if a significantly large or vital fragment of bone is void of soft tissue attachment, consider retaining in a non-contaminated or clean and well-perfused portion of the wound bed [11]. An example includes periarticular bone fragments with cartilage. Fragments of bone with articular cartilage should be retained if the associated joint is being preserved, as reconstructive options are limited for joints with significant articular loss. Consider placing these fragments in a subcutaneous pouch remote from the zone of injury (communicate effectively with receiving surgeons); abdominal pouch works as well for sterile loose bone fragments. Bone with soft tissue attachments should be preserved. Prior to stabilization, fractures may be displaced to allow access to the deep tissues; subsequent exposure will be limited by provisional and definitive skeletal stabilization.

Please note a consistent theme: preservation of viable tissue. While this is an important concept, the wound should look vastly different after an effective debridement than it did at the time of arrival. It should be clean, the soft tissue margins and flaps relatively stable, and bleeding controlled. When applying dressings, place deep wicks or Penrose drains to prevent deep fluid collection while avoiding deep placement of isolated sponges that may be missed and left in place during subsequent surgery. When using negative pressure wound therapy (NWPT) dressings, long strips that extend outside the skin are preferable to small pieces placed deep that may be missed at later operations. Consider placing deep drains that exit into and are powered by the NPWT sponge. Cover the wound with a bulky, lightly compressive dressing, and splint if indicated. Document on the dressing or in the medical records the extent and nature of findings along with the procedures performed, and recommendations for the timing of follow-on debridement. Repeat debridements are the rule; therefore, preserve tissue of questionable viability at the initial debridement.

A hallmark of wound care of contaminated war wounds has been to “leave wounds open.” This concept of wound management should guide initial wound care. Several points of open wound care are worth discussion. At higher echelons of care, NPWT has proven to be a significant advancement in management of war wounds until definitive closure can be accomplished [12]. Advantages of NPWT include improved hemostasis of wounds, reduction in dead space and wound volume, minimizing the need for dressing changes and dressing management, early promotion of angiogenesis, and recruitment of fibroblasts encouraging wound healing. NPWT environments reduce gram-negative bacterial load, and the use of silver-impregnated dressings has been demonstrated to reduce gram-positive bacterial load [13]. NPWT, however, is not often available at lower echelons of care. Compounding this, it is at these echelons of care that patients present immediately after sustaining massive injury and are physiologically unstable with large base deficits, large blood volume loss, and coagulopathy. After fracture stabilization,

**Fig. 20.5** Temporary closure of amputated leg—not visible is the hemostatic dressing packed inside the wound. Author's personal photo

wound debridement, and irrigation of wounds, simply placing a bulky dressing with or without hemostatic agents in large open wound beds with extended incisions in a patient that remains coagulopathic and still undergoing resuscitation will not result in hemostasis and subsequently the wounds will continue to ooze and bleed. In efforts to prevent continued blood loss and help with resuscitation, wounds and incisions may need to be packed and partially or completely "temporarily closed," over a drain or wick to prevent continued blood loss (Fig. 20.5). In these cases, whipstitching the wound with a nonabsorbable non-braided suture with explicit and clear instructions or plans at the next level of care for removal of the whipstitch and drain, packing, and evaluation of the wound after the patient has been stabilized is required to aid in patient resuscitation and preservation of life.

## Skeletal Stabilization

The stabilization of long bone fractures will minimize ongoing blood loss and damage to injured soft tissues and improve pain control. In the management of fractures sustained in combat, particularly of the lower extremity, pelvis, and in upper extremity vascular injuries, external fixation is the primary initial form of skeletal stabilization. In general, external fixation is meant to span an area of bony instability by placing partially threaded Schanz pins into bone. Typically, two pins above and below the area to be spanned are sufficient. Be familiar with safe zones to avoid damaging vital structures. Classic teaching is to place the pins outside the zone of injury; however, pins placed close to the fracture site within the zone of injury may create a more rigid construct due to shorter working length and minimize damage to normal tissue.

It is important to remember that external fixation is not the only available technique for fracture management in the combat setting, and the effective use of external splinting such as Hare Traction Splints or the use of contralateral limbs, a circumferential sheet, or pelvic binder for an unstable pelvis fracture or commercially available wire, plaster, or fiberglass splints for other appendicular injuries is preferred in some cases to external fixation. Knowledge of extremity bone, neurovascular, and muscle and joint anatomy is essential for safe and effective placement of external fixation pins, in particular when intraoperative radiographic imaging is not available to assist with pin placement. Skeletal traction with hanging weights is contraindicated in patients requiring transport. Another option to consider is placement of a small plate spanning a fracture with two locking screws above and below the fracture line. This serves as "internal" external fixator and facilitates dressing coverage, especially NPWT-type dressings. They are also less bulky and can be biomechanically more stable. This plate/screw construct can then be removed at subsequent debridements prior to definitive fixation.

## External Fixation

External fixators used in the provisional stabilization of combat casualties are typically "spanning external fixators" which gain control of the unstable segment of the limb by inserting threaded Schanz pins into bone remotely above and below the zone of injury and connecting these pins with carbon fiber or metal rods external to the body to neutralize the forces across the zone of injury, thereby stabilizing it. The minimally invasive nature of this technique also minimizes the risk of potential future implanted orthopedic devices and allows access to the wounds for follow-on care without having to destabilize the limb. The specific steps required to insert Schanz pins into bone vary depending on each system, some of which require predrilling. While image intensification is desirable, it often is not available in austere environment settings.

Schanz pins must be inserted through safe zones of access to the long bones which minimize the risk to the neurovascular structures. In general, these safe zones include the anterolateral surface of the proximal humerus, the lateral surface of the distal humerus above the elbow, the subcutaneous border of the ulna, and dorsal surfaces of the metacarpals in the upper extremity. In the lower extremity, the anterior and lateral surfaces of the femur are available, as is the anteromedial surface of the tibia and the calcaneal tuberosity (Fig. 20.6). Despite the relatively superficial nature of these safe zones, major neurovascular injury can occur at any of these levels in the absence of proper technique. An excellent reference for the deploying combat surgeon who may need to apply an external fixator is *The Atlas for the Insertion of Transosseous Wires and Half Pins*.

A minimum of two pins are usually required to gain control of a long bone/limb segment. Insert two pins in the same bone above the zone of injury and two below.

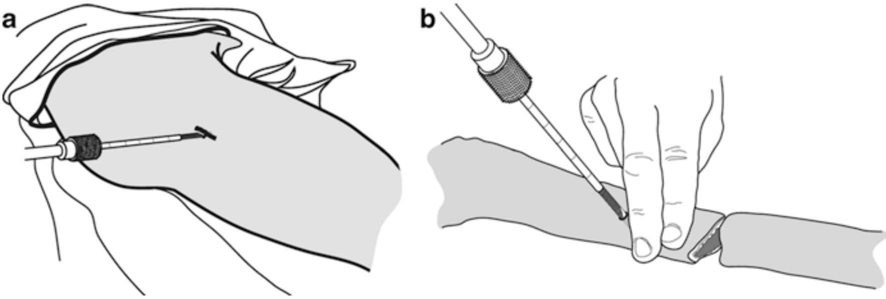


**Fig. 20.6** Safe zones for pin placement in the femur (**a**) and tibia (**b**) (Reprinted from Emergency War Surgery, 3rd Revision, 2004. Compiled by Walter Reed Army Medical Center Borden Institute, US Department of Defense, US Army. The fourth edition is available here: https://bookstore.gpo.gov/products/sku/008-300-00050-0-0)

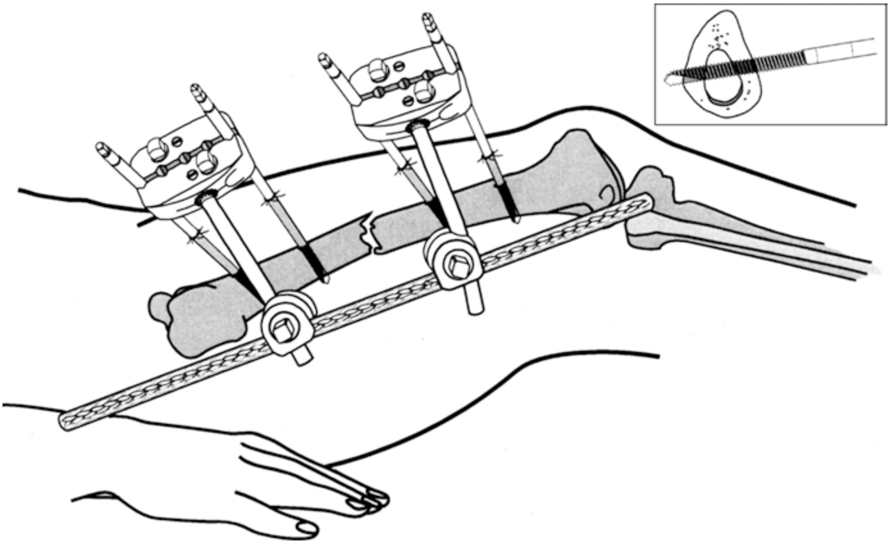

**Fig. 20.7** Example of a spanning external fixator stabilizing a femur fracture. The *inset* shows ideal bicortical pin placement (Reprinted from Emergency War Surgery, 3rd Revision, 2004. Compiled by Walter Reed Army Medical Center Borden Institute, US Department of Defense, US Army. The fourth edition is available here: https://bookstore.gpo.gov/products/sku/008-300-00050-0-0)

Meticulous pin insertion technique should be used: the skin is incised sharply directly over the region of intended pin placement, and sharp and blunt dissection (using a Kelly clamp) is used to gain access to the bony surface. A saline cooled drill bit is used to drill a pilot hole through a drill sleeve utilized to minimize injury to the local soft tissue when available, or self-drilling half pins with a hand drill can reliably be used in the austere setting. The pin is then inserted through the sleeve deep enough to engage the far cortex of the bone and obtain bicortical purchase (Fig. 20.7). Image intensification is very useful in ensuring proper pin placement and depth, but pins can be placed without fluoroscopy if careful attention is paid to local anatomy and the “feel” of the bone on pin insertion. When the tip of the pin engages the far cortex, increased torque is required to insert the pin further. This information along with the knowledge of thread pitch (and therefore how many “turns” are required to advance the pin into bone after initial engagement) allows for safe bicortical pin placement without image intensification. Many times, this is 6–8 turns after the initial resistance of the far cortex is encountered. After two pins are placed in each bone or bone fragment, they are connected with a multiple pin bar clamp or to a bar isolated to that segment. The fracture is reduced (using imaging if possible), or the extremity is stabilized when imaging is not available and the two segments connected with additional bars and bar-to-bar clamps as required. The sequence of pin placement and frame assembly varies according to the experience of the surgeon, treatment goals, and local anatomy. There are several commercially available external fixator devices, each with their own nuances (Fig. 20.8). An important step after the application of spanning external fixators is to verify the postoperative neurovascular status of the limb. When discovered, the etiology of the change in the neurovascular status must be determined and rectified.

**Technique Overview**

**1**
**Insert Schanz screws**
Use the 6-Position Drill Guide Handle (392.963) or pin clamp technique to ensure proper pin spacing.

**2**
**Attach pin clamp**
Tighten the vise plates.

**3**
**Attach outrigger posts**
Thread posts into the vise plates to a hard stop.
For angled posts, turn the post counterclockwise to the desired orientation. Lock in position by turning the lock nut clockwise until tight.

**4**
**Attach carbon fiber rods**
Attach carbon fiber rods to outrigger posts with combination clamps.

**5**
**Reduce fracture**
Reduce the fracture and tighten all clamps.

**Note:** To increase stiffness, add a second rod to the frame by repeating Steps 3 and 4 on the opposite side of the pin clamps.


**Fig. 20.8** Instructions for applying a simple box external fixation frame (Figure courtesy of Synthes Corporation, Philadelphia, PA)

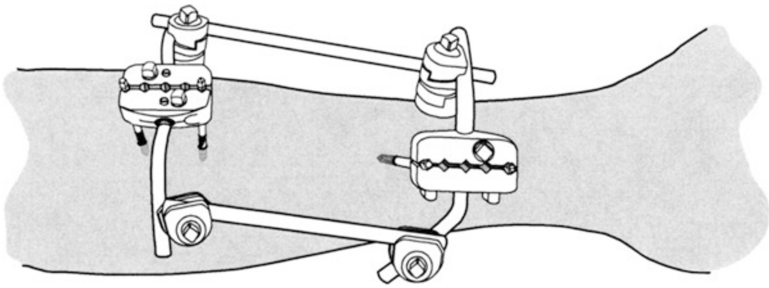

**Fig. 20.9** Addition of a second longitudinal bar increases the stability of the external fixator construct (Reprinted from Emergency War Surgery, 3rd Revision, 2004. Compiled by Walter Reed Army Medical Center Borden Institute, US Department of Defense, US Army. The fourth edition is available here: https://bookstore.gpo.gov/products/sku/008-300-00050-0-0)

In the lower extremity, the most practical insertion position of the pins will be straight anterior. Since spreading out the pins will give you the most stability, put them just above the ankle, just below or above the knee and just below the greater trochanter. The position of the fracture will determine where the intervening pins go. The long bones are about 2–3 cm in diameter, so once the anterior cortex is engaged, make a visual cue of the pin against the skin to serve as a rough guide of how far to advance the pin. Add as many longitudinal bars as needed for stability (Fig. 20.9), but keep constructs as simple as possible, and use as little as is necessary to provide stabilization of the soft tissues and bone fragments.

**Example Fixation Situations** It is safe to assume an external fixator will be required to stabilize an open tibia fracture. It is safe to put all the pins anterior in the medial crest. Pin spread increases stability. Make a little knick in the skin with a knife and spread down to the bone with a Kelly clamp. Put a pin against the desired location on the cortex of the bone and tap lightly to "seat" the pin. This will create a little divot, so the pin won't spin away from its target when initiating drilling. The pin should feel solid when it is in both cortices; if it seems like it toggles too much, it may not be in the bone deep enough. When the pins are in, reduce the tibia by applying axial traction so it looks grossly well aligned and connect all the bars.

If treating a fractured femur, you can place the pins in safely from lateral to medial or anterior to posterior (see Fig. 20.6). If it is anticipated, the patient will have the external rotator removed within a short amount of time, and then note that the lateral pins seem to snag on transfer gurneys, so anterior pins are more convenient. However, if it is suspected that the external fixator will remain for longer than 7–10 days, then anterolateral pin placement is desired to avoid scarring of the quadriceps muscles and subsequent arthrofibrosis of the knee. Near the hip is the easiest way to find the desired pin location by palpating the greater trochanter as a reference. Of note, a proximal femur fracture can present significant challenges because the proximal part is hard to obtain pin purchase due to much thinner cortices. In this setting, it is probably worth either splinting the legs together or using a traction device for transport to a higher level of care.

Arm and forearm external fixation is challenged by smaller bones and higher neurovascular risk with pin placement. The distal radius will accept pins on the radial/lateral side. The humerus will accept pins laterally, but care must be taken to protect the radial nerve, which travels from posterior to anterior along the junction of the middle and distal one-third of the humerus. Use the same placement and drilling techniques for the lower extremity. Make a small superficial incision, bluntly dissect to bone, and then drill. The radius will need a much smaller pin diameter (3–4 mm), and the thickness of the radius can be very deceiving due to thinner cortices. Metacarpal pins should not exceed 3 mm in diameter.

## Final Thoughts

**War Trauma Management Is a Team Effort** Help your patients survive evacuation to the next level of care to optimize recovery and preservation of limb function. Be familiar with the theater medical treatment and evacuation policy, and do what is necessary to advocate for and optimize patients' care in these austere environments. Establish open chains and multiple methods of communications with field medics, commanders, physicians and surgeons transferring and receiving patients at lower/higher echelons, and MEDEVAC personnel in order to accomplish this goal. Seek and provide feedback on patient care approaches and techniques to improve the medical team's ability across these multiple echelons of care.

## Civilian Translation of Military Experience and Lessons Learned

George Velmahos
In this truly practical and exceptionally well-written guide of "what to do with extremity injuries," Drs. Horne and Robins offer all the important principles of severe extremity trauma management. As expected, they focus on the early stage, which is probably the most important one for the stabilization of the injured victim and determines the eventual preservation of life and limb. Even if injuries in the battlefield may be distinctly different than those of the civilian setting, the medical tenets are astonishingly similar. Let's list them:

- Careful debridement of dead tissues and removal of foreign bodies are key maneuvers to promote the ultimate healing of tissues. As simple as this rule is, inadequate debridement during the first surgery is extremely common. Surgeons should realize that dead tissue does not become alive again; it only promotes infection and further necrosis.
- Early stabilization of fractures controls bleeding and prevents complications. It can be achieved relatively easily by splints, casts, and external fixators.
- Tourniquets can save limb and life, but to do so, they should be placed expertly, which is not always the case. As simple as the placement of a tourniquet may seem, inadequate training leads to incorrect placement.

- Compartment syndrome is on occasions hard to diagnose, particularly in intubated patients. Increased vigilance, targeted clinical exam, and compartmental pressure monitoring will prevent catastrophes.
- Different scores do not predict the need for amputation and should not be used, definitely not in the acute setting.

On the other hand, there are also important differences between the military and civilian management of these injuries:

- Major civilian extremity injuries are caused typically by blunt trauma, as opposed to penetrating trauma and explosions in the military setting.
- While damage control principles are always applicable, the likelihood of using them in civilian extremity injuries is low. An abbreviated exploration of an extremity is rarely needed, unless dictated by associated, overwhelming, non-extremity injuries, or it happens in a rural, resource-restrained environment. For example, even in a mass casualty scenario, as happened at the Boston Marathon bombing, damage control was not necessary.
- The authors make the point of always trying to salvage the leg, unless it is nearly auto-amputated or a risk for the patient's life; this advice is based more on emotional than medical reasoning, as the authors want to assure the military patient that everything was done to save the extremity. Although I agree that amputation does not need to be offered hastily, the LEAP studies have repeatedly shown that a well-fitted prosthesis is more acceptable to the patient than a poorly functional extremity, subjected to multiple operations. There are no rules to govern when an amputation should be offered, but the reluctance to remove an obviously failing extremity is far more common than an unnecessary amputation before all possibilities are exhausted. Given the resources of a civilian setting, an amputation can be offered promptly after appropriate work-up and consultations, saving the patient from pain, complications, and financial loss.

War surgery has offered amazing knowledge and experience to the field of trauma. Diagnostic and treatment principles cross over from the battlefield to the civilian arena and vice versa; civilian trauma surgeons have learned a tremendous amount from those who give their lives and those who fight to save them.

## Relevant Joint Theater Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Acute extremity compartment syndrome – fasciotomy.
2. Amputation.
3. Management of war wounds.
4. Orthopedic trauma: extremity fractures.

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# Traumatic Amputations

# 21

Eric G. Puttler, Stephen A. Parada, Brandon R. Horne, R. Judd Robins, and James C. Krieg

**Deployment Experience**

| | |
|---|---|
| *Eric G. Puttler* | Commander, 102nd Forward Surgical Team, Baquba and Mosul, Iraq, 2004–2005 |
| *Stephen A. Parada* | Chief of Orthopedic Surgery, 10th Combat Support Hospital – NATO Hospital, Role IIE, Heart, Afghanistan, 2011–2012 |
| *R. Judd Robins* | Chief, Orthopedic Surgery, 655 Forward Surgical Team, Ghazni, Afghanistan – Operation Enduring Freedom, 2010 |
| *Brandon R. Horne* | Chief, Orthopedic Surgery, 447 Expeditionary Medical Support Squadron, Baghdad, Iraq, 2006–2007<br>Chief, Orthopedic Surgery, Craig Joint Theater Hospital, Bagram, Afghanistan, 2009 |

E.G. Puttler (✉)
Good Samaritan Hospital, Department of Surgery, Puyallup, WA, USA
e-mail: e.puttler@proliancesurgeons.com

S.A. Parada
Orthopedic Residency, Dwight D. Eisenhower Army Medical Center, Department of Orthopedic Surgery, Fort Gordon, GA, USA

B.R. Horne
Wright-Patterson Medical Center, Department of Orthopaedics, Wright-Patterson AFB, Dayton, OH, USA

R.J. Robins
Uniformed Services University of the Health Sciences, United States Air Force Academy Ambulatory Surgical Center, Department of Orthopaedic Surgery, Sports Medicine Service, USAF Academy, Colorado Springs, CO, USA

J.C. Krieg
Thomas Jefferson University, Rothman Institute of Orthopaedic Surgery, Philadelphia, PA, USA


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*In reality there is no way to separate today's surgery and our practice from the experiences of all the surgeons who have preceded us.*

Ira M. Rutkow

**BLUF Box (Bottom Line Up Front)**

1. Damage control principles apply to traumatic amputations.
2. There is no reason that you can't operate on the injured extremity while another team is operating on the trunk or head. The use of multiple teams can reduce operative times and blood loss.
3. Properly applied tourniquets save lives. Use tourniquets liberally in the prehospital setting. Prior to surgical control of bleeding, tourniquets should be left in place during evacuation.
4. Consider tourniquet use during the evacuation process even after initial debridement and vascular control – tourniquets (marked clearly) can be loosely applied and left loose during transport to ensure their availability during evacuation should the need arise.
5. Distally ligate major vessels, obtain hemostasis, and remove all debris and devitalized tissue at the first operation (preserve tissue of questionable viability for later reassessment).
6. Leave the wound open; preserve any viable skin, soft tissue, and bone to allow for length preservation with atypical flaps/closure techniques.
7. Preserve the bone/length; stabilize with an external fixator if possible. Avoid the convenience of shortening the limb through a fracture.
8. Know how to apply a basic external fixator – even if you're not an orthopedic surgeon.
9. For casualties who will eventually be evacuated from the theater of operations, do not perform definitive amputations in forward positions.
10. Management of traumatic amputations in local nationals should be done in coordination with the local medical support system.

## Initial Assessment and Resuscitation

With the ongoing improvement in body armor and ballistic helmets as well as advances in modern combat casualty care, more and more combat casualties will survive following injury long enough to be resuscitated. As such, the severity of extremity injuries among survivors of combat injuries is increasing. Such injuries rarely occur in the context of civilian medicine, even at Level I trauma centers. So the first thing you have to do when you enter a combat zone is realize you are in a combat zone: the game is changed and you need to adapt to a different injury paradigm.

Rule number one is do not get distracted. Traumatic amputees can still die from an unsecure airway if you do. Prepare yourself for the inevitable emotional reaction to the graphic nature of blast injuries. Develop a plan of how to react, and then when you begin treating your first triple amputee, you and the casualty will be better prepared to meet that challenge successfully. Despite being at times massive injuries, familiar and effective treatment strategies can be adapted and used successfully in the combat zone. ATLS is your friend, so after identifying a significant extremity injury, return to the primary survey and manage it initially in that context.

Rule number two is to know where your tourniquets are and how to use them. Limb-threatening injuries due to blast will become life threatening the quickest through massive hemorrhage. This can be through characteristic pulsatile bleeding from an arterial injury or sustained low-pressure bleeding from venous sources, injured muscle, and fractures. As opposed to the civilian setting where tourniquets are generally used as a last resort, in the combat setting, they should be used early and often. Find out what kind of tourniquets you can expect to be available in your unit and which kinds the units you will be supporting are using – learn how to use them. Also become familiar with their unit SOPs – often you can find a tourniquet on the injured casualty himself in a predetermined pocket or pouch in their combat gear.

Rule number three is to stop the bleeding. A well applied tourniquet will control hemorrhage while doing as little damage as possible. In the prehospital setting, hemostatic dressings and direct pressure and tourniquets must be effective to prevent exsanguination in those scenarios. If you have extremity bleeding that cannot be controlled with a tourniquet, surgical control is the only option – get to the OR. *You must begin resuscitation of these patients immediately!* Even if they arrive with no active bleeding and stable vital signs, they have lost a significant amount of blood and plasma volume.

Once acute hemorrhage has been controlled, the casualty has an opportunity to respond to resuscitation, and the bleeding risk from the traumatic amputation is temporized; proceed as required to manage ongoing threats to life, but remain mindful of tourniquets that have been placed. Make note of when a tourniquet was applied, and be sure this information is passed on to higher echelons of care. Mark your casualty in an obvious way so all care providers know the presence and location of tourniquets and the time they were placed. Administer tetanus toxoid, a first-generation cephalosporin (typically cefazolin), an aminoglycoside (typically gentamycin – remain mindful of shock and the potential for renal impairment), and penicillin (or other agent to cover for anaerobic organisms). If you are in a mature theater, consider tailoring your antibiotic regimen according to historical infection and colonization rates. If the patient is stable enough to go to the OR, then proceed as indicated, if not then remove gross contamination and irrigate with copious amounts of sterile saline. In austere environments, consider a mild soap solution or clean water if sterile saline is not available. Lastly, be sure you have a clear understanding of the appearance of the wounds, and cover them with a clean dressing, which should be left in place until the casualty is in the operating room.

In civilian trauma, trauma surgery is generally done in series. The trauma surgeon does a laparotomy and then is followed by the orthopedics team to nail the femur. In combat trauma you must learn to operate in parallel! Prep the entire body, including all involved extremities, and all teams operate simultaneously. It is not uncommon to have four to six staff surgeons operating simultaneously on a severely injured patient. This will save time, resources, and get your patient off of the table

**Fig. 21.1** Application of pneumatic tourniquets above injury sites prior to surgery

and to the ICU rapidly. In the operating room, before removing field tourniquets, apply and inflate a pneumatic tourniquet proximal to the operative field if possible (Fig. 21.1). If needed, prep the tourniquet into the sterile field prior to removal in an attempt to minimize blood loss between the time of tourniquet removal and surgical control. The goal of the first operation is to control hemorrhage and to debride the wound, in that order. As a completion amputation can be considered in the context of both hemorrhage control and debridement, at this time, determine if an amputation is required for a mangled extremity. Such decision-making is covered under a separate chapter in this text.

## Amputation: Forward Techniques

Commonly accepted principles of amputation surgery apply in the combat zone; however, blast and other high-energy mechanisms often produce wounds where the zone of injury exceeds that which initially might be suspected. The guiding principles for combat amputations are similar to those of limb salvage: control of hemorrhage, debridement of nonviable tissue, stabilization for transport, and infection control.

One of the evolving management principles of wartime amputation surgery in the twenty-first century is the concept of the length-preserving amputation. The open circular amputation is no longer preferred or required. In the theater of operations, every attempt should be made to retain any viable soft tissue and bone (Fig. 21.2). With modern reconstructive amputation techniques, irregular skin flaps and soft

**Fig. 21.2** Traumatic amputation being prepared for initial debridement. Only devitalized tissue should be removed and no attempt made to formalize or close the amputation

tissue envelopes can often be augmented with rotational or free tissue transfer and skin grafting to preserve limb length and functional joints. The exposed bone should be left long to provide an internal splint for the soft tissues and to allow for maximum creativity and flexibility in the reconstructive process. You must resist the temptation to amputate at the level of a long bone fracture simply because it is there. Amputation can be combined with osteosynthesis of fractures to maximize limb length and function. A distal amputation may be combined with more proximal debridement and external fixation of fractures to effectively manage a complex injury.

Performing an amputation within the zone of injury requires diligent debridement as described below; wounds should be left open to allow for drainage and to minimize the risk of infection. Remain mindful that this is not a definitive operation; it is the initial phase of reconstruction. The goal is to stabilize the casualty and prepare them for follow-on debridement and eventual reconstruction while preserving maximal tissue and future options.

Named vessels should be identified and doubly ligated as distally as possible; tourniquet control is recommended to minimize intraoperative blood loss. The skin should be sharply incised preserving as much as possible (the skin is a valuable commodity in the reconstruction of traumatic amputations), and the subcutaneous tissues debrided. Peripheral nerves should be identified, incised sharply as required within the wound, and tagged with a nonabsorbable monofilament suture. Traction and crushing techniques should be avoided. As opposed to the definitive amputation where ideally the nerves retract away from the weight-bearing areas, leaving the nerves well identified and accessible in this setting facilitates subsequent surgery and follow-on definitive amputation. Fascia stripped from muscle and bone should be excised along with nonviable muscle. Muscle viability can be evaluated by its color, consistency, capacity to bleed, and contractility following electrocautery stimulation (conserve tissue of questionable viability). The bone should be cut with a saline-cooled oscillating saw or Gigli saw, preserving length where possible. The bone denuded of periosteum within the context of a traumatic amputation is likely devitalized, but be conservative with your cuts: the retained bone can help splint the soft tissues, resist soft tissue retraction, and always be cut more proximally at subsequent operations. Remember to debride the intramedullary canal. Lastly, do not hesitate to extend the wounds to be sure you have thoroughly debrided the wound; knowledge of common amputation flaps can facilitate the placement of incisions, but atypical flaps and a clean wound are preferred to an ongoing deep infection due to lack of effective exposure and debridement. Lastly, apply a bulky dressing and consider augmenting this with non-circumferential plaster splints to minimize soft tissue shear and bleeding as well as to assist with pain control. Postoperative antibiotics should continue throughout the evacuation process.

## Skeletal Stabilization

The stabilization of long bone fractures will minimize ongoing blood loss and damage to injured soft tissues, improve pain control, ultimately preserve length, and maximize function following traumatic amputations. In the management of fractures sustained in combat, external fixation is the primary provisional skeletal stabilization technique. Often, surgeons not familiar with external fixation techniques are faced with the requirement to use such techniques. If you are preparing to deploy in support of combat operations, it behooves you to become familiar with external fixation techniques as much as possible prior to leaving home. It is also important to remember that external fixation is not the only available technique for fracture management in the combat setting. External fixation pins placed through peripheral nerves or vessels can preclude successful limb or length salvage – *primum non nocere*. Refer to the chapter on open fracture management of this text for a detailed description of safe pin placement and external fixation techniques. The effective use of external splinting, whether that is a Hare traction splint or the contralateral limb for a femur fracture, a circumferential sheet or pelvic binder for an unstable pelvis fracture, or commercially available wire, plaster, or fiberglass splints for other appendicular injuries, is preferred to the errant placement of an external fixation device. Be familiar with the advantages and pitfalls of using these devices to avoid complications. *Do not place circumferential casts*.

## Definitive Amputation Closure

Although you will rarely do the definitive formal amputation and closure on soldiers, you may be called on to provide definitive surgical care for local nationals or others. After applying the basic principles outlined above for preservation of all available soft tissue, you should have a clean and healthy wound that is ready for formal closure.

This will most commonly be either a below-knee or above-knee amputation and at this point is no different than any civilian-type amputation closure. When revising a traumatic injury to a definitive amputation, the first consideration is length. With modern prosthetic techniques, there is no longer an “ideal” length, and generally the more length preserved the better. However, adequate soft tissues must be available to cover the bone. Transfemoral amputations should retain as much of the femoral diaphysis as possible with the soft tissues available. Transtibial amputations should be through the viable bone, although it may be in the zone of injury, preserving one third to one half of the tibia and avoiding amputation in the distal one third to one quarter of the tibia. In addition to the techniques described below, surgical techniques for additional levels of amputation can be found at www.ampsurg.org.

## Transtibial Amputation Technique: Long Posterior Myofascial Flap

Carefully plan out the skin incisions by first determining the anterior to posterior diameter of the leg at the level of the tibia cut (Fig. 21.3). The anterior flap is drawn from a point slightly more posterior than half the diameter of the leg. Mark the anterior apex of the anterior flap in the midline approximately 1 cm distal to the level of the tibia cut. The length of the posterior flap is the anterior to posterior diameter of the leg plus 1 cm. Mark the medial and lateral extensions of the posterior flap and then connect these markings with a transverse posterior line at the distal end of the flap. Make definitive incisions through the skin, subcutaneous tissues, and crural fascia to avoid devitalizing the margins of the flap. Ligate the saphenous vein and pull distally and transect the saphenous nerve sharply. Identify and doubly ligate the anterior tibial vessels after separating them from the deep peroneal nerve, which lies adjacent to the vessels on the anterior aspect of the interosseous membrane. Apply gentle traction to the deep peroneal nerve, and divide it sharply, allowing it to retract into the proximal soft tissues. Similarly divide the lateral compartment musculature at the same level, identifying the superficial peroneal nerve (between the muscle bellies of the peronei proximally), and divide it sharply after applying gentle traction.

Incise the tibial periosteum at the level of the proposed cut, and cut the tibia transverse to its long axis with a saline-cooled oscillating saw or Gigli saw (Fig. 21.4a). Similarly cut the fibula transversely. Apply tension to the distal segment, and remove it by elevating the flap from the posterior surfaces of the bones, leaving the deep and superficial posterior musculature with the posterior flap. Isolate the muscle bellies of the deep posterior compartment, the peroneal and posterior tibial vessels, and the tibial nerve (Fig. 21.4b). Doubly ligate the arteries, and ligate the veins after separating them from the nerve, which is subsequently divided under gentle tension. Transect the muscle bellies of the deep posterior compartment at or just distal to the tibial cut. Bevel the anterior surface of the tibia with the saw starting at the cut surface of the bone just anterior to the medullary canal, angling approximately 45° anteriorly and exiting the anterior tibial cortex approximately 1 cm proximal to the original bone cut. Smooth the cut surfaces of the tibia and

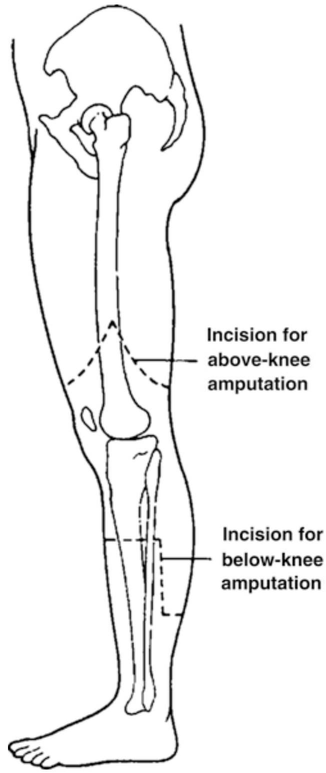


**Fig. 21.3** Standard incisions for lower extremity amputation creating a long posterior myofascial flap for below-knee amputation and a "fish-mouth" flap for above-knee amputation. Combat amputations often require modifications with whatever amount and shape of tissue is available (This figure was published in Operative Surgery Manual, 1st ed., Vijay P. Khatri, Juan A. Asensio, Lower extremity amputation, Copyright Elsevier 2003)

fibula with a rasp. Irrigate to remove all bony debris and ensure surgical hemostasis. Identify, pull distally, and sharply transect the sural nerve in the posterior flap.

Closure begins by securing the posterior flap to the tibia (myodesis). This is done by suturing the investing muscular fascia at the end of the flap to the anterior periosteum of the tibia with heavy (0 or #1) nonabsorbable suture. If the tibial periosteum is inadequate, then the flap can be secured through drill holes in the anterior tibia on either side of the anterior tibial crest. Place a drain deep to the flap. Securely close the crural fascia and subcutaneous tissue to allow for a tension-free skin closure on the anterior leg rather than at the end of the stump (Fig. 21.4c).

## Transfemoral Amputation Technique

Equal anterior and posterior flaps are described here, but other skin flap variations exist. Measure the anterior to posterior diameter of the limb at the level of the proposed bone cut. Mark the apices of the flaps in the midposition of the thigh medially and laterally. The lengths of the anterior and posterior skin flaps are one half the diameter of the thigh plus 1 cm. Incise the skin, subcutaneous tissue, and deep fascia definitively. Divide the quadriceps muscle at its insertion into the patella,

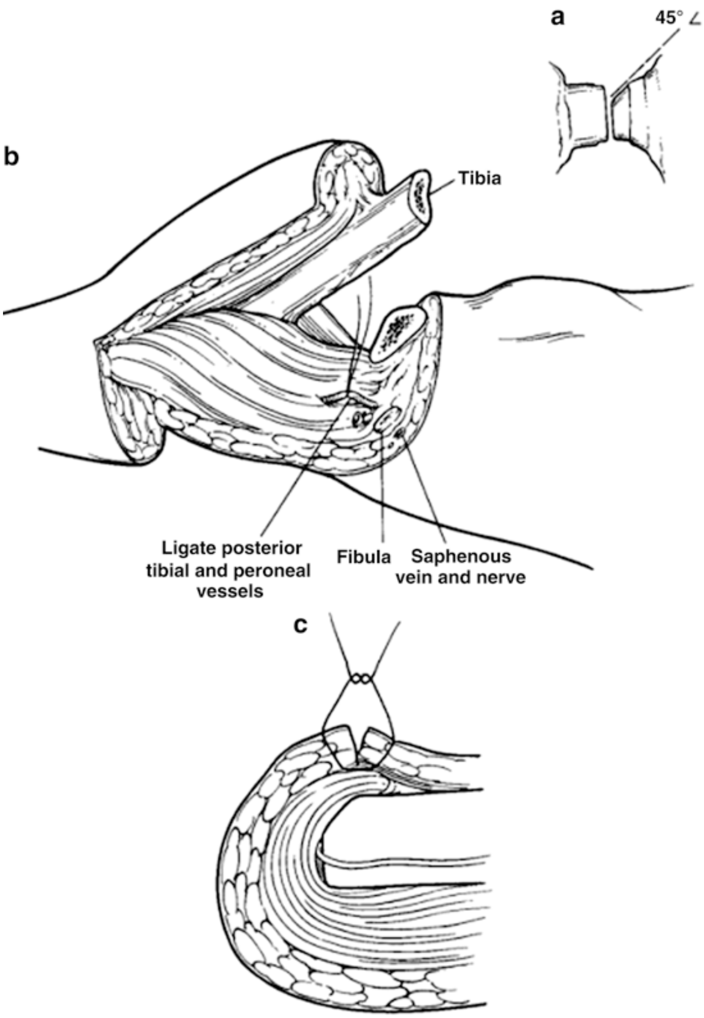


**Fig. 21.4** Basic technique for below-knee amputation. (**a**) Transtibial cut and 45° bevel, (**b**) vascular ligation and soft tissue transection leaving long posterior myofascial flap, and (**c**) final fascial and skin closure (This figure was published in Operative Surgery Manual, 1st ed., Vijay P. Khatri, Juan A. Asensio, Lower extremity amputation, Copyright Elsevier 2003)

and reflect the vastus medialis off of the intermuscular septum. Identify the adductor magnus tendon at its insertion on the adductor tubercle, and detach it, tagging it with heavy suture for later myodesis. Reflect the adductor proximally, and identify the femoral vessels at Hunter's canal for ligation. Identify the sartorius and medial hamstrings, and divide them 2 cm longer than the proposed bone cut. Divide the biceps femoris at the level of the proposed bone cut. Identify the sciatic nerve in the posterior compartment of the thigh, apply gentle traction, ligate it with absorbable suture, divide it sharply, and allow it to retract into the proximal soft tissues (Fig. 21.5a).

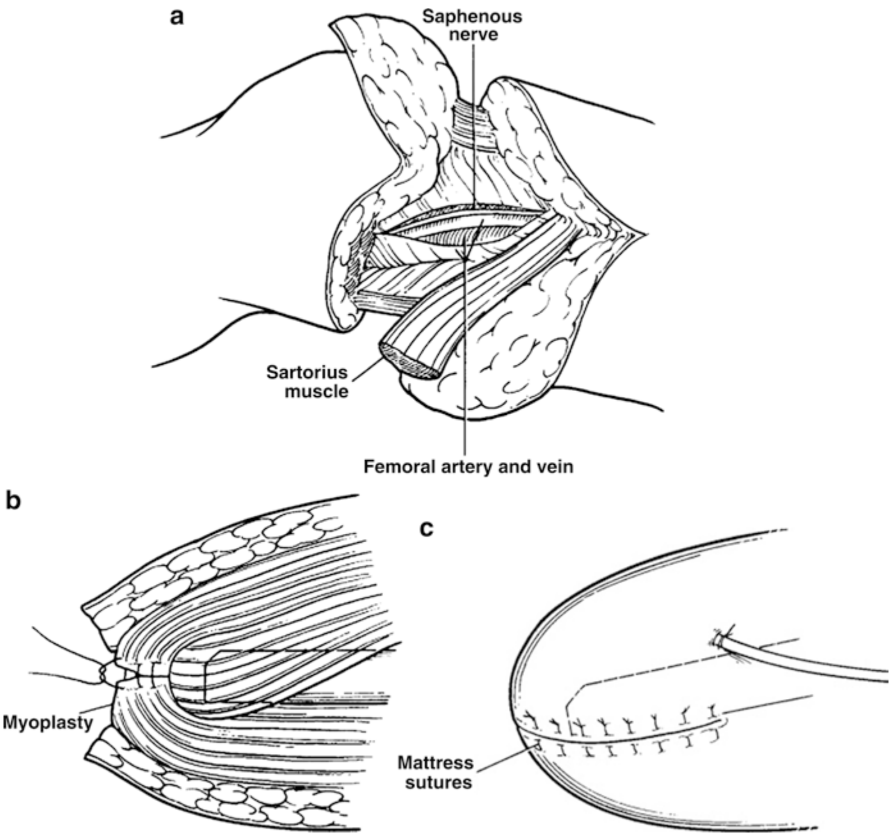


**Fig. 21.5** Basic technique for above-knee amputation. (**a**) Vascular control and division of thigh musculature, (**b**) midline myoplasty which can be facilitated with suture fixation to the femur, and (**c**) final fascial and skin closure (This figure was published in Operative Surgery Manual, 1st ed., Vijay P. Khatri, Juan A. Asensio, Lower extremity amputation, Copyright Elsevier 2003)

Expose and isolate the distal femur, and cut it with a saline-cooled oscillating saw or Gigli saw perpendicular to its long axis. Remove the distal segment and ensure hemostasis; irrigate to remove bony debris. Drill four unicortical holes in the distal femur. The first is anterior and 1.5 cm proximal from its cut surface, and the others migrate proximally and laterally a similar distance. Pass heavy nonabsorbable sutures through these holes, and use these sutures to perform a myodesis of the adductor tendon which is secured around the end of the femur with the limb placed in maximum adduction. The medial hamstrings are passed around the end of the femur and attached also via these drill holes or to the posteromedial aspect of the distal femur by sewing them to the adductor tendons. Additional sutures are placed in the soft tissues to further secure the myodesis as needed and to stabilize the distal femur in the muscle mass (Fig. 21.5b). The quadriceps is drawn over the end of the femur, and its fascia is sewn to that of the hamstrings with the hip maximally extended to avoid creating a hip flexion contracture. Deep drains are placed, and the superficial fascia and skin are closed in a similar fashion as described in the transtibial amputation technique (Fig. 21.5c).

## Hip Disarticulation Technique

While the need for hip disarticulation is rare, even in combat surgery, the surgeon must be prepared for and understand the technique for the procedure. Hip disarticulation also depends on the typical anterior and posterior flaps. After incising the skin, the femoral vessels are identified and ligated with at least two sutures. The muscles of the anterior thigh and the adductors are typically divided at their origin. The abductors and the gluteus maximus musculature are divided at their insertion. The hip capsule is opened, the head is disarticulated, and the residual femur is removed. The sciatic nerve should be suture-ligated to prevent bleeding from the vasa nervorum and cut under tension so that it retracts out of the potential area for weight bearing. Closure consists of myodesis of the preserved muscles over the acetabulum, followed by closure of the gluteus fascia to the inguinal ligament. Avoid injury to the spermatic cord or round ligament. The skin is closed in the typical fashion. Deep drains should be left in place to avoid hematoma formation.

In a combat scenario, typically the limb has already been traumatically amputated with damage to the surrounding tissues (Fig. 21.6a). Depending on injury and remaining viable healthy tissue, variations of the technique are often required, but the principles remain the same: coverage of the exposed bony pelvis with muscle to support weight bearing followed by skin coverage (Fig. 21.6c, d).

## Care for Local Nationals

Surgeons supporting combat operations in the twenty-first century must be prepared to care for enemy combatants, local and third-country nationals, allied forces, and civilian contractors in addition to directly supported military units. Generally speaking, allied forces and civilian contractors can be treated using algorithms similar to wounded US soldiers as they can be expected to be evacuated to modern medical facilities eventually. For enemy combatants and local and third-country nationals, however, the deployed military medical capability may exceed the capabilities for the host nation, and therefore deployed surgeons may often definitively manage this population.

When treating traumatic amputations and mangled extremities in this patient population, you must become familiar with the local medical capability and the rules of engagement for the care of these casualties, in addition to your own capability for managing such injuries, both in terms of your own expertise, facility limitations, and the availability of consultants and subspecialty care. It does no good to embark on a complicated limb salvage plan if there is no opportunity to provide or arrange for required follow-on care such as flap coverage, delayed bone grafting, or

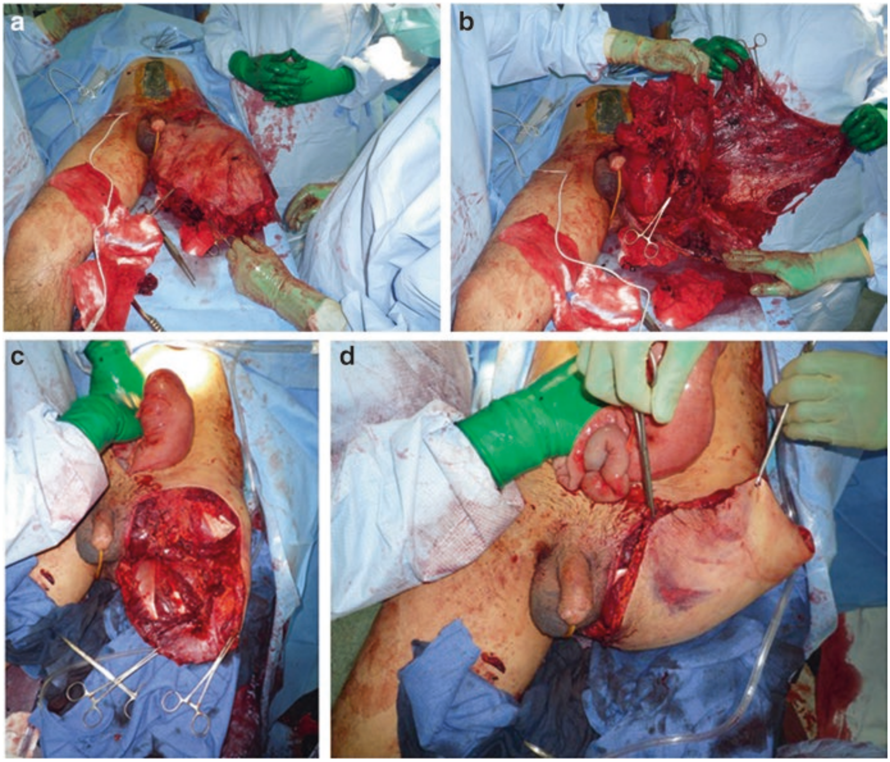

**Fig. 21.6** Hip disarticulation. (**a**) Appearance of the injury on presentation after blast injury. (**b**) Exploration to expose the extent of the wound – note the "umbrella effect." (**c**) After hip disarticulation with debridement of grossly contaminated tissues, fashioning of flap and coverage of the acetabulum. (**d**) Flap closure (Note simultaneous abdominal and extremity surgery. Author's personal photos)

sophisticated reconstructive techniques. At the same time, access to artificial limbs may be nonexistent, and an otherwise very functional amputation can be totally disabling without prosthetic support in a Third World country. These decisions are hard to make, and there are no right answers, but suffice it to say, you may embark on limb salvage under less than ideal situations to salvage an extremity with significantly compromised function, or you may choose to amputate a limb that may be reconstructable with techniques which are not available. These challenging scenarios can also be the most rewarding for creative thinkers with imaginative treatment strategies and diligent technique. In order to maximize your patient's functional outcome, you must be familiar with local resources and then operate within those constraints and have realistic goals appropriate for your patients given their cultural biases, expectations, and norms.

## Final Thoughts

You do not exist in a vacuum. Don't exceed your capabilities in austere environments if your casualty can survive evacuation to the next level of care. Be familiar with the theater medical treatment and evacuation policy; you are part of a team and a system that is designed to operate cohesively. The better you fit in to the big picture, the more useful you are to your casualty and to the supported commands. Reassess bleeding if a tourniquet has been placed but evacuation is not expected soon. For traumatic amputations, ensure the tourniquet is applied at the most distal, effective level to minimize ischemia time for the remaining soft tissues while preventing further blood loss.

## Civilian Translation of Military Experience and Lessons Learned

James C. Krieg

While written for the military surgeon working in a forward position setting, this chapter on traumatic amputations provides many pearls of wisdom for civilian surgeons. The authors have done an excellent job of summarizing the current standard of care for lower limb-threatening injuries.

Context is important in guiding treatment of limb-threatening trauma. In a military setting, the vast majority of the patients will be young and physiologically fit. In that regard they are likely to be patients with the maximal ability to heal and recover from a physical perspective. In the present situation, they also have access to healthcare and follow-up treatment that is arguably among the best available to anyone in the world. In a civilian population, patients may be predominantly younger and male, but will obviously represent a more diverse group. This demographic includes a wider representation of age, medical comorbidities, social support, and access to care in the acute and recovery phases.

The authors point out the unique nature of polytrauma and survivorship in the military. Most of the injuries will be due to blast injury or high-energy penetrating trauma. Advances in body armor and vehicle reinforcement have improved protection from injury, but the overall picture of severe limb-threatening injury, often in the face of life-threatening blast injury, remains. In the civilian world, improved automobile safety and improved access to early trauma care as a result of trauma system organization have improved survivorship from polytrauma. One of the ironies of trauma care in both settings is that improved survivorship has increased the challenge of dealing with severe limb-threatening injuries.

Several aspects of trauma care have not translated readily from the military into the civilian population. One of those is the widespread use of tourniquets in early management of life-threatening hemorrhage from limb trauma. This may be due in part to the unique nature of blast injuries. Unlike blunt trauma or low-energy penetrating trauma, high-energy blast injuries are often not controllable by pressure alone. As a result, the use of tourniquets in the military has become popular and been proven to be quite effective. Whether due to the perceived risk of tourniquet use, an historical bias, or the availability of simpler means of hemorrhage control, such as pressure application, tourniquet use in civilian trauma is still relatively rare.

Despite the differences in limb trauma in the military and civilian settings, the common themes are much more significant, and lessons learned in one venue provide valuable lessons in the other. First and foremost, trauma care is a team effort, and care must be coordinated and cohesive. Like the tenents of ATLS, evaluation and treatment must be coordinated, simultaneous and continuous. The authors remind us that in the military care, it is often provided by multiple teams providing care in parallel. These principles are true across all spectrums of trauma care and remind care providers that life comes before limb, but often the care of severe limb trauma can be lifesaving.

Another principle that has been learned through the recent military experience in lower extremity amputation is that length should be preserved, even if it means managing a fracture above the level of amputation. This seems to run counter too much of the conventional wisdom in trauma care, and the lessons learned should be shared. Prosthetic design has changed much of the old thinking about hindfoot amputations in particular, with the use of the Intrepid Dynamic Exoskeletal Orthosis (IDEO).

General principles hold true and are summarized quite well by Puttler, Parada, Horne, and Robins. These include early management of hemorrhage, systematic wound debridement, skeletal stabilization, and staged comprehensive reconstruction. Often this means a team approach. Technical pearls of amputation are also well summarized and apply to amputation done in any setting.

Despite the obvious differences in military and civilian care, the similarities and shared lessons are more significant. They provide all healthcare professionals with valuable lessons learned. Those lessons are well summarized here.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Amputation.
2. Management of war wounds.

# 22 Peripheral Vascular Injuries

Robert Jason Thomas Perry and Charles J. Fox

**Deployment Experience**

| | |
|---|---|
| *Jason T. Perry* | 67th Forward Surgical Team (Airborne), Bala Murghab, Afghanistan, 2011–2012 |
| *Charles J. Fox* | Department of Surgery, 10th Combat Support Hospital, Baghdad, Iraq, 2006 |

*"It is better to see the outside of the vessel before you see the inside."*

Unknown

Vascular trauma in the military has special importance as combat-related injuries to major vessels offer unique surgical challenges and comprise the majority of potentially preventable deaths on the modern battlefield. The front lines of a battleground are predictably dirty, noisy, and located in predominantly harsh climates. You will routinely perform surgery in tents or abandoned buildings that lack suitable light and ventilation. These austere conditions demand early deliberate preparation to ensure successful management of vascular wounds. Lessons learned during US military operations continue to advance the practice of vascular trauma surgery and now translate into the current recommended surgical practices. The widespread adoption of endovascular techniques to manage peripheral arterial disease has decreased exposure of general surgery trainees to the surgical techniques they will require to treat vascular

R.J.T. Perry (✉)
Vascular Surgery, Madigan Army Medical Center, Department of Surgery, 9040A Jackson Ave, Tacoma, WA, USA
e-mail: Jason.t.perry12.mil@mail.mil

C.J. Fox
Vascular Surgery Denver Health, Denver Health and the University of Colorado Hospitals, Department of Surgery, Denver, CO, USA


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injuries in a theater of war. Despite the fact that vascular surgery has become largely separated from general surgery, all military surgeons must be well versed in basic vascular anatomy and reconstruction techniques. The majority of combat vascular injuries are not being handled by vascular surgeons, and you are unlikely to have one available to guide or assist you. One invaluable resource for improving vascular exposure skill prior to deployment is completion of the American College of Surgeons Advanced Surgical Skills for Exposure in Trauma. All deploying surgeons should consider completing this course prior to deployment, with a vascular surgery colleague, if desired, and it should be required of military general surgery trainees every academic year. Be prepared; you can be the difference between limb salvage and loss.

**BLUF Box (Bottom Line Up Front)**

1. Early initiation of damage control resuscitation concepts is crucial to performing a successful simultaneous vascular reconstruction.
2. A vascular assessment should begin in the trauma bay using physical exam and a handheld continuous wave Doppler device.
3. A CT angiogram, if available, may be useful for cervical or truncal vascular injuries to plan the best approach but is rarely necessary for extremity vascular injury.
4. Prehospital tourniquets should be augmented with the pneumatic type and should only be removed in the operating room once the patient is stable and the surgeons are prepared to control hemorrhage.
5. Vascular repairs often require massive transfusion; therefore, temporary shunting with delayed repair should be the default at far forward surgical facilities. The exception to this rule is care provided to local nationals who, depending on the local healthcare environment, may face debilitating limb loss if they are treated with shunting and not definitively repaired.
6. A second surgical team can save time by placing external fixation and performing saphenous vein harvests or fasciotomy.
7. A vein interposition graft is durable when there is adequate muscle coverage; otherwise a longer bypass tunneled out of the zone of injury should be chosen to prevent desiccation or delayed rupture.
8. Don't forget the vein – ligate if necessary, but shunting or repair of major venous injuries will improve outflow and augment your arterial repair.
9. Trust your physical exam, and remember that it is hard to improve upon a palpable pulse and perfused limb.

## Initial Assessment and Operative Planning: Peripheral Vascular Injury

The effectiveness of early tourniquet application observed in Iraq and Afghanistan has led to doctrinal changes that have produced a surge of patients presenting with vascular injuries that in past conflicts would never have reached a field hospital alive. Theater policy in Afghanistan dictated all deployed soldiers had at least one Combat Application Tourniquet to render self- or buddy aid. Therefore, during your deployment you will find yourself fixing more vascular injuries than you may ever have imagined. Optimal management requires proper planning and recognition of the essential priorities necessary to prevent immediate hemorrhagic death. Explosion-associated injury, the most common vascular wounding pattern, involves fractures, thermal injury, and embedded fragments over a majority of the body surface.

While in a civilian trauma setting definitive airway control is often the first management priority, in a deployed environment priority shifts to immediate hemorrhage control and vascular access for resuscitation. It should be emphasized that both of these activities may be carried out simultaneously between the nurses, surgeons, and anesthesia providers involved in the patient's care. Clear delineation of team member responsibility is critical to success, and the surgeon should act as the team leader, setting and assessing the accomplishment of care priorities. A volume-depleted patient may not always manifest active arterial bleeding at the time of admission. Prehospital tourniquets should nonetheless be inspected and readjusted, augmented, or replaced once the resuscitation restores adequate peripheral perfusion.

Recognizing the need for vascular reconstruction at the time of the trauma admission is crucial for success as indecision and progressive ischemic burden can result in ultimate graft failure and subsequent limb loss. Most of the extremity injuries involve fractures and large soft tissue wounds that can make the diagnosis by physical exam alone inaccurate. Radiographs can provide early clues that extremity vascular injuries exist, and you should take a close look at the plain films as you enter the admitting area. For example, supracondylar femur and tibial plateau fractures are frequently associated with injuries to the distal femoral and popliteal artery. These are among the most common lower extremity vascular injury patterns that you will encounter. Deformed extremities are straightened, and the onset of additional hemorrhage is controlled with direct pressure, gauze packing, hemostatic dressings, or additional tourniquets. Alternatively, in stable patients without active bleeding, prehospital tourniquets should be carefully loosened to determine the degree (if any) of vascular injury. A Doppler assessment is advised to confirm the absence of pedal pulses and to perform an ankle-brachial index when possible. A patient assessment done in concert with an orthopedic surgeon will facilitate the necessary discussion regarding the sequence of the operation and preferred techniques for external fixation that best aid in the anticipated vascular exposure. The usual proper sequence should be (1) stabilize the patient, (2) stabilize the fracture, and (3) repair the vascular injury. Important information to relay to the entire operative team should include ideal patient positioning, the plan for vein harvesting in a contralateral extremity, and the desire for a C-arm or arteriography. Special instruments located in “peel packs” can ease the apprehension of not having the favored instruments when needed quickly. The earlier you relay this information to the OR, the easier and faster your case will be.

## Surgical Management: General Tips and Techniques

A dedicated two-team approach is recommended for the surgical management of military vascular injuries. For extremity injury this practice reduces ischemic time as the primary team may be preoccupied with thoracotomy or laparotomy to control hemorrhage or other damage control maneuvers. Ultimately, however, if resources are limited – as they usually are at far forward facilities – always follow the axiom of “life over limb.” A perfectly revascularized limb is of absolutely no use to a dead patient. When available, do not hesitate to involve a second team as they can be used to apply external fixation, perform fasciotomies, begin a peripheral vascular exposure, or harvest vein from a noninjured or amputated extremity (Fig. 22.1). It is important to take some extra “careful” time when doing the vein harvest. The quality of the venous conduit is the best predictor of graft patency. Unnecessary haste and carelessness in harvest may lead to conduit injuries, the repair of which will degrade the conduit quality. You should always caution your assistant on the potential for injury to the saphenous vein when performing a fasciotomy as the vein is located right where the medial fasciotomy incision is usually performed. Position the patient to enable unimpeded access to another body cavity or limb in the event of unexpected deterioration or need for additional vein harvesting.

Initial control of hemorrhage is often accomplished by digital occlusion using an assistant’s hand prepped directly into the bleeding wound bed with betadine spray. This is followed by a careful dissection proximal and distal to the site of injury. It is always safer and more prudent to proceed from known, undisturbed anatomy to the

**Fig. 22.1** Three teams operating simultaneously on a patient with orthopedic injuries and a vascular injury at the combat support hospital in Baghdad

zone of injury than to dive into a hematoma. Balloon catheters may also tamponade hemorrhage when a tourniquet or manual pressure is not effective, but blind insertion of surgical instruments can be unproductive or harmful and is discouraged. Tourniquets are left in place until the anesthetist has sufficient time to resuscitate the patient. You may find that the transected vessel ends can be difficult to identify in the destroyed tissue. Although often thrombosed at the time, these vessels must be found and ligated because they will rebleed later after the patient is resuscitated. Retrograde advancement of a Fogarty catheter from an uninjured distal site can also be used to locate the transected artery in a horrific wound that is no longer bleeding. When making a decision to amputate or salvage an extremity, you should consider the patient's condition, extent of injury, and your willingness to commit the patient to the necessary definitive orthopedic care and physical rehabilitation. No one situation or scoring system can replace the surgical judgment developed by an experienced team.

While often not feasible in war wounds because of the extent of injury, a primary end-to-end repair is preferred when lateral sutures cannot repair the injured vessel. Advantages of this repair include a single anastomosis and use of autologous tissue. Dividing nearby branches may gain some length in noncalcified vessels, but this repair should be both expedient and tensionless. If the vessel has not been transected, realize that the ends will retract significantly once you complete the division, so it can be helpful to place several stay sutures that traverse the injured area to hold it in place and facilitate the anastomosis (Fig. 22.2). A complete debridement of any disrupted tissue is an essential step of the repair, and sacrifices made to avoid an interposition conduit should be keenly resisted as a comprised repair will not be durable. It cannot be overstated that the complexity and additional operative time required for vein harvest and interposition grafting or bypass, particularly by surgeons who don't perform these operations regularly, are significant. The time used to tie up, potentially, the only operating table for a lengthy vascular reconstruction, may preclude the definitive management of another patient's more life-threatening injuries.

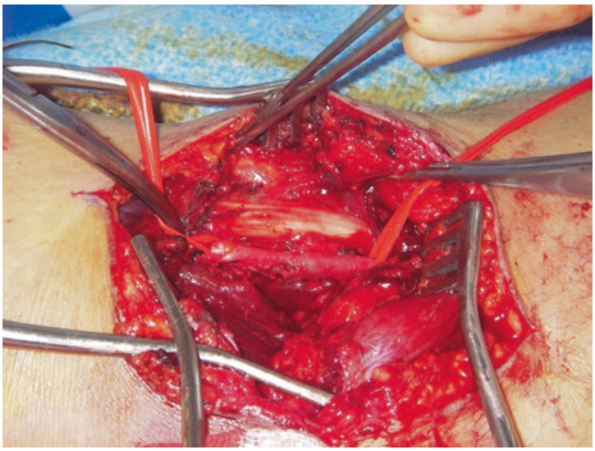

**Fig. 22.2** Fragment injury to the superficial femoral artery. This should be amenable to primary end-to-end repair, but beware that the ends will retract significantly once you complete the transection and debride the injured vessel wall

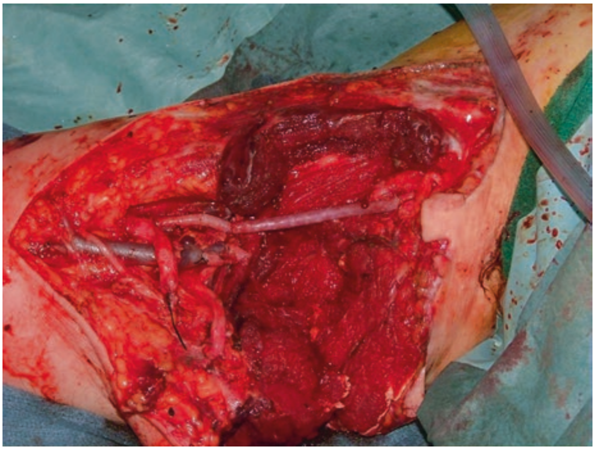

**Fig. 22.3** Cavitary wound with significant tissue loss. Femoral artery has been repaired with an interposition graft, but obtaining adequate soft tissue coverage of the vessels will be a challenge

The final operative plan and estimated time should be communicated early to the entire operative team with contingency bail out plans should a more critically wounded patient arrive.

The saphenous vein is the preferred conduit for military vascular injuries. The poor historical results of prosthetic material when used in contaminated war wounds are the justification for this approach. In my experience, prosthetic grafts placed in larger vessels with good muscle coverage have been used successfully. I have used prosthetic grafts for "clean" subclavian and carotid wounds. However, inferior long-term patency of prosthetic materials and the potential for infection in war wounds and subsequent pseudoaneurysm formation have restricted its widespread use in combat-related extremity wounds. Prosthetic may also be used as a temporary repair, with a plan for subsequent re-exploration and replacement with vein graft if necessary.

Military munitions produce large cavitary wounds with numerous disruptions of the skin and loss of underlying muscle that may thwart attempts to achieve suitable graft coverage (Fig. 22.3). When you are confronted with this situation, a longer vein graft tunneled completely around the zone of injury should be chosen over a shorter, poorly covered vein interposition conduit. Appropriately applied external fixation will take this issue into consideration, and this is an important subject to discuss before fasciotomy incisions are made. Devitalized tissue is excised and irrigated under low pressure, with careful evaluation of muscle tissue for viability. A lengthy and meticulous debridement at the outset is not necessary as these wounds look much better in a few days after subsequent washouts and vacuum dressings.

Ballistic trauma can transmit kinetic energy and result in intimal injury well beyond the transected arterial segment. Therefore, perform your debridement with a great deal of concentration focused on the quality of the luminal surface and strength of the arterial inflow relative to the patient's hemodynamics. When necessary, a Fogarty catheter should be carefully advanced as prehospital tourniquets and incomplete heparin dosing in trauma may result in thrombus accumulation proximally and distally.

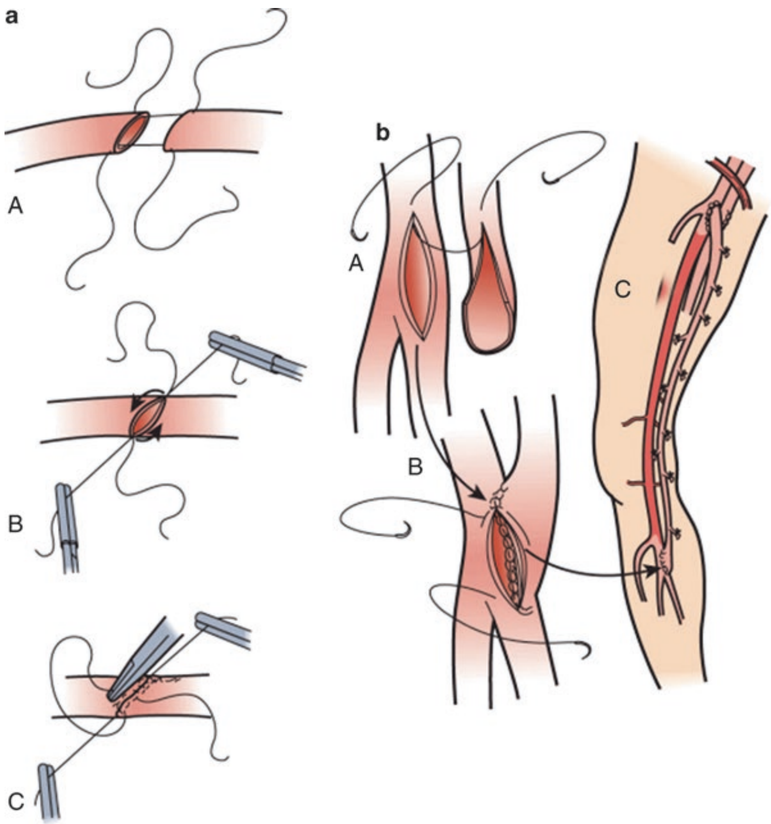


**Fig. 22.4** Technique for simple vascular anastomoses. (**a**) Primary end-to-end anastomosis is performed by spatulating the vessel ends and placing opposing prolene sutures from heel to toe (*A*); the sutures can then be used to rotate the vessel to perform a running closure of the posterior wall (*B*); the other suture is then run along the anterior wall to complete the anastomosis. (**b**) Technique for end-to-side anastomosis with interposition graft begins with a longitudinal arteriotomy and matching size spatulation of the graft (*A*); begin the anastomosis at the heel and run the posterior (or deep) wall first (*B*), followed by completion of the anterior anastomosis (*C*) (Reprinted from Peripheral Arterial Occlusive Disease. In: Townsend CM, et al., eds. *Sabiston Textbook of Surgery*, 18th edition. With permission from Elsevier)

In military trauma, lack of adequate lighting, fine surgical instruments, desired monofilament sutures, and loupe magnification may hinder the careful tissue handling that is crucial to a successful vascular operation. To overcome these expected obstacles, a four quadrant, heel-to-toe anastomosis that is well spatulated is the easiest method to teach and perform in difficult situations (Fig. 22.4). Small Heifetz clips or Bulldog clamps can also minimize the chance of a clamp injury and should be your clamp of choice for peripheral vessels.

Upper extremity injuries should not be underestimated in their propensity to require massive transfusions from ongoing blood loss and resuscitation

**Fig. 22.5** Temporary intravascular shunts in the femoral artery and vein. These must be well secured proximally and distally to prevent dislodgment during patient transport

requirements. The arm swelling and wound expansion that can result highlight the importance of a wide tunnel for a saphenous vein graft. There has been a sustained interest in repair of venous injuries to avoid the potential for early limb loss from venous hypertension or long-term disability from chronic edema. With combined injuries, arterial repair should precede venous repair to minimize further ischemic burden unless the vein repair requires very little effort.

The temporary use of shunts for military trauma is a very effective damage control technique to allow for delayed reconstruction (Fig. 22.5). The value of temporary shunting should be compared with the consequences of simple ligation. For example, ligation of the brachial artery after confirming distal signals and palmar blood flow allows for elective delayed reconstruction if indicated. Surgeons at smaller remote facilities may prefer shunting when rapid evacuation to places capable of matching transfusion requirements or performing emergent complex vascular repairs is necessary. Shunts are also an excellent option to temporarily restore blood flow if a prolonged orthopedic stabilization is required prior to definitive repair. This will also allow you to assess the distal flow with the shunt in place.

While arteriography remains the gold standard for guiding surgical reconstruction, static film arteriography has largely been replaced with portable C-arm units capable of digital subtraction angiography. This technology is not typically available at far forward facilities so static films with a portable X-ray machine may have to suffice. Contrast arteriography is *not* required for single penetrating wounds with hard signs of a vascular injury but is very useful for locating the injured vascular bed when there are diffuse fragmentation wounds or fractures to the extremity. It is also useful to define issues with the runoff vasculature if there is suspicion for distal thrombosis. Hand-injected contrast images using butterfly needles without special wires or catheters can be acquired quickly using the digital subtraction mode on a mobile C-arm unit. If utilizing static imaging, it is useful to “pre-load” the vascular bed with contrast prior to taking a single X-ray. Alternatively, you can easily place a percutaneous femoral arterial line and use this to inject contrast for your study.

Rotating the table before the start of the case may be necessary to properly maneuver the C-arm. When all else fails, holding the feet off the end of the table may allow for the acquisition of serial images to satisfactorily complete the case. The logistics of maintaining a robust inventory in a field hospital continue to limit the capability to carry out these interventions in combat. Completion assessments following open repair or endovascular interventions make use of a combination of physical exam, the handheld Doppler, and selective arteriography.

## Specific Injuries and Approaches

### Femoral and Popliteal Vessels

It can be difficult to obtain proximal control of proximal femoral artery injuries, particularly if the vessel is transected and the end has retracted. Do not waste time digging in a hole or performing a laparotomy and attempting to control the external iliac deep in the pelvis. There is nothing sacrosanct about the inguinal ligament; extend your incision superiorly onto the abdominal wall, and divide the musculature and inguinal ligament to enter the preperitoneal space. Gently retract the peritoneum medially to gain excellent exposure of the distal external iliac vessels. If the hematoma from a proximal thigh wound does extend all the way to the inguinal ligament, however, a better strategy is to either expose the iliac artery via a retroperitoneal "transplant incision" approach or via a laparotomy, depending on surgeon experience and comfort and the need for laparotomy for coexistent intra-abdominal injuries.

Figure 22.6 shows the usual incisions used for lower extremity vascular exposure. Do not skimp on the incision, and do not hesitate to extend wounds proximally and distally to gain adequate exposure and control. Common femoral and superficial femoral artery exposure for either an injury or to gain proximal control is relatively

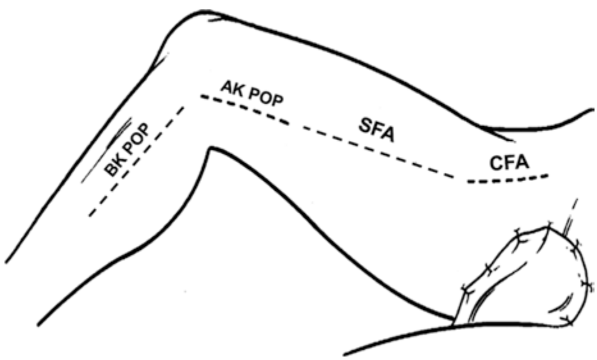


**Fig. 22.6** Typical incisions for exposure of lower extremity vascular injuries. *CFA* common femoral artery, *SFA* superficial femoral artery, *AK POP* above-knee popliteal, *BK POP* below-knee popliteal (This figure was modified with permission from *Operative Surgery Manual*, 1st ed., Vijay P. Khatri, Juan A. Asensio, Femoropopliteal Bypass Grafting, Copyright Elsevier 2003)

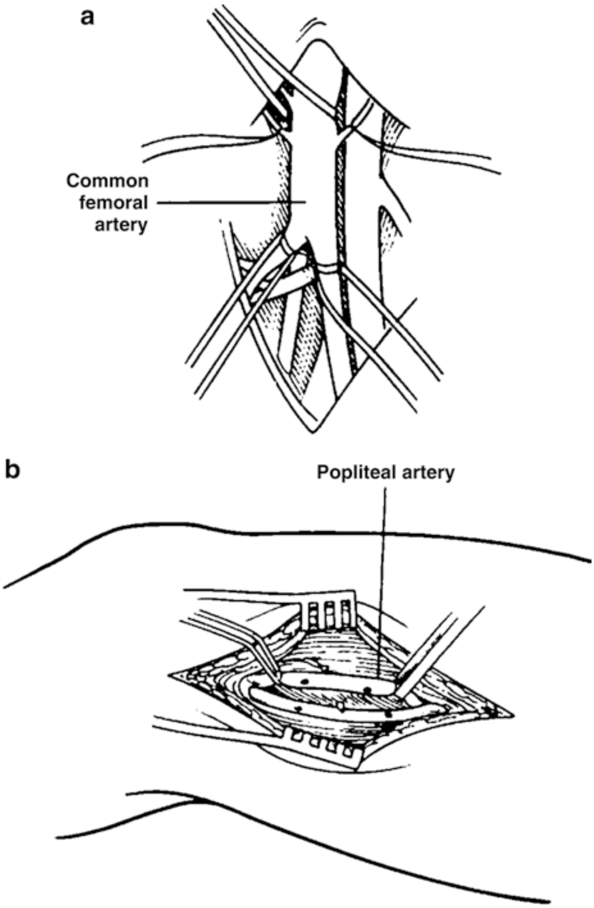


**Fig. 22.7** (**a**) Exposure of the common femoral and proximal superficial femoral arteries via a longitudinal medial groin incision. (**b**) Exposure of the distal superficial femoral and above-knee popliteal vessels via a medial approach (This figure was reproduced from *Operative Surgery Manual*, 1st ed., Vijay P. Khatri, Juan A. Asensio, Femoropopliteal Bypass Grafting, Copyright Elsevier 2003)

straightforward as shown in Figs. 22.7a and 22.8. Ultrasonography, available at even the most far forward locations, may be utilized to localize the artery and plan the exposure. If needed, you can easily perform an on-table arteriogram of the entire leg from this exposure. You can also introduce an embolectomy catheter via a small arteriotomy and feed it distally to remove acute clot. You typically should not waste time trying to salvage a badly damaged profunda femoris artery if injured; simply ligate it and move on. If the repair can be easily carried out, however, the profunda should be preserved. It may prevent limb loss should the in-line repair fail.

The medial approach is preferred for femoropopliteal injuries (see Figs. 22.6 and 22.7b). The approach in relation to the knee joint is directed by the level of the

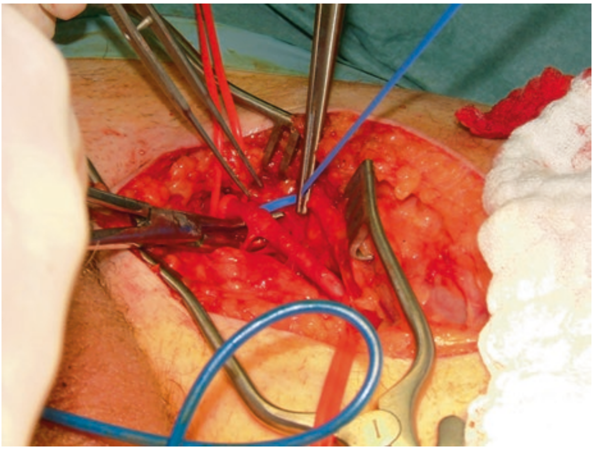

**Fig. 22.8** Control of the common femoral, profunda femoris, and superficial femoral arteries in the groin

wound; however, total division of muscular attachments at the knee is sometimes required to control hemorrhage of transected arteries and veins. Note that there will be multiple collaterals of the popliteal vein that surround the artery and will need to be divided for full exposure. An alternative approach to the popliteal vessels is the posterior approach with the patient in prone position. Although this provides excellent exposure of the behind-knee popliteal vessels, this approach is rarely indicated for combat wounds, needlessly complicates the total surgical care of the multiply injured trauma patient, and should be discouraged. Saphenous vein interposition graft should be used to repair these injuries if primary repair is not feasible, particularly for repairs that cross the knee joint. If the injury is deep in the popliteal fossa, then an acceptable option is to exclude the injured popliteal artery by ligating it above and below the knee and performing a vein bypass from the distal SFA to below the distal ligation, analogous to the bypass and exclusion technique in the management of popliteal artery aneurysms. Attempt to salvage an injured popliteal vein if at all possible, but it can be ligated if complex reconstruction would be required or in a damage control situation. Have a low threshold for performing a fasciotomy, and *always* perform one if both the artery and vein have been injured.

## Upper Extremity Vessels

For proximal axillo-subclavian wounds, sternotomy or left anterior thoracotomy and clamping of the subclavian artery eliminate the error of uncontrolled dissection through an expanding hematoma of the chest. You should approach distal axillary and proximal brachial arterial injuries with infraclavicular incisions and extend across the deltopectoral region into the upper arm as needed (Fig. 22.9). The course of the brachial artery and line for incision is along the medial border of the biceps muscle, with an S-shaped incision across the antecubital fossa for exposure of the brachial bifurcation (Fig. 22.10). Similar techniques as described with the lower

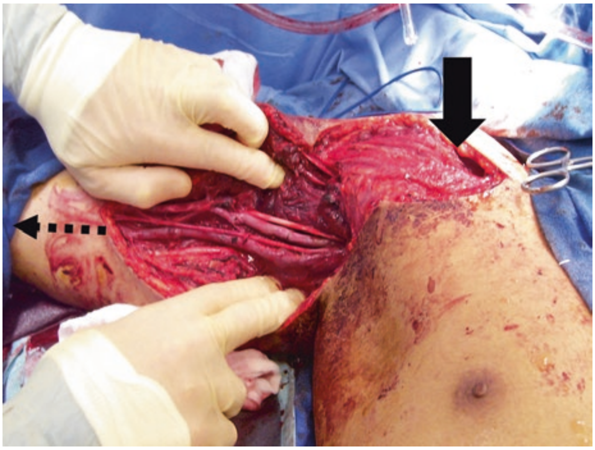

**Fig. 22.9** Upper arm vascular exposure obtained with an incision starting on the chest and following the medial border of the biceps. Note full exposure of the artery, vein, and associated nerves by anterior retraction of the biceps and posterior retraction of the triceps muscles. More distal exposure obtained by distal extension to the antecubital fossa (*dotted arrow*). Control of the proximal axillary/distal subclavian vessels can be obtained by dissection through the deltopectoral groove (*large arrow*)

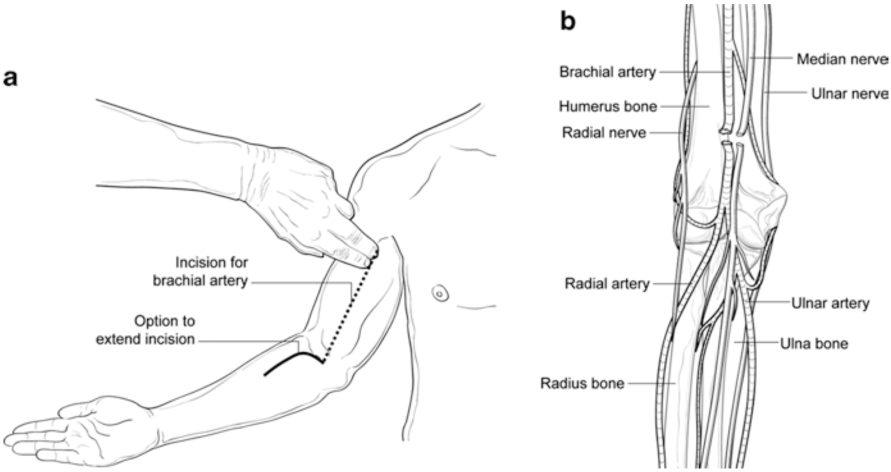


**Fig. 22.10** Diagram showing distal brachial artery exposure (**a**) and relation of important nerves (**b**)

extremity should be followed for vascular repairs. Note that kinking of a vein graft that crosses the elbow is of major concern, so examine your graft in both flexed and extended positions and tunnel it through deeper planes as needed. The other issue of particular importance with brachial artery injuries is the common association with injury to the median or ulnar nerves. Care should always be taken

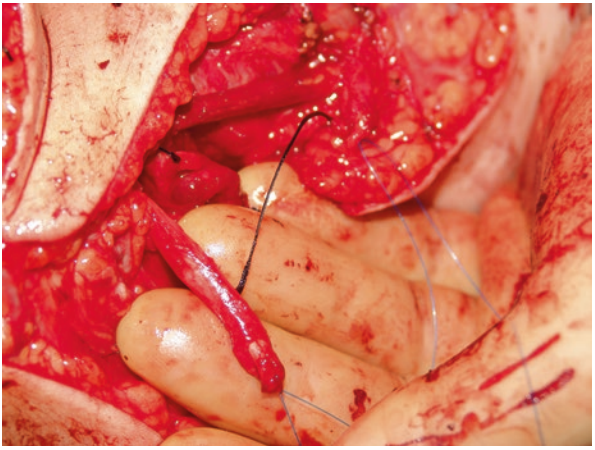

**Fig. 22.11** Brachial artery injury status post repair with transection of the median and ulnar nerves. The cut ends of the nerve are identified and tagged with different-colored suture for later identification (*blue* = median nerve, *black* = ulnar nerve)

to do a thorough preoperative exam of hand function if possible and to identify the nerves intraoperatively. If injured, the nerve ends should be clearly tagged for later repair (Fig. 22.11). Radial artery injuries can always be ligated as long as there is adequate flow to the hand via the ulnar artery.

### Pseudoaneurysms

Although physical exam is excellent for identifying any flow-limiting peripheral vascular injury, small injuries to the vessel wall resulting in the delayed presentation of a pseudoaneurysm are not uncommon. This is particularly true for blast mechanisms with multiple soft tissue fragments, somewhat analogous to civilian shotgun wounds. Unless there is vessel thrombosis with ischemia, these are not emergencies, and most should be referred to a vascular surgeon. They may require surgical repair but often can be managed with ultrasound-guided or endovascular occlusion. Distal radial artery pseudoaneurysms (from wounds or from iatrogenic injury by arterial catheterization) can be treated with simple proximal and distal artery ligation and decompression of the sac.

## Postoperative Care and Evacuation

The early postoperative period is focused on patient warming, resuscitation, and hourly vascular checks that should be performed with a handheld continuous wave Doppler probe. Palpable pulses and sometimes normal ankle-brachial ratios (>0.9) may be delayed until an appropriate resuscitation period has occurred. Patients should remain in the ICU for at least 24 h. In addition to ensuring overall cardiopulmonary and metabolic stability, plans for evacuation out of the war zone should take the threat of early graft failure and postoperative bleeding into consideration.

The vascular injured patient should not be hurried unnecessarily thru the chain of evacuation. External fixators are readjusted based on the appearance of plain film radiographs, and a wound inspection is normally performed within 24 h. The typical patient is returned to the operating room every 48–72 h for additional washouts, debridements, and negative pressure vacuum-assisted closure dressing changes. A careful assessment for the development of a compartment syndrome is essential, especially when the patient is transferred out of the combat zone to providers unfamiliar with the initial postoperative exam. You should always maintain a low threshold for performing a fasciotomy for patients with extremity vascular injury. The morbidity of a prophylactic fasciotomy is minimal and that of a missed compartment syndrome is significant.

## Final Points

The simultaneous management of peripheral vascular injuries in the pursuit of life and limb is very challenging. The decision to amputate or reconstruct an ischemic limb requires sound judgment that often comes with experience gained on the battlefield. These patients have significant transfusion requirements, and the resuscitation should not be separated from the surgery. A two-team approach is an effective method that will keep speed on your side. Not all vessels have to be repaired, as brachial and tibial vessels can be ligated when a Doppler signal is obtainable in the distal limb. Systemic heparin is not necessary; however, adequate intimal debridement and liberal local flushing with heparinized saline during the repair are essential. A well-covered interposed saphenous vein graft is a durable conduit and favored over prosthetic materials. Venous reconstruction should be performed when time permits. Completion arteriography is usually not necessary, but you should confirm your pulse exam with a continuous wave Doppler. Remember, your completion assessment should be continuous over the next 24 h, and if fasciotomies were not performed, then you must focus on early identification of a compartment syndrome. Trust yourself, give the patient time to "catch up," and recognize that the vascular exam will improve over time with successful repairs.

## Civilian Translation of Military Experience and Lessons Learned

Charles J. Fox

**Key Similarities**
- Large numbers of patients with complex injuries
- Highly capable surgical teams
- Workflow efficiency
- Prehospital systems of care

**Key Differences**
- Resource and workspace limitations
- Resident workforce and educational mission
- Environmental conditions
- Degree of wound contamination

## Discussion

There are many important advances spanning the current wartime experiences. Lessons learned during US military operations have continued to advance the field of vascular trauma surgery and now translate into many new civilian surgical practice patterns. This has been particularly evident around prehospital hemorrhage control strategies and implementation of new protocols that allow for rapid transfusion of blood products in the emergency department. No other injury pattern so suddenly causes blood loss, shock, and potential for death as vascular injury. Vascular injuries that can produce significant hemorrhage have therefore been recognized much earlier, and patients with extremity vascular injury have been saved with prehospital tourniquet application. This has shifted the focus of vascular injury diagnosis and management in modern civilian practice. The net result has been a tenfold increase in the early discovery of vascular injuries, many occult, and undoubtedly enhanced by multi-detector row computed tomography angiography in both civilian and military settings. Throughput seems remarkedly similar in the sense that both civilian and military hospitals have advanced diagnostic imaging collocated with emergency rooms, adjacent operative theaters, and adequately resourced intensive care beds that facilitate highly efficient workflow of a steady and large number of severely injured patients.

Resource availability and workspace limitations in combat continue to disrupt the expectations of specialized surgical teams trained in the modern era. While space constraints in the military are inconvenient at best and jeopardize patient safety at worst, the net result has been to produce an adaptable and flexible team focused on mission rather than quality of the infrastructure. For example, in the military, it is not infrequent that two casualties may share a single operating theater, while two or three surgical teams work simultaneously in a noisy confined space with poor lighting. This invaluable experience teaches one what is essential and what is not. While mass casualty events can occur in either setting, they occur more frequently in the military, and the result is a high state of readiness. The redundancy of military wounds may also enhance the preparedness for the next major incident. In civilian trauma centers, wounding patterns are more variable, and the same surgical team may not be present for the benefit of repetitious learning. To avoid mistakes in either setting, a consolidated and continuous training effort is mandatory. Regarding training, graduate medical education remains a mission essential component and source of manpower in civilian trauma centers. The absence of surgical trainees in deployed military settings consolidates the workforce, focuses the goal on direct patient care, and allows for direct communication between attending surgeons. This may represent a key difference between the military and civilian experiences.

Modern times have also used endovascular techniques to treat selected vascular injury. Recognized in the civilian sector as a favored option for blunt aortic and central vascular injuries, these methods have limited application in a theater of war where a robust inventory, hybrid suites, and a skilled endovascular team are lacking. What has emerged is the permeation of highly selective endovascular skills within the military such as resuscitative aortic balloon occlusion or ultrasound-guided placement of a femoral arterial sheath for hemodynamic monitoring. Once a familiarity is obtained with wires, sheaths, and catheters, the use of various adjuncts may be more achievable in austere environments. The military population tends to be younger, male, with a higher proportion of penetrating injury. The civilian population has the added challenge of comorbid conditions that produce profound physiologic deterioration in the setting of hemorrhagic shock. Therefore, endovascular solutions to these blunt civilian vascular injuries may reduce physiologic and metabolic derangements associated with the estimated blood loss of difficult surgical exposures.

Injury severity and mangled extremity scores tend to be higher in the military group. While the limb revascularization techniques and incidence of compartment syndrome are similar, the rate of amputation still appears higher in the military and is probably associated with the devastating effects of a heavily contaminated dismounted complex blast injury that requires continuous surgical debridement. These blast incidents produce horrific wounds, and the challenges of a multisystem dismounted complex blast injuries (DCBI) that have emerged in recent conflicts are a frequent topic of interest. The response to this unique injury pattern can apply to any severely injured patient regardless of the setting. Civilians with crush injury or open pelvic fractures share similar initial hemostatic resuscitation and early management strategies, and just like DCBI during the wars in Iraq and Afghanistan, survival for these pelvic wounds has steadily improved when treated with evidence-driven protocols. A thorough understanding of this management strategy is crucial for any surgeon as a civilian setting can quickly become like a military one. Our nation, for example, frequently experiences similar sudden and unexpected enemy attacks. The truck bombing of the World Trade Center in 1993, the 1995 truck bombing in Oklahoma City, and the 1996 pipe bomb at the Summer Olympic Games produced almost 2000 casualties. Recently, the 2013 Boston Marathon bombing produced 264 DCBI-like casualties similarly described as mostly devastating lower extremity blast wounds that spared the chest and upper torso, resulting in 14 traumatic amputations from nails, ball bearings, and bits of metal. Those casualties went to 27 different local area hospitals and required the surgeon on call to deal with the unexpected blast-injured patient.

The translatable lessons learned, replete with both similarities and differences, serve as an instruction manual for managing patients with peripheral vascular injuries regardless of location. In this context partnerships between military and civilian surgeons are vitally important. Undoubtedly, the ability to respond to the vascular injuries experienced in Iraq and Afghanistan can be attributed to the excellent training received in large high-volume civilian trauma centers by world-renowned surgical educators. The reciprocal benefits of exchanging translatable experiences have proven invaluable to our nation's preparation and maintaining surgical readiness to treat peripheral vascular injuries in both civilian and military settings.

# 23 The Neck

John S. Oh and Demetrios Demetriades

**Deployment Experience**

| | |
|---|---|
| *John S. Oh* | Trauma Surgeon, 749th Forward Surgical Team, Afghanistan 2005–2006 |
| | Trauma Surgeon, 102nd Forward Surgical Team, Baghdad, Iraq 2007–2008 |
| | Trauma Director, 10th Combat Support Hospital, Camp Bastion, Afghanistan 2011–2012 |
| | Trauma Director, 28th Combat Support Hospital, Baghdad, Iraq 2016 |

*"The surgeon must have the heart of a lion, the eyes of a hawk, and the hands of a woman."*

John Halle, 1529–1568

**BLUF Box (Bottom Line Up Front)**

1. Secure the airway early, major neck injuries result in rapid compromise.
2. Mandatory neck exploration should be your default approach in the combat and low resource settings.
3. The wounded neck is unforgiving and full of potential areas prone to iatrogenic injury. Start by identifying key structures *away* from the injury and then work your way in.

(continued)

J.S. Oh (✉)
Division of Trauma, Acute Care, and Critical Care Surgery, Penn State Hershey Medical Center, Hershey, PA, USA
e-mail: johnoh1@hmc.psu.edu

D. Demetriades
Acute Care Surgery, LAC+USC Medical Center, Department of Surgery, Trauma Division, Los Angeles, CA, USA


M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_23

(continued)

4. You can control carotid hemorrhage with one finger – don't panic.
5. Repair carotid injuries, if at all possible, or place a shunt and come back later. Ligate only as a last option.
6. Reinforce an esophageal repair with buttressed tissue to separate suture lines; a failed esophageal repair will take others down with it. A missed esophageal injury = mediastinitis and death; therefore always drain the neck, even after a "negative" exploration.
7. Large volume bleeding from the wound after a "negative" neck exploration is a vertebral artery injury.
8. Median sternotomy should be your next move for large volume hemorrhage from the proximal carotid or subclavian (zone 1) area. Have both the neck and chest prepped and draped.

## Why Is the Neck an Important Area to Understand the Anatomy and Injury Patterns?

Major vascular and aerodigestive structures pass through the neck with little or no protection from overlying bone, muscle, or soft tissue. This means an injury to the neck can result in loss of the airway from a tracheal injury, exsanguination from injury to a major blood vessel, or sepsis from a major pharyngeal or esophageal injury. It is also an area that most general surgeons infrequently operate on, so thorough preparation is the only way to make up for the lack of familiarity in an emergent case. In addition to reviewing textbooks and journal articles, trauma exposure courses using cadavers is an excellent way to stay prepared.

## Mechanisms and Types of Injuries to the Neck

In order to prioritize management decisions, it is helpful to elucidate the mechanism of injury to the neck. Mechanisms of injury include blunt versus penetrating, stab wounds versus missile injury, and low versus high-velocity missile injury. Stab wounds and low velocity missile injuries can cause little damage to surrounding structures in the neck in comparison to high-velocity missile injuries. Shotgun injuries and blast injuries may cause multiple penetrating injuries to the neck, and identifying multiple trajectories and possible injuries require thorough work up. Combat wounding mechanisms tend to include high-velocity missiles as well as multiple fragments from blast injuries.

## What Are the Life-Threatening Neck Injuries?

Immediately life-threatening injuries to the neck include injuries to major vascular structures such as the internal jugular vein or carotid artery and injury to the trachea. The main priority with any of these injuries, whether it is a vascular injury or a direct tracheal injury, is to secure the airway and control hemorrhage. A missed esophageal injury can also be a cause of late morbidity and mortality from infection, sepsis, and possibly mediastinitis as infection may spread along fascial planes from the neck into the mediastinum.

## What Are the Injuries that Are Easy to Miss But Can Lead to Late Morbidity or Death?

In the civilian trauma literature, a selective operative management algorithm is useful in decreasing negative neck explorations but only if you have high-quality CT angiograms or interventional radiologists available to confirm that there are no major vascular, airway, or esophageal injuries present. Clinical signs, while also useful, can be unreliable for ruling out major injuries that require a neck exploration. In a deployed setting, you will often not have the luxury of a CT scan or angiography. You also may not even have the time or resources to carefully observe the patient and do serial exams to rule out an injury – particularly on a patient who needs to go into the evacuation chain back to the United States. That means you must have a low threshold to explore the neck.

A negative neck exploration has a low morbidity rate, and mortality from a negative exploration is virtually unheard of. There are several injuries to consider that are easy to miss but have devastating potential.

1. Occult vascular injuries to the carotid such as a dissection or small pseudoaneurysm may be asymptomatic initially but can progress to complete thrombosis or rupture.
2. Small penetrating esophageal injuries. Due to the lack of a serosal layer, the longitudinal muscularis may hide small mucosal perforations. Thus, you should always drain the neck with closed suction drains, even after a "negative" exploration.
3. Penetrating oropharyngeal injuries – remember to look in the mouth and posterior pharynx for all penetrating neck wounds.

## How Should I Evaluate a Patient with a Neck Wound?

The approach to a patient with a penetrating neck wound is the same as with all other traumas. The priority is to establish a definitive airway in the unstable patient, then proceed with the remainder of the A-B-C's. In evaluating the trajectory of the injury to the neck, it is helpful to divide the neck into three anatomic zones. Zone I lies between the clavicles and the cricoid cartilage, zone II lies between the cricoid cartilage and the angle of the mandible, and zone III lies between the angle of the mandible and the base of the skull (Fig. 23.1). Remember that these refer to anterior and lateral neck wounds and not wounds that are confined to the posterior neck or superficial wounds that have not penetrated the platysma muscle.

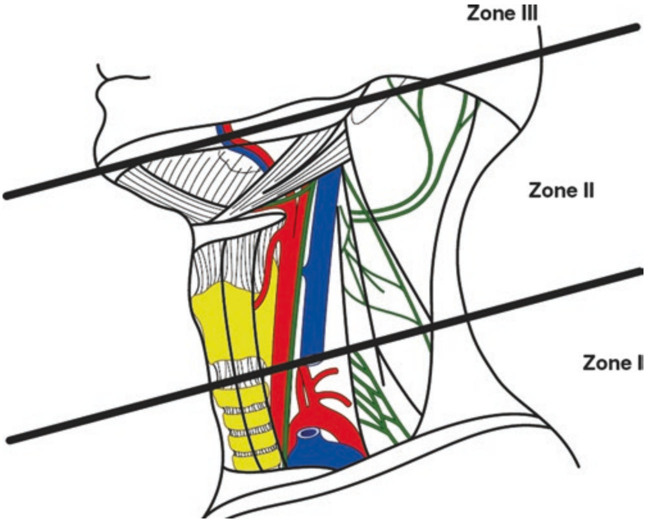


**Fig. 23.1** Zones of the neck (Reprinted from *Oral and Maxillofacial Surgery Clinics of North America*, 20(3), Shahrokh C. Bagheri, H. Ali Khan, R. Bryan Bell, Penetrating Neck Injuries, 393–414, Copyright 2008, with permission from Elsevier)

One of the first problems examining the neck is that someone has often placed a cervical collar, and no one wants to remove it for fear of a spinal column injury. The first maneuver you should perform is removing the collar – it is an obstruction to completing a thorough physical exam, which is of paramount importance. The likelihood of causing further neurologic injury by removing the collar is low as the degree of neurologic injury in penetrating trauma is mostly related to the initial injury.

If necessary, the collar can be replaced after your evaluation. A thorough evaluation of the neck should include observation for hematomas, pulsatile masses, arterial bruits, bleeding or air from wounds, and tracheal deviation. Feel for crepitus, carotid pulses, and bony injuries. Auscultate for bruits and breath sounds, and assess the voice for hoarseness or stridor. Examine the cranial nerves and don't forget a good intraoral examination. Observe for any obvious hematemesis or hemoptysis. You can also have the patient spit on a gauze pad to look for any blood in the saliva suggestive of hemoptysis.

The majority of wounds to the neck lie within zone II, where the aerodigestive tract, carotid artery, vertebral artery, internal jugular vein, and cervical spine are at risk (Fig. 23.2). In addition to these structures, injuries to zone I include structures in the thoracic inlet, such as the aortic arch, proximal carotid, and subclavian vessels. Injuries to zone III include the cranial vault and pharynx. In an unstable patient with penetrating trauma to the neck, you should proceed directly to the operating room. The presence of "hard signs" of injury such as obvious uncontrolled hemorrhage, expanding or pulsatile hematomas, "sucking" neck wounds, unexplained hypotension, or lateralizing neurologic signs should also prompt immediate surgical exploration.

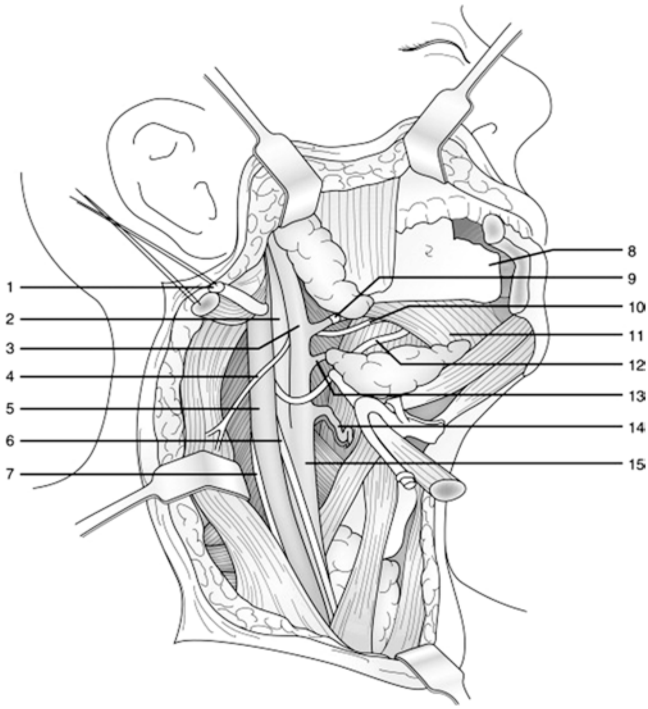


**Fig. 23.2** Critical anatomy of the neck for trauma neck exploration: (1) facial nerve; (2) internal carotid artery; (3) external carotid artery; (4) spinal accessory nerve; (5) internal jugular vein; (6) vagus nerve; (7) cervical plexus; (8) mandible; (9) facial artery; (10) lingual nerve; (11) mylohyoid muscle; (12) hypoglossal nerve; (13) lingual artery; (14) superior thyroid artery; (15) common carotid artery (Reprinted from *Oral and Maxillofacial Surgery Clinics of North America*, 20(3), Shahrokh C. Bagheri, H. Ali Khan, R. Bryan Bell, Penetrating Neck Injuries, 393–414, Copyright 2008, with permission from Elsevier)

If you have a hole in the neck and hard signs of a vascular injury, you do not need a CT scan to confirm the injury or to tell you where it is. You need to be in the OR for a neck exploration and prepared to do a sternotomy or clavicular extension.

In the civilian literature, zone I and III injuries are often first evaluated by a combination of CT scan, bronchoscopy, esophagoscopy, esophagogram, and angiography. Zone II injuries are typically explored in the operating room if they present with classic "hard signs." Otherwise, they are managed nonoperatively with imaging and close serial examination. In austere settings where thorough, nonoperative evaluation is not possible, penetrating injuries to any of these zones require surgical exploration. In these cases, you will do some negative or nontherapeutic explorations, but you will find significant injuries much more commonly than is reported with civilian trauma mechanisms. However, due to the low morbidity and mortality of a negative exploration, this is acceptable. It is far more devastating to have a missed injury or delayed therapy. All wounds penetrating the platysma muscle, as well as all high-velocity and transcervical neck wounds, should prompt exploration.

The blast victim who has multiple tiny fragment wounds involving the neck without hard signs of neck injury can pose a diagnostic dilemma. These fragments could have caused significant injuries to any neck structure, or they may just be superficial injuries that have not penetrated the platysma. If the patient has a normal neck examination as outlined above and is hemodynamically stable, then you should obtain a CT arteriogram of the neck if available. This should identify the vast majority of major neck injuries and also identify the location of any retained fragments. If the exam and the CT scan are normal, then the patient can be safely observed. If there is any concern for an esophageal injury, then swallow study and/or endoscopy must be added to your evaluation. Watch this patient for at least 24 h to ensure stability and no delayed manifestation of an occult injury. If close observation for up to 48 h and these diagnostic adjuncts are not available, then neck exploration is recommended.

## Techniques of Exposure, Exploration, and Repair of the Common Injuries

### Vascular Injuries: Common, Internal, and External Carotid Arteries, Jugular Vein

The general approach to a penetrating neck injury is to prep and drape from the base of the skull to the knees. Shave the groin and thighs for possible saphenous vein harvest. In addition, take the time to position your patient properly. This includes a shoulder roll underneath the shoulder blades to help extend the neck. If you have unilateral injury, turn the head slightly away from you, and use a head support. Proper positioning will greatly enhance the operative exposure of the neck. If there is concern for cervical spine injury, this may not be possible, and the neck should be maintained in the neutral position.

There are multiple incisions and extensions that can be used in the neck (Fig. 23.3). For trauma exploration, the basic incision for penetrating neck trauma is along the anterior border of the sternocleidomastoid muscle (SCM), just as you would for a carotid endarterectomy. The incision should extend from the mastoid process to the sternal notch. This incision will allow access to the major vascular and aerodigestive structures of the neck. Exposure of the esophagus is best gained via the left neck but can be obtained from either side. You should always be prepared to extend your incision inferiorly into a median sternotomy for proximal vascular control or to "hockey stick" the inferior end of the neck incision transversely across the clavicle to expose the subclavian vessels. Do not hesitate to resect a portion of the clavicle or disarticulate it from the manubrium to gain full exposure of the subclavian vessels. Finally, for bilateral neck explorations, you can either make mirror image standard incisions or make a collar incision with bilateral superior extensions along the SCM.

The first landmark you must look for after dividing the platysma muscle is the anterior border of the SCM. Retract the SCM laterally and maintain your dissection

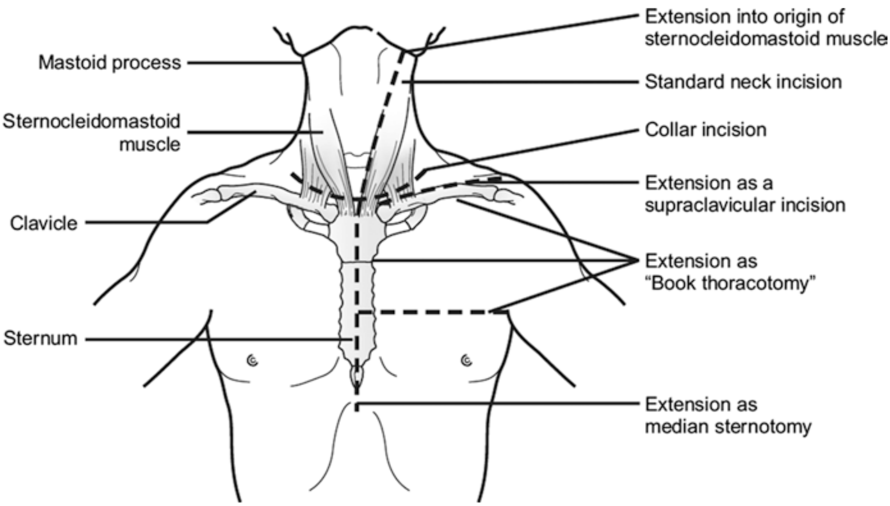


**Fig. 23.3** Incisions for standard trauma neck exploration and optional extensions for zone I and zone III vascular control (Reprinted from *Oral and Maxillofacial Surgery Clinics of North America*, 20(3), Shahrokh C. Bagheri, H. Ali Khan, R. Bryan Bell, Penetrating Neck Injuries, 393–414, Copyright 2008, with permission from Elsevier)

along this plane. If you are in the correct plane, the dissection will proceed easily with proper traction and counter-traction. If you encounter longitudinal muscle fibers, your dissection is too lateral. Move anteriorly until you find the anterior muscle border (see Fig. 23.2).

This will lead you directly into the fascia of the middle cervical space. As you open this fascial layer, the first vessel you encounter is the internal jugular (IJ) vein. This is the most commonly injured vessel in the neck. If the injury to the IJ is obvious and repair is straightforward, proceed with primary repair using a 5-0 Prolene suture. Otherwise, you should not hesitate to ligate the vein and move on to identifying more significant injuries. The next landmark to look for is the facial vein – this is a useful landmark to the carotid artery. It also lies superficial to the carotid bifurcation. Ligate and divide the facial vein in order to facilitate exposure and gain control of the carotid artery. As you mobilize the jugular vein laterally, the carotid artery will lie medial and deep to the vein. The carotid bifurcation will be immediately underneath the facial vein, with the external carotid immediately diving medially into the deep neck and face area and the internal carotid coursing superiorly (Fig. 23.4). Nerves to watch out for in this area are the vagus nerve, which runs longitudinal in the carotid sheath on the posterior surface of the carotid artery and the hypoglossal nerve running transversely across the internal carotid just below the ramus of the mandible (see Fig. 23.2). Beware of direct injury to this nerve or traction injury from superior wound retraction.

The first decision that you need to make after exposing the carotid artery is to repair or ligate. Unilateral *external* carotid artery ligation may be performed without

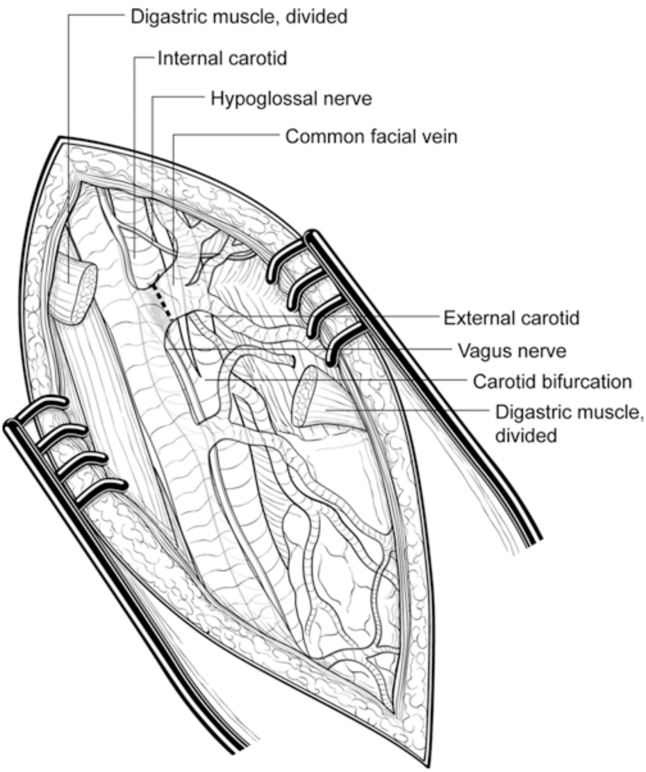


**Fig. 23.4** Exposure of the right carotid artery and carotid bifurcation by ligation of the facial vein and retraction of the internal jugular vein laterally

significant sequelae. However, ligation of the common or internal carotid artery can result in devastating cerebral ischemia. Therefore, ligation of these vessels should only be performed in extreme circumstances such as uncontrolled hemorrhage, devastating injuries where repair is not possible, or in cases where the patient presents in frank coma. In all other cases, repairing the artery results in improved outcomes and should be attempted. The concern over repairing an "occluded" artery that may subsequently shower emboli or cause intracranial hemorrhage with a worsening neurologic deficit appears to be theoretical. Accumulating evidence shows that these patients do better with repair. If you don't have the equipment, time, or expertise to repair the vessel, then your next choice should be placing a shunt rather than ligating (see below).

Use the principal of proximal and distal control when exposing the injured carotid artery. Obtain proximal control first outside of the hematoma associated with the injured artery. This may require a median sternotomy to gain adequate proximal control of the vessel. If that is required, do not hesitate. Place a Rummel tourniquet and proceed with the dissection along the carotid artery. Stay in the peri-adventitial plane; this will prevent inadvertent injury to adjacent structures,

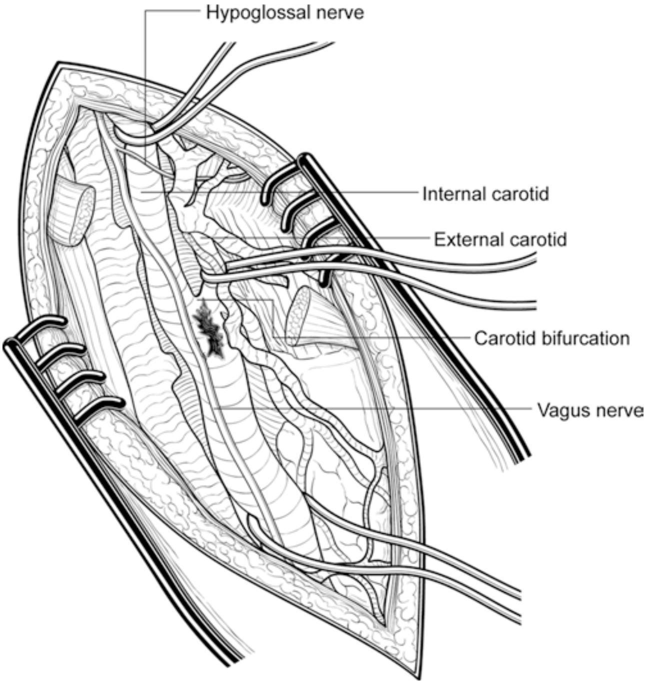


**Fig. 23.5** Vascular control of the carotid artery

such as the vagus nerve that lies within the carotid sheath running parallel to the artery. Also remember that the hypoglossal nerve overlies the internal carotid artery just after the bifurcation. During your dissection, try to avoid cutting structures you encounter. A safer strategy is to bluntly push the adjacent structures aside.

Next, obtain distal control in uninjured territory outside of the hematoma whenever possible. You will often find that the hematoma extends to the mastoid process. In this case, you need to enter the hematoma directly. Be prepared to encounter back bleeding from the internal and external carotid arteries as you expose the injury. In order to rapidly gain hemostasis, use direct pressure with your finger first, then gain distal control with a Rummel tourniquet or vascular clamp. If those maneuvers fail, inflate a No. 3 Fogarty catheter into the lumen of the vessel with a three-way stopcock attached to the end. When inserting a Fogarty catheter into the internal carotid artery, take care not to rupture the carotid siphon. This means advancing the Fogarty no more than 2–3 cm beyond the bifurcation. Once you gain control of the common, internal, and external carotid artery, you have achieved complete vascular control (Fig. 23.5).

If you find that the injury to the internal carotid artery extends into zone III, you have few repair options available. First, divide the posterior belly of the digastric muscle to improve exposure of the distal carotid artery. You can also gain an additional 2–3 cm of exposure by anterior subluxation and fixation of the mandible (Fig. 23.6). If you have an ENT or OMFS colleague available, they can be of great assistance

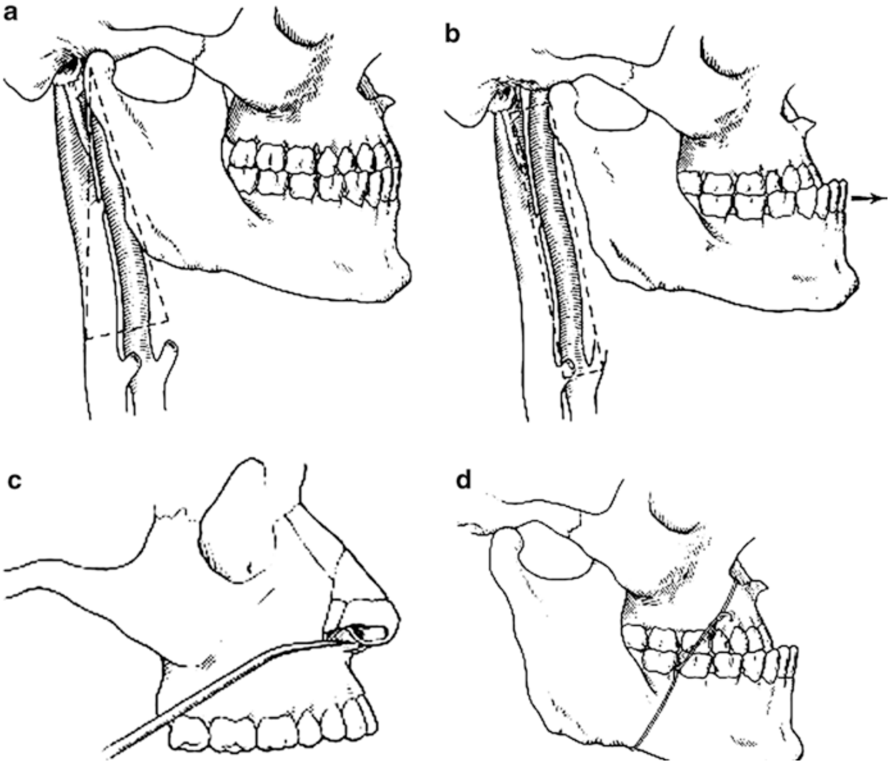


**Fig. 23.6** The distal internal carotid artery exposure is hindered by the manibular ramus, creating a triangular space with a narrow apex (**a**). Forceful anterior traction on the mandible will convert this to a rectangular space providing several centimeters of additional distal exposure (**b**). The mandible can be maintained in this position by manual retraction or placement of trans-nasal fixation wires (**c**, **d**) (Reprinted from *Current Problems in Surgery*, 44(1), Demetrios Demetriades, Ali Salim, Carlos Brown, Matthew Martin, Peter Rhee, Neck Injuries, 13-85, Copyright 2007, with permission from Elsevier)

with this. If you encounter vigorous back bleeding and are unable to obtain distal control, the only real option is to attempt to ligate the distal artery if you can gain purchase of it. Otherwise, inflate a Fogarty balloon within the lumen, place vascular clips on the balloon catheter, and cut the distal end. This will end up being your definitive repair.

Definitive repair of the carotid artery can be performed primarily with interrupted 5-0 Prolene suture if the injury is a simple laceration – rarely seen in combat injuries. Otherwise, you may use a patch or interposition graft. In general, a prosthetic graft should be used for the common carotid artery (Fig. 23.7) and a reversed saphenous (or other site of appropriate size) vein graft for the internal carotid artery. The necessary steps are to debride to healthy, uninjured intima proximal and distal to the injury. Next, perform a catheter embolectomy proximally and distally with a No. 3 Fogarty catheter, and flush the ends with heparinized saline. If you need to place

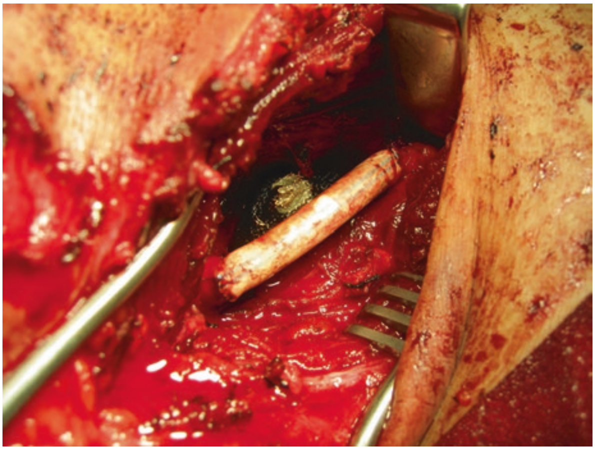

**Fig. 23.7** Prosthetic interposition graft (PTFE) of the common carotid injury for a large fragment wound to the neck

an interposition graft, perform the distal anastomosis first, applying the posterior row of sutures first, working anteriorly. When you get to the last several sutures of the repair, open the external carotid to allow back bleeding to flush out any clot. Then complete the repair, and open the common and external carotids to allow any remaining clot to be flushed into the external system. Open the internal carotid to antegrade flow last. Another repair option for a proximal internal carotid artery injury is to divide the external carotid artery and transpose the proximal end to the internal carotid artery distal to the injury (Fig. 23.8). Confirm flow using a sterile Doppler flow probe, if available.

What if your patient has multiple injuries or needs a damage control operation due to physiologic deterioration? One option is to ligate the carotid artery, as mentioned previously. Another damage control option is to place a shunt while you address the other injuries or complete your resuscitation in the ICU. You can always return to the OR for definitive repair later. There are various sets of carotid shunts that are specifically designed and sized for use in the common and internal carotid arteries. If you do not have these available, you can use a pediatric feeding tube or intravenous tube cut to proper length and flushed with heparin solution. Make sure to secure the shunt in place with silk ties around the proximal and distal vessel ends taking care to preserve as much vessel length as possible.

## Esophagus

Within the neck, the esophagus lies deep to the carotid sheath, anterior to the cervical spine, and posterior to the trachea slightly left of midline. Place a nasogastric tube to help you palpate the esophagus. You can approach the esophagus by retracting the carotid sheath laterally (the anterior approach). This may be the easier approach if you have already explored the vessels in the carotid sheath. An alternative approach is to move the carotid sheath medially and approach the esophagus posteriorly.

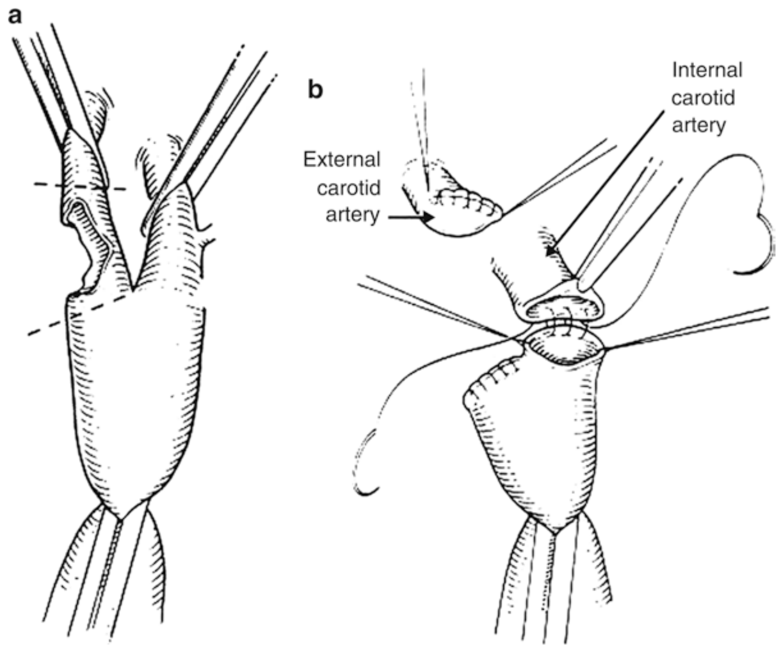


**Fig. 23.8** External to internal carotid artery transposition procedure. (**a**) Injury to the proximal internal carotid artery is excised. (**b**) The external carotid artery is divided, and the proximal end is anastomosed to the distal end of the internal carotid artery, reestablishing cerebral perfusion (Reprinted from *Current Problems in Surgery*, 44(1), Demetrios Demetriades, Ali Salim, Carlos Brown, Matthew Martin, Peter Rhee, Neck Injuries, 13-85, Copyright 2007, with permission from Elsevier)

This may be the preferred approach if you are attempting to stay out of a large hematoma within the carotid sheath. You will find, however, that the anterior approach provides better exposure of the cervical esophagus. To fully expose the esophagus, you will need to divide the omohyoid, middle thyroid vein, and inferior thyroid artery (Fig. 23.9). Do not bother to take time looking for the recurrent laryngeal nerve as it will often be obscured, but avoid dividing any longitudinal structures in the tracheoesophageal groove. Once you have your planes identified, you can use blunt finger dissection or a large angled clamp to encircle the esophagus. Placement of an umbilical tape or Penrose drain above and below the injured area allows retraction of the injury into your operative field.

Whatever route you choose in your approach, understand that the esophagus easily contains "hidden" injuries. Due to the lack of a serosa, injuries are more difficult to identify, and the extent of mucosal injury is often greater than the injury to the muscular layers. Consider this when debriding devitalized tissue in an esophageal injury. Another option, if available, is to perform an intraoperative esophagoscopy to identify occult mucosal injuries. Otherwise, you can ask the anesthesia provider to pull back the nasogastric tube and insufflate the esophagus with air as you instill

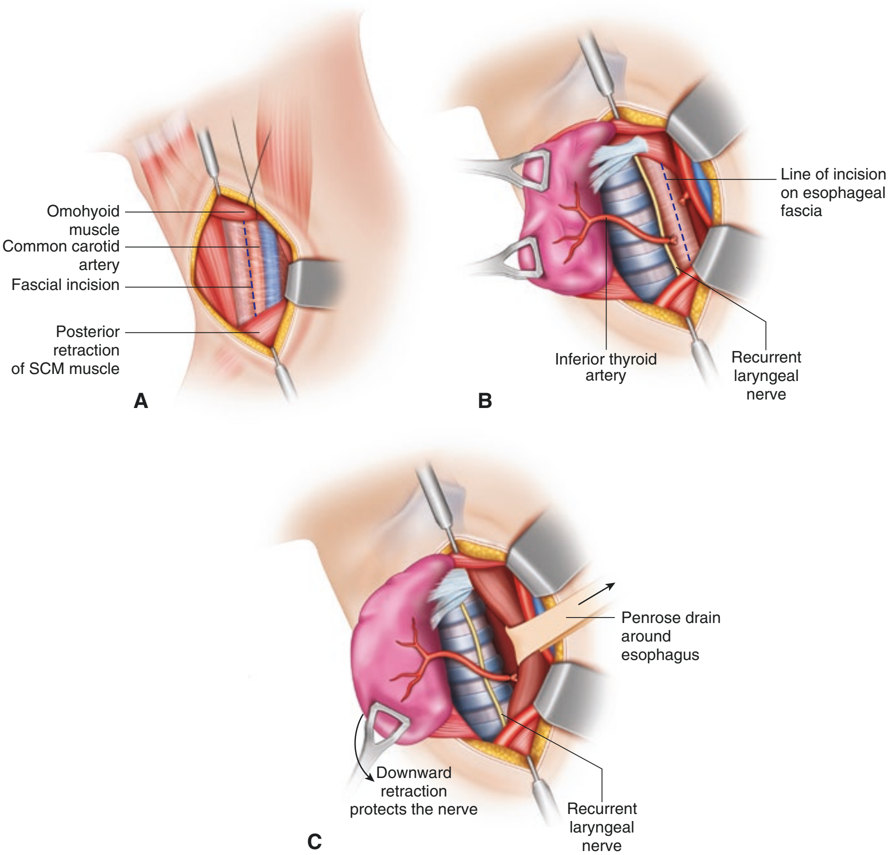


**Fig. 23.9** Exposure of cervical esophagus. (**a**) Incision of superficial fascia along anterior border of sternocleidomastoid; (**b**) incision of deep-investing fascia over the esophagus, posterior to the recurrent laryngeal nerve; (**c**) circumferential mobilization of the esophagus

saline into the wound, looking for an air leak. Once you have identified the injury, use conservative debridement to healthy tissue. Remember that the internal mucosal injury is often longer than the external muscular layer injury. Extend the muscular defect to identify the edges of mucosa, which can then be elevated into the wound and repaired (Fig. 23.10). If the injury is amenable to primary repair, use an absorbable monofilament suture. You can use a one- or two-layer technique, ensuring that there is no tension on the repair. Alternatively, use a linear stapler on the mucosa and then suture repair of the muscular layer (see Fig. 23.10). Once your suture line is complete, buttress it with a piece of healthy, vascularized tissue by mobilizing the strap muscles, omohyoid, or SCM. These structures can be easily mobilized from their attachment to the sternum. Buttressing your repair is especially important if you have to repair another injured structure in the neck, such as the carotid vessels or the trachea.

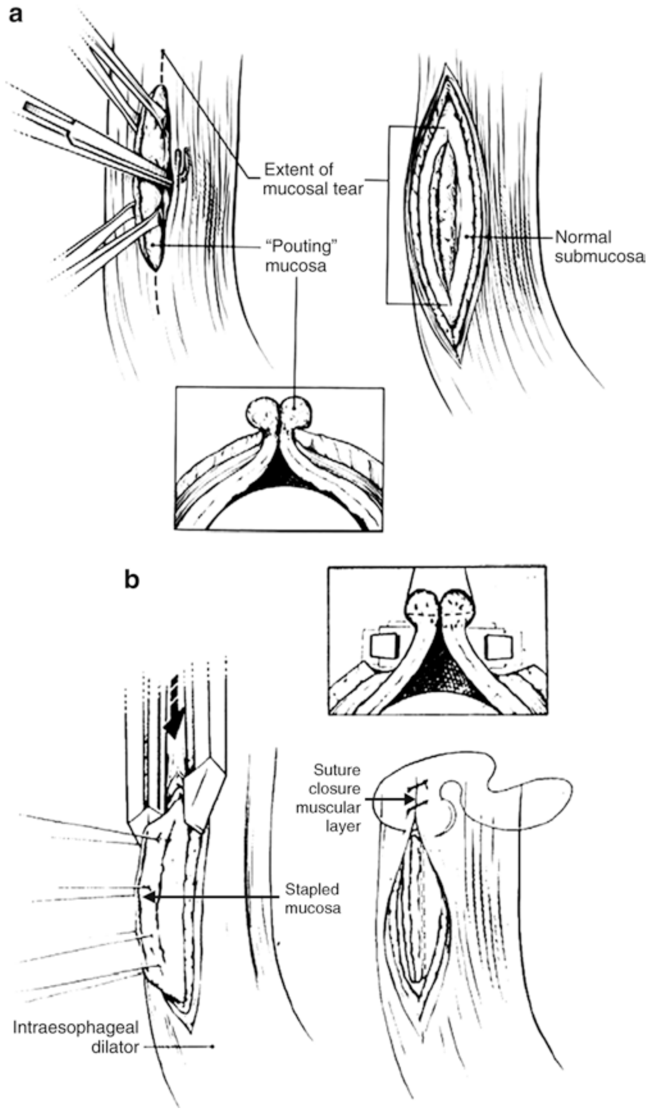


**Fig. 23.10** Stapled repair of an esophageal injury. (**a**) Extend the muscular defect proximally and distally to expose the extent of the mucosal injury. Grasp and elevate the mucosa into the defect using forceps or stay sutures. (**b**) A linear stapler is used to close the mucosal defect, and the muscular layer is approximated with interrupted or running suture (Reprinted from The Journal of Thoracic and Cardiovascular Surgery, 109(1), Richard I. Whyte, Mark D. Iannettoni, Mark B. Orringer, Intrathoracic esophageal perforation: the merit of primary repair, 140–146, Copyright 1995, with permission from Elsevier)

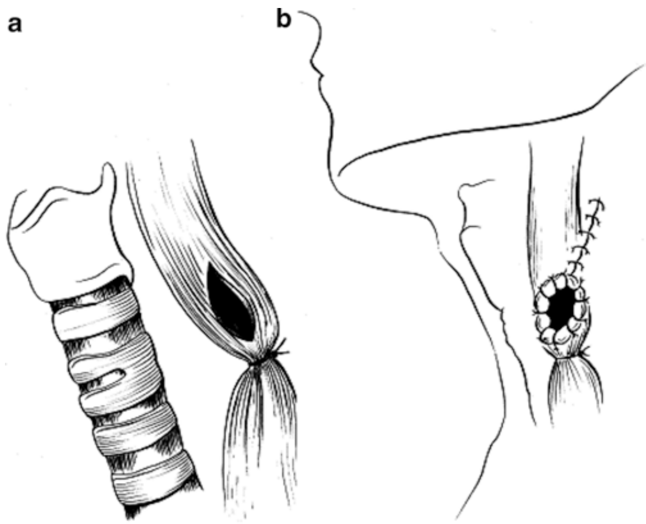


**Fig. 23.11** Creation of a cervical esophagostomy. (**a**) Ligate the distal esophagus, and make a longitudinal esophagotomy in the most mobile portion (or use the injury itself). (**b**) Mature the esophagostomy into the inferior part of the incision with interrupted sutures to the skin (Reprinted from *Journal of the American College of Surgeons*, 6(3), Leonidas G. Koniaris, Seth A. Spector, Kevin F. Staveley-O'Carroll, Complete esophageal diversion: A simplified, easily reversible technique, 991-993, Copyright 2016, with permission from Elsevier)

If the injury cannot be repaired primarily, the best option is to create a controlled fistula by performing a lateral esophagostomy (Fig. 23.11) or by placing a drain and exteriorizing it. If you can, place a large closed suction drain into the lumen of the esophagus through the injury, and purse string around it. If you have a high injury in the hypopharynx, simply place an exteriorized drain adjacent to the suspected injury. These injuries will often close on their own with appropriate drain management. If you have an unstable patient with multiple injuries and a circumferential or near circumferential destructive injury to the cervical esophagus, simpler and faster is better. You can exclude the injured area rapidly with a TA stapler fired above and below or use umbilical tapes to ligate the esophagus above and below the injury.

What if you suspect an injury to the contralateral side of the esophagus? One tactic is to make a contralateral incision in the neck. Another, more difficult option is to attempt to fully mobilize the esophagus. This is not recommended unless you have experience with esophageal surgery. With mobilization, there is a high risk of iatrogenic injury to the esophagus, recurrent laryngeal nerve, and trachea. An alternative option is to simply place an exteriorized drain until more definitive repair can be accomplished. An air insufflation test can help with this decision – if you have a small leak, leave a drain and get out. If you have a large air leak, explore and repair/drain the other side.

## Trachea

The simplest thing to do with an anterior injury to the tracheal wall is to insert an appropriate size tube and convert it to a tracheostomy. Otherwise, simple lacerations to the trachea may be repaired primarily with an absorbable, monofilament suture with the knot tied on the outside. It is important to create a completely tension-free repair. If you have a large defect with significant loss of cartilage, you may attempt to mobilize the trachea and perform a primary anastomosis. However, I would only recommend this if you are experienced with tracheal surgery. Otherwise, use one of following damage control options:

1. Place an oral or nasotracheal tube with the balloon inflated past the injury.
2. Intubate directly through the injury itself.

These damage control options will allow you to transfer the patient to definitive care.

## Vertebral Arteries

This can be one of the most frustrating injuries encountered in the neck. This is because the vessel is deep and posterior in the neck and is encased in the transverse process of the cervical vertebrae (Fig. 23.12a). Upon exploration of the neck, what you will find is an intact carotid sheath with copious bleeding from the paravertebral muscles posteriorly. Mobilize these muscles laterally with a periosteal elevator to expose the transverse processes. You can guide your exposure by palpating the

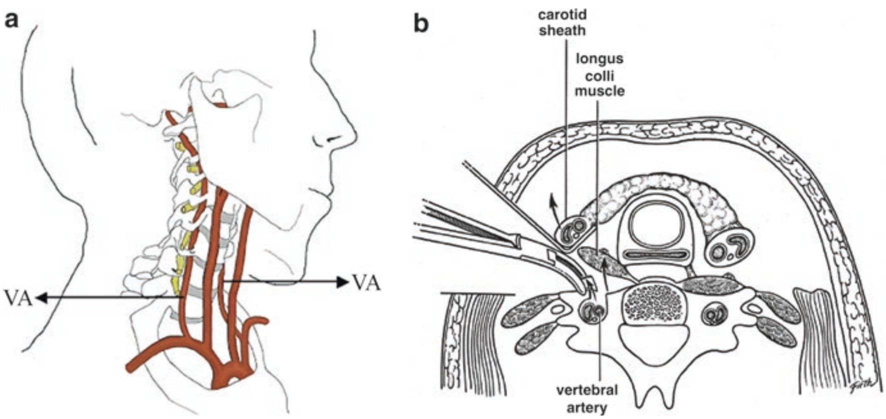


**Fig. 23.12** Management of vertebral artery injuries. (**a**) Vertebral arteries (VA) ascend in the neck within the vertebral foramina of the cervical spine; (**b**) posterior approach to the vertebral artery and exposure using rongeur to remove the surrounding bone and open the vertebral foramen (Reprinted from *Current Problems in Surgery*, 44(1), Demetrios Demetriades, Ali Salim, Carlos Brown, Matthew Martin, Peter Rhee, Neck Injuries, 13–85, Copyright 2007, with permission from Elsevier)

transverse processes (Fig. 23.12b). Exposure of the vertebral artery is difficult at best, and the preferred management of a vertebral artery injury in civilian trauma centers is angiography and embolization. You will likely not have this luxury. You may be able to clip the vessel ends if visible between the cervical vertebrae, but if not then use a rongeur to remove the lateral portion of the transverse process and expose the vessel. An alternative simple solution is to plug the hole with bone wax. Hemostatic dressings such as QuikClot have also been used with excellent results. This will work for most small injuries. If you still have bleeding, identify the vessel at the base of the neck as it comes off the subclavian artery. It is not encased in bone at this point and is relatively easy to expose and ligate. You may still get some back bleeding from the distal end; place a balloon catheter into the lumen of the vessel distally.

## Final Thoughts

Management of the combat neck wound will often take you out of your usual comfort zone, so run through the anatomy and scenarios in your head to prepare for the real thing. Focus on the two major immediate threats to life – bleeding and major tracheal injury; everything else can wait and be approached in a more thorough manner. Get help – you cannot perform exposure and dissection in this area on your own, and a second pair of trained hands and eyes is invaluable. Have a low threshold for performing a neck exploration and a high threshold for attempting nonoperative management. Before you transfer your patient to another facility or place them in the evacuation chain, you should either have definitively addressed their major neck injuries or have assured yourself that there is no significant injury. Remember that speed and simplicity are critical factors in combat trauma surgery and will lead you to success in the "high-value" territory of the neck.

## Civilian Translation of Military Experience and Lessons Learned

Demetrios Demetriades

### Civilian Versus Battlefield Injuries

Neck injuries pose major diagnostic and therapeutic challenges because of the dense concentration of many important organs in a small anatomical area and the difficult surgical exposure of many of these structures. However, only about 20% of civilian gunshot injuries and 10% of stab wounds require operative intervention. The remaining patients can safely be managed nonoperatively. Routine surgical exploration of civilian-penetrating neck injuries is not an acceptable practice because of the unacceptable rate of nontherapeutic operations.

Civilian injuries may differ from battlefield injuries, which are often the result of high-velocity missiles or explosions, diagnostic resources may not be available, and the continuity of care may be problematic. However, if the appropriate resources are available, the principles of evaluation and management used in civilian injuries are applicable to war injuries.

## Clinical Evaluation

A careful clinical examination according to a written protocol almost always diagnoses or highly suspects all significant injuries requiring operative intervention. In order to avoid missing significant signs or symptoms, it is strongly recommended to perform the examination according to a written protocol. Appropriate investigations such as CT angiogram, color flow Doppler (CFD), and endoscopy confirm with certainty the presence or not of any injuries to vital structures.

The clinical examination should be systematic, and evaluate for injuries to the vessels, the aerodigestive tract, the spinal cord, the nerves, and the lungs. The presence of hard signs is highly diagnostic of significant injuries requiring operation. Patients with "soft signs" require further evaluation by means of vascular or endoscopic studies.

### Vascular Injuries

"Hard" signs and symptoms highly diagnostic of vascular trauma include active bleeding, unexplained shock, expanding or pulsatile hematoma, absent or significantly diminished peripheral pulses, and a bruit on auscultation.

"Soft" signs and symptoms suggestive but not diagnostic of vascular trauma include mild shock, stable hematoma, slow bleeding, abnormal brachial–brachial index (BBI), and proximity missile tract. Unexplained neurological findings (coma, hemiplegia) may be due to a carotid injury. Only about 22% of patients with soft signs have any type of vascular injuries, and fewer than 5% need an operation.

### Aerodigestive Injuries

"Hard" signs or symptoms highly diagnostic of significant laryngotracheal trauma include respiratory distress, air bubbling through a neck wound, and massive hemoptysis. There are no hard signs diagnostic of pharyngoesophageal trauma.

"Soft" signs and symptoms suspicious of aerodigestive trauma include subcutaneous emphysema, hoarseness, painful swallowing, and minor hemoptysis. These patients need evaluation by esophagogram or endoscopy. Only about 15% of patients with soft signs have a significant aerodigestive injury.

### Neurological Injuries

The examination of the nervous system should include the Glasgow Coma Score, localizing signs, pupils, cranial nerves, spinal cord, brachial plexus (median, ulnar, radial, axillary, musculocutaneous nerves), the phrenic nerve, and the sympathetic chain (Horner's syndrome).

## Operation or Observation

Patients with hard signs of vascular injury (pulsatile bleeding, large or expanding hematoma, shock) or aerodigestive tract (major hemoptysis, hematemesis, air bubbling through the wound) should be taken directly to the OR. The absence of any clinical signs or symptoms suggestive of vascular or aerodigestive injury reliably excludes significant injuries to these structures that require therapeutic intervention. All patients with soft signs of vascular or aerodigestive tract injury should undergo CT angiography. Selective use of catheter-based angiography, endoscopy, and contrast swallow for equivocal CT results should be considered in the appropriate cases.

## General Management

Any external bleeding should be controlled by direct digital pressure. Protective C-spine collars should be avoided or applied loosely in the presence of large neck hematomas because of the risk of airway obstruction. C-collars are not necessary in knife injuries. In order to reduce the risk of air embolism, all patients with suspected venous injuries should be placed in the Trendelenburg position, and the neck wound should be occluded with gauze. In zone 1 injuries, intravenous lines should be avoided on the same side as the injury because of the possibility of a proximal venous injury.

### Airway Establishment

Some patients with penetrating neck trauma present with airway compromise due to direct laryngotracheal trauma or due to external compression by a large hematoma. Securing the airway in these patients is a top priority, but it can be a difficult and potentially dangerous procedure. Pharmacological paralysis for endotracheal intubation should always be performed in the presence of a surgeon ready to perform a cricothyroidotomy, if the intubator cannot visualize the cords or there is concern about a false extratracheal passage of the endotracheal tube. On the other hand, endotracheal intubation without pharmacological paralysis can cause patient straining and coughing and may precipitate massive hemorrhage from a previously contained vascular injury. If the patient is stable, fiber-optic nasotracheal intubation under light sedation is the safest option. The optimal method of airway establishment should be individualized.

### Temporary Bleeding Control

In most cases, any neck bleeding can be controlled by direct digital pressure in the wound. If digital pressure is not effective because of difficult anatomical location, such as in zone 1 or 3, insertion of the tip of a Foley catheter into the wound and inflation of the balloon with sterile water may control the bleeding.

Patients arriving in the emergency department with imminent or established cardiac arrest should undergo an emergency resuscitative thoracotomy, cardiac massage, thoracic aorta cross clamping, and aspiration of the right ventricle of the heart for air embolism in suspected venous injuries. Any injuries to the left subclavian vessels can be accessed and controlled at the apex of the pleural cavity through the thoracotomy.

## Tips and Pitfalls

- Cervical collars in the presence of a neck hematoma can cause airway obstruction.
- Never place an intravenous line in the arm on the same side as a supraclavicular injury, because of the possibility of the presence of a subclavian venous injury.
- In zone I injuries, the presence of a peripheral pulse does not exclude a significant subclavian or axillary arterial injury.
- Reduce the risk of air embolism in venous injuries by placing the patient in the Trendelenburg position and occluding the wound with gauze.
- Always prepare the chest in case an extension sternotomy is needed.
  - In esophageal or tracheal injuries, do not miss a second back wall injury.
  - Delayed revascularization (>4–6 h after the injury) of carotid injuries in patients with neurologic deficits can convert an ischemic brain infarct into a hemorrhagic infarct.
  - Anterior subluxation of the mandible may improve the exposure of the distal internal carotid artery by an additional 2–3 cm.
  - Distal control of internal carotid injuries at the level of the base of the skull may be achieved with intravascular balloon catheter tamponade.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Vascular injury.

# Genitourinary Injuries (Excluding Kidney) 24

Jack R. Walter and Andrew C. Peterson

**Deployment Experience**

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|---|---|
| *Andrew C. Peterson* | Chief of Urology and Theater Urology Consultant, 47th Combat Support Hospital, Mosul, Iraq |
| | 10th Combat Support Hospital, Baghdad, Iraq, 2005–2006 |

*"The testicle having been thus cleared is to be gently returned through the incision along with the veins and arteries and its cord; and it must be seen that blood does not drop down into the scrotum, or a clot remain anywhere."*

Celsus, 25 BC–AD 50

**BLUF Box (Bottom Line Up Front)**

1. Most general surgeons will not be deployed in conjunction with a urologist; *they* must be the urologist.
2. In the combat setting, there is no reliable method to establish whether the testicular or scrotal contents are involved in penetrating or blunt trauma, and therefore, prompt surgical exploration is recommended.
3. In settings of complicated genitourinary trauma (e.g., if you think bilateral orchiectomy may be required), consider damage control maneuvers and evacuation to the in-theater urologist.

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J.R. Walter (✉)
Urology, Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA
e-mail: jack.r.walter.mil@mail.mil

A.C. Peterson
Duke University, Department of Urology, Durham, NC, USA


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4. Early surgical exploration of penetrating trauma to the penis with complete repair of the urethra and corporal bodies leads to a significantly better long-term outcome.
5. Relative contraindications to placement of the Foley catheter without imaging include blood at the urethral meatus, a nonpalpable prostate on rectal examination, perineal or penile hematoma, and any suspicion of a urethral injury.
6. Consider full lower genitourinary tract imaging with retrograde urethrogram followed by catheter placement and cystogram in all cases with suspected urethral injury.
7. The indicators of bladder injury in both blunt and penetrating traumas include gross or microscopic hematuria, concomitant perineal or genitourinary trauma, pelvic fracture, abdominal distension, suprapubic pain, and free fluid on abdominal CT or FAST.
8. Operative exploration of bladder injuries requires opening the dome of the bladder with careful inspection from the inside.
9. Suprapubic catheters are *not* required for most bladder injuries. Repair and then drain from the inside (Foley) and outside (JP drain).

## What Genitourinary Injuries Will I Have to Deal with in Combat?

You get called to the ER tent for an “abdominal gunshot wound” and begin planning your laparotomy during the walk. When you arrive, you discover that the wound is actually a degloving of the pubic area with a large laceration and partial scrotal avulsion. Suddenly you are not so confident about what to do next. Many general surgeons will be deployed for extended periods of time without the assistance of a urologic surgeon. This chapter addresses the basic evaluation and management of lower genitourinary trauma for the surgeon when no urologist is available.

Although uncommon in civilian injuries, genital trauma occurs in up to 60% of patients injured on the battlefield. The current reports from the conflicts in Iraq and Afghanistan are consistent with historical experience from Vietnam, Korea, and World War II. Explosion injuries can account for up to 75% of the lower urinary tract injuries. While isolated injuries to the genitourinary system and perineum may occur, it is exceedingly important to remember that these injuries often accompany trauma to multiple other organ systems. Therefore, stabilization of the patient with initial resuscitation is paramount as the majority of the external genitalia injuries can be safely managed initially with simple debridement, urinary diversion, and local wound care.

When evaluating the patient with genitourinary trauma, consider the mechanism of injury and the weapon used. Genitourinary trauma can be classified as blunt (e.g., from flying debris from explosives), low-velocity penetrating injuries (fragments from explosive devices), high-velocity gunshot wounds, avulsions, burns, and crush injuries. The majority of injuries to the perineum and scrotum are most likely to arise from improvised explosive devices (IED), oftentimes presenting the surgeon with devastating injuries to the perineum, scrotum, and urethra which require urinary diversion and wound debridement. Some of these are accompanied by fecal contamination, thus requiring fecal diversion as well (see later). The treatment principles are the same for the entire perineum, scrotum, and penis. These include immediate exploration for penetrating injuries, copious irrigation, excision of all foreign matter, antibiotic prophylaxis, and surgical closure.

## What Do I Need to Assess in a Patient with Scrotal or Penile Wound?

While the obvious injuries in these cases are at the skin level with significant maceration, burn wounds, and traumatic avulsion of skin of the perineum, scrotum, and penis, it is imperative to appreciate the possible involvement of surrounding structures (Fig. 24.1). Always completely evaluate the urethra, bladder, and penile corporal bodies. When not detected, injuries to the corporal body may result in prolonged bleeding and possible future erectile dysfunction. Likewise, untreated urethral and bladder injuries may result in prolonged urinary leak with extravasation of possibly infected urine causing urinoma, abscess, and sloughing along with infection of the perineum, penis, and scrotum. These can be devastating complications! Therefore, the retrograde urethrogram and cystogram should be used liberally in all patients with any injury to the penis, scrotum, and perineum. They should also be used in any patient with blood at the meatus or any difficulty with urination when there are penetrating or blunt injuries anywhere near the urethra and lower abdomen.

**Fig. 24.1** Most trauma to the perineum and genitalia in the current conflict will consist of a mixture of penetrating, blunt, and avulsion injuries from improvised explosive devices

## How Can I Best Diagnose a Bladder or Urethral Injury?

Initial evaluation for trauma to the lower genitourinary tract depends upon the presence or absence of hematuria (gross or microscopic) and the mechanism and location of the injury. In all cases perform a careful genitourinary examination including diligent palpation of the penis, scrotum, abdomen, and perineum with a digital rectal examination in order to evaluate for the location of the prostate as well as to palpate any fragments or foreign bodies. Complete radiographic evaluation is necessary when there is blood at the meatus on presentation, gross hematuria, or penetrating trauma to the lower abdomen or perineum. Obtain imaging in patients with microscopic hematuria who have accompanying shock with any mechanism of injury. In the absence of hematuria, if the mechanism of injury is concerning for a genitourinary injury (pelvic fractures or blunt trauma to the lower abdomen, penis or scrotum, and perineum), a complete radiographic evaluation should be performed. Think of the evaluation in this region as starting with the tip of the penis moving proximally to the bladder. When imaging is indicated, start with the retrograde urethrogram, then place a urethral catheter, and proceed with the cystogram (see later for details on how to perform these studies). An algorithm outlines the complete evaluation and management for lower genitourinary tract trauma in Fig. 24.2.

Contraindications to placement of a Foley catheter without imaging in the face of lower genitourinary trauma include blood at the urethral meatus, a nonpalpable prostate (indicating distraction of the urethra from the membranous urethra), perineal hematoma, or the suspicion of a urethral injury such as the presence of a butterfly hematoma, scrotal hematoma, or penetrating penile injury. If you do not have imaging capabilities, you may attempt to gently pass a small Foley catheter into the bladder. This will often be successful with partial urethral injuries and will serve as an initial stent until the injury can be further evaluated by a specialist. Stop any attempt at passage if you meet resistance or do not get return of urine.

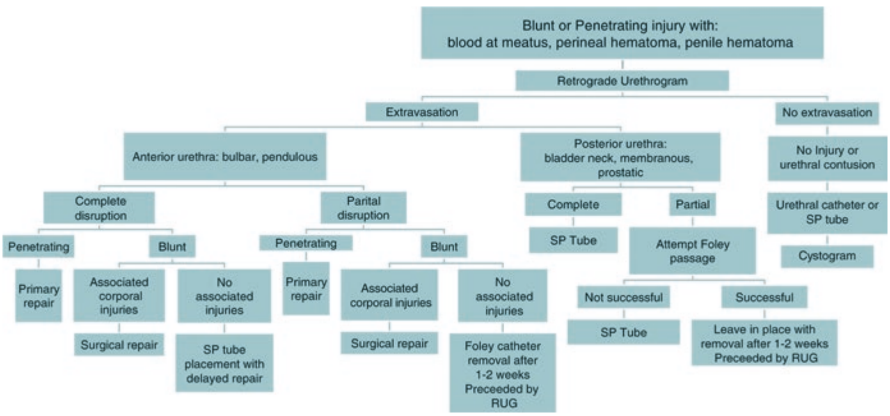


**Fig. 24.2** Proposed algorithm for workup of perineal/scrotal/penile trauma. Evaluation of the urethra should be completed prior to proceeding with cystogram. This algorithm assumes there is no urologic surgeon available

## Management for the General Surgeon

### Penis

External injuries to the penis may include damage to the corporal bodies and the urethra in up to 50% of the cases despite the absence of blood at the meatus on presentation. Early surgical exploration is indicated to repair injuries to the urethra and corporal bodies and gives a significantly better long-term outcome with respect to erectile dysfunction and voiding. Use of the retrograde urethrogram is imperative prior to exploration in order to plan the surgical approach and repair.

The best way to expose the penis for penetrating or blunt injuries is through a circumcision incision. The shaft skin may be degloved from the penis and the corporal bodies and urethra directly inspected. On exploration significant hemorrhage can be controlled initially with direct compression and gauze sponges. Should bleeding be extremely brisk, control may be easily obtained through the use of a tourniquet at the base of the penis consisting of a Penrose drain held in place with a Kelley clamp. Any lacerations or injuries to the corporal bodies are closed with interrupted 2-0 Vicryl for a watertight closure. In the uncircumcised patient, a completion circumcision will usually be required to avoid phimosis and paraphimosis from the postoperative edema.

Traumatic amputation of the penis is rare but may result from explosion injuries. While reconstruction of the urethra with anastomosis of the corporal bodies and microsurgical repair of penile vessels can achieve remarkably good results, these are rarely indicated nor often possible in a deployed environment. In these cases the penile stump should be formalized by closing the corporal bodies in a watertight fashion to prevent bleeding, spatulation of the end of the urethra ventrally into a neo-meatus, and closure of the remaining skin. These injuries will require urinary diversion with a urethral catheter or suprapubic tube until medical evacuation.

### Urethra

Any penetrating or blunt trauma to the penis, perineum, scrotum, or pelvis may include the injury to the urethra. The urethra should be completely evaluated prior to surgery with a retrograde urethrogram. A delayed or missed diagnosis of a significant urethral injury can have devastating consequences including urinoma, abscess formation, infection, and urethral stricture. When considering isolated urethral trauma, it is best to classify these injuries based on location rather than mechanism of injury. Urethral injuries in the male can be subdivided into posterior and anterior.

The posterior urethra includes the bladder neck, prostatic urethra, and membranous urethra. In men with pelvic fracture, 10% will also have a concomitant urethral injury – so a high index of suspicion is required. In the posterior urethra, injury is most commonly from blunt trauma where the membranous urethra is distracted from the prostate at the apex, resulting in a pelvic fracture urethral distraction defect (Fig. 24.3). The membranous urethra is most commonly involved in these injuries

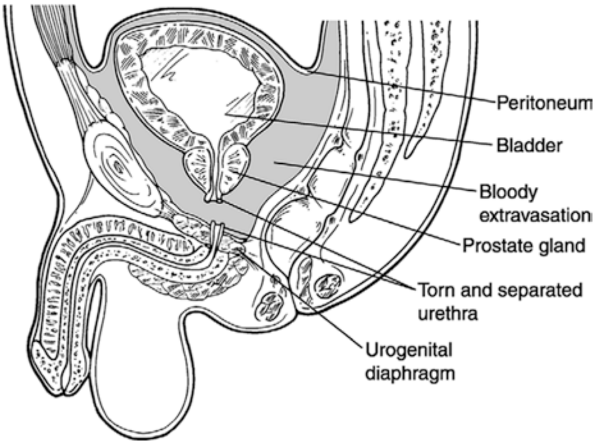


**Fig. 24.3** Posterior urethral injury with detachment from the prostate gland resulting in "high-riding" prostate due to gland retraction and bloody extravasation causing periprostatic hematoma (Reprinted with permission from Rosenstein D, McAninch JW. Urologic emergencies. *Med Clin North Am* 2004;88:495–518, with permission from Elsevier)

because the prostate is protected by ligaments which secure it to the pelvis. This is what results in a high-riding prostate, the physical exam finding of a prostate that is displaced cranially and difficult to palpate. On radiographic evaluation, a high-riding prostate is otherwise known as the "pie in sky" bladder on cystogram.

Management of the prostatic or membranous urethral injury resulting from high-velocity projectiles is best achieved with suprapubic drainage and a Foley catheter placement if possible. A diverting colostomy is often required as there are frequently other injuries of the distal gastrointestinal tract. Early attempt at repair is not indicated as it may cause a significant amount of bleeding, incontinence, and erectile dysfunction. In the case of blunt trauma causing urethral distraction defect, initial management has been hotly debated in the literature. Some authors recommend early realignment of the urethra through endoscopic techniques, while others recommend early suprapubic drainage only with a delayed repair after 3–6 months of healing. Currently, our thoughts are that the latter is the more logical in the combat trauma setting as it allows acute decompression of the urinary system, convalescence of the patient, and a definitive reconstruction at a controlled time. There are, however, some cases that require early laparotomy with pelvic exploration and repair of the distraction. These include concomitant injury to the rectum or bowel, concomitant bladder neck injury requiring closure, and large distraction defect where the pelvic hematoma needs to be drained acutely. Exercise caution in exploring a pelvic hematoma with a pelvic fracture as it can cause troublesome bleeding.

Anterior urethral injuries can be subdivided into pendulous and bulbar location. The bulbar urethral injuries are typically caused by blunt trauma consisting of a straddle injury or direct blow to the perineum where the urethra is crushed against the pubic bone. These may present with butterfly hematoma on the perineum as well as scrotal hematoma and blood at the meatus. The pendulous urethra may also be injured by straddle trauma or direct blows to the penis which present with sleeve hematomas of the penis where the blood is confined to Buck's fascia.

Penetrating wounds can also cause bulbar, pendulous, or posterior urethral injuries. These typically are from high-velocity gunshot wounds or low-velocity penetrating trauma from explosive devices. Treatment of any penetrating injury to the urethra classically consisted of simple suprapubic tube or Foley catheter urinary diversion to allow the injury to heal. Recent reports, however, have indicated that exploration with primary closure of the penetrating injury to the urethra results in a better long-term outcome with decreased scar and stricture formation. When urethral injury is found on surgical exploration, the edges need to be carefully debrided and the penetration or laceration to the urethra closed with interrupted fine absorbable sutures such as 4 or 5-0 Vicryl. At that point, leave a small Foley catheter (12–14 French) in place for 3 weeks. A pericatheter retrograde urethrogram should be performed to show no extravasation of contrast prior to removal of the catheter (see Fig. 24.2). If the urethral injury is too significant for an acute repair or there is too much tissue loss for adequate debridement and closure, place a suprapubic tube in order to stabilize the patient for transport and a definitive repair at a later date.

Overall, there are three valid options for management of urethral trauma regardless of the location and mechanism of injury: (1) immediate suprapubic tube placement with delayed urethral repair, (2) immediate realignment by placing a catheter across the urethral injury with delayed urethral repair, and (3) immediate repair with surgical anastomosis of the urethral destruction or penetration.

With increasing numbers of female service members in the deployed environment, female urethral injury may be encountered. Similar management with early recognition is critical. The female urethra's location, protected in the boney pelvis, makes injury rare. Evaluation by speculum-assisted vaginal exam will show urethrovaginal injuries. These injuries should be debrided and closed if sufficient tissue is present. Injuries to the bladder neck and proximal urethra will require surgical exploration and closure similar to male bladder neck injuries.

## Scrotum and Testicles

The scrotal contents may be significantly injured by both penetrating and blunt trauma. Non-penetrating injuries resulting from crush or saddle injuries to the penis, scrotum, and perineum can cause significant damage to the internal structures without disrupting the skin. High index of suspicion is needed in these instances. The scrotum is much more often involved in penetrating trauma than the penis, and prompt surgical exploration is recommended in these cases. In the combat setting, there is no reliable method to establish whether the testicles or spermatic cords are involved; hence, prompt surgical exploration is recommended for all these cases. Should one want to perform imaging of the scrotal contents with the goal of avoiding exploration, scrotal ultrasound is the modality of choice, and the most sensitive

**Fig. 24.4** Penetrating trauma to the scrotum with damage to the ipsilateral testicle. This amount of tunical loss is easily closed with running Vicryl suture for testicle preservation. The RUG prior to scrotal exploration was normal

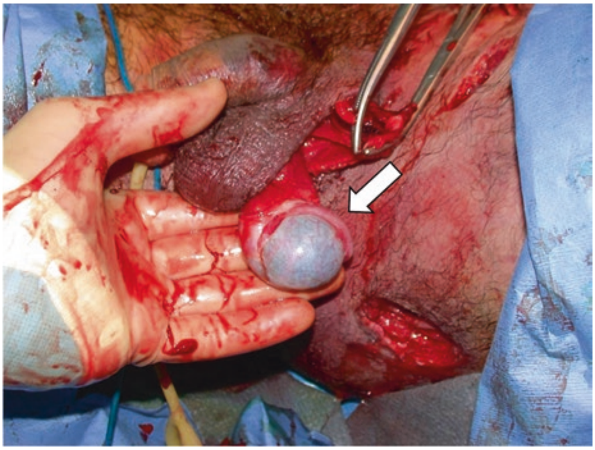

**Fig. 24.5** The contralateral testicle is easily delivered through the same incision and inspected. Note the normal anatomy with the lateral sulcus between the testicle and epididymis (*arrow*)

finding for injury to the testicle is the presence of heterogeneity within the testicle. Otherwise, the study is often of no use in this clinical setting. The urethra still needs to be evaluated prior to exploration per the outline in Fig. 24.2.

Access the scrotum through a midline median raphe incision where both of the hemiscrotal compartments can be opened and both testicles delivered, inspected, and repaired (Fig. 24.4). During this procedure, it is important to note that the lateral raphe, the crevice between the epididymis and the testicle, should always lie laterally in an anatomically normal testicle (Fig. 24.5). This is a good landmark for

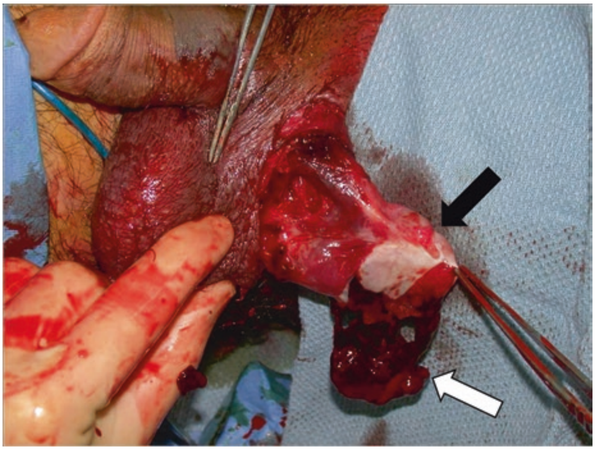

**Fig. 24.6** Trauma to the scrotum and testicle with significant loss of the tunica albuginea (*black arrow*) and extrusion of seminiferous tubules (*white arrow*). There is not enough tunica left in this case to preserve the testicle, and it must be removed

orientation while placing the testicles back into the scrotal compartment after exploration and avoids twisting of the testicle with possible concomitant ischemia from torsion. When the testicle is injured and the tunica albuginea has been ruptured or lacerated, any extruded seminiferous tubules should be debrided and the tunica closed with running 4-0 Vicryl suture for a watertight repair. If there is not enough tunica albuginea left after the injury to successfully close the testicle, the testicle must be removed in order to avoid the accumulation of necrotic debris or abscess and hematoma formation (Fig. 24.6). The testicles should be placed back into their respective hemiscrotal compartments in the normal anatomic alignment and the compartments closed with running 3-0 Vicryl suture. The skin can be closed with a running 4-0 absorbable suture.

There is rarely a need to leave the scrotal wound open unless it has been severely contaminated with debris, necrotic material, or abscess formation. Do not hesitate to perform an orchiectomy on one side. Orchiectomy may be required in up to 90% of penetrating trauma cases, and the remaining testicle will provide enough testosterone for normal sexual characteristic maintenance as well as fertility. If bilateral orchiectomy may be indicated, consider damage control maneuvers – hemorrhage control, irrigation, and debridement of contamination of the scrotum – followed by evacuation to a urologist, if possible. If this is not possible, consider photographic documentation of the extent of injury before proceeding with bilateral orchiectomy. Multiple testicle prostheses currently exist which are excellent and easily placed after completed convalescence. It is always a good idea to leave a Penrose drain in each of the hemiscrotal compartments for 24 h to allow drainage. Because of the elasticity and redundancy of the scrotal skin, it is almost always possible to close a scrotal laceration even after significant debridement and tissue loss. However, for very complex and large avulsion injuries, it may be necessary to apply local wound care for 12–24 h to allow the edges to clearly demarcate for further debridement. After this, one can try to close the scrotal wound in stages. In some cases skin grafting may be required at a later time for formal reconstruction. It is safe to temporarily manage testicles by wrapping in moistened gauze until patients can be evacuated to higher levels of care. In the rare case where there is significant avulsion or tissue injury requiring removal of the entire scrotum and the testicles have no covering, it may be required to place them into thigh pouches. This can be easily done by making a tunnel from the perineal/scrotal incision or wound into a subcutaneous thigh pouch on the ipsilateral medial thigh. This will allow delayed reconstruction with skin grafting to the perineum and scrotum; after which the testicles can be removed from the thigh pouches and placed back in the midline.

## Bladder

Bladder injuries can be divided into intraperitoneal and extraperitoneal injuries. Intraperitoneal injuries typically are caused by penetrating trauma, pelvic fractures, or blunt insults to the abdomen with a full bladder. These require exploratory laparotomy and watertight closure of the bladder injury in multiple layers with absorbable suture. Extraperitoneal ruptures are usually associated with pelvic fractures such as pubic rami fractures and fractures of the iliac bones. Many of these can be managed with simple catheter drainage, but complex injuries or those associated with pelvic fractures are often better managed by surgical repair. When a laparotomy is required for other reasons, it is also recommended to explore and close the bladder injury.

To approach the bladder during exploration, make a vertical midline skin incision from the symphysis pubis to 2–3 fingerbreadths below the umbilicus. Incise the external oblique fascia, and split the rectus muscles in the midline. It is not necessary to separate them from their insertion on the pubic bone. Stay extraperitoneal and identify the bladder in the midline. Place two silk stay sutures on each side of the dome of the bladder, and make a vertical incision in the dome of the bladder with electrocautery or knife. When performing a laparotomy, if the bladder injury is not easily identified, retrograde instillation of methylene blue through the urethral catheter may help identify the leak. In all cases, perform a cystotomy large enough to allow internal inspection of the bladder and identification of all injuries. Close the injuries with running absorbable 3-0 and 4-0 suture for watertight closures. The placement of a suprapubic tube is controversial and is unnecessary for most injuries as long as an adequate caliber transurethral catheter is in place. A suprapubic tube should be placed for all complex injuries or if there is a concurrent urethral injury. Placement of a drain in the space of Retzius is appropriate in order to manage any persistent leakage.

After closure of any bladder injury, obtain a cystogram 2–3 weeks postoperatively prior to the Foley catheter removal. If a suprapubic tube was placed in addition to a Foley catheter, the best approach is to leave the suprapubic tube in place clamped for 3–4 days after removal of the Foley catheter thereby serving as a pop-off valve or emergency drain should the patient not be able to urinate immediately after removal of the Foley catheter.

## Ureter

Ureteral injuries are extremely uncommon with blunt trauma but are often seen with penetrating combat wounds. Any injury to the iliac vessels, bladder, or ascending and descending/sigmoid portions of the colon should prompt immediate identification and exploration of the ureter. In addition, you can have the anesthesia provider administer intravenous methylene blue and observe for extravasation – but this *does not* substitute for adequate exploration. Base your management of the injury on the portion of the ureter involved and the patient stability. Remember that ureteral injuries are *never* life-threatening emergencies that require immediate repair. In a damage control setting, the best thing to do is simply establish drainage and leave repair for a subsequent operation.

You must appreciate the anatomy of the ureter as identification can be difficult, particularly in obese patients or in a bloody and injured field (Fig. 24.7). The colon

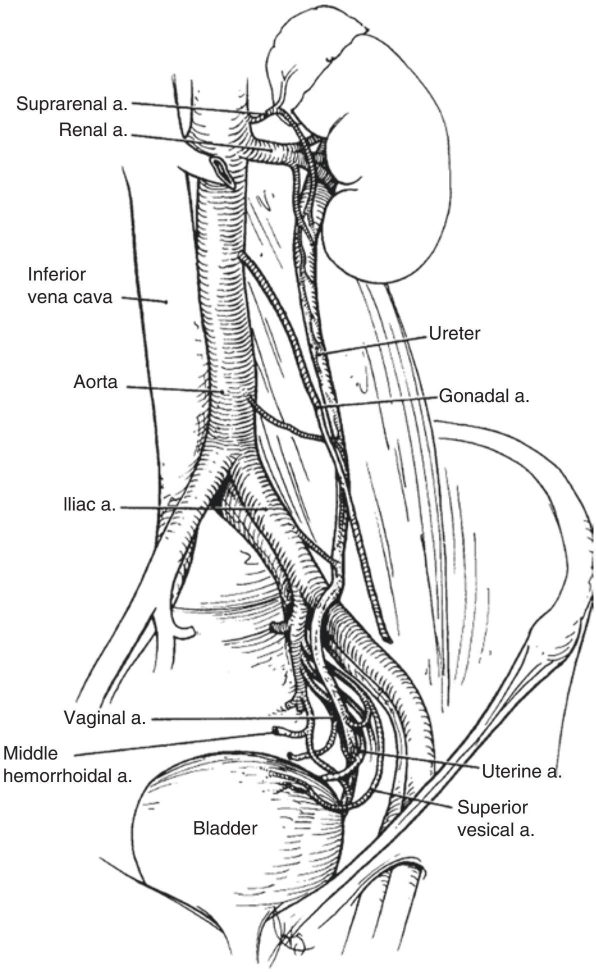


**Fig. 24.7** Anatomic course and relationships of the ureter. Note close proximity of the ureter to the gonadal vessels. The ureter can be reliable found as it crosses over the iliac vessels and drops into the pelvis. (Reprinted from Elliott SP, McAninch JW. Ureteral injuries: external and iatrogenic. *Urol Clin North Am* 2006;33:55–66, with permission from Elsevier)

must be mobilized medially, sweeping the mesentery with it and the retroperitoneal tissue (including gonadal vessels and ureter) away from it. If you are having trouble finding it, trace the iliac artery to its bifurcation, and the ureter should be running directly over the bifurcation from lateral to medial.

For a simple transection or laceration of the mid- or proximal ureter, perform a primary repair over a "double-J" stent. Spatulate the ends of the ureter after debridement of the injury, and place multiple interrupted absorbable sutures to create a circumferential anastomosis (Fig. 24.8). If the distal ureter has been injured, then it should be debrided and reimplanted into the bladder. A simple technique is shown in Fig. 24.9. If the ureter will not reach the bladder due to mobility and tissue loss, then you can bring the bladder to the ureter using a psoas hitch technique (Fig. 24.10). Although techniques of hooking the injured ureter into the contralateral uninjured one are described, they should be avoided in most trauma situations. Temporary drainage can be easily established by placing a 5 French catheter into the proximal intact ureter and externalizing the other end until the patient is stable to undergo reconstruction. Error on leaving a closed suction drain near to any repair made to scavenge urine leaks. In some situations with combined severe abdominal injuries and a destructive ureteral injury, the patient may be better off with a nephrectomy rather than attempts at complex reconstructive procedures.

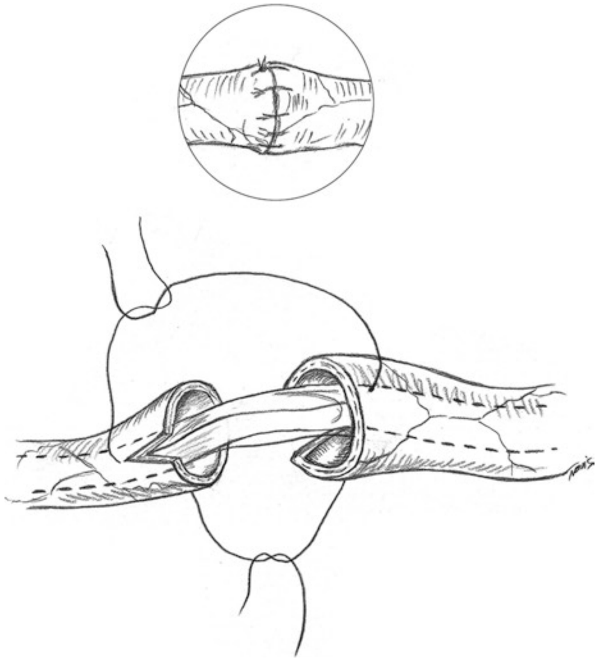

**Fig. 24.8** Technique for primary ureteral repair (ureteroureterostomy). The debrided ends of the ureter are spatulated and repaired over a stent using multiple absorbable interrupted sutures to achieve a watertight seal (Image reprinted with permission from Medscape Drugs & Diseases (http://emedicine.medscape.com/), 2017, available at: http://emedicine.medscape.com/article/440933-overview)

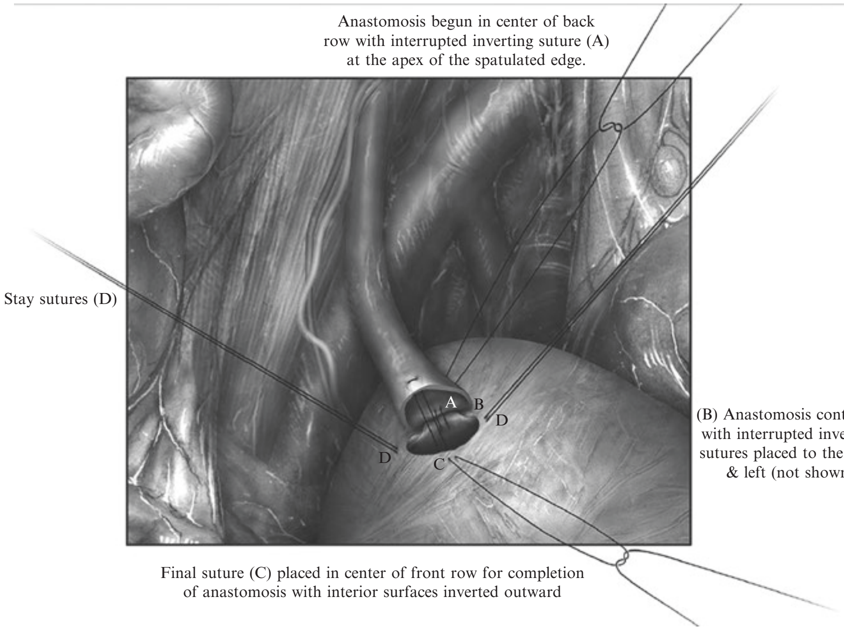


**Fig. 24.9** Technique for ureteral reimplantation into bladder (ureterocystostomy). Ensure a tension free, water tight anastomosis. Use absorbable sutures for the anastomosis. Do not forget to drain the repair from the inside (Foley) and outside (JP drain). (Reprinted from LaFontaine P. Management of ureteral injury. *Operative Techniques in General Surgery* 2007;9:167–174, with permission from Elsevier)

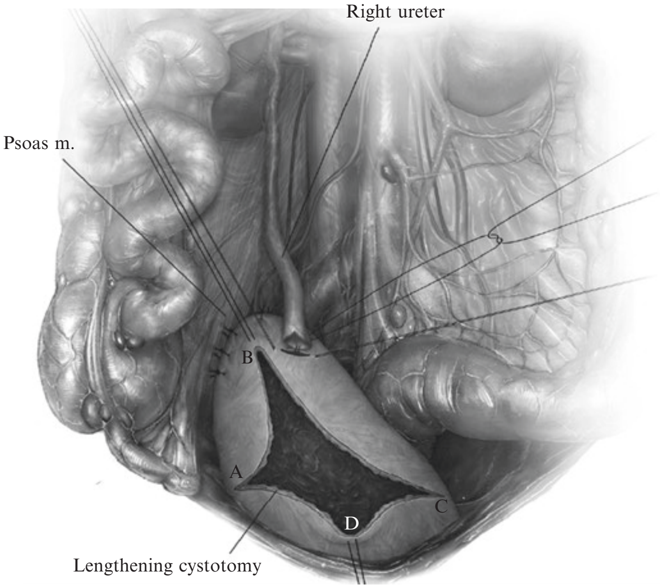


**Fig. 24.10** Technique for performing a psoas hitch procedure. The bladder is elongated by creation of a long cystotomy and secured to the psoas muscle, and then a tension-free ureteral reimplantation is performed. The cystotomy is then closed in two layers (Reprinted from LaFontaine P. Management of ureteral injury. *Operative Techniques in General Surgery* 2007;9:167–174, with permission from Elsevier)

## Tips and Techniques

### Difficult Foley Placement

There are several reasons for the inability to place a bladder catheter through the urethra including urethral stricture, prostate enlargement, difficult to negotiate bladder neck, bladder neck stricture, or obstructing foreign body or tumors. The majority of the time, a Foley catheter cannot be placed by a medic or nursing staff because of technique. We have found the "hyperlube" technique to be very helpful in these circumstances. If this is unsuccessful, then cystourethroscopy or retrograde urethrogram is indicated to rule out a mechanical obstruction. Should one find an obstruction such as a urethral stricture, the best choice for initial management is placement of a suprapubic tube with no further manipulation and delayed surgical repair after evacuation.

### The "Hyperlube" Technique of Foley Catheter Placement

Place the patient supine on the examination table. Fill a Toomey syringe with 30 cc of lidocaine jelly, and prep and drape the patient's penis in the usual fashion that would be required for Foley catheter placement. Infuse the lidocaine jelly in a retrograde fashion into the penis by placing the tip of the Toomey syringe into the meatus of the penis. After infusing 20–30 cc of the lidocaine jelly retrograde into the urethra, grasp and hold the glans of the penis in order to keep the lidocaine jelly within the urethra. After allowing 2–3 min for anesthesia, a Foley catheter is then easily inserted, oftentimes successfully negotiating any portion of the urethra where obstruction was encountered on prior attempts.

We find that the lidocaine jelly helps the patient relax the external sphincter and distends the urethra to allow the catheter to slide through a pool of jelly rather than scrape along the side of the urethra. Again, should this technique not be successful on one or two attempts, obtain a retrograde urethrogram or cystourethroscopy to rule out any mechanical obstruction, and consider placement of a suprapubic tube as described below.

### Suprapubic Tube Placement

Suprapubic cystotomy is a simple procedure that may be placed with an open or percutaneous technique. To place a well-functioning suprapubic tube that has minimal discomfort, one must observe simple certain rules. Common errors in the placement of suprapubic tubes include placing it too low on the abdomen and too low inside the bladder. The latter may cause the tip of the tube to contact and irritate the trigone of the bladder, leading to significant urgency and frequency. Placing a suprapubic tube too low on the abdominal wall may cause irritation against the symphysis pubis and periosteum leading to bone irritation and pain while walking. Another common error includes placing the suprapubic tube through the peritoneal cavity rather than leaving it in the space of Retzius. This may result in leakage of urine into the peritoneal cavity if the tube becomes loose or dislodged. It is important to restate that all sutures in the bladder should be absorbable, as any nonabsorbable suture will lead to stone formation and difficulty in the later management of the patient.

## Open Suprapubic Tube

Make a vertical midline skin incision from the symphysis pubis to 2–3 fingerbreadths below the umbilicus. Incise the external oblique fascia, and split the rectus muscles in the midline. It is not necessary to separate them from their insertion on the pubic bone. Stay extraperitoneal, and identify the bladder in the midline as it likely will be full of urine at this point. Place two silk stay sutures on each side of the dome of the bladder, and make a vertical incision in the dome of the bladder with electrocautery or knife. Once urine is obtained, extend the cystotomy in order to provide inspection of the inside of the bladder should there be concomitant bladder injuries. Place a 20–24 French Foley catheter through the cystotomy, and close the opening with a purse string suture of absorbable 2-0 or 3-0 Vicryl suture for watertight closure. Inflate the balloon on the suprapubic tube with 10 cc of sterile water. Bring out the suprapubic tube through the inferior portion of the abdominal wound or through a separate stab incision only 2–3 cm lateral to the wound. Place tension on the suprapubic tube to bring the cystotomy in contact with the anterior abdominal wall in order to reduce leakage. Secure the suprapubic tube to the skin with a permanent nylon suture.

## Percutaneous Placement of the Suprapubic Tube

A percutaneous cystotomy tube may need to be placed in situations where a laparotomy is not required. Successful placement requires some planning. Place the patient supine on a stretcher in as steep Trendelenburg as can be tolerated to pull the bowels away from the dome of the bladder. If the bladder is fully distended with urine, it should be palpable in the lower abdomen. If ultrasound is available, this can be used to help guide the placement. Make a puncture incision 3–4 fingerbreadths above the symphysis pubis in the midline. One can use a finder needle in order to establish the depth needed to penetrate and obtain urine. Place a trocar into the dome of the bladder at a 45° angle with the tip of the finder needle directed caudally. Once urine is obtained with a puncture cystotomy tube, it is important to advance the tube 1–2 cm deeper prior to inflating the balloon in order to ensure that the balloon is within the dome of the bladder. Once placed, inflate the balloon with 10 cc of sterile water, and place tension on the suprapubic tube in order to pull the dome of the bladder flush with the anterior abdominal wall. Secure the tube to the skin with nylon suture.

## Performance of the Retrograde Urethrogram

To perform an appropriate retrograde urethrogram preparation is paramount. It is important to gather the supplies needed first. These include a 60 cc Toomey syringe, lidocaine jelly, Betadine swabs, Cysto-Conray or Renografin, 4 × 4 sponges, and fluoroscopy.

The patient must be appropriately positioned for the scout film. The retrograde urethrogram should be performed in a semi-oblique position (Fig. 24.11). This is necessary in order to fully view the entire urethra as many injuries in the posterior urethra and proximal bulbar urethra can be missed on an anterior–posterior film. To verify appropriate amount of oblique, the obturator fossa should be obliterated on the scout film (Fig. 24.12).

One should mix 40 cc of contrast material (specifically Cysto-Conray if available) in 10 cc of lidocaine jelly and place this into the Toomey syringe with sterile technique. Prep the penis with Betadine swabs at the tip of the penis. Use sterile gloves, and place 4 × 4 sterile gauze under the tip of the penis. Grasp the penis, and instill the contrast solution into the penis in a retrograde fashion. Place the tip of the Toomey syringe inside the meatus of the penis, and grasp the glans of the penis with the nondominant hand. Then under fluoroscopy, bend the penis downward in order to view the location of the suspensory ligament of the penis (see Fig. 24.12). Under fluoroscopy retrograde infusion of the contrast is placed into the penis until it can be

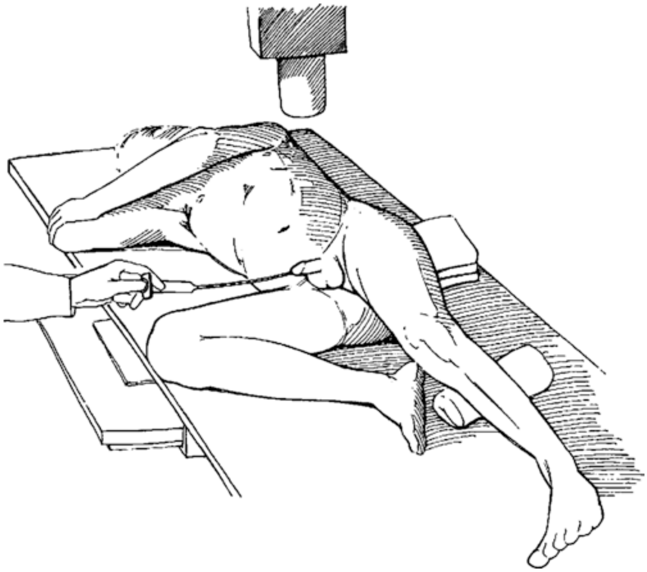

**Fig. 24.11** The appropriate positioning for a retrograde urethrogram (RUG). The patient is oblique with a role placed under the top leg and the bottom leg bent. The RUG is performed with fluoroscopy (Reprinted from Rosenstein DI, Alsikafi NF. Diagnosis and classification of urethral injuries. *Urol Clin North Am* 2006;33:73–85, with permission from Elsevier)

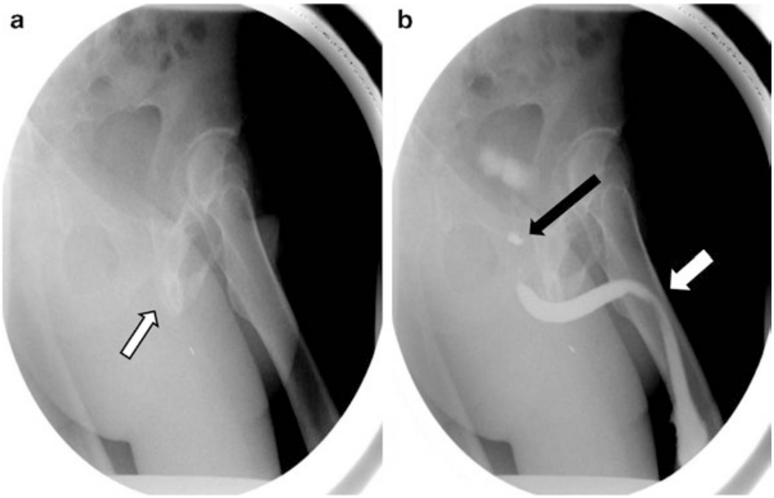


**Fig. 24.12** (**a**) The appropriate scout film for the retrograde urethrogram (RUG). The patient is in the oblique position, the right obturator fossa is visible, and the left is not (*arrow*) indicating appropriate positioning. (**b**) The RUG is performed showing small amount of contrast extravasation at the membranous-prostatic urethra indicating injury (*black arrow*). The suspensory ligament of the penis demarcates the separation of the pendulous urethra from the bulbar urethra (*white arrow*). Note the small piece of shrapnel in the patient's thigh

seen to fill the entire urethra, and a small amount can be seen to infuse into the bladder. Afterward, allow the patient to void in the same position to show complete emptying of the contrast from the system thus providing a voiding phase of the retrograde urethrogram.

## Performance of the Cystogram

Prior to performing a cystogram, if there is any question of a urethral injury, it is best to obtain a retrograde urethrogram (see Fig. 24.2). Place a Foley catheter into the bladder. You may perform a cystogram with fluoroscopy or CT scan imaging if available. If fluoroscopy is chosen, scout anterior–posterior films are required to ensure no calcifications, foreign bodies, or fragments are present. Fill the bladder retrograde to 350 cc of Cysto-Conray or an appropriate contrast agent under gravity. Under no circumstances should you force contrast into the bladder with a Toomey syringe or with pressure. After instilling 350 cc, clamp the Foley catheter and obtain anterior–posterior films with oblique films. Allow the bladder to empty, and obtain films to ensure no contrast is left behind, indicating a possible injury to the posterior bladder wall that may be missed on anterior–posterior imaging. Do not rely on antegrade filling of the bladder with excreted IV contrast as this will miss injuries in up to 20% of cases. The filling must be retrograde.

Should CT scan be available, no scout or emptying films are needed as the CT scanner provides 360° evaluation of the bladder. Place a Foley catheter only after any injury to the urethra is excluded with a retrograde urethrogram or cystourethroscopy. Again, instill 350 cc of contrast into the bladder under gravity in a retrograde fashion. CT scanning through the pelvis should show the bladder to be smooth walled with no extravasation and in the bladder may be drained with no further imaging needed.

It is imperative to fill the bladder only under gravity and not to force any contrast into the bladder as this may induce an iatrogenic injury. The optimum volume to fill into an adult is 350 cc as multiple studies have indicated that any less may miss some bladder injuries.

## Summary

The deployed general surgeon will be called upon to manage a wide variety of combat trauma-related injuries to the external genitalia and lower urinary tract. The majority of the injuries to the perineum and scrotum are from explosions. These include blunt injuries, penetrating injuries, crush injuries, burns, or a combination of all of these mechanisms. Most of these injuries can be accurately diagnosed with physical exam and simple imaging studies, and the mainstay of treatment is direct surgical exploration and repair. Because most general surgeons do not get much exposure to such cases in their peacetime jobs, it is imperative that the deploying surgeon review the basic management principles as described in this chapter. Such review will allow the surgeon to successfully manage or at least temporize the majority of the lower genitourinary injuries encountered.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Urologic trauma management.

# Neurosurgery for Dummies

# 25

Hans Bakken and Alex B. Valadka

**Deployment Experience**

| | |
|---|---|
| *Hans Bakken* | Theater Consultant, Neurosurgery, Air Force Theater Hospital, LSA Anaconda, Balad, Iraq, 2005–2006 |
| | Commander, 207th MED DET, Air Force Theater Hospital, Joint Base Balad, Iraq, 2008–2009 |

*The abdomen, the chest, and the brain will forever be shut from the intrusion of the wise and humane surgeon.*

John Erichsen, 1818–1896

**BLUF Box (Bottom Line Up Front)**

1. "A, B, and C" come before "N."
2. The presence of a serious head injury must not impede the resuscitation of the trauma patient. (A gruesome "distracting" injury can distract the physician as well as the patient.)
3. Normotension, normovolemia, normoventilation, and normothermia must prevail in the brain-injured patient. Time = neurons, so act immediately and decisively.
4. In patients with suspected ICP problems or mass lesions, the use of hypertonic saline is preferred over mannitol, especially in the multiply injured patient.

(continued)

H. Bakken (✉)
Brooke Army Medical Center, Department of Radiology, San Antonio, TX, USA
e-mail: hans.e.bakken.mil@mail.mil

A.B. Valadka
Virginia Commonwealth University, Department of Neurosurgery, Richmond, VA, USA



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(continued)

5. The primary role of the trauma surgeon in the head-injured patient is to follow point 3 above.
6. Do not transfer the unstable head-injured patient because you don't have a neurosurgeon – see point 2 above.
7. Timely transfer of the stabilized head-injured patient to a neurosurgeon is generally the best way to treat a severe head injury after initial stabilization.
8. A trauma craniectomy or ICP monitor can be safely performed by a general surgeon who understands the indications, technique (described here), and complications.
9. Be aggressive early, but know when to quit – resources are scarce and should not be used on non-survivable injuries or injuries with a very low probability of meaningful recovery.

## Introduction

During one of the editors first week in Iraq, a soldier with an obvious severe head injury from a roadside bomb was brought in. He was rapidly tagged as "needing urgent transfer" to the neurosurgery team in Balad. While waiting for the helicopter, his nurse fortunately noted that he was becoming more hypotensive and alerted one of the trauma surgeons. A more thorough evaluation was performed, a FAST exam demonstrated hemoperitoneum, and the patient underwent emergent splenectomy with subsequent rapid stabilization and then transfer. The most important point of this chapter is: *the presence of a head injury should not change the initial treatment of the trauma patient.* As a corollary, the premature transfer of a trauma patient to a neurosurgeon prior to appropriate initial treatment will adversely affect outcomes.

War-related trauma differs significantly from trauma seen in the civilian world. The prevalence of burn, penetrating and blast injuries sets the stage, and a multitude of other factors, including environmental conditions (e.g., mountains and deserts), physical settings (e.g., tents), and supply issues serve to make the wartime physician's job worlds apart from anything else on the planet. Setting aside uniquely military aspects of being in a theater of operations (carrying a weapon and wearing body armor), this chapter will provide you with the basic information that you need to care for head-injured patients prior to their transfer to a higher echelon of care.

With medical operations in the various theaters fairly mature after years of combat operations, lack of ready access to a neurosurgeon in theater is becoming an infrequent problem. However, this access depends on the ability to transport the patient to the proper facility with a neurosurgical team. This means that as the initial receiving physician or surgeon, you *are* the neurosurgeon until that patient is put on a helicopter out of your facility. This results in a number of situations that will require a general or trauma surgeon to manage the patient with a head injury and occasionally even have to perform a neurosurgical operation. This chapter will provide a cookbook-type approach for this initial management and provide guidance to the general surgeon on when and how to proceed should the situation call for basic neurosurgical intervention when there is no neurosurgeon available.

As with other types of traumatic injuries, there are head injuries that are fatal, no matter what intervention is undertaken. The phrase "arrived dead, stayed dead" does apply occasionally, although you do not need to take it upon yourself to determine whether or not a head injury is survivable. Your job is avoiding secondary neurologic injury, most of which can be attributed to decreased oxygen delivery to the brain. If you have optimized the hemodynamics and blood oxygenation, then you have addressed the two most important factors which will save neurons. The third major factor is intracranial pressure (ICP). There are a limited number of maneuvers that you can perform in order to manage ICP, which will be described in the pages to follow. The final steps in the management of refractory ICP are surgical. While this chapter will provide guidelines which will allow a general or trauma surgeon to perform a decompressive craniectomy with a reasonable degree of safety, the carrying out of that surgical procedure does require a certain degree of surgeon comfort and confidence. The decision to perform a decompressive craniectomy is not an easy one. Only the combination of a known or suspected ICP problem, deteriorating neurologic function, and the unavailability of neurosurgical care (timely transport via *medevac* assets) should trigger this decision.

## The Basics

Glasgow Coma Scale (GCS) is a very simple, yet useful assessment in the head-injured population. It gives a reproducible numerical scale from 3 to 15 which correlates very well with outcomes, especially when used to separate "severe" head injuries from all others (mild and moderate). Many times patients will arrive already intubated or under sedation. In these cases you should attempt to glean a GCS from the *medevac* crew or piece it together from a *brief* interview with the medics (what was the soldier/patient doing at the scene). Also remember that intubation does not preclude assessing mental status – if the patient is awake or moving, get a good basic neurologic exam before you re-sedate or paralyze. GCS pearl: don't use the "squeeze my fingers" test to determine if the patient is following commands. Grasping can be a reflexive motor function. Tell the patient to do something and observe for the proper response, such as "give me a thumbs-up" or "move your left foot."

## When Do I Need a CT Scan/What If I Don't Have a CT Scan?

When evaluating patients at a location that has ready access to CT, the following are general indications for obtaining a CT scan of the head:

1. Loss of consciousness
2. Amnesia for the event
3. Abnormal neurological exam
4. Penetrating head injury

Computed tomography is in such common use that we as physicians find it difficult to fathom evaluating a patient without a “pan-scan.” However, there are many locations in a war zone that do not have CT units. Not all trauma patients require evaluation by CT, but if they have a mild head injury, they must be *closely* observed for signs of deterioration. Patients that have abnormal head CT findings generally should have the study repeated 6–12 h after the original study, sooner if they deteriorate neurologically.

Most, if not all, patients with a penetrating head injury will require treatment by a neurosurgeon; thus transfer to an appropriate facility should be planned in order to minimize delay after their assessment, stabilization, and resuscitation have been initiated. In patients that meet the above criteria for CT scan when there is *no scanner*, transfer to another medical asset needs to be considered *after* appropriate initial stabilization, assessment, and resuscitation.

## How Do I Know If There Is an “ICP Problem”?

Many people mistakenly think the neurologic exam doesn’t come until the secondary survey. After the ABCs have been done, the next step is D – disability. The goal of D is simple – identify significant head injury and any evidence of ICP elevation. This is done by calculating the GCS and examining the pupils. Remember that GCS is a measure of overall cerebral function, not localized neurologic function. A patient can have complete hemiparesis and still have a GCS of 15. You must understand the clinical signs of rising or elevated ICP. These include rapid neurologic deterioration or coma, unilateral or bilateral fixed/dilated pupils, and motor posturing (flexor or extensor). Cushing’s triad of hypertension, bradycardia, and altered respirations is a classic response to elevated ICP, and this pattern is rarely seen in non-head-injured trauma patients. If these signs are present, begin treatment immediately – you don’t need to wait for a CT scan.

After establishing your baseline neurologic exam and initiating any interventions, you then decide on whether the patient needs immediate operation, transfer, or admission. In any case, the patient should have frequent serial neurologic examinations done to immediately identify deterioration (rising ICP) and intervene. A decline in GCS of two points in the absence of confounding factors is generally significant and requires further diagnostic and therapeutic maneuvers. The worse the head injury, the more important a good and detailed neuro exam is! Anyone can pick up a GCS decline from 15 to 13, but identifying a drop from eight to six requires much more attention to detail.

## The Isolated Severe Head Injury

CT scan should be obtained if available. Follow the “four N’s” from the BLUF box (above). If initial GCS is greater than 8, serial neurological examinations can be used to follow the patient’s status. Call the neurosurgeon on call to let him or her know what you are doing; they will likely provide good advice. If the initial GCS is 8 or less, consider placing an ICP monitor or external ventricular drain if available (technique to follow). Employ the ICP management strategy (see the excellent JTTS clinical practice guideline) to keep sustained ICP less than 20. If this cannot be accomplished, consider performing decompressive craniectomy (technique to follow). Decompression should be performed on the side with the most abnormality on CT, or in the absence of CT, laterality can be determined based in the following neurologic findings: (1) ipsilateral to a penetrating head injury or dilated pupil and (2) contralateral to a hemiparesis/hemiplegia/Babinski's sign. In a patient who has not had neuromuscular blockade, the presence of bilaterally large and nonreactive pupils (*without* significant globe injuries), the absence of all cranial nerve reflexes (cough, gag, corneal reflexes), and the absence of any response to peripheral and central noxious stimulation are extremely poor prognostic factors, and consideration should be given to treating them as expectant.

## Severe Head Injury in the Multiple Trauma Patient

With the increasing prevalence of explosive injury mechanisms in combat trauma, multi-system injury including severe brain trauma is much more common than seen in civilian practice. Blast injuries will often result in a devastating combination of skull fractures, blunt parenchymal injury, and multiple fragmentation injuries (Fig. 25.1). These patients will typically present intubated and having received sedation and neuromuscular blockade. It is very important to try and obtain a GCS from the scene of the trauma to assess for a head injury. A patient with a low GCS at the scene, even in the absence of physical findings or CT findings consistent with a head injury, may indeed have a severe brain injury. Even with CT at your disposal, patients may harbor unrecognized head injuries. Occasionally, there will be a great

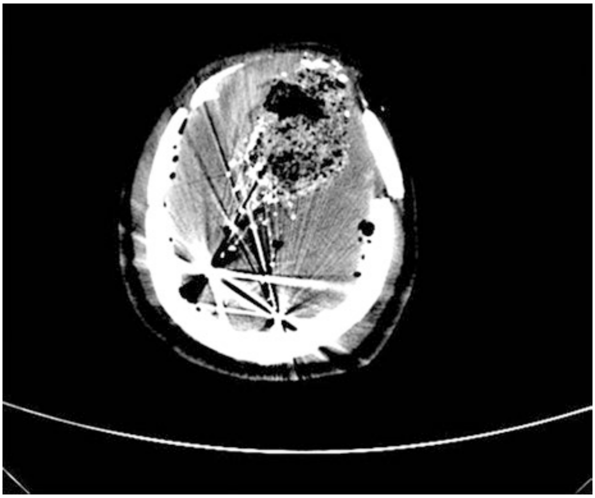


**Fig. 25.1** Head CT following a roadside bomb injury. Note the combination of multiple skull fractures, diffuse parenchymal injury and edema, and multiple fragmentation wounds

deal of effort expended by the trauma/general surgeons in order to stabilize a patient, after which it is determined that the patient has an extremely poor neurologic prognosis (see paragraph above). Again, consideration must be given to palliating the patient. Also remember that the classic hemodynamic response of hypertension and bradycardia may not be present in the hypovolemic trauma patient.

In a patient who is hemodynamically unstable due to ongoing hemorrhage, resuscitation and assessment need to be initiated in order to save the life of the patient. Once this has occurred, the head injury can be addressed as in the previous scenario. If the patient requires prolonged surgical intervention, place an ICP monitor or EVD in order to optimize the ICP during the surgical procedure. Due to limitations in positioning, it can be quite difficult to manage ICP during general surgical procedures. If the ICP is refractory, consider decompressive craniectomy in conjunction with the other ongoing trauma procedures.

## Placement of ICP Monitor "Bolt" or EVD (Required Kits Must Be Available)

In general, placement of an ICP monitor (or "bolt") is easier than the placement of an EVD, as it is a simple intraparenchymal sensor and does not have to be in a specific location, whereas an EVD is fairly useless unless you actually get it into the ventricle. If the patient has significant edema or midline shift, the ventricle can be very difficult to hit, and a bolt should be placed. The main advantages of an EVD over a bolt are that it can be used to both measure ICP and to treat it. The EVD allows for drainage of CSF, which will lower ICP.

## Preparation

Normalize coagulation status. Administer 1 g cefazolin IV, if no allergies. Get the equipment. Get an assistant. Get a small stand on which you will place the equipment. You will need (1) Cranial Access Kit (the Cranial Access Kit is designed to allow you to place either an ICP monitor or an EVD; there are two drill bits in the kit; you use the small diameter drill bit for ICP and the big drill bit for EVD) and (2) ICP device (Codman) and monitor *or* EVD kit and drainage bag. Pick a side. Place the monitor or EVD on the side that is already damaged. If there are no lateralizing findings on exam or CT, place the device on the right (nondominant) side. Place the patient's head *straight midline*. This will minimize your chance of misplacing the device.

## Marking the Patient

Make all markings *prior* to prepping the field. Stand directly behind the patient. First, make a heavy straight line right down the midline. This is your most important landmark. Then, the standard entry point for both an EVD and an ICP monitor is

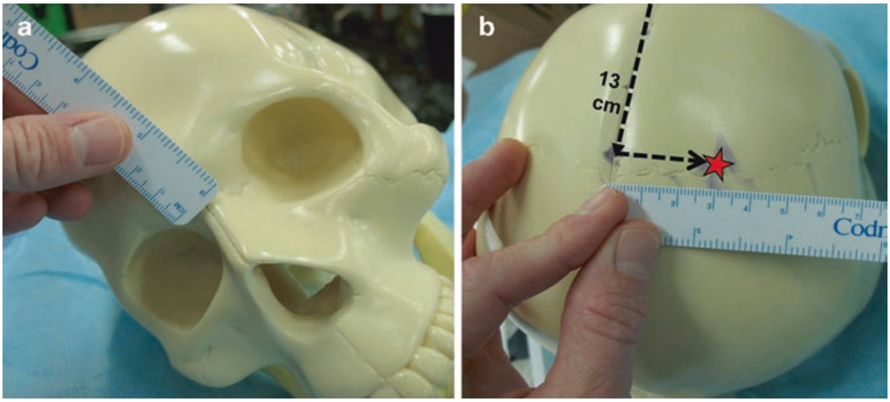



**Fig. 25.2** Landmarks for placement of an ICP monitor or ventriculostomy. (**a**) Begin measurement at the nasion (bridge of nose). (**b**) Measure 13 cm back from the nasion and then 3 cm lateral to the midline to identify the entry point (*red star*) for catheter placement

13 cm *back* from the nasion (the bridge of the nose) and 3 cm *lateral* to midline (Fig. 25.2). This will be just a bit anterior to the coronal suture. In a very young child, the entry will be 3 cm off midline and 1 cm anterior to the coronal suture, which should be palpable. Prep a wide area around your marked entry point. Drape out so you can clearly see your markings, including midline.

## Placing the Device (ICP Monitor)

Use the local anesthetic in the kit; make a wheal under your entry point. Fill one of the wells in the kit with a pool of sterile saline; this will be used to calibrate the transducer. Have your assistant power up the monitor box. Take the small drill bit, and remove the aluminum "drill stop" using the small Allen wrench. Put the bit into the hand drill. The "bolt" that threads into the skull has a small white plastic donut on the threaded portion. Remove it unless you are placing the bolt into a pediatric patient (thin skull). Make a stab incision directly on your marked entry point. Don't worry about the bleeding. Take the drill and put it directly through the stab, *perpendicular* to the skull (Fig. 25.3a). This small bit is very sharp, and you do not need to exert much downward pressure while drilling. You will feel the drill bit sink into the skull, and after just a few turns, it will drop through the inner table. Don't worry if it seems to plunge, this is an intraparenchymal monitor that you will be sticking into the brain tissue. Remove the drill. Take the spinal needle and insert it into the hole you just drilled. If it stops against the skull, you need to drill more. Once you are through the skull, the needle will puncture the dura, and you may see a bit of blood or CSF. Take the "bolt" and thread it into the hole you just drilled, finger tighten (Fig. 25.3b).

Now take the wire (the actual monitor) taking care not to kink it (it is fiber optic and is easily broken). Your assistant will be holding the female end (non-sterile).

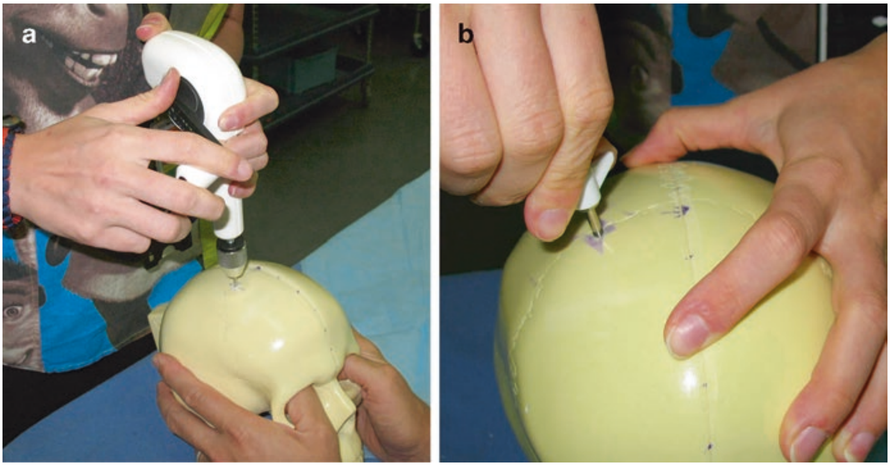



**Fig. 25.3** Drill through outer and inner table of skull (**a**) and place the bolt into the hole, screwing it in until finger tight (**b**)

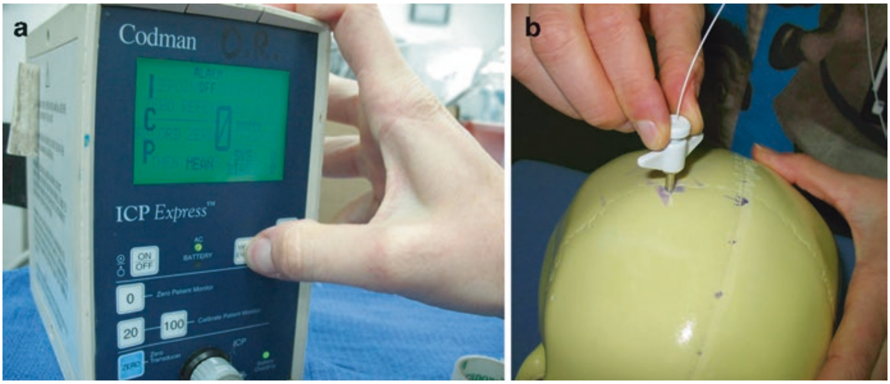



**Fig. 25.4** Zero the ICP monitor (**a**) while the catheter tip is submerged in saline. Place the monitor catheter through the bolt and into the brain parenchyma (**b**)

Your end has a very small plastic screw which needs to be facing up so you can turn it to calibrate the monitor. You will insert this male end (sterile) and then place the distal end of the wire into the saline pool. The assistant will then press the button to calibrate the monitor. A number will appear on the box; you take the tiny plastic screwdriver and turn it until the number on the box is zero (Fig. 25.4a).

Loosen the white plastic knob on the bolt ½ turn counterclockwise, and take the small metal rod, pass it down the hole in the bolt fully (there is a stop on it) to clear out any bone fragments which might damage the transducer, then remove it. Then insert the wire that you just calibrated up to the double lines (see Fig. 25.4b), and tighten the knurled white cap finger tight. Look at the reading on the box. If the reading is extremely high, the monitor is likely pressing on arachnoid or some other tissue which is falsely elevating the reading. In this case, loosen the knob and pull back slightly on the wire; it should move freely. Make sure that you still have a waveform on the monitor box, and then retighten the cap, then put the seal down over the cap and apply a tape dressing.

## Placing an EVD

Placement of an EVD is essentially the same as placement of an ICP monitor, with the following differences. If you have a CT and the patient has a significant amount of midline shift, it will be very difficult to cannulate the ventricle; thus, an ICP monitor is a better choice. There is usually no "bolt" with this kit. Make a linear incision rather than a stab, and use the small self-retaining retractor to maintain the exposure. The purpose of this incision is to allow you to "tunnel" the EVD after you pass it into the ventricle. Use the larger drill bit. Once you are through the skull, continue to turn the drill bit forward a few turns while maintaining the same depth in order to remove small fragments of the skull from the hole. You will need to make a large hole in the dura after you drill, in order to be able to pass the EVD. The trocar which is on the EVD itself works well for this (Fig. 25.5a). Pass the sharp end of the trocar through the hole in the skull, you will feel it penetrating the dura, and you should pass it about ½ cm further once it penetrates the dura. Don't be worried about passing it into the brain; remember, you are going to push a large Silastic catheter *through* the brain into the ventricle. Place the inner stylet into the EVD (see Fig. 25.5b). Pass the EVD *perpendicular* to the skull; you should feel it "pop" into the ventricle at about 4–5 cm depth from the surface of the skull. Do not pass it more than 7 cm; the catheter is marked in 5 cm increments on its external surface. After you feel the pop, hold the EVD right at its insertion into the skull with one hand, and use the other hand to withdraw the stylet approximately 1 cm, while maintaining the depth of the EVD. This will allow you to "soft pass" the EVD to a total depth of 6 cm from the outer table of the skull once you know it is within the ventricle. You may see CSF emanating from around the stylet at this time, and it will likely be blood tinged.

An assistant with sterile gloves is quite helpful for the next several steps. Taking care to hold the EVD securely at the skull surface, attach the trocar to the proximal end of the catheter and use it to tunnel the catheter for 3 cm laterally and then bring it out through the scalp. Cut the trocar off the EVD, and place the Luer Lock adapter into the EVD. Suture the EVD at its exit from the scalp using a roman-sandal-type knot, and then close the linear incision. Apply tape and gauze dressings. Level the drainage kit and maintain the drain open at 10 cm above the ear – this should allow CSF to drain if the ICP rises. ICP readings can be obtained hourly by hooking up an arterial line transducer to the stopcock on the drainage bag (do *not* use a pressure bag) and then closing the system distal to the transducer for a few minutes. This will directly measure the CSF pressure, but be sure to open the system again in order to allow drainage.

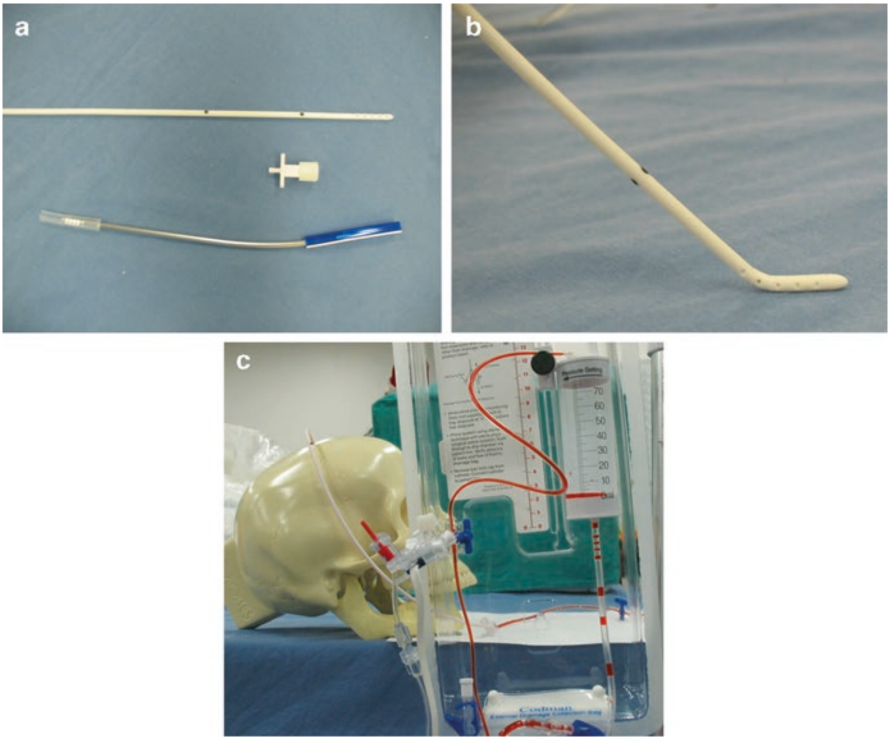



**Fig. 25.5** (**a**) Ventriculostomy (EVD) catheter (*top*) and sharp-tipped trocar (*bottom*); (**b**) catheter with stylet inserted to stiffen tip; (**c**) level the drainage kit at the external auditory meatus and then maintain it at 10 cm above the ear

## Decompressive Craniectomy Tips

Only you, as the operative surgeon, can make the call whether or not to perform this procedure. Telephone contact with a neurosurgeon will likely provide helpful information about indications, especially since you may now have access to web-based radiology systems. Transfer to a neurosurgeon is always the best option, but craniotomy/craniectomy has been done in both Iraq and Afghanistan by general surgeons in emergent situations. The utility of the "exploratory burr hole" is limited. If surgical intervention is going to be performed, you should proceed directly with a unilateral decompressive craniectomy (laterality based on the lateralizing findings discussed earlier, or on CT findings of mass effect or extra-axial blood, either epidural or subdural). Acute epidural hematomas and subdural hematomas are very difficult to evacuate through burr holes, and you will certainly not be able to identify a source of ongoing bleeding, if it exists. By proceeding directly to the definitive surgical intervention, you will save valuable time and the life of the patient. I will now describe a basic and effective all-purpose operative approach for these cases.

## Preparation

When you arrive at your place of duty, inquire as to the status of equipment required to perform a basic craniectomy. At a minimum, you will need a periosteal elevator, craniotome with bits, Gigli saws with saw passers and handles, a Leksell Rongeur, and a Metzenbaum scissors. Normalize coagulation status (crucial). Type and cross-match at least four units PRBC. Give 2 g cefazolin if no allergy. Clip the hair as completely as possible without wasting undue time. Place the head straight midline, and stand directly behind the patient in order to correctly visualize landmarks. *Mark the midline!* This is your most important landmark, as you will be staying *away* from it in order to avoid problems (Fig. 25.6). Palpate the zygoma and mark it. Make a gentle, question mark-shaped line from the anterior hairline in the midline extending to the base of the zygoma 1 cm in front of the tragus (Fig. 25.7). Making the skin incision in the midline will make it easy to remember where the midline is and to stay *away* from it during bony work. Position the patient with a shoulder roll under the ipsilateral shoulder (decreases the amount of tension on the neck), and rotate the head away, fully exposing the craniectomy side. If the patient has a known or suspected cervical spine fracture, be less aggressive with positioning, and consider leaving the cervical collar in place. Place the head on a donut headrest. The head should be nearly lateral when you are done positioning and elevated above the level of the heart. Prep and drape widely, and do not worry about the ear being in the field; it is a good landmark. Incise the scalp all the way down to the bone, beginning at the hairline. Secure the scalp edges with Raney clips as you go. When you get to the temporalis muscle, incise it in line with the scalp incision, and use of the monopolar will minimize bleeding. Retract the scalp flap forward and dissect the flap and

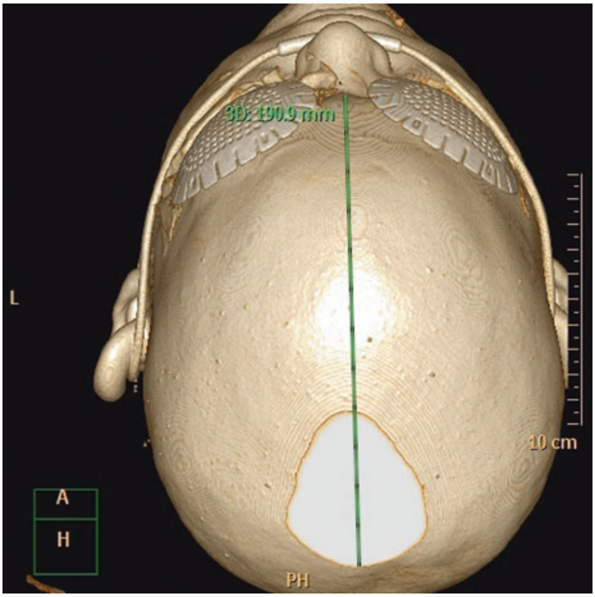



**Fig. 25.6** Clearly mark the midline from the bridge of the nose to the occiput

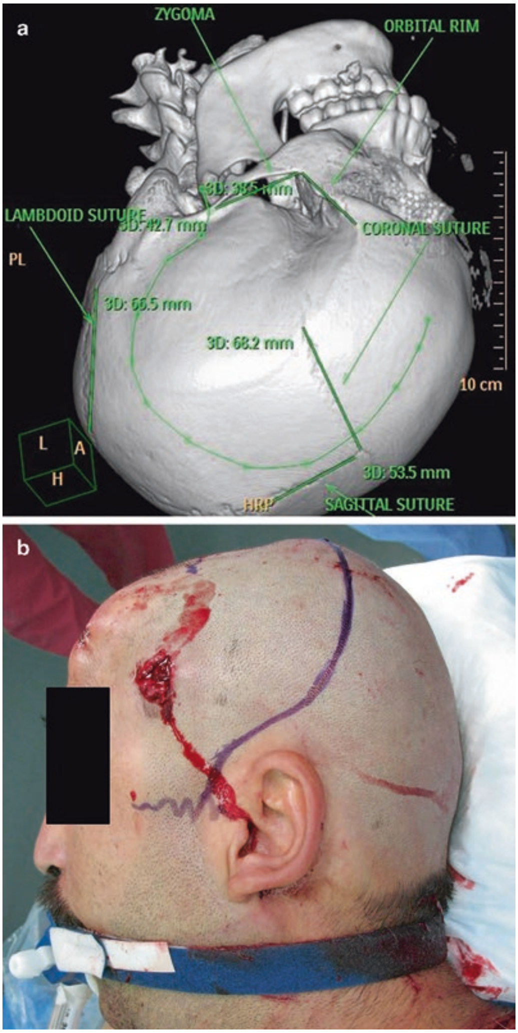



**Fig. 25.7** Planned incision is a gentle curve ("question mark") from the midline at the anterior hairline to the base of the zygoma and 1 cm anterior to the tragus. (**a**) Operative surgeon's view and (**b**) lateral view

the temporalis muscle off the surface of the skull along the entire length of the incision (Fig. 25.8). You will need to expose the root of the zygoma and the posterior edge of the orbital rim. Before drilling the perimeter burr holes, *mark the midline and stay at least 2–3 cm lateral with all bony work* (Fig. 25.9a). With the skin incision extending to the midline, you will be able to see and feel the sagittal (midline) suture easily, and your skin edge is also a landmark for midline. Mark each site for the proposed burr holes (6–7 should suffice) and create them (see Fig. 25.9b). Use bone wax on your finger for bone bleeding. Use the Penfield no. 3 to circumferentially strip the dura from the inner table of the skull. The Gigli saw set is used to connect the burr holes and complete the "bone flap." Place the saw (the wire) over the hook on the

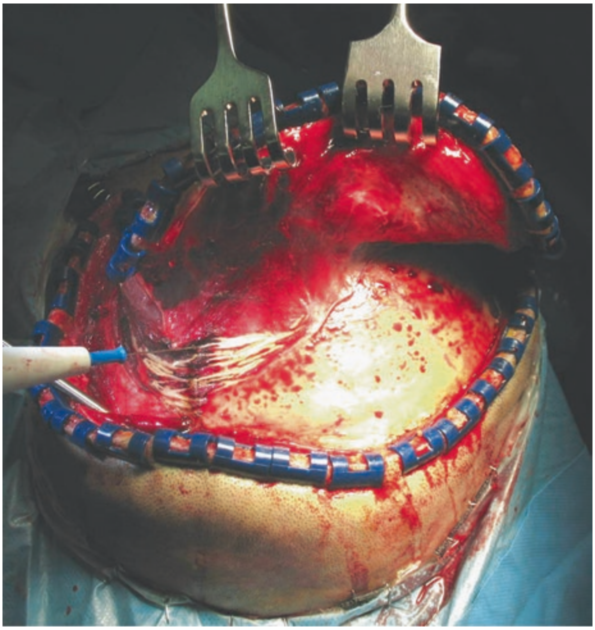
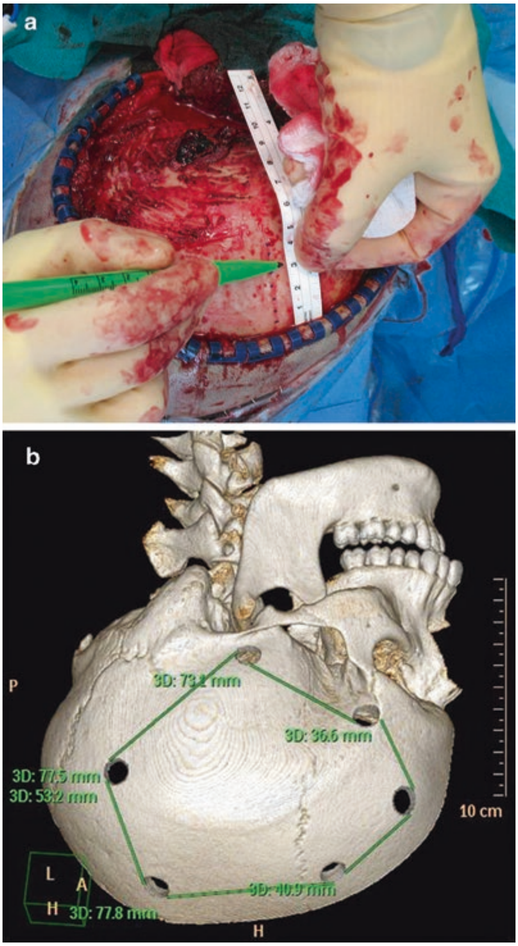


**Fig. 25.8** Raise a broad-based temporalis muscle flap to expose the underlying skull

"saw passer," pass from one burr hole to the next, leaving the passer in place, then attach a handle to each end of the saw, and pull back and forth with arms as wide as possible to avoid kinking the saw. Use a fresh saw for each cut. If you can't pass the saw in one direction, try passing it from the other hole. Once you have completed the bone flap, use the periosteal elevator to pull up on the edge, and sweep it under the flap to free up any last dural adhesions (Fig. 25.10). Remove the flap from the field. In general, do not implant the flap (some recommend "preserving" the flap in a subcutaneous abdominal pocket for reimplantation). Use a Leksell rongeur to remove the squamous portion of the temporal bone, just above the zygoma. This will decompress the temporal lobe and address "uncal herniation."

You must then open the dura. Adson tissue forceps (the ones with teeth) and a sharp no. 15 blade work best (Fig. 25.11a). Make a 1 cm linear score in the dura, pick up the edge with the Adson, and deepen the cut until you obtain CSF. You may lacerate the brain, especially if there is a great deal of edema. Then pick up the dural edge and complete the question mark-shaped durotomy in line with, but smaller than, the bone flap, again staying well away from the midline (see Fig. 25.11b). If there is active bleeding from a large, visible vessel, use the bipolar coagulator, if available, or clamp and tie off. The decompression is now complete (Fig. 25.12). You may now place an ICP monitor or EVD directly at this time. Take the ICP wire from the kit, pass a 14 gauge Angiocath from inside the scalp to outside the scalp across midline near the coronal suture, then pass the ICP wire from outside the scalp to inside, through the Angiocath, remove the Angiocath, and then simply pass it into

**Fig. 25.9** Outline the proposed bone flap, making sure to always stay at least 3 cm off of the midline (**a**). Mark five to six equally spaced burr holes (**b**)



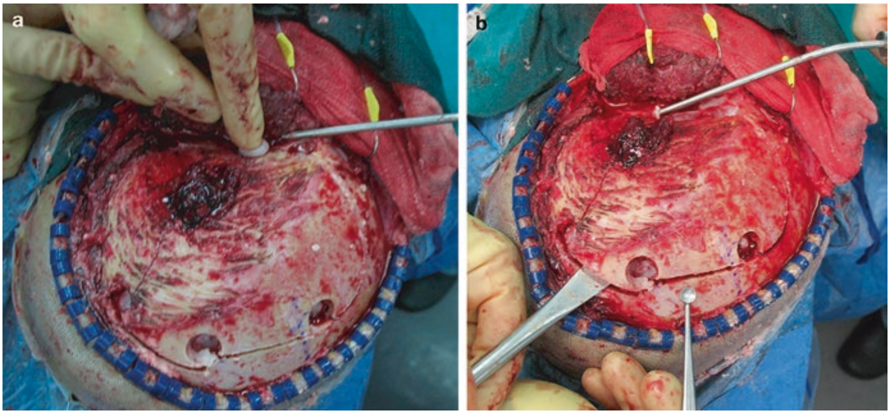




**Fig. 25.10** (**a**) Completed burr holes and bone wax being applied to control bleeding from the middle meningeal artery; (**b**) connect the burr holes with a Gigli saw and then use the periosteal elevator to lift the flap and free any dural adhesions

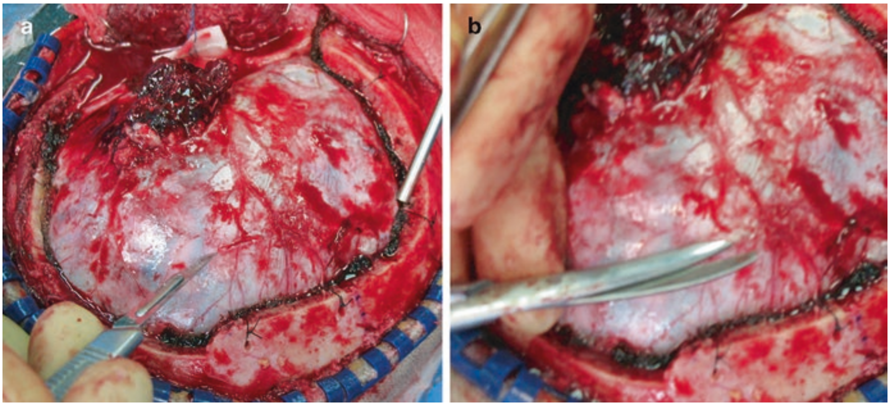


**Fig. 25.11** Opening the dura. (**a**) Incise sharply with a scalpel; (**b**) open widely along the margins of the bone flap using scissors

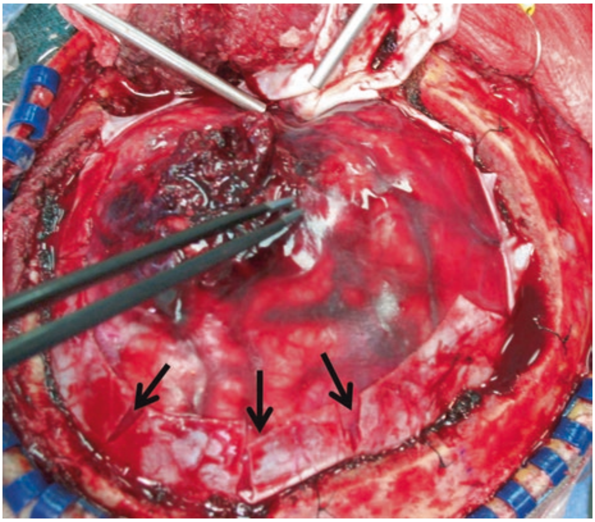


**Fig. 25.12** Additional radial incisions in the dura (*arrows*) provide wide decompression. Control parenchymal bleeding with bipolar cautery and topical hemostatics

the brain after first calibrating it as described in the section on placement of ICP monitors above. The location of placement is not crucial for this device, but placing it near the midline, non-mobilized portion of the scalp incision makes it easy to avoid displacement of the device during closure. You also want to keep the location anterior to avoid the motor strip, so use the coronal suture as a landmark.

For closure, if dural substitute is available (DuraGen or similar), simply lay it over the exposed brain; do not sew into place. If not available, a compressed Gelfoam sheet is acceptable (Fig. 25.13). Another option is fascia lata if you have someone to harvest it in a timely fashion. Lay a 7 mm JP drain over this dural covering, and pass out through a separate stab incision. Close the galea with interrupted inverted 2-0 Vicryl (CT-1 needle works well) and complete with surgical staples. A *loose* head wrap is then applied, and the patient maintained in the ICU with an appropriate ICP algorithm to be used for postoperative management.

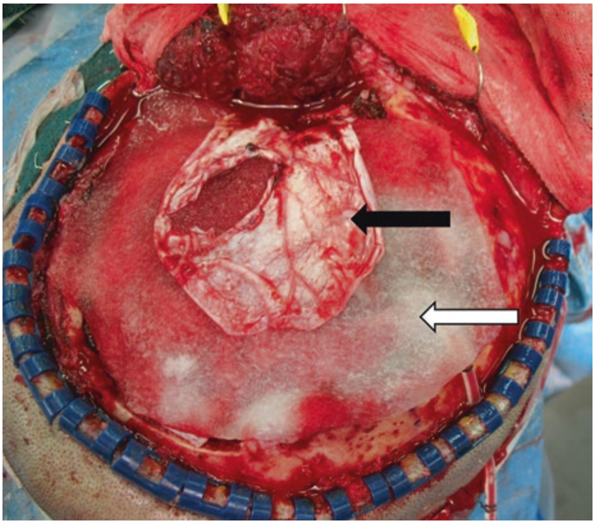


**Fig. 25.13** Duraplasty prior to skin closure. A compressed Gelfoam sheet (*white arrow*) is used to cover the exposed brain. The retracted dural edge (*black arrow*) is shown

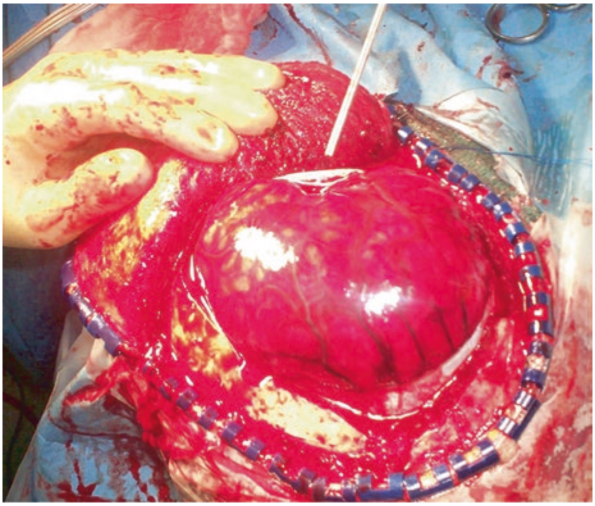


**Fig. 25.14** Non-survivable brain injury with massive hematoma and cerebral edema despite decompressive craniectomy

## Final Thoughts

Severe brain injuries are among the most devastating and unfortunately common injuries you will see in combat trauma. Know when to say "when"; if the patient has a non-survivable injury, then the best thing you can do is recognize it and use your time and resources elsewhere (Fig. 25.14). Remember that time is neurons, and the importance of what you do with the patient in that fabled "golden hour" can mean the difference between a meaningful recovery and severe disability or death. As a general surgeon in an austere environment, you should be familiar with the basic neurosurgical techniques outlined here – you never know when you might need them.

## Civilian Translation of Military Experience and Lessons Learned

Alex B. Valadka

One thing must be made clear: brain surgery is *not* something to be undertaken by amateurs. Basic principles of setting up the neurosurgical operating room, positioning a patient, planning an approach, opening the scalp and bone, opening the dura, performing the actual "brain" part of the surgery, and closing the incision are very different from the concepts learned during training in other surgical disciplines. Many complications or unpleasant surprises that are unique to brain surgery are not encountered by other surgeons, and they can end in disaster, especially if they are managed ineptly. In reports from parts of the world where inclement weather often prohibits aeromedical evacuation of surgical traumatic brain injury (TBI) patients, poor results from non-neurosurgeons attempting surgical evacuation of acute hematomas are well documented, including outright failure to evacuate the hematoma or even placement of the craniotomy flap in a completely wrong location.

An old but still persistent belief is that patients with TBI or other neurosurgical emergencies just need a few burr holes, and then they'll be okay. Unfortunately, a large acute epidural or subdural hematoma that covers most of a hemisphere is a solid clot that cannot be evacuated through a few small holes in the skull. The same is true for large parenchymal contusions. Limited exposure greatly lessens the ability to control intracranial bleeding. In other situations, patients may not require surgical procedures because they have diffuse brain injuries with no associated mass lesion. In such cases, drilling a few burr holes does not lower intracranial pressure (ICP) or afford any other benefit. It must also be remembered that even something as apparently straightforward as drilling burr holes can have catastrophic complications.

Several published articles describe insertion of ICP monitors by non-neurosurgeons. Unfortunately, these are parenchymal monitors. If inserted and calibrated safely and properly (which is a big "if"), these devices can provide a numerical value for ICP. But unlike ventriculostomy catheters, they cannot drain cerebrospinal fluid, which is one of the simplest and safest ways to treat elevated ICP. It should be remembered that a trial recently conducted in the developing world found that outcomes were no different if elevated ICP was detected via a parenchymal monitor or if it was diagnosed by findings on physical exam and by results of imaging studies.

What is the best way for the non-neurosurgeon to contribute to the care of a TBI patient? Answer: focus less on procedures and more on preventing secondary insults. The recently injured brain is highly vulnerable to even mild deviations from normal homeostasis that it would usually tolerate well, such as brief dips in blood pressure or brief periods of mild hypoxia. Because many common and potentially devastating secondary insults are extracranial in origin, any practitioner who can manage oxygenation, blood pressure, and other systemic parameters in critically ill patients can prevent and treat secondary insults.

Another key point is to recognize that less is more. Many anxious clinicians feel a strong need to be proactive in managing TBI patients. However, a large body of literature going back decades documents that attempts to prevent elevated ICP or other adverse cerebral events do not improve outcomes. In fact, they often make things worse. So far, the best that we can do is to focus on normalizing blood pressure, oxygenation, and other key parameters while closely monitoring patients and intervening promptly when things start to go south.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Neurosurgery and severe head injury.

# Traumatic Brain Injury and Neurocritical Care

# 26

Stacy Shackelford, Peter Rhee, and Bellal Joseph

**Deployment Experience**

| | |
|---|---|
| *Peter Rhee* | Chief surgeon, Charlie Medical Company, Forward level II facility, Ar Ramadi, Iraq, 2006 |
| *Stacy Shackelford* | General surgeon, Qatar, 2005 |
| | General surgeon, Bagram Afghanistan 2008 |
| | Joint Theater Trauma System director, Afghanistan 2012 |
| | Deputy Chief Clinical Services, Bagram Afghanistan 2016 |

S. Shackelford (✉)
Joint Trauma System, Defense Center of Excellence, Fort Sam Houston, TX, USA
e-mail: stacy.a.shackelford.mil@mail.mil

P. Rhee
Grady Health System, Department of Trauma, Atlanta, GA, USA

B. Joseph
The University of Arizona Banner Medical Center, Department of Surgery, Tucson, AZ, USA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**BLUF Box (Bottom Line Up Front)**

1. A-B-C comes before D but try to obtain a brief neurologic exam (pupils, Glasgow Coma Score, extremity movement) on all trauma patients prior to sedation or airway interventions.
2. Identify and control all bleeding—hemorrhage control is the best treatment for the injured brain as well.
3. Normotension, normovolemia, normoventilation, and normothermia are the initial objectives. Treat aggressively and decisively.
4. Recognize a severe brain injury when you see it, and treat empirically for elevated ICP.
5. Do not hesitate to administer hypertonic saline to casualties with altered mental status—there is no downside.
6. Intubate all casualties with GCS $\leq$ 8, especially if they are being transported.
7. Ketamine is a good initial pain and sedation medication for brain-injured casualties. This can be transitioned to short-acting agents (e.g., fentanyl and propofol) once hemodynamics are stabilized.
8. Monitor end tidal $CO_2$ and avoid hyper- and hypoventilation. Ensure you have the capability to monitor $ETCO_2$.
9. Don't forget to elevate the head!
10. Give mannitol (1 gm/kg IV) for severe TBI if hemodynamically stable and bleeding has been ruled out (if unable to exclude hemorrhage, then give hypertonic saline).
11. Work with your EMS and transport teams closely. It does not do any good to have perfect management by the surgical team if the casualty deteriorates during transport. Even a single episode of hypoxia or hypotension is associated with worse outcomes—this has been shown to be common during transport.

## Introduction

Traumatic brain injuries (TBI), ranging from mild to severe, are one of the most common injuries a deployed surgeon will encounter. The surgeon must be properly trained and facile on the initial management of TBI. Although TBI encountered in combat is not distinctly different than civilian injuries, there are unique challenges in managing such injuries in the austere environment without immediate access to CT scan, critical care capabilities, and neurosurgical specialty care.

For TBI in particular, it is important to optimize the early care starting at the point of injury and continuing until arrival to a higher level of care where neurosurgical capabilities are available. Even a single episode of hypotension and/or hypoxia is associated with worse neurologic outcomes.

The surgeon must know the resources available to assist in management and decision-making. Probably the most important resource is the telephone—early teleconsultation with a neurosurgeon is important, particularly for severe TBI patients. The Defense and Veterans Brain Injury Center (DVBIC) website and the Joint Trauma System (JTS) clinical practice guidelines provide additional guidance.

In the multiple-injured casualty, do not let the brain injury become the priority until the trauma basics are controlled. A, B, and C come before D in all cases. Although every surgeon knows this, there are times when the motivation to get the patient to a neurosurgeon may lead to a decision to transport the patient prematurely. It is critical to ensure that bleeding is controlled before transporting a patient away from a surgical capability.

Be an optimist and give your casualty the best possible chance for a good outcome. Brain injuries may seem hopeless, and recovery is slow. However, we have had some amazing survivors—you may hear their stories from time to time. Listen for these long-term follow-ups—it will motivate you when things are not looking good.

On the other hand, even unsurvivable brain injuries may receive maximal initial care in some cases, with the hope of reuniting a casualty with their family before death. However, expectant management is necessary when resources are limited and with clearly unsurvivable open brain injuries.

## The Basics: Primary Survey

Recognizing a brain injury starts with the initial assessment. It is critical to gather the information required for a neurologic assessment during the primary survey. If advanced airway management occurs before the neurologic exam, then the ability to obtain an accurate neurologic exam is lost. The basic neurologic exam can be obtained quickly prior to intubation by checking the pupils, talking to the patient, and asking them to follow commands to move the upper and lower extremities. This only takes seconds to do and provides valuable information to make decisions. If the casualty is unable to follow commands, then a painful stimulus should be applied to upper and lower extremities, and the response is observed. The eye opening, verbal, and motor responses are noted. This will give you all of the information you need to establish a Glasgow Coma Score as well as look for a spinal cord injury. In nearly every case, this can be done quickly just prior to intubation. It is also important to note any lateralizing signs—unequal pupils or asymmetric motor exam. Casualties with lateralizing signs have approximately 10% risk of a surgical hemorrhage in the brain.

It is not necessary to memorize the Glasgow Coma Score, as long as one remembers to assess eye opening, verbal, and motor responses. It is then an easy task to check a reference and calculate the GCS. The initial GCS is one of the most important prognostic indicators and is also a key factor in decision-making in regard to airway management, treatment of elevated intracerebral pressure (ICP), and surgical intervention. A baseline GCS should be obtained during the initial assessment of every trauma patient.

It is difficult to determine whether decreased mental status is the result of hemorrhagic shock, brain injury, toxic ingestion, or any combination of the above. Always remember that hemorrhagic shock can alter the initial neurologic exam. It is therefore important to first look for and identify all sources of hemorrhage immediately—hemorrhage control is the best initial treatment for the injured brain as well.

## Mild TBI

Mild TBI is by definition based on initial GCS of 14–15. Mild TBI (aka concussion) casualties may or may not have a history of loss of consciousness (LOC). If LOC occurred, it is usually brief (<5 min). LOC is not the sole determinant of TBI—some patients may have deficits and potentially serious TBI with or without LOC. Due to the many long-term sequelae related to concussions, recurrent concussions, and post-traumatic stress disorder within the DoD, it is mandated that all service members exposed to a potentially concussive event (involvement in vehicle blast event, collision, or rollover, presence within 50 m of a blast, direct blow to the head, witnessed LOC, or exposure to more than one blast event) should undergo a medical assessment involving, at a minimum, completion of the Military Acute Concussion Evaluation (MACE). Since mild TBI is extremely common, every provider should be familiar with the MACE exam. Pocket cards for the MACE can be ordered for free on the DVBIC website (dvbic.dcoe.mil) or referenced online via the DVBIC or JTS websites. A MACE score < 25 mandates a 24-h recovery period, with no return to duty until symptoms are resolved and exertional testing is performed.

Routine use of head CT is not required for all mild TBI casualties. This is especially important to note if evacuation is required in order to obtain a head CT. Red flags suggesting the need for head CT, per DoD guidance, include declining level of consciousness, declining neurologic exam, pupillary asymmetry, seizure, repeated vomiting, GCS < 15, motor or sensory deficit, LOC > 5 min, double vision, worsening headache, inability to recognize people or disoriented to place, slurred speech, or unusual behavior. CT scan is typically used to determine if there is intracranial bleeding that can kill the casualty—altered mental examination is the key component to diagnose brain injury, and not the CT scan.

Although the DoD mild TBI policy is only mandated for service members, it does provide excellent guidance that will optimize outcomes in any casualty, and should be applied to all mild TBI casualties to the extent that resources are available.

Mild TBI is rarely an emergency. Urgent medical evacuation solely for management of mild TBI is not indicated; however, mild TBI casualties may be evacuated with other urgent casualties, and operational necessities may override medical indications to determine the degree of urgency.

## Moderate and Severe TBI

Moderate and severe TBI are uncommon in comparison to mild TBI. According to DoD statistics for 2000–2015, 8.7% of brain injuries were defined as moderate (GCS 9–13), and 1% of brain injuries were severe (GCS $\leq$ 8). However, such injuries are the most challenging in terms of medical and surgical management.

In cases of suspected TBI, early patient management has a direct impact on the long-term outcome beginning at the point of injury. The same principles apply to prehospital and early inhospital care and should be reviewed with EMS providers in detail.

## Avoid Secondary Brain Injury

Secondary brain injury occurs when the injured brain is subjected to further insult through inadequate perfusion and hypoxia. Hypotension and hypoxia must be aggressively treated or avoided, targeting systolic blood pressure (SBP) > 90 mmHg, mean arterial pressure > 70 mmHg, and SaO2 > 95%. This does require a delicate balance in casualties with uncontrolled hemorrhage and TBI, in whom the avoidance of over-resuscitation with target SBP 80–90 mmHg is otherwise recommended in the absence of brain injury. In such cases, the treatment of hemorrhage always comes before treatment of the brain injury, and hypotension should be avoided through aggressive resuscitation with blood products and definitive control of bleeding. Vasopressors may be used very judiciously to augment blood pressure, particularly if not volume responsive. Placing an arterial line if available will facilitate blood pressure management. Emerging data shows that natural vasopressin is quickly depleted and exogenous vasopressin is often required. Therefore, in some civilian trauma centers, vasopressin is the initial vasopressor of choice.

Hypertension may represent the normal physiologic response to elevated ICP, naturally raising the cerebral perfusion pressure. Hypertension in an unconscious patient should be assumed to be due to increased ICP, and antihypertensive medications should not be given, although judicious doses of pain medications may be used.

Hypoxia has been shown to be surprisingly common in brain-injured casualties, particularly during evacuation (both intra-theater and inter-theater). It is imperative to ensure that oxygen is applied as early as possible after injury, airway and ventilator management is optimized, and dedicated critical care personnel are responsible for patient care during evacuation. Patients with GCS $\leq$ 8 should be intubated to ensure adequate airway protection, oxygenation, and ventilation. It is controversial, however, whether intubation should occur prehospital or on arrival to the hospital. Some clinical studies have shown no benefit to prehospital intubations, and many have shown that prehospital intubation is associated with a worse neurologic outcome. In the prehospital scenario, the patient can be adequately oxygenated and ventilated with bag-valve mask; however, most trauma centers would prefer that the patient was not intubated until arrival to the hospital. This should be discussed in advance with prehospital providers—many military prehospital providers are not experienced with endotracheal intubation but are well trained in nasopharyngeal airway, bag-valve-mask ventilation, supraglottic airway, and cricothyroidotomy.

Paramedics, en route critical care nurses, and resuscitative teams may perform rapid sequence intubation. Intubation is a high-risk period, with a danger of hyper- and hypoventilation, hypoxia, and hypotension; it should be done with adequate preparation by the most experienced provider available. If the patient is intubated, the optimal management of the patient includes monitoring end tidal $CO_2$.

Avoidance of iatrogenic injury is also important. Hypotension may be precipitated by administration of narcotic or sedation medications. The prehospital pain medication of choice for TBI casualties is ketamine based on current Tactical Combat Casualty Care guidelines. Ketamine is also a good choice for initial inhospital use since it is an effective analgesic and sedative that does not lower the blood pressure or the respiratory rate. Earlier reports that ketamine caused an increase in ICP have been disproven, and ketamine is currently recommended for use in TBI patients. Ketamine is synergistic with narcotics as well as versed and propofol, allowing lower doses of these other medications to reduce the hemodynamic effects. Ketamine does, however, complicate the neurologic exam—many times casualties who received prehospital ketamine will be much more obtunded on arrival to the hospital, compared to those who received narcotics. Additionally, there is no reversal agent for ketamine as there is for narcotics and benzodiazepines. Once a stable blood pressure is confirmed and the airway is controlled, short-acting pain and sedation agents are preferred. A propofol drip is preferred for sedation, while intermittent pain control with narcotics is preferred over continuous infusion.

Another cause of iatrogenic cerebral ischemia is hyperventilation. Since both hyper- and hypoventilation are harmful, it is imperative to monitor end tidal $CO_2$. Ultracompact inline $ETCO_2$ monitors are now available, as well as integrated $ETCO_2$ monitoring capability in virtually every portable monitor. There is no excuse for not having this capability even in the most austere environment. It is also helpful to monitor arterial or at least venous blood gases. A PCO2 in the low normal range, 35–40 mmHg, is the target.

## Treat Elevated Intracerebral Pressure (ICP)

Any casualty with a severe brain injury (GCS $\leq$ 8) or declining neurologic exam should be treated empirically for elevated ICP up until the point in their care that a CT scan can be obtained and/or an ICP monitor can be placed.

The earliest intervention for control of ICP is administration of hypertonic saline, most commonly 250–500 cc of 3% saline bolus, and then 50–100 ml/hr infusion. Evidence also supports initial bolus of up to 500 cc of 5% saline—this higher concentration is commercially available. Hypertonic saline can be given early after arrival to the hospital, or prehospital, as there is no adverse effect even in the presence of hemorrhagic shock.

Pain control is an important component of controlling ICP. Even unconscious patients may sense pain, and judicious use of pain control and sedation in conjunction with airway management and ventilation is indicated.

Chemical paralysis of intubated casualties is frequently required for patient transport and does help to reduce ICP through relaxation of musculature in the chest and abdomen, with the obvious downside of preventing further neurologic exam. If used for patient transport, vecuronium is the preferred agent since it is relatively short-acting and does not require refrigeration.

In casualties who are not hypotensive, the simplest and most commonly forgotten means of lowering ICP is to elevate the head, ideally by raising the head of the bed 45°. If that is not possible, any amount of reverse Trendelenburg that can be gained by adjusting the litter is helpful. If the mechanism of injury indicates the possibility of associated spinal injury, then full spinal precautions must be maintained until a CT scan is obtained, which precludes elevating the head of the bed; however, reverse Trendelenburg can still be implemented. Placing the head in straight alignment also decreases ICP as well as loosening of the cervical collar if it is on too tight and impedes venous drainage.

For isolated brain injury, or once hemorrhage and hypovolemia have been excluded, mannitol (25–50 grams IV) can also be given. Mannitol lowers ICP through osmotic diuresis and may be given to hemodynamically stable patients with severe head injury. Preferably only give mannitol if ICP is suspected to be elevated or has been shown to be elevated, and the elevated ICP is not controlled by conventional means including hypertonic saline. If giving mannitol, ensure that a Foley catheter is in place to monitor the urine output and observe for signs of hypovolemia which can occur due to the mannitol use since it is a diuretic.

Hypercarbia causes cerebral vasodilation and further elevation of ICP. This is best avoided through intubation, mechanical ventilation, and end tidal $CO_2$ monitoring. Most guidelines also recommend temporary hyperventilation for control of elevated ICP if transtentorial herniation is suspected (unilateral or bilateral dilated pupils). This is only useful for brief periods until surgical decompression can be performed and in general is thought to cause more harm through vasoconstriction than benefit through lowering ICP if done for hours. If hyperventilation is implemented, the target $PCO_2$ should be 30–35 mm Hg. Severe hypocarbia has only been associated with poor outcome and has not been shown to be helpful.

Brain death may occur following severe brain injury or ischemic insult. If resources are adequate, formal declaration of brain death may be delayed and the patient supported medically until they can be evacuated to a location where the family is able to meet them and a predetermined wish to donate organs can be supported. The JTS guideline on "catastrophic care" provides details on the medical management of such casualties. Evacuation and support of these casualties is a difficult and resource-intensive undertaking. Expectant management of the brain-dead patient is indicated if resources are limited.

## Additional Treatments

- The neurologic exam should be monitored and recorded hourly, with particular attention to the GCS and pupillary exam.
- Seizure prophylaxis should be given for the first 7 days if intracerebral hemorrhage is suspected or confirmed by CT. Levetiracetam (Keppra) is the antiseizure

medication best suited to the deployed environment since it does not require drug level testing.

- If active seizure occurs, treat initially with lorazepam and load with levetiracetam, phenytoin, or fosphenytoin IV. For refractory seizure, propofol, versed, or ketamine drip may be implemented.
- Normothermia should be maintained, avoiding both hypo- and hyperthermia. Fever should be treated early with acetaminophen and cooling. Hypothermia management kits are routinely used during transport of casualties—temperature must be closely monitored and cooling implemented if the core temperature rises over 100 F. The use of non-steroidal anti-inflammatory medication should be avoided due to platelet inhibition. Surface cooling measures should be used with caution as they may induce shivering. Shivering also elevates the ICP and should be treated with warming and possibly Demerol.
- Early administration of antibiotics is indicated for open head injuries and may be continued for 24–72 h.
- Avoid hypo- or hyperglycemia. Blood sugars should be checked at least every 6 h and maintained <180 mg/dL.
- Monitor serum sodium levels closely. In TBI, sodium control is preeminent. It is the most important electrolyte to monitor. The target sodium level is slightly above normal, 145–150 mmol/L. Hypotonic fluids should be avoided, as this will increase brain edema. The maintenance IV fluid of choice is normal saline, and others should be avoided. Brain injury may lead to disorders of sodium balance, including SIADH (syndrome of inappropriate antidiuretic hormone secretion), cerebral salt wasting, and diabetes insipidus. If sodium is low, free water restriction and salt supplementation should be implemented. If the sodium is elevated >150, particularly when associated with polyuria >200 cc/hr, diabetes insipidus must be considered. Vasopressin should be used to treat diabetes insipidus. Usually, diabetes insipidus is indicative of severe brain injury or impending brain death.
- Nutrition is important for all brain-injured patients. If the patient is unable to eat, enteral feeds should be started within 24–48 h if not otherwise contraindicated. Even in the scenario of vasopressor use, enteral feeding should be considered.

## Civilian Translation of Military Experience and Lessons Learned

Bellal Joseph

Traumatic brain injury (TBI) remains the leading cause of death and disability among trauma patients. The management of TBI patients is complex and includes specialized prehospital care, inhospital acute care management, and for some, long-term rehabilitation. Improvements in and better understanding of pathophysiology associated with TBI, management guidelines (i.e., sensible use of ICP monitoring) and critical care (i.e., use of hypertonic saline) have led to a pronounced reduction in deaths and disability resulting from TBI. Several of these novel concepts evolved from battlefield injuries and military experience that have now emerged as potential therapies for limiting primary insult as well as prevention of secondary brain injury following head trauma. The prime focus of this chapter is to discuss the impact of military experience and research on civilian neurocritical care and management of severe TBI.

## Strategies for Neuroprotection

### Hyperosmolar Therapy: Hypertonic Saline in Traumatic Brain Injury

The objective of hemodynamic therapy in TBI is to ensure adequate brain perfusion and to keep intracranial pressure within normal limits. Among the various methods to control ICP and maintain cerebral perfusion, one of the key pharmacological interventions is hyperosmolar therapy. Hyperosmolar therapy (mannitol) has been utilized to reduce elevated intracranial pressure and edema from TBI for nearly five decades; however, only recently the use of hypertonic saline as a hyperosmolar agent has gained popularity for both resuscitation and maintenance therapy in TBI patients.

Hypertonic saline was heavily investigated for use as resuscitation fluid in patients with hemorrhagic shock on the battlefield. It was observed that in patients with both hemorrhagic shock and TBI, resuscitation with hypertonic saline was associated with better survival. Over time hypertonic saline evolved as an alternative to mannitol in treating cerebral edema and raised ICP following traumatic brain injury. Although there is not enough evidence to support its definitive superiority over mannitol, hypertonic saline has clear advantages over mannitol in treatment of TBI as it is more effective in reducing ICP and does not cause hypovolemia and hypotension. Mannitol has the potential of causing hypovolemia and increased crystalloid use if normal saline is required to replace urine output.

The most commonly used concentration of HTS is 3%. Recently 5% saline has gained popularity due to studies demonstrating that 5% HTS has sustained higher serum osmolarity and sodium concentration within the first 72 h without any increase in adverse effects in comparison with 3% HTS. Most laboratory and clinical studies have actually used 7.5% hypertonic saline; however, this concentration is not commercially available, whereas 5% is available.

### Selective Brain Cooling

Suspended animation, the ability to put a person's biological processes on hold, has long been a staple of science fiction. Interest in the field blossomed in the 1950s as a direct consequence of the space race. Most of the studies to date have utilized whole-body cooling. This technique is associated with increased risk of adverse effects including coagulopathy, hypotension, and infections and is generally not recommended. A recent international, multi-institutional, randomized controlled trial (Eurotherm 3235) which examined the effects of titrated therapeutic hypothermia (32–35 °C) as treatment of raised ICP demonstrated worse outcomes with lower Glasgow Coma Outcome Score among patients with therapeutic brain cooling compared to standard of care therapy. Another multi-institutional trial to assess the utility of therapeutic hypothermia for 48–72 h with slow rewarming after severe traumatic brain injury in children was terminated early due to ineffectiveness of the therapy as compared to standard treatment. In current practice, based on these randomized trials, cooling is not recommended for traumatic brain injury.

### Coagulopathy After Traumatic Brain Injury

TBI is often associated with disturbances in coagulation profile, and this may affect up to one-third of TBI patients. Proposed mechanisms by which TBI induces coagulopathy include local and systemic inflammation leading to the release of tissue factor, activation of the protein C pathways, platelet dysfunction, and disseminated intravascular coagulation. The coagulopathy after TBI is a dynamic process that goes through stages of hypocoagulability and hyperfibrinolysis to ultimately a state of hypercoagulability and thrombosis. TBI-induced coagulopathy is diagnosed with traditional measures of coagulation such as prothrombin time, activated partial thromboplastin time, and international normalized ratio. It has also been shown that development of coagulopathy after TBI is associated with higher mortality. In recent years, viscoelastic tests such as thromboelastography (TEG) and rotational thromboelastometry (ROTEM) have been frequently used to assess the TBI coagulopathy. These coagulation tests are both more sensitive and specific than conventional assays and are more efficient in predicting therapy for TBI-induced coagulopathy.

The reversal of TBI-induced coagulopathy requires the replacement of coagulation factors. Classically, fresh frozen plasma (FFP) has been used to reverse coagulopathy in TBI patients. Studies have demonstrated that PCC when used in conjunction with FFP is associated with complete and more rapid reversal of coagulopathy without any increase in complications as compared to FFP alone. PCC in conjunction with FFP also leads to a faster time to craniotomy in all patients with TBI-induced coagulopathy. Recombinant factor VIIa has also been shown as an effective therapy in reversing coagulopathy; however, there is no difference in its effectiveness when compared with PCC.

## Clinical Management of Traumatic Brain Injury

### Non-operative Management Guidelines for TBI

Traditionally, patients with suspected TBI are seen by neurosurgeons for initial evaluation and computed tomography (CT) scan irrespective of the severity, clinical presentation, or associated risk factors. Subsequently, patients with any abnormal findings on CT scan undergo one or more follow-up scans. Recently this approach has been challenged for two fundamental reasons. Firstly, the vast majority of these patients never undergo any form of neurosurgical intervention and are managed non-operatively by critical care physicians in the ICU. Secondly, indiscriminate use of repeat imaging in these patients results in expenditure of valuable human and financial resources. TBI is a clinical diagnosis, and the decision for a repeat head CT scan or need for neurosurgical intervention can be unfailingly predicted by considering the size of initial head bleed, close clinical examination, and the presence of risk factors for bleed progression such as coagulopathy. Patients with TBI undergoing non-operative management can be reliably followed for any sign of neurological decline without a routine repeat head imaging. The brain injury guidelines (BIG) have demonstrated safe and effective management of TBI patients with minimal injury based on neurologic examination without the need for neurosurgical consultation or repeat head CT scan. This practice has resulted in a significant reduction in the use of valuable resources such as neurosurgical consultation, repeat CT scans, and hospital costs without affecting patient care.

## Intracranial Hypertension and ICP Monitoring

The use of ICP monitoring varies greatly in clinical practice, with inconsistent reports analyzing the effect of such monitors on clinical outcomes and survival in patients with TBI. According to the Brain Trauma Foundation (BTF) guidelines, ICP monitoring should be performed in all TBI patients with a Glasgow Coma Scale (GCS) score $\leq 8$ with an abnormal head CT or a normal head CT scan with systolic blood pressure $\leq 90$ mmHg, posturing, or age $\geq 40$ years. Additionally, according to BTF, it is recommended that ICP should be maintained $\leq 25$ mm of Hg and cerebral perfusion pressure $\geq 60$ mmHg. A vast majority of patients with severe TBI meet the criteria for ICP monitoring according to these guidelines. However, only a small subset of these patients actually receive ICP monitoring based on institutional guidelines. In fact, there is no level 1 evidence that clinical outcomes are improved in patients who receive ICP monitoring, and management with an established protocol of neuroimaging and clinical examination may be a reasonable alternative. Additionally, a recently published trial comparing the role of standard non-operative management to decompressive bifrontotemporoparietal craniectomy demonstrated favorable patient outcomes with standard non-operative management. Medical management remains the standard of care for elevated ICP, with a possible role for ICP monitoring and operative intervention in a subset of patients; however, more research is required to better define this subset of patients.

## Enteral Nutrition in Traumatic Brain Injury

Following TBI, there is a cascade of inflammatory cytokines released into the blood stream that initiates rapid catabolism and increased energy expenditure. Therefore, TBI patients require appropriate nutritional support at the right time for optimal recovery. Nutritional support after TBI provides patients with appropriate substrates, essential nutrients, and enough calories to inhibit catabolism and promote rapid neurological recovery. Based on this evidence, current Brain Trauma Foundation (BTF) guidelines and the American Association of Neurological Surgeons (AANS)Traumatic brain injury (TBI): guidelines recommend initiation of enteral nutrition within 72 h and full nutritional replacement by the seventh day. However, a recent study showed that initiation of tube feeds within the first 24 h of injury may inhibit the post-injury acute phase response leading to slower recovery and higher incidence of pneumonia. For optimal clinical results and rapid recovery in traumatic brain injury, nutrition can be safely started after the first 24 h post-injury and should advance toward optimal nutritional goals over next 48–72 h.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Catastrophic non-survivable brain injury.
2. DoD policy guidance for the management of mild traumatic brain injury/concussion in the deployed setting.
3. Neurosurgery and severe head injury.
4. Use of MRI in the management of mTBI in the deployed setting.

## Suggested Reading


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# Spine Injuries

# 27

Matthew J. Martin, Ryan Gocke, and John G. DeVine

**Deployment Experience**

| | |
|---|---|
| *Matthew J. Martin* | Chief of Surgery, 47th Combat Support Hospital, TF Vanguard, Tikrit, Iraq, 2005–2006 |
| | Chief of Trauma, Theater Consultant, General Surgery, 28th Combat Support Hospital, Baghdad, Iraq, 2007–2008 |
| | Commander, 655th Forward Surgical Team, FOB Ghazni, Afghanistan, 2010 |
| | Chief of Surgery, 758th Forward Surgical Team, FOB Farah, Afghanistan, 2013 |
| *Ryan Gocke* | USSOCOM Surgical Support, 2015, 2016 |

*"The expert surgeon is smarter than the algorithm."*

Charles Abernathy

M.J. Martin (✉)
Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA
e-mail: traumadoc22@gmail.com

R. Gocke
Naval Medical Center Portsmouth, Department of Orthopedic Surgery, Portsmouth, VA, USA

J.G. DeVine
Medical College of Georgia at Augusta University, Department of Orthopedic Surgery, Augusta, GA, USA



M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_27

**BLUF Box (Bottom Line Up Front)**

1. There are limited spine surgery resources in a combat theater, so *you* are likely to be the spine surgeon.
2. With combat spinal cord injuries, what is done is done, and there is little you can do acutely to improve or worsen.
3. Therefore, do not worship at the altar of "spinal precautions"; do what you need to do to take care of the patient's injuries.
4. A quick and thorough neurologic exam is key to distinguishing between complete and incomplete spinal cord injuries.
5. If there is any question about a spinal column or canal wound, wash it out and get tissue coverage.
6. Irrigation, debridement, and broad coverage of antibiotics are the key to wound management success.
7. There is little role for steroids in penetrating spine trauma and even less in a combat theater. Steroids should never be given for any penetrating SCI. Steroids are no longer recommended by most guidelines.
8. Treat the spine injury like a brain injury – always avoid hypotension and hypoxia.
9. Don't forget the airway! Particularly with high cervical spine injuries, delayed decompensation is common, so anticipate and intubate (always before transfer).
10. Run-of-the-mill blunt spine injuries happen in combat also – use CT scan liberally for blast and vehicular incidents.

You arrived in the theater of operations several weeks ago, and injured patients from your first mass casualty event are streaming into the emergency room (ER). With the exception of the uniforms and the fact that your ER is a tent, it looks a lot like a civilian trauma event. Multiple patients arrive bleeding and moaning, almost all of them on spine boards and with cervical collars in place. One patient has multiple fragment wounds to his chest, neck, and face and is having a hard time breathing. He is bleeding around his cervical collar, but no one wants to remove it or move the patient for fear of violating "spinal precautions." Suddenly, the experienced triage physician arrives and wastes no time in removing the collar, sitting the patient upright, and assessing his neck wounds. Miraculously the patient survives with an intact spinal cord and neurologic function.

Before we begin a discussion of how to manage spine injuries in a combat setting, it is critical to understand their epidemiology and limitations of available therapies. Most will be penetrating or a combination of blunt and penetrating (blast) mechanisms. This means that most often the die has been cast long before they arrive at your facility, and either they have a neurologic injury or they don't. What you do in terms of moving them or placing them in "spinal precautions" will have little to no impact for the vast majority. The patient with no motor deficit but a spine that is so unstable that removing their collar and turning their head will suddenly "pith" them and result in paralysis is so rare that it should not be a consideration when you are faced with *real* and *present* injuries. This may be somewhat heretical, but do not let spinal precautions prevent you from doing what you need to do to take care of the patient.

The other important consideration is that there are almost no spinal emergencies that you will encounter in the combat setting. Almost all other injuries should take precedent in both evaluation and management, unless the spinal cord injury is impeding the airway (cervical spine) or the hemodynamics (neurogenic shock). No emergent imaging of the spine is required prior to a laparotomy or other surgeries, and you can always just keep them immobilized until the spine can be safely assessed. Even if one of the rare spinal cord emergencies is encountered, such as a progressively worsening exam with a cord compression that requires surgical decompression, your job will be to stabilize and transfer the patient to a spine surgeon.

## Assessing Spinal Cord Injuries

The vast majority of combat trauma is the result of explosions or gunshot wounds. Considering the fact that most of the thorax is protected by body armor, penetrating spine injuries in modern combat are quite uncommon. Most of the spine injuries tend to occur in civilians and soldiers from forces that do not routinely wear body armor. However, blasts and vehicular accidents also happen in combat zones, and these can result in the regular, run-of-the-mill spinal column and cord injuries that you see in civilian trauma. The main difference is that you usually will not have a spine surgeon available, so *you* will be the spine expert. You also may not even have a CT scanner available, so you may have to base your management on your physical examination and plain x-rays. Fortunately, anyone with an interest can provide 99% of the critical early management that is required.

It is important to realize that recovery of neurological function after any spinal cord injury in any setting is not very good. Nevertheless, the distinction of complete and incomplete cord injury should be made as patients with incomplete injuries may derive some benefit from operative intervention such as decompressive laminectomy or removal of bone fragments that are compressing the spinal cord. However, as a relatively strict rule, spinal column injuries should not be treated in a down range setting unless there is evidence of progression of neurologic deficits. Documentation is critical to assess any changes in neurologic function. Physical examination skills are still the most important factor in the evaluation, so you should have a good basic spinal exam committed to memory. A "complete" injury is an injury pattern in which there is absolutely no function below the level of the injury. An "incomplete" injury is one in which there is *any* function below the level of injury. Sacral root sparing, which may allow some residual anal sphincter function or sensation or slight movement of a great toe, is an indication that the injury is incomplete and carries a better prognosis for some recovery. Furthermore, the presence or absence of spinal shock should be assessed by way of assessing the bulbocavernosus reflex.

Non-penetrating trauma is more likely to produce an incomplete injury. High-energy penetrating trauma will more commonly produce "complete" injuries. Since distinguishing between complete and incomplete spinal cord injuries is a critical task, it is important that trauma providers learn to perform a rapid yet thorough neurologic exam. The performance of such an exam is frequently overlooked in busy trauma bays. There are many different ways to do such an exam, but the main points are that in addition to global neurologic disability (Glasgow Coma Scale and pupil exam), the secondary survey of the patient should include strength testing in upper and lower extremity muscle groups and a rectal exam for tone and sensation (Fig. 27.1). Not every muscle group in the upper and lower extremities must be tested if there are no focal injuries on the extremities. For example, if the patient can flex his deltoids (C5) and extend and spread his fingers (finger flexion and intrinsic muscles of the hand, C8/T1), chances are good that everything in-between is intact. Similarly, lower extremity muscle groups can be quickly and easily tested (knee extension, L2/3, and great toe extension, L5, or ankle dorsiflexion, S1/S2) with the assumption that everything in-between is intact in the absence of any other symptoms or obvious injuries. Both upper and lower extremities and both right and left sides should be tested, as certain syndromes may cause "skip" patterns or have unilateral deficits (e.g., central cord syndrome, Brown-Sequard).

For patients who complain of a neurologic deficit or have been noted to have paralysis, this testing can become more challenging. Both knowledge of which muscle group is fired by each spinal cord level and more thorough checking for neurologic function distal to the apparent spinal cord level (including rectal exam) can help identify patients with incomplete injuries who may benefit from more urgent operative intervention. In addition, such an exam may help identify the possible injury location in order to better immobilize and prevent iatrogenic extension of the neurologic deficit. Remember that if spinal shock is present, you cannot determine whether the injury is complete or incomplete. Spinal shock variably persists, and serial examinations should be completed when feasible to assess evidence of spinal cord recovery.

Your exam should establish several key factors about any spinal cord injury and which any receiving spine surgeon will want to know. Both the motor and the sensory level (Fig. 27.2) of the injury should be identified and documented. The presence or absence of spinal shock should be established as described below. Finally, the injury should be assessed as complete or incomplete (in the absence of spinal shock). With communication of these simple facts combined with the anatomic imaging findings (CT scan), the consulting spine surgeon can make immediate recommendations and develop the majority of the treatment plan. The evaluation and scoring sheet developed by the American Spinal Injury Association (ASIA) provides all the information you need about performing and documenting the motor and sensory exam (Fig. 27.3).

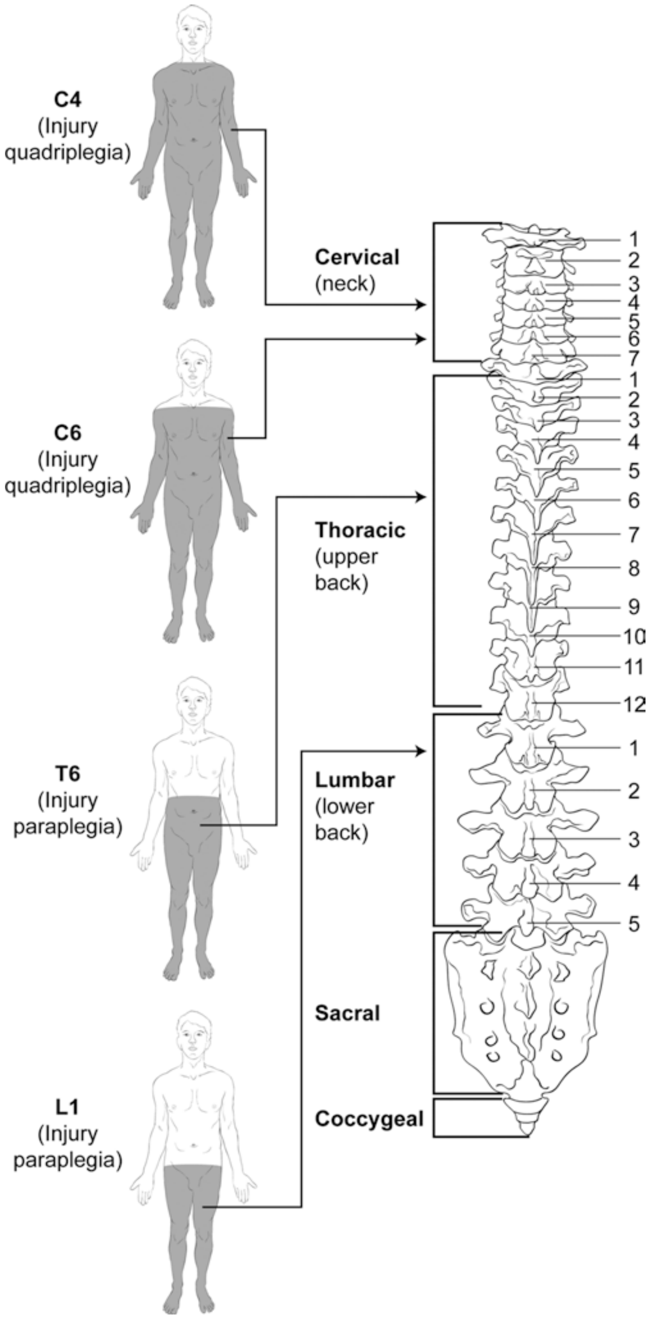



**Fig. 27.1** Extent of muscle paralysis associated with different levels of spinal cord injury. Injuries above C7 will typically result in quadriplegia, while injuries below C7 will result in paraplegia

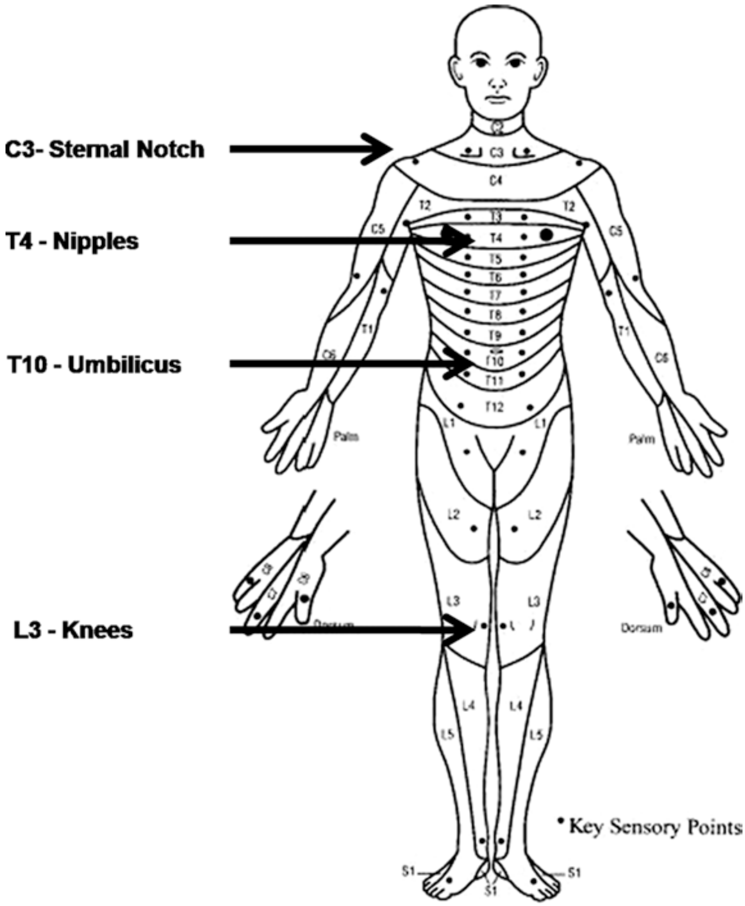
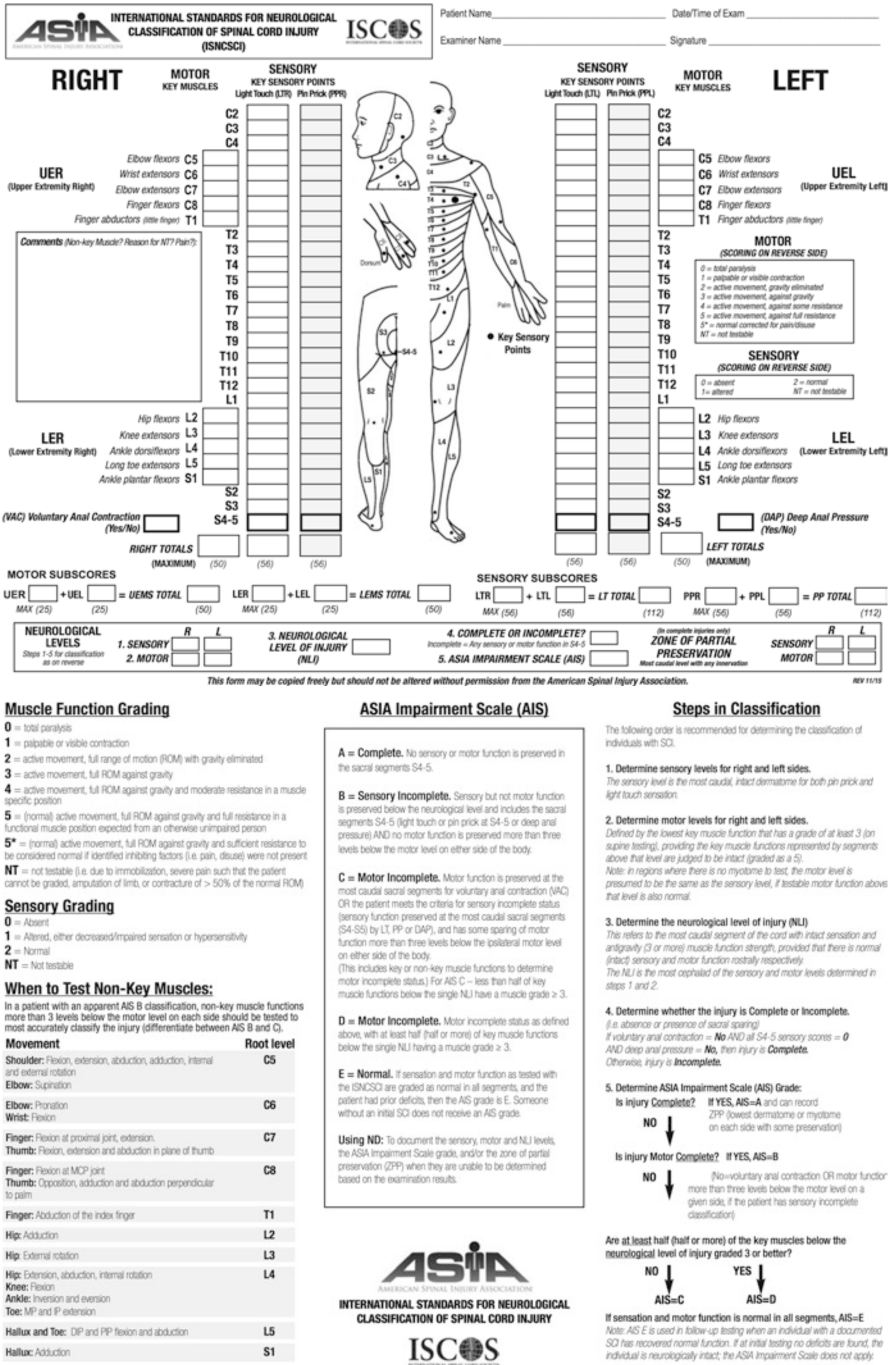



**Fig. 27.2** Sensory dermatomal map and the key sensory levels with anatomic landmarks. The lowest level with intact sensation to light touch and pinprick should be identified and documented (Reproduced with permission from American Spinal Injury Association)

## Shocking: Spinal Shock Versus Neurogenic Shock

This is a favorite board exam question, but it is surprising how many physicians continue to confuse or misunderstand these concepts. Neurogenic shock is the hemodynamic consequence of the spinal cord injury, classically characterized by bradycardia and hypotension. Cervical spine and high thoracic spine injuries are the usual culprits due to loss of sympathetic cardiac stimulation (bradycardia) and vasomotor tone in the lower body (hypotension). This is one situation in trauma where immediate pressor use is warranted, and the mean arterial pressure should be restored as soon as possible. Some data supports aggressive resuscitation to euvolemia and using pressors to target a mean arterial pressure of >85, and this may



ASIA — INTERNATIONAL STANDARDS FOR NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY (ISNCSCI) — ISCOS

Patient Name ____ Date/Time of Exam ____

Examiner Name ____ Signature ____

**RIGHT** — MOTOR KEY MUSCLES — SENSORY KEY SENSORY POINTS: Light Touch (LTR), Pin Prick (PPR)

**LEFT** — SENSORY KEY SENSORY POINTS: Light Touch (LTL), Pin Prick (PPL) — MOTOR KEY MUSCLES

C2, C3, C4

UER (Upper Extremity Right) / UEL (Upper Extremity Left): Elbow flexors C5; Wrist extensors C6; Elbow extensors C7; Finger flexors C8; Finger abductors (little finger) T1

T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12, L1

Comments (Non-key Muscle? Reason for NT? Pain?):

LER (Lower Extremity Right) / LEL (Lower Extremity Left): Hip flexors L2; Knee extensors L3; Ankle dorsiflexors L4; Long toe extensors L5; Ankle plantar flexors S1

S2, S3, S4-5

(VAC) Voluntary Anal Contraction (Yes/No)

(DAP) Deep Anal Pressure (Yes/No)

● Key Sensory Points

MOTOR (SCORING ON REVERSE SIDE): 0 = total paralysis; 1 = palpable or visible contraction; 2 = active movement, gravity eliminated; 3 = active movement, against gravity; 4 = active movement, against some resistance; 5 = active movement, against full resistance; 5* = normal corrected for pain/disuse; NT = not testable

SENSORY (SCORING ON REVERSE SIDE): 0 = absent; 1 = altered; 2 = normal; NT = not testable

RIGHT TOTALS (MAXIMUM) (50) (56) (56)

LEFT TOTALS (MAXIMUM) (56) (56) (50)

MOTOR SUBSCORES: UER ___ + UEL ___ = UEMS TOTAL ___ MAX (25) (25) (50); LER ___ + LEL ___ = LEMS TOTAL ___ MAX (25) (25) (50)

SENSORY SUBSCORES: LTR ___ + LTL ___ = LT TOTAL ___ MAX (56) (56) (112); PPR ___ + PPL ___ = PP TOTAL ___ MAX (56) (56) (112)

NEUROLOGICAL LEVELS (Steps 1-5 for classification as on reverse): 1. SENSORY R L; 2. MOTOR R L

3. NEUROLOGICAL LEVEL OF INJURY (NLI)

4. COMPLETE OR INCOMPLETE? Incomplete = Any sensory or motor function in S4-5

5. ASIA IMPAIRMENT SCALE (AIS)

ZONE OF PARTIAL PRESERVATION (In complete injuries only) Most caudal level with any innervation: SENSORY R L; MOTOR R L

*This form may be copied freely but should not be altered without permission from the American Spinal Injury Association.* REV 11/15

## Muscle Function Grading

**0** = total paralysis

**1** = palpable or visible contraction

**2** = active movement, full range of motion (ROM) with gravity eliminated

**3** = active movement, full ROM against gravity

**4** = active movement, full ROM against gravity and moderate resistance in a muscle specific position

**5** = (normal) active movement, full ROM against gravity and full resistance in a functional muscle position expected from an otherwise unimpaired person

**5*** = (normal) active movement, full ROM against gravity and sufficient resistance to be considered normal if identified inhibiting factors (i.e. pain, disuse) were not present

**NT** = not testable (i.e. due to immobilization, severe pain such that the patient cannot be graded, amputation of limb, or contracture of > 50% of the normal ROM)

## Sensory Grading

**0** = Absent

**1** = Altered, either decreased/impaired sensation or hypersensitivity

**2** = Normal

**NT** = Not testable

## When to Test Non-Key Muscles:

In a patient with an apparent AIS B classification, non-key muscle functions more than 3 levels below the motor level on each side should be tested to most accurately classify the injury (differentiate between AIS B and C).

| Movement | Root level |
|---|---|
| **Shoulder:** Flexion, extension, abduction, adduction, internal and external rotation<br>**Elbow:** Supination | C5 |
| **Elbow:** Pronation<br>**Wrist:** Flexion | C6 |
| **Finger:** Flexion at proximal joint, extension.<br>**Thumb:** Flexion, extension and abduction in plane of thumb | C7 |
| **Finger:** Flexion at MCP joint<br>**Thumb:** Opposition, adduction and abduction perpendicular to palm | C8 |
| **Finger:** Abduction of the index finger | T1 |
| **Hip:** Adduction | L2 |
| **Hip:** External rotation | L3 |
| **Hip:** Extension, abduction, internal rotation<br>**Knee:** Flexion<br>**Ankle:** Inversion and eversion<br>**Toe:** MP and IP extension | L4 |
| **Hallux and Toe:** DIP and PIP flexion and abduction | L5 |
| **Hallux:** Adduction | S1 |

## ASIA Impairment Scale (AIS)

**A = Complete.** No sensory or motor function is preserved in the sacral segments S4-5.

**B = Sensory Incomplete.** Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-5 (light touch or pin prick at S4-5 or deep anal pressure) AND no motor function is preserved more than three levels below the motor level on either side of the body.

**C = Motor Incomplete.** Motor function is preserved at the most caudal sacral segments for voluntary anal contraction (VAC) OR the patient meets the criteria for sensory incomplete status (sensory function preserved at the most caudal sacral segments (S4-S5) by LT, PP or DAP), and has some sparing of motor function more than three levels below the ipsilateral motor level on either side of the body.
(This includes key or non-key muscle functions to determine motor incomplete status.) For AIS C – less than half of key muscle functions below the single NLI have a muscle grade ≥ 3.

**D = Motor Incomplete.** Motor incomplete status as defined above, with at least half (half or more) of key muscle functions below the single NLI having a muscle grade ≥ 3.

**E = Normal.** If sensation and motor function as tested with the ISNCSCI are graded as normal in all segments, and the patient had prior deficits, then the AIS grade is E. Someone without an initial SCI does not receive an AIS grade.

**Using ND:** To document the sensory, motor and NLI levels, the ASIA Impairment Scale grade, and/or the zone of partial preservation (ZPP) when they are unable to be determined based on the examination results.

ASIA — AMERICAN SPINAL INJURY ASSOCIATION — INTERNATIONAL STANDARDS FOR NEUROLOGICAL CLASSIFICATION OF SPINAL CORD INJURY — ISCOS

## Steps in Classification

The following order is recommended for determining the classification of individuals with SCI.

**1. Determine sensory levels for right and left sides.**
*The sensory level is the most caudal, intact dermatome for both pin prick and light touch sensation.*

**2. Determine motor levels for right and left sides.**
*Defined by the lowest key muscle function that has a grade of at least 3 (on supine testing), providing the key muscle functions represented by segments above that level are judged to be intact (graded as a 5).*
*Note: in regions where there is no myotome to test, the motor level is presumed to be the same as the sensory level, if testable motor function above that level is also normal.*

**3. Determine the neurological level of injury (NLI)**
*This refers to the most caudal segment of the cord with intact sensation and antigravity (3 or more) muscle function strength, provided that there is normal (intact) sensory and motor function rostrally respectively.*
*The NLI is the most cephalad of the sensory and motor levels determined in steps 1 and 2.*

**4. Determine whether the injury is Complete or Incomplete.**
*(i.e. absence or presence of sacral sparing)*
*If voluntary anal contraction = **No** AND all S4-5 sensory scores = **0** AND deep anal pressure = **No**, then injury is **Complete**.*
*Otherwise, injury is **Incomplete**.*

**5. Determine ASIA Impairment Scale (AIS) Grade:**
Is injury Complete? If YES, AIS=A and can record ZPP (lowest dermatome or myotome on each side with some preservation)
NO ↓
Is injury Motor Complete? If YES, AIS=B
NO ↓ (No=voluntary anal contraction OR motor function more than three levels below the motor level on a given side, if the patient has sensory incomplete classification)

Are at least half (half or more) of the key muscles below the neurological level of injury graded 3 or better?
NO ↓ AIS=C    YES ↓ AIS=D

**If sensation and motor function is normal in all segments, AIS=E**
*Note: AIS E is used in follow-up testing when an individual with a documented SCI has recovered normal function. If at initial testing no deficits are found, the individual is neurologically intact; the ASIA Impairment Scale does not apply.*

**Fig. 27.3** (**a**, **b**) Spinal cord injury evaluation and scoring sheet from the American Spinal Injury Association (ASIA) (Reproduced with permission from American Spinal Injury Association: International Standards for Neurological Classification of Spinal Cord Injury, revised 2011; Atlanta, GA, Revised 2011, Updated 2015)

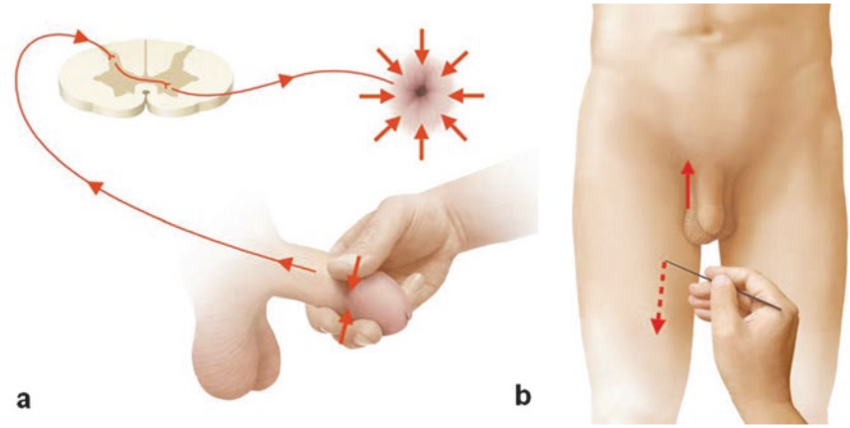



**Fig. 27.4** (**a**) Bulbocavernosus reflex is tested by pulling on the shaft of the penis (and/or the Foley catheter in a female) and observing for reflex contraction of the anal sphincter. (**b**) Cremasteric reflex tested by stimulation of the inner thigh, which should elicit retraction of the ipsilateral testicle (Reproduced from *Spinal Disorders*, Neurological assessment in spinal disorders, 2008, 291–318, Uta Kliesch, Armin Curt, with permission from Springer)

result in some degree of improved neurologic function. Think of the spine just like the brain after injury; avoid secondary injury due to either hypotension or hypoxia.

Spinal shock is the complete loss of reflexes below the level of injury, including the monosynaptic pathways. If spinal shock is present, this means that you don't yet know what the ultimate amount of recovery of function will be. You will have to wait until the spinal shock period is over. If spinal shock is not present, or it has resolved, then whatever neurologic deficits you have at that time are likely to be permanent. So for someone with paralysis, being in spinal shock is actually preferable since it leaves hope for some recovery of function. To diagnose spinal shock, check the bulbocavernosus and/or cremasteric reflexes (Fig. 27.4). If they are absent, then the patient is in spinal shock, and when they return the shock period has ended.

## Steroids

There is little role for steroids in a combat theater. The associated complications are significant, the neurological recovery is questionable, and all the literature that their use is based upon is in blunt trauma with no other associated injuries. Steroids should never be given in any penetrating SCI. The National Acute Spinal Cord Injury Study (NASCIS) trials showed that the use of steroids in any SCI patient is unequivocally associated with much higher rate of complications and very little evidence to suggest any clinically significant benefit. Nonetheless, the use of steroids is still employed at some regional trauma centers in the USA because of medical-legal concerns.

## Managing Closed Spine Trauma

The management of closed spine trauma is simply spine precautions (logrolling, cervical collar) and evacuation. Neurogenic shock should not be forgotten, but initial hypotension should be considered hemorrhage until proven otherwise. Neurogenic shock may manifest as hypotension which is poorly responsive to fluid resuscitation but responds immediately to pressor agents. Often in isolated neurogenic shock there is no associated tachycardia, the extremities may be warm and dry rather than cold and clammy, and typically the patient has a significant cervical spinal cord injury. After ensuring hypotension is not from hemorrhage, treatment involves limiting volume resuscitation and judicious use of pressors to support blood pressure. A pure vasoconstrictor such as neosynephrine is often utilized, but in the multi-trauma patient or the patient with associated bradycardia, a balanced pressor such as norepinephrine is a better choice.

Keep the patient in spinal immobilization, but this does not mean lying flat and motionless. You can sit these patients up to 30° as long as they are flat, and begin participatory pulmonary toilet if they are not intubated. Ensure adequate pain control to maximize tidal volumes. Have a low threshold for nasogastric decompression as gastric ileus often accompanies spinal cord injury with paraplegia or quadriplegia. Similarly, bladder dysfunction is common and a urinary catheter should be placed if not already present. Begin management of pressure points with padding and frequent patient repositioning immediately for paralyzed patients. Do not forget the psychological and emotional aspects of these injuries, particularly in young acutely injured soldiers. Have a mental health professional and/or chaplain available to begin helping them deal with the almost uniform depression and grieving over the loss of body function that accompanies these injuries.

## Managing Open Spine Trauma

The management options for open spine trauma are not much different than those for closed spine trauma, even in patients with open vertebral column fractures. The wound must be managed like any open wound. This means irrigation and debridement and early antibiotics. The choice of antibiotics is generally the same as for patients with open extremity fractures. Patients with associated intestinal injuries, particularly if those injuries communicate with the spinal column injury, may require broader coverage. The above scenario arises from a penetrating wound that goes through the spine into the abdomen or one that goes through the abdomen into the spine. Such an injury will obviously require multidisciplinary care (general surgeon plus neurosurgeon or spine surgeon).

The abdominal and the posterior wound will need to be addressed. It probably does not matter which one is done first, but you must irrigate both. The posterior wound can be addressed with the patient in prone or in a lateral position. There will be no practical management strategy for dural leaks. High volume of clear fluid saturating dressings may be the first clue, or actual visualization of leaking cerebrospinal fluid during operative debridement of the wound may be noted. For most patients, pack the wound, expect significant amounts of drainage, and change the dressings as needed. In patients with complete transection of the spinal cord, ligation of the thecal sac and spinal cord at the level of the injury has been used to control the leak and may be considered when there is no chance for neurologic function below the injury. More complex repairs will likely require neurosurgical or orthopedic spine expertise and may involve dural closure and perhaps diversion through drains at a higher echelon of care.

## A Is for Airway

Outside of the usual issues of airway management for trauma patients which have been discussed extensively elsewhere in this book, the need for appropriate airway management is of particular importance for patients with cervical spinal cord injuries. Most patients with high cervical spinal cord injuries will present with quadriplegia and respiratory distress or arrest and clearly require intubation. The difficult patient population is the lower cervical spine injury (C5–C7), who frequently present with no obvious respiratory distress due to the ability to continue shallow breathing. Be wary of these patients – civilian data has demonstrated that up to 50% will slowly decompensate and require a delayed emergent intervention. This can result in secondary spinal cord injury due to hypoxia and trauma from manipulation during emergent intubation attempts.

In the combat setting, you often do not have the luxury of close and prolonged observation of these patients, or you may be required to place the patient in the medical evacuation system shortly after arrival. Over a period of several hours to days, the shallow breathing will result in progressive atelectasis, pulmonary consolidation or pneumonia, and finally acute hypoxic decompensation. The insidious airway collapse in this setting can be severely harmful or even fatal and should be anticipated. Have a low threshold for intubating these patients semi-electively for the initial hospital period or prior to transfer into the medical evacuation system. Factors that should prompt you toward early intubation include higher level of injury (above C5), complete paralysis, the presence of associated injuries (particularly chest wall or intrathoracic), and low lung volumes on chest x-ray. If you have the capability to measure and follow vital capacity, then this may be a useful adjunct to identify the patient progressing to respiratory failure.

The final issue involving airway now that you have established the need for intubation is how to do it. Volumes have been written about the various methods for intubation in the patient with a cervical spine injury and how they impact spinal mobility. Again this comes back to the understanding that most of these injuries are already fully manifest and your method of intubation will have little to no impact. However, you should always follow good basic principles of minimizing excess spinal motion during intubation. If available, a fiber-optic intubation is safe and avoids significant spinal motion. If standard direct laryngoscopy is being performed, then have an assistant hold in-line stabilization (and cephalad traction) during the procedure. Finally, a surgical airway is always an option and may be required for patients who will require long-term mechanical ventilation and/or pulmonary toilet. But in the emergent setting, do not let a concern for cervical immobilization hinder your ability to quickly and safely intubate the patient.

## Spinal Immobilization and Spinal Stability

The bony spinal column is a very sturdy structure, and it takes significant disruption of multiple structures to result in spinal instability. Blunt spinal injury is more likely to disrupt multiple areas and result in spinal instability compared to penetrating mechanisms, so isolated projectile wounds to the spine are rarely unstable. The stability of the spine primarily depends upon the integrity of three areas or columns: anterior, middle, and posterior (Fig. 27.5). The anterior column includes most of the vertebral body and the anterior longitudinal ligament. The middle column is the posterior vertebral body and the posterior longitudinal ligament. The posterior column is the spinous process and the ligamentum flavum/interspinous ligaments. If two of these three ligamentous structures are disrupted, then the injury is likely to be unstable. Other injury patterns associated with instability are compression fractures with >50% loss of height of the vertebral body and type II or III odontoid fractures (Fig. 27.6).

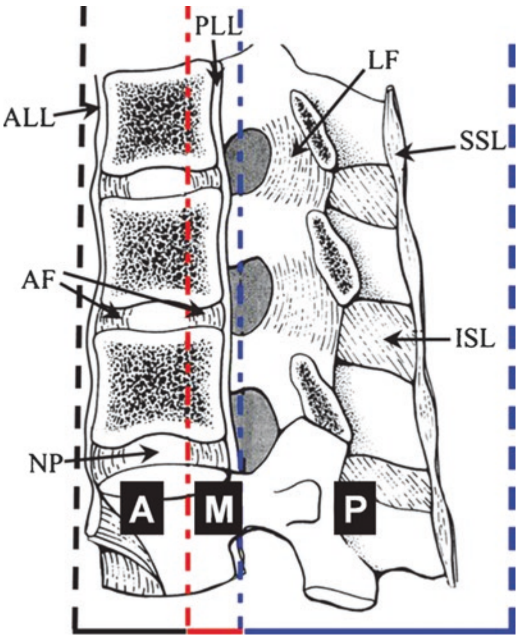



**Fig. 27.5** Three-column model of spinal body trauma. The primary ligament for each column is the anterior longitudinal ligament (*ALL*) for the anterior column, the posterior longitudinal ligament (*PLL*) for the middle column, and the ligamentum flavum/interspinous ligaments (*ISL*, *SSL*) for the posterior column (Image reprinted with permission from Medscape Drugs & Diseases (http://emedicine.medscape.com/), 2017, available at http://emedicine.medscape.com/article/398102-overview)

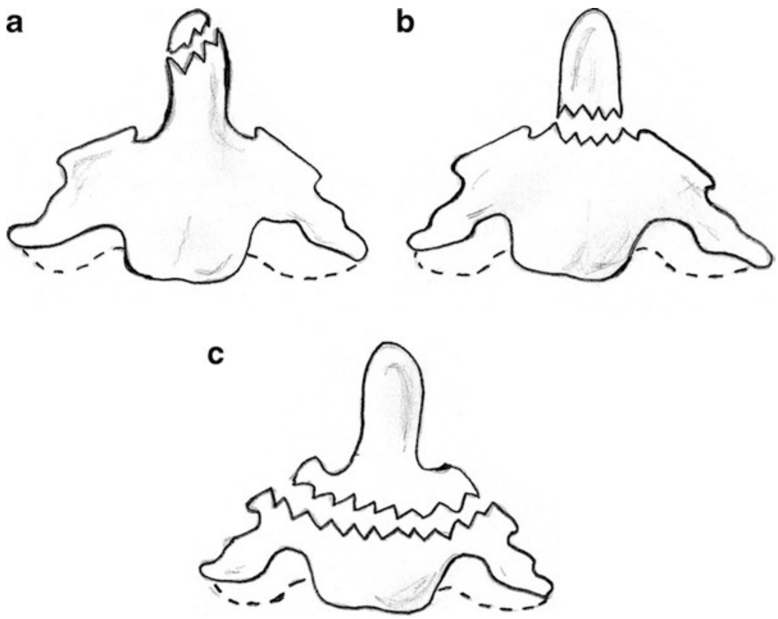



**Fig. 27.6** Odontoid fractures. (**a**) Type I involves the tip of the odontoid process only and is typically stable but may be associated with atlantoaxial dissociation, (**b**) type II involves the base of the odontoid process, and (**c**) type III involves the body of C2 (Image reprinted with permission from Medscape Drugs & Diseases (http://emedicine.medscape.com/), 2017, available at http://emedicine.medscape.com/article/824380-overview)

## Spinal Cord Syndromes

The presentation of a traumatic spinal cord injury is usually pretty straightforward, with a dense and complete neurologic deficit below the level of injury. However, there are several spinal cord syndromes involving injuries to an isolated segment that have a much more varied and subtle presentation. These can be easily missed or misdiagnosed if you do not do a thorough neurologic examination and consider them in your differential. Table 27.1 reviews the etiology, diagnosis, and management for the common spinal syndromes that you may encounter. For fixed and established defects, management is usually expectant and aimed at treating symptoms and pain. However, for any patient with a progressively worsening neurologic deficit, emergent consultation with a spine surgeon for possible decompression should be your first priority. Remember that the spine is just like the heart: time = neurons and they won't grow back.

**Table 27.1** Spinal cord syndromes

| Syndrome | Etiology | Exam findings | Management |
|---|---|---|---|
| Central cord | Hyperflexion or extension, usually elderly with existing spinal stenosis; most common syndrome | Motor weakness of arms > legs with sacral sensory sparing | No proven benefit of prolonged immobilization<br>Course of steroids may benefit<br>Physical therapy and rehab<br>Spinal decompression |
| Brown-Sequard (cord hemisection) | Spinal hemisection, often gunshot or knife wound | Ipsilateral loss of motor and proprioception; contralateral loss of pain and temperature sensation | Spinal stabilization if unstable<br>Course of steroids<br>Physical therapy |
| Anterior cord | Damage to anterior 2/3 of cord, usually direct injury or ischemia from anterior spinal artery injury | Loss of motor function and pain/temperature with preserved proprioception and light touch sensation | Worst prognosis with low chance of muscle recovery<br>Physical and occupational therapy |
| Conus medullaris | Injury to sacral cord and lumbar nerve roots, upper lumbar (L1) fractures, disc herniation, tumors | Bowel, bladder, and sexual dysfunction with areflexia, normal leg motor function, bulbocavernosus present with high lesion | Emergent surgical decompression<br>Course of steroids<br>GM1 ganglioside (100 mg) IV<br>Bowel/bladder training |
| Cauda equina | Injury to lumbar/sacral nerve roots, lumbar (L2 or lower) or sacral fractures, also pelvic fractures, herniated disc, tumors | Weakness or flaccid leg paralysis; high lesions spare bowel/bladder; bulbocavernosus absent | Emergent surgical decompression<br>Course of steroids<br>GM1 ganglioside (100 mg) IV<br>Bowel/bladder training |

## No Spine Consult or CT Scan Needed

You may be used to consulting a spine service for any and all injuries involving the vertebral column in civilian trauma. There are multiple types of bony injuries that do not require any intervention or further evaluation, other than pain control. These include single or multiple transverse process fractures, spinous process fractures, small wedge fractures (<25% loss of height), osteophyte fractures, or chip fractures. The most common ones you will encounter are spinous process and transverse process fractures. If the neurologic exam is normal, then these should all be treated with appropriate pain control, physical therapy, and a soft collar (cervical) or support belt (thoracolumbar) for comfort. You can (and should) begin immediate ambulation as tolerated based on their other injuries. The other issue that you will commonly encounter, particularly at the Role 2 setting, is not having access to a CT scanner. Physical examination and plain x-rays, while not 100% sensitive for identifying all spine fractures, should be adequate to diagnose the majority of clinically significant or unstable fractures. Evacuation to a Role 3 facility with a CT scanner is often requested simply to "rule out" a spine injury. This decision should carefully consider the risks of transport and the resource utilization versus the index of suspicion or likelihood of an actual injury. Observation or management with a cervical collar and then reexamination in 12–24 h might be preferable in many scenarios versus evacuation to a higher level of care.

## Final Comments

The impact of a spinal column or spinal cord injury in any trauma patient can range from a minor nuisance to devastating paralysis, and unfortunately these are frequently seen in combat trauma. Although, as we have stated, much of the injury is done and irreversible immediately, adherence to good basic care aimed at treating the injury and preventing secondary injury may make a significant difference for the patient's ultimate functional outcome. Every deployed physician should be able to perform a quick but thorough neurologic exam and understand the implications of significant exam findings like spinal shock. You don't have to be a fellowship trained spine surgeon to deliver high-quality and effective care of combat spine injuries. Even if you can't cure them, you may mean the difference between a life of total dependence or being able to function independently. Last, it should be remembered that surgical intervention is rarely indicated in the combat setting down range. Only when appropriate resources are available (such as a Role 3 hospital) and there is well-documented evidence of progression of neurologic injury should surgical stabilization and/or decompression be attempted.

## Civilian Translation of the Military Experience and Lessons Learned

John G. DeVine

### Evolution

Modern trauma care has evolved over the last century utilizing many of the lessons learned after each major conflict in which wartime casualties are treated. Interestingly, the types of injuries have changed as the weapons of combat and the combatant's armor have evolved. The most recent conflict is no exception. It is difficult to determine if the incidence of spinal column injuries has changed over the last hundred years because many patients sustaining thoracic or abdominal trauma in previous conflicts did not survive. Body armor has significantly changed the landscape of combatant's injuries, and extremity injuries have become more prevalent. In addition, the use of improvised explosive devices (IEDs) utilized as "roadside bombs" has increased the incidence of blunt trauma. With this in mind, the combatant surviving the initial injury and cared for in the combat setting can be viewed as a "multi-trauma" patient, including potential spinal column and spinal cord injuries.

## ATLS

As pointed out in the preceding chapter, the primary assessment never changes: airway, breathing, and circulation. Resuscitation guidelines as recommended by the American College of Surgeons and ATLS are well described. The potential spine injury is of little significance if the primary assessment and the actions taken while addressing these are not successful. However, the importance of spinal immobilization during the resuscitation cannot be overstated. Historically, spine immobilization was one of the most frequent prehospital procedures in the USA. However, recent literature has questioned the efficacy and safety of spinal immobilization in all trauma patients. Historically, spinal immobilization was implemented based on mechanism of injury. However, current practice is to use clinical findings to determine whether continued immobilization is required. This is critical because prolonged use of c-collars and/or spine boards is associated with complications such as skin necrosis and compartment syndromes. In an environment in which a patient may be in transport for a prolonged period, such as evacuation from combat hospital, this must be taken into account.

## Clear the Spine

The decision can be made in theater on "clearing" a spine and removing spinal precautions provided the patient has no evidence of the following: altered level of consciousness or mental status, intoxication, neurologic symptoms or signs of a distracting injury, and midline spinal pain or tenderness. If the patient has any of the above, then precautions must be used. C-collars used in transport can be removed while the head is held in-line with mild traction for examination, for intubation, or to obtain a surgical airway. Patients should be removed from the backboard as soon as feasible and logrolling implemented as the primary form of thoracolumbar spine precautions. The backboard should be utilized only for transport from one bed to another.

## Spine Surgery Emergencies: The Rural Hospital and the Combat Hospital

There are very few spine surgery emergencies in the civilian trauma center. The most serious is the progressive neurologic deficit – either a cauda equina syndrome or progressive spinal cord injury (incomplete). The progressive neurologic deficit requires emergent management in the civilian setting. However, emergent management is not feasible in many rural settings in the USA. This is not unlike the combat hospital environment. With limited spine surgery resources and imaging modalities, these scenarios are unfortunate – and definitive care must await resuscitation efforts and eventual transport to a higher and appropriate level of care. Being able to recognize the neurologic deficit becomes the most important variable in this setting – because it sets in motion the planned eventual evacuation plan. Documenting a thorough neurologic examination will localize the injury. Maintaining appropriate spinal precautions will avoid continued neural trauma. Avoiding hypotension and hypoxia during the resuscitation and transport will limit secondary injury to the neural elements.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Cervical and thoracolumbar spinal injury evaluation, transport, and surgery in deployed setting

# Face and Head (Non-ocular) Injury

# 28

Nici Eddy Bothwell

**Deployment Experience**

Otolaryngology – Head and Neck Surgery

Theater Consultant for Otolaryngology – Head and Neck Surgery

115th Combat Support Hospital

Camp Dwyer, Afghanistan

2011

*"The human body is a work of art and artistry is needed in dealing with its delicate tissues."*

Berkeley Moynihan, 1865–1936

**BLUF Box (Bottom Line Up Front)**

1. Obtain a definitive airway by *any* means necessary. Once the airway is obtained, *secure* it!
2. If you are even thinking about a surgical airway, just do it and don't hesitate.
3. It is hard to improve a patent airway in a spontaneously breathing patient – don't poke the skunk unless you have to.
4. Combat wounds to the neck can be life threatening and usually require neck exploration.
5. Examine *every* ear including the tympanic membrane. The most common blast injury is a ruptured eardrum.

(continued)

N.E. Bothwell (✉)
Ear, Nose, Throat and Allergy Associates, a Division of Proliance, Puyallup, WA, USA
e-mail: nicieddy@yahoo.com



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(continued)

6. Dedicated maxillofacial CT scans can wait until the patient has been stabilized.
7. Explore, clean, and debride *every* wound, and do so in the OR. Close clean wounds (rare), and pack contaminated wounds (common).
8. Adapt, improvise, and overcome.
9. Seek out help and advice from your teammates across specialties for all challenging cases.

## Getting Started

Combat injuries to the head and neck region are very common, representing about 30% of all wounds seen in Iraq and Afghanistan. You will see a lot of it, so be ready. The two busiest surgeons in our Combat Support Hospital were the otolaryngologist and the orthopedic surgeons because most of the survivable trauma is inflicted to the areas of the body that are exposed: face, neck, and extremities. As opposed to civilian trauma which consists mostly of blunt trauma from motor vehicle accidents or low-velocity penetrating trauma, combat trauma is defined by high-velocity penetrating injuries and by blast injuries which combine penetrating, blunt, burn, and concussive trauma into one (Fig. 28.1). Whatever the mechanism, and no matter how devastating the injury appears, the same dogmatic principles of trauma and wound management still apply.

## The Basics: Airway

If the airway is compromised, nothing else matters until a definitive airway is obtained and secured. Many patients arrive already intubated in the field, but you may encounter your patient in the trauma bay without a definitive airway. Maxillofacial trauma, as seen in combat, can cause markedly distorted anatomy and make

**Fig. 28.1** (**a**, **b**) Typical combat trauma facial injuries with massive contusions, lacerations, avulsed fragments, and burn components

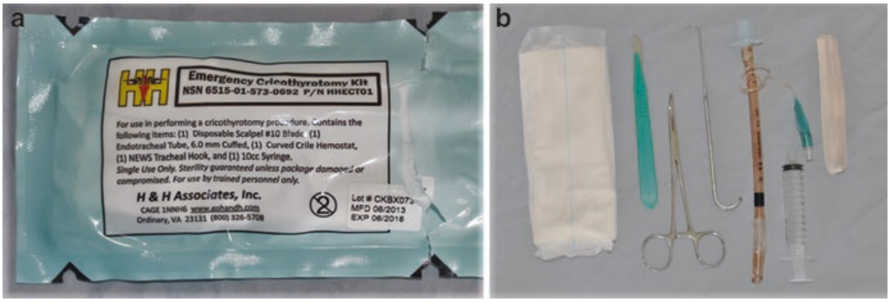


**Fig. 28.2** (**a**, **b**) You'll find the bare essentials and no superfluous instruments in this compact and field-ready tracheostomy kit that fits nicely in your uniform pocket

endotracheal intubation challenging or impossible. One of the biggest amateur mistakes is to jump to immediate intubation based on the appearance of the wound (peek and shriek) rather than an assessment of the airway. A patient that is moving air without distress and maintaining oxygenation is stable from an airway standpoint. If the airway is compromised in any way, the decision between endotracheal intubation versus a surgical airway must be quick and definitive. Anticipate a difficult intubation and the potential for airway obstruction with chemical paralysis, and have adjuncts available such as suction, a nasal trumpet, an oral airway, and a tracheostomy set ready for a surgical airway (Fig. 28.2). It is entirely appropriate to prep the neck during endotracheal intubation in anticipation of a potential failed airway. If your assessment (and your gut) tells you this patient needs a surgical airway, then make your decision and move forward with confidence and without delay.

Whether the patient was intubated in the field or in the trauma bay, it is paramount to confirm and secure the airway. Any patient that is intubated, either nasally or orally, is at risk for tube displacement during transfers and transport. Commercial tube-securing devices are generally adequate, but the movement of patients in theater is often less smooth than in CONUS environments and requires a more effective means of securing the tube. In the case of a nasal intubation, you can secure the endotracheal tube to the nasal septum in a pattern similar to securing a JP drain to the skin: take a 2-0 nylon suture and wrap it around the tube several times, and then pass the suture needle through the nasal septum and tie. If the patient has been orally intubated, the tube can be secured by wrapping a 24-gauge wire (or 2-0 nylon) around the adjacent teeth (circumdental), tightened by twisting, and then wrapping the wire around the endotracheal tube. These suturing and wiring techniques eliminate the need for circumferential tube taping and devices that may be detrimental to the skin and soft tissues of burn patients and can inadvertently hide facial injuries (Fig. 28.3). Keep in mind that these suturing and wiring are not intended to be used long term, due to secondary movement of the wired teeth and pressure necrosis of the nasal septal cartilage. Therefore, if the patient is expected to be intubated for several days, is repeatedly transferred during medevac or airevac, is taken to the operating room for multiple surgeries, or has facial polytrauma, then an elective tracheostomy should be considered. If a cricothyroidotomy was performed, it should be converted to a formal tracheostomy as soon as possible to avoid development of subglottic stenosis.

**Fig. 28.3** Intubated patient with taping and devices obscuring other facial injuries and at risk for becoming displaced during transfer

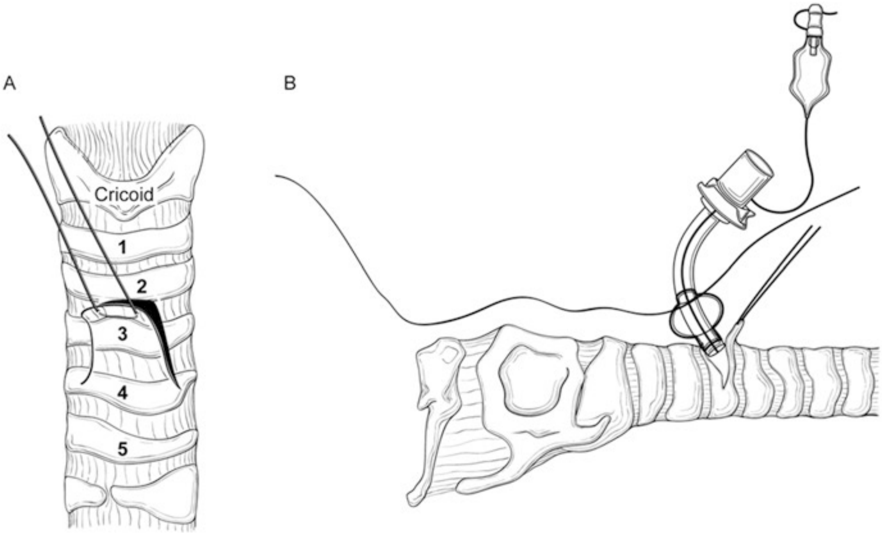


**Fig. 28.4** Technique for modified Bjork flap tracheostomy

There are numerous techniques for entering the trachea: vertical incision (best for pediatrics), square resection of 1–2 tracheal rings, horizontal incision, or a Bjork flap. Regardless of the technique, it is helpful to place stay sutures with a 2-0 or 3-0 nylon through the tracheal cartilage and then secure the sutures to the skin with Mastisol or Steri-Strips. If the tracheostomy tube becomes dislodged or extrudes, the stay sutures are gently retracted upward and outward to keep the stoma patent and elevated for easy reinsertion of the tube. A tried and true tracheostomy technique is the Bjork flap creating an inverted "U" incision to facilitate entry into the trachea (Fig. 28.4). A horizontal incision is made between the 2nd and 3rd tracheal rings, and two lateral incisions are extended inferiorly through the 3rd tracheal ring creating an inferiorly based flap. Prior to making the inverted "U" incision, capture the tracheal flap with a 3-0 nylon suture, taking care to avoid perforating the cuff of the endotracheal tube. After removing the suture needle, the nylon suture can hold anterior traction on the wall of the trachea while the vertical incisions through the tracheal rings are made. Then, insert the tracheostomy tube over the flap, into the airway, and verify placement with end-tidal CO2 and chest rise. The nylon suture is then secured to the skin below the tracheostomy with Mastisol skin adhesive or Steri-Strips. The placement of this suture into the tracheal flap allows for control of the trachea in the event that the tube becomes displaced; it also prevents intubation of the pre-tracheal space in the face of edema or hemorrhage. Alternately, the free end of the Bjork flap can be directly sutured to the dermis of the inferior skin flap with 3-0 Vicryl. In the event of displacement of the tracheostomy tube, the tracheal cartilage has already been sutured open to the skin and retracted anteriorly, so replacement of the tracheostomy tube is relatively unencumbered. Be sure to suture the edges of the tracheostomy tube collar to the skin with 2-0 silk, and place a length of umbilical tape through the tracheostomy tube collar and around the neck for further protection against displacement. After a week the stoma is generally "matured" and the stay sutures can be removed, and the umbilical tape can be replaced with foam Velcro tracheostomy ties.

In the civilian setting, it is not instinctive to intubate or trach a patient with a stable airway because you have the luxury of admitting the patient to the hospital and closely monitoring their airway. However, in the combat setting, the circumstances are markedly different. These combat trauma patients may be stabilized and medevac'd to stateside within a few hours. Their airway may be fine at this moment, but you must anticipate whether the patient's airway status has the potential to change. If so, better to obtain and secure the airway now rather than losing an airway en route. Besides the obvious head and neck trauma requiring airway interventions, here are a few injuries that should get a definitive airway prior to transport: penetrating injuries to the tongue, pharynx, or midface with the potential for significant swelling, burn injuries to the face and neck, inhalational injuries, and comminuted mandible fractures.

## The Basics: Hemostasis

Following the initial evaluation of the airway, a comprehensive inspection of the head and neck is necessary while simultaneously addressing the areas of active hemorrhage. Most of the injuries to the face are not immediately life threatening, and treatment can be delayed until the patient is stable from an airway and hemodynamic standpoint. Facial bleeding can be controlled with pressure, packing, and then surgery when it is optimal. For more robust, superficial bleeding, a 2-0 or 3-0 silk suture on a straight Keith needle is invaluable in temporarily controlling actively hemorrhaging wounds. Secure the bleeding tissue by pinching it between the index finger and thumb of the non-dominant hand, then hold the straight Keith needle in the dominant hand (with or without a needle driver), and place a figure-of-eight or horizontal mattress suture through the tissue and tie. Once the bleeding is controlled, you can move on to the next part of your exam. If the bleeding can't be controlled with these maneuvers, you need to transfer the patient to the OR and prepare for proximal and distal control.

Aside from the obvious airway concerns, injuries to the neck are serious. Vascular injuries can lead to immediate exsanguination and rapid hemodynamic compromise, while injuries to the aerodigestive tract can lead to delayed morbidity and mortality due to deep space neck infection and fistula formation. Unilateral or bilateral neck explorations are indicated in most patients with penetrating neck trauma and some with blunt neck trauma in theater. The head and neck trauma patients that do not require mandatory neck exploration must meet all of these criteria: (1) minimal or superficial injuries, (2) totally stable, and (3) normal CT of the head and neck.

Approach the neck exploration using the standard vertical neck incision over the anterior border of the sternocleidomastoid muscle. This approach provides excellent access to the carotid sheath and aerodigestive tract. The neck exploration includes opening the carotid sheath, obtaining proximal and distal vascular control, and identifying and then repairing injuries to the great vessels where indicated (Fig. 28.5). Once hemorrhage control has been established, take a deep breath and move on to a systematic examination of the vital neck structures. Start at the skull base and work inferiorly, including a visual and manual inspection of the entire head and neck region. Injuries to the aerodigestive tract including the pharynx, larynx, trachea, and cervical esophagus are identified and repaired as indicated. Small perforating injuries to the trachea can heal spontaneously and do not necessarily require an elective tracheostomy or primary repair. However, larger tracheal defects should be repaired using a 3-0 Vicryl through the cartilage, avoiding sutures through the mucosa as this may induce tracheal scarring and stenosis. Laryngeal and tracheal fractures need to be repaired, but the repair can be delayed for 2–3 days as long as the patient has a tracheostomy. Laryngeal fractures are reduced and stabilized with 26-gauge

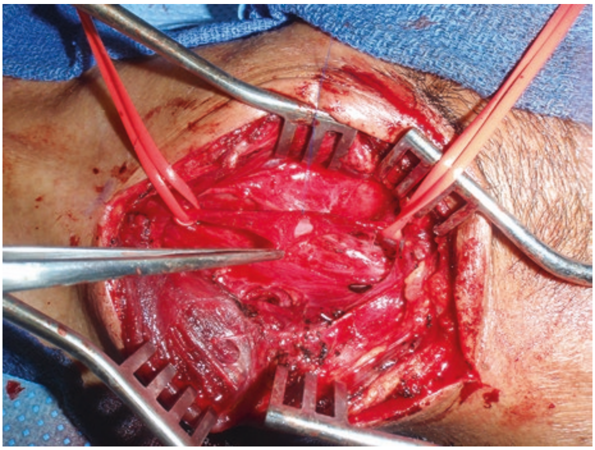

**Fig. 28.5** A hemodynamically stable patient with penetrating neck trauma, but the CT was suspicious for a vascular injury. The neck exploration confirmed a laceration through the internal jugular vein

wire or microplates with 4 mm screws. Most massive laryngeal fractures require a laryngofissure to access the lumen. To prevent laryngeal stenosis, major laryngeal injuries with damage to the mucosa should get a soft stent. Prior to repair and closure of the laryngeal cartilage, make a soft stent by cutting the finger off of a sterile glove, loosely pack a sponge into the finger of the glove, and then close the opening with a 3-0 silk suture. This soft stent is then placed in the lumen of the larynx with the superior aspect above the level of the vocal cords. The stent is secured with 2-0 nylon brought through the tracheal cartilage inferiorly and then through the skin and secured externally. This stent can be removed in 2–3 weeks under direct visualization.

Next, inspect and address the pharyngeal and esophageal injuries. These should be repaired primarily with a zero-tension Connell stitch using 3-0 Vicryl suture. Be generous with your repair because there is usually more tissue damage than is grossly apparent, and these structures are at risk for delayed dehiscence. Finally, copiously irrigate and place drains if aerodigestive tract injuries are indeed found, and monitor them closely for the aforementioned complications. At this point, you are still in the operating room and you have assessed and repaired the life-threatening injuries to the neck. The patient is hopefully stable. Now, it's time to assess the other injuries that were temporized with dressings, packing, and quick sutures in the trauma bay. Remove all tape, dressings, and packing one by one. Make sure you remove tape that was placed around the endotracheal tube. There are usually a lot of facial and lip lacerations hiding there. Irrigate and gently explore the wounds. Cauterize or suture small bleeding vessels. The face and neck have an excellent blood supply, and most wounds, even contaminated wounds, will heal well after copious irrigation and primary closure. For deeper wounds, especially in the neck, place a drain. If there is massive tissue loss, close the visceral and muscular layers, and either pack the wound or consider a wound V.A.C. ® These massive injuries can be repaired secondarily by a head and neck surgeon using free tissue transfer or regional myocutaneous flaps.

## Diagnostic Workup

Imaging, such as a CT scan, should never be obtained at the risk of placing the patient in a vulnerable position with regard to their airway or hemodynamic stability. There are generally two situations dictating when head and neck imaging is obtained (Fig. 28.6): Either the patient is stable enough to go through the scanner after their primary and secondary trauma surveys or the patient arrives to the trauma bay unstable and is immediately taken to the OR for a neck exploration. In the latter scenario, after stabilization in the OR, the patient should get a dedicated CT scan of the head, face, and neck with fine cuts through the maxillofacial region. The primary role of the CT scan in the post-neck exploration patient is to look for skeletal maxillofacial injuries that need to be reduced and stabilized. The role of the CT scan in a patient that has not had a neck exploration is twofold: (1) look for signs of occult vascular and aerodigestive tract injuries and (2) examine for skeletal maxillofacial injuries. Once you have a stable patient and a CT scan, it's time to assess their radiographic findings and make a plan to manage their injuries.

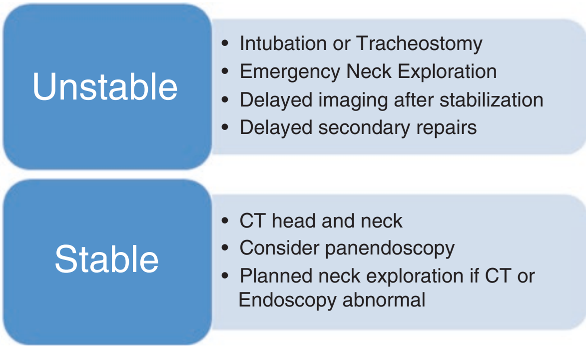


**Fig. 28.6** Simplify your algorithm for the head and neck trauma patient

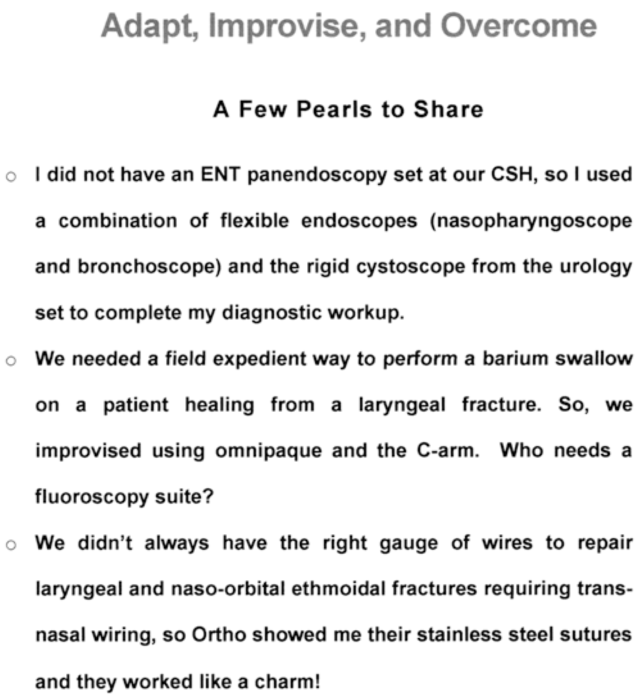


**Fig. 28.7** Adapt, improvise, and overcome

Not all neck trauma requires a neck exploration. Assuming there are no signs of vascular injury and the patient is stable, but there remains suspicion for aerodigestive tract injuries, you may perform a pan-endoscopy, which includes a direct laryngoscopy, bronchoscopy, and esophagoscopy (Fig. 28.7). This diagnostic exam is performed under general anesthesia and can be performed with flexible and/or rigid endoscopic instruments. The purpose of the pan-endoscopy is to look for mucosal disruption; bruising of the pharynx, trachea, or esophagus; or displacement of laryngeal structures. If the pan-endoscopy is positive, then definitive management will likely require open exploration and repair of the injuries. If the pan-endoscopy is negative, the patient does not require further diagnostic testing, but should be monitored for a few days before discharge.

## The Soft Tissue

As a surgeon, you may be looking at blast victim's face with hardly any identifiable features and asking yourself, "Where do I even begin?" Start with cleaning, irrigating, and debriding the wounds. As a general rule, combat wounds are contaminated wounds. Biologic shrapnel, dirt, glass, metal, rocks, and any other form of debris imaginable are found in these wounds. With tissue impregnated with macro- and micro-contamination, aggressive debridement and irrigation is essential. In addition to contamination, macerated and devitalized tissue is common due to the concussive effects of blast injuries, and this soon-to-be necrotic tissue will quickly become infected tissue. It should be carefully and conservatively debrided using sharp scissors rather than electrocautery. My instruments of choice for the initial inspection and debridement of these types of wounds are a fine tonsillar hemostat and fine DeBakey forceps. By "picking" and "spreading," wounds can be efficiently explored and debrided. The delicate nature of these two instruments enhances the tactile sensation as you encounter foreign bodies that are otherwise hidden in macerated, bloody tissue or trapped at the base of a penetrating injury. After you have cleaned and explored the wounds, take a few moments to revise the skin edges using delicate tissue scissors like a Joseph or Tenotomy and a 15 blade scalpel. Revision of skin margins, including excision of charred or grossly contaminated tissue and excision of beveled skin lacerations, will result in clean, vascularized, and healthy tissue that is amenable to a cosmetic closure and functional reconstruction (Fig. 28.8). Table 28.1 outlines the approach and closure for the various facial lacerations that you may encounter.

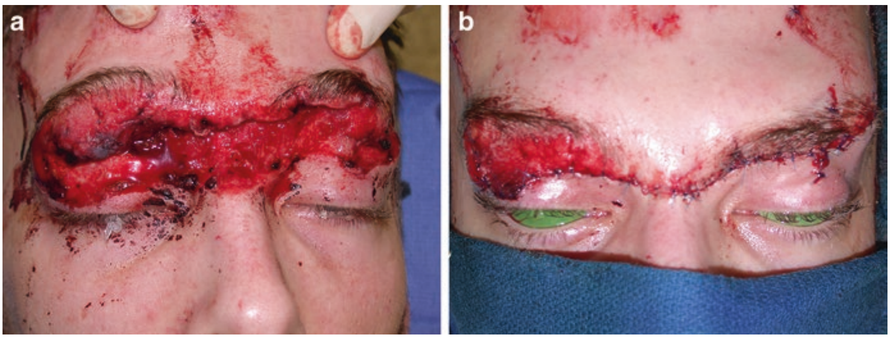


**Fig. 28.8** (**a**, **b**) Complex forehead laceration involving bilateral eyebrows and after two-layer repair with realignment of brow line

**Table 28.1** Technical highlights and suture selection for reconstruction

| Location | Technical points | Suture material |
|---|---|---|
| Scalp | • Re-approximate galea, muscular aponeurosis, subcutaneous tissue, skin (generally 3–4 layers)<br>• Subgaleal drain (Jackson-Pratt or Blake) recommended for larger lacerations | • 2-0 or 3-0 Vicryl for galea<br>• 3-0 Vicryl for aponeurosis and subcutaneous<br>• 3-0 Prolene or staples for skin |
| Forehead | • Re-approximate galea, frontalis muscle, skin (3 layers of closure) | • 3-0 or 4-0 Vicryl deep<br>• 4-0 Monocryl subcuticular<br>• 5-0 or 6-0 Prolene skin |
| Eyebrow | • Re-approximate inferior extension of galea, orbicularis oculi muscle, skin (3 layers) | • 5-0 Vicryl deep<br>• 5-0 Monocryl<br>• 5-0 or 6-0 Prolene skin |
| Nose | • Re-approximate cartilage if torn/lacerated<br>• Subcutaneous closure is challenging on or in the nose<br>• Sebaceous skin of the nose tears easily with cutting needles | • 5-0 clear nylon for cartilage suture<br>• 5-0 Monocryl deep<br>• 5-0 Prolene for thick skin, 6-0 Prolene for thin skin |
| Ear | • Re-approximate cartilage with clear suture<br>• Ensure complete coverage of cartilage with skin<br>• Apply bolster dressings as necessary | • 5-0 clear nylon for cartilage<br>• 6-0 Prolene for skin |
| Lip | • Re-approximate orbicularis oris muscle first<br>• followed by mucosal re-approximation and then subcutaneous and skin (3 or 4 layers as indicated by injury)<br>• Place first skin suture at opposing vermillion borders | • 3-0 or 4-0 chromic gut or Vicryl for mucosa<br>• 4-0 Vicryl for muscle<br>• 5-0 Monocryl for subcutaneous<br>• 6-0 Prolene for skin |
| Cheek | • Inspect Stenson's (parotid) duct for damage using lacrimal probes or angiocatheter<br>• Beware of facial nerve branches<br>• Re-approximate mucosa, muscular (buccinator) layer, subcutaneous layer, skin | • 7-0 or 8-0 nylon over Silastic tubing to repair Stenson's duct, or widely marsupialize into oral cavity<br>• 3-0 or 4-0 chromic gut or Vicryl for mucosa<br>• 4-0 Vicryl for muscle<br>• 5-0 Monocryl for subcutaneous<br>• 6-0 Prolene for skin |

*Never* use chromic gut or silk on the skin of the face! It causes significant inflammatory reaction leaving permanent marks and poor cosmesis

Now that you have a clean wound, it is time for reconstruction and closure. Identify anatomic structures and reconstruct from deep to superficial starting with the mucosa of the oral cavity or pharynx and then the muscles of facial expression including platysma, followed by the subcuticular and skin closure. This layered closure will close dead space, reduce the risk of a pharyngo-cutaneous or trachea-cutaneous fistula, and reestablish function and cosmesis. The subcuticular repair is perhaps the most important suture as it uses the strength of the dermis to keep the skin edges approximated, establishes the proper skin levels of opposing edges, and sets up the skin edge closure for proper eversion. Otherwise, if the subcuticular suture is loosely or poorly placed, the skin edges will not meet at the proper height, dehisce, or invert leaving a cosmetically unacceptable scar. Unless you are forced to close the skin rapidly for hemostasis, avoid overtightening the skin sutures as this will cause permanent “rail road” marks from pressure necrosis. Do not put staples in the face, but staples in the neck and scalp are acceptable. Permanent skin sutures and staples can be removed from the face and neck in 5–7 days. In general, most head and face wounds can be closed primarily after a thorough washout and debridement. However, if you are looking at a severely contaminated wound, then pack the wound and proceed with serial washouts and delayed closure. Similarly, if there is too much tissue loss to close the skin, then you should pack the wound, apply dressings, or consider a wound V.A.C.®. This type of wound may require regional tissue flaps or free tissue transfer for closure.

Now let’s talk about closure of a few specific anatomic regions. The lips are surrounded by the orbicularis oris muscle that acts like a sphincter and allows people to pucker and suck from a straw or spoon. If a laceration extends through this muscle, it needs to be re-approximated (Fig. 28.9). Then, the anatomic landmarks of the lip (white roll and vermillion) should be precisely aligned.

An avulsed ear may be surgically challenging as the distal portions are easily devascularized and prone to necrosis. Your options for traumatic amputations of the ear are to dispose of the amputated portion, or you can reimplant the cartilage for delayed repair. Before reimplantation, remove the skin from the amputated cartilage. Make a post auricular incision, bluntly dissect a subcutaneous pocket, place the amputated cartilage in the pocket, and sew it closed. This will preserve the cartilage until reconstruction is appropriate. If the auricular cartilage is fractured, it should be approximated with a 5-0 PDS before closing the skin. Don’t fret if there is missing cartilage or if you have to excise cartilage to obtain healthy tissue. Wedge excision of devitalized or macerated portions of the helix or antihelix may be required (Fig. 28.10) and will ultimately result in a better outcome rather than trying to preserve dead or deformed tissue. The auricular skin is tightly adhered to the cartilage and does not mobilize without wide undermining. Use a pair of Tenotomy or Iris scissors to undermine the skin, and then advance for tensionless closure. After a procedure like this,

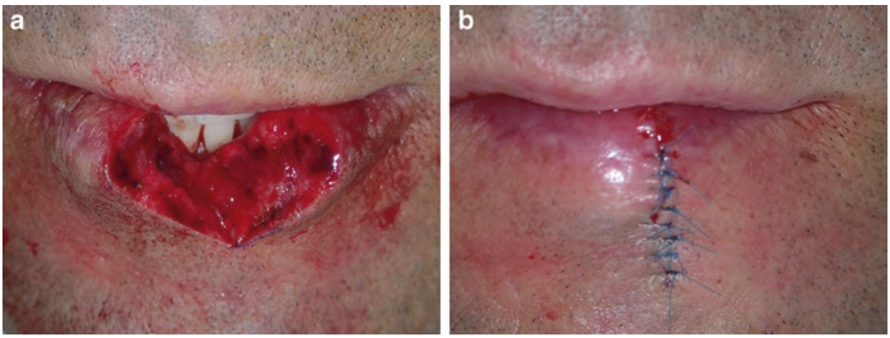


**Fig. 28.9** (**a**, **b**) Full-thickness laceration of lower lip requires re-approximation of orbicularis oris, alignment of vermillion border, and superficial skin closure

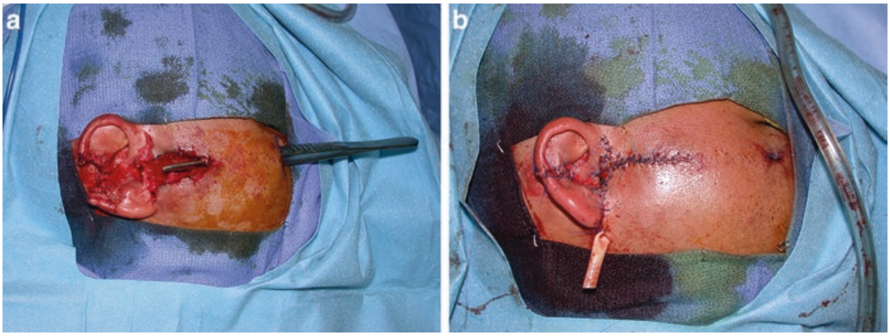


**Fig. 28.10** (**a**, **b**) Complex face and ear laceration with loss of helical cartilage repaired after wedge excision of devitalized cartilage and re-approximation over Penrose drain

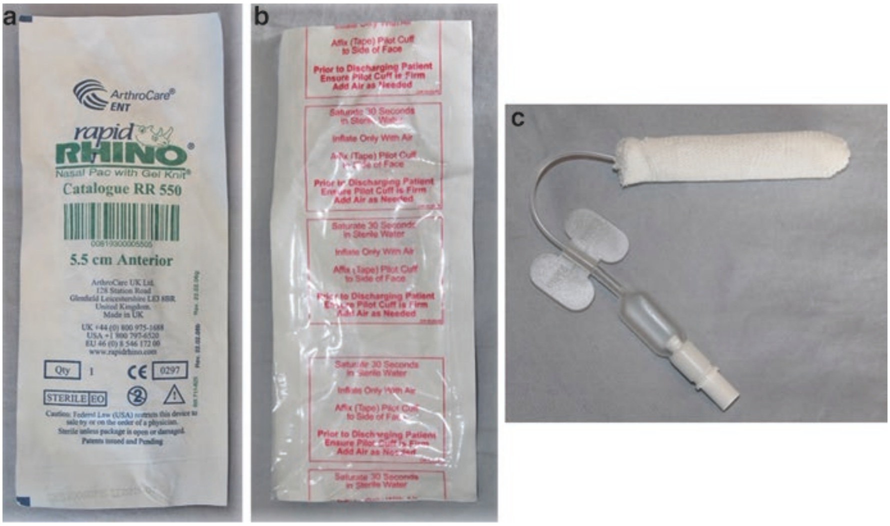


**Fig. 28.11** (**a**–**c**) Rapid Rhino® device for controlling epistaxis comes in different lengths and the option for anterior and posterior balloons. Simply soak in water for 30 s, insert into the nasal cavity, and inflate the balloon

the skin of the ear will be bruised and almost appear necrotic. Don't worry, this can be normal. Be patient and let the wound declare itself.

Penetrating injuries to the nose should be cleaned and the skin closed. Don't worry about layered closure of the nose. The intranasal mucosa can be left open to heal by secondary intention, and unless you are comfortable with rhinoplasties, leave the cartilage and septum alone. If there is epistaxis, control bleeding with topical TXA or oxymetazoline spray, pack with gauze strips or cottonoid patties, or most preferably insert a commercial epistaxis control device like the Rapid Rhino® (Fig. 28.11). If the nose is packed, the patient should be placed on antibiotics to avoid toxic shock, and nasal packing should be removed in 2–3 days.

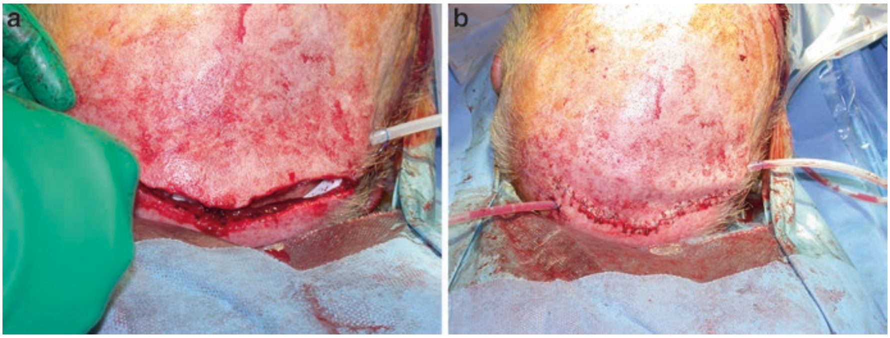

**Fig. 28.12** (**a**) Scalp laceration with significant tissue loss was able to be re-approximated after wide tissue undermining and interrupted closure of galea. (**b**) Final closure with staples and a closed suction drain left in the subgaleal dead space

Scalp lacerations bleed a lot. Because there is a thick and dense layer of connective tissue in the scalp, the vessels are literally restricted from vasospasm and collapse. Electrocautery doesn't stop the bleeding and this is why scalp clips were invented. If you don't have scalp clips, you can use Babcocks or just work quickly with a scrub tech applying pressure and using suction. The dense connective tissue also restricts advancement of the scalp for tensionless closure, so widely undermine the galea from the forehead to the occiput before closure (Fig. 28.12). For scalp closure, take a 2-0 Vicryl with a large needle and make a generous buried throw to capture the bleeding vessels in your stitch. Once you tighten the stitch, the bleeding will stop. After the deep stitches in the scalp are placed, close the scalp with staples or 2-0 nylon. If there is a large scalp defect, you can pack and do daily dressing changes, or try a wound V.A.C.® until reconstruction with a regional flap or skin graft can be arranged.

## The Bones

Some mandibular fractures, such as a flail segment, or a "bucket-handle" fracture, can lead to airway obstruction. This is because the anterior tongue attaches to the inside rim of the mandible, and if this segment of the mandible is fractured on both sides or is displaced posteriorly, the tongue loses its anterior traction and will fall back and obstruct the airway. In this situation, the airway should be secured first and then the fractured segment reduced and stabilized with rigid fixation. Midface (Le Fort) or posteriorly displaced condyle fractures can be associated with skull base fractures, and therefore passing gastric or other tubes or lines through the nasal passages puts the patient at risk for penetration of the skull base. Either avoid the nasal passage all together or use extreme caution, and be sure to get post procedure imaging to confirm correct placement.

During the exploration and cleanup, be a hoarder and save large fragments of bone or cartilage in saline (Fig. 28.13). If there are large segments of missing bone

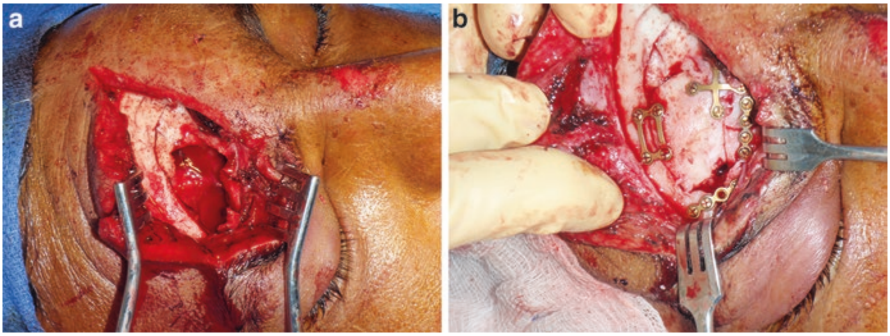


**Fig. 28.13** (**a**, **b**) Complex facial trauma with forehead laceration, frontal sinus fracture, and superior orbital rim fracture. Each fragment of bone should be preserved and used for reconstruction

**Fig. 28.14** Monophasic external fixation for comminuted fracture of the right mandible

due to comminuted fractures or devitalized tissue, then you should consider grafts such as the iliac crest, split calvarial bone, or conchal cartilage, depending on the type and location of the defect. Of course, regional and microvascular free flaps have been used in theater, but should be reserved to those with the time and expertise.

When prepping the bone for rigid fixation, avoid extensive or aggressive stripping of the periosteum or soft tissue pedicles as this can potentially devitalize otherwise viable bone. Internal fixation is contraindicated when the wound is highly contaminated or when the bones are markedly comminuted. External fixation, however, has proven to be an effective treatment option for severely comminuted and contaminated mandible and midface fractures (Fig. 28.14). While there are external fixation sets specifically for the mandible, don't be surprised if you can't find one in your theater OR. This is the perfect opportunity to talk to your orthopedic teammates about an upper extremity or wrist external fixation set (Fig. 28.15). Either one will suffice. Ask the orthopedic surgeon to assist you on the case if you are unfamiliar with the system. In fact, let them assist in all of your facial fracture cases if they

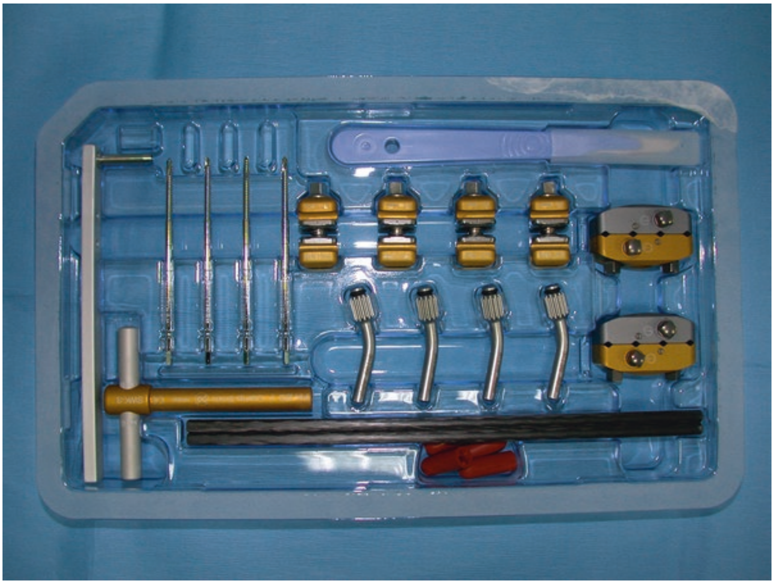

**Fig. 28.15** The Hoffman II orthopedic wrist instrument set will give the same results for external fixation as a dedicated maxillofacial set

have time. They are very crafty with screws, pins, and plates. The advantage to the monophasic external fixator appliance is the ease of pin placement into the bone, followed by the ease of external framework design and application. Each fitting is infinitely adjustable, allowing the surgeon to precisely position bony fragments, as well as refine the occlusal relationships of the maxillary and mandibular dentition. You can also consider external skeletal fixation for the midface, such as the zygoma, and for maxillo-mandibular fixation. A distinct advantage to the external fixation system is the ability to make additional adjustments postoperatively, even with the patient awake. Of course the disadvantages of the external fixation are that it is bulky, the pins leave large scars on the face, and the device isn't removed until the bones have healed which can be as long as 4–6 weeks.

## The Ears

Every ear of every combat trauma patient needs to be examined. Tympanic membrane ruptures are the most common combat injury and can occur from blast, penetrating, or blunt trauma. Unfortunately, many of these injuries are not identified in theater because they are not considered life threatening. Nonetheless, this part of the trauma exam should not be forgotten because otologic injuries are serious and have significant effects on quality of life if they are missed or untreated.

So, start the otologic exam by asking the patient if they have new hearing loss or ringing in one or both ears. If yes, then they have an otologic injury. Next, we want to sort out if it's an injury to the inner ear (sensorineural), middle or outer ear (conductive), or both. Now, take a look at the ear, ear canal, and tympanic membrane. If there is blood in the canal, on the eardrum, or in the middle ear behind the eardrum, assume they have a tympanic membrane rupture at the very least and potentially a temporal bone fracture. If the ear is clear (no blood, no fluid), the patient may have a purely sensorineural hearing loss and may benefit from treatment. So, the next step in the exam is to check their hearing. If you happen to have a tuning fork, you can do a Weber test. Tap the tuning fork to make it vibrate and place it in the middle of the patient's forehead. If you don't have a tuning fork handy, ask the patient to hum in a low tone. If they hear the tone or the hum in the same ear with the subjective hearing loss, then they have a conductive hearing loss in that ear, meaning the hearing loss is most likely due to fluid, rupture, etc. If they hear the hum or tone in the opposite ear, then they may have a sensorineural hearing loss. If the patient complains of hearing loss in both ears, or the patient is unconscious, then the Weber exam is not very helpful and you have to rely on your exam findings and imaging to direct therapy.

A patient with an otologic injury should have a dedicated CT of the temporal bone to evaluate for a temporal bone fracture. If you have confirmed or suspect a temporal bone fracture, then the patient should be treated for a presumed skull base injury. The patient should be put on neurologic precautions and checked for a CSF leak by looking for clear fluid in the ear canal or behind the eardrum. Of note, temporal bone fractures can cause both conductive and sensorineural hearing loss and are very likely to have other major closed head injuries requiring intensive care and airevac.

If you suspect acute sensorineural hearing loss or damage to the inner ear, the patient should be treated with high-dose steroids (10 mg/kg of prednisone daily for 1–2 weeks) within a few days of the injury. This can potentially save the patient's hearing. These patients should also be placed on a temporary hearing profile which will restrict their exposure to unnecessary noise and hopefully prevent further hearing loss. A patient with suspected conductive hearing loss only does not require treatment with steroids. However, if there is blood or debris in the ear canal or a tympanic membrane rupture, then they should be treated with otic drops such as ofloxacin (five drops twice a day for 5–7 days). This will clear out the blood and contaminates and prevent a secondary middle ear infection. The patient with a tympanic membrane rupture should also be placed on profile for dry ear precautions which means no water in the ear and no swimming or bathing until they are cleared by an otolaryngologist. These patients should not wear earplugs, but should use alternative hearing protective devices such as earmuffs. Ideally, all patients with acute ear injuries or new onset hearing loss or tinnitus should be properly diagnosed and treated within a few days of their injury. Of course, these injuries take a back seat to life-threatening injuries, so the window of opportunity for otologic treatment is often missed and patients may be left with a permanent hearing loss. If you are not an otolaryngologist or are not comfortable with hearing loss and ear injuries, this is an excellent example of when to consult the theater consultants via phone or email.

## Finally

Time in the combat operating room is of the essence. Make the most of the precious time you are given, but be flexible with your management plan when you are in the middle of a case and someone more critical needs your OR. It is not unusual for the facial surgeon to be asked to pack off the wound mid-surgery, take the patient to the unit intubated, and return to the operating room the next day to finish the case. Unless it's an unstable patient with penetrating neck trauma, most head and neck injuries are not emergencies, and they may be managed in increments over the course of several days, such as cleaning and debriding 1 day and then reduction and fixation the next day. Head and neck wounds tend to be forgiving and, thanks to an excellent blood supply, tend to heal well despite contamination and devitalized tissue.

In the combat setting, you won't always have the subspecialists around to help you. So, when you are asked to manage a patient with a depressed skull fracture because you're the closest thing to a neurosurgeon, take a deep breath and go back to the basics. This is your opportunity to overcome adversity. Ask for help and tap into the collective expertise of your teammates. If another surgeon is available, ask them to scrub in with you for support. Talk to the scrub techs. A lot of scrub techs are highly trained in subspecialties like neurosurgery, orthopedics, and vascular and may have some pearls that could prove to be helpful. If you have time before you scrub in to the case, take a few moments to review the surgical technique. Have faith in your knowledge and skills. And last, never waiver from exercising sound surgical principles. Do this and you will save patients' lives.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Aural blast injury/acoustic trauma and hearing loss.

## Suggested Reading

2. Brennan JA, Holt GR, Thomas RW, editors. Otolaryngology/head and neck surgery combat casualty care in Operation Iraqi Freedom and Operation Enduring Freedom. Fort Sam Houston: Virginia Borden Institute; 2015.

# 29 Managing Eye Trauma in the Combat Environment

Morohunranti O. Oguntoye and Robert A. Mazzoli

**Deployment Experience**

| | |
|---|---|
| *Morohunranti O. Oguntoye* | Battalion Flight Surgeon, 1-501 Attack Reconnaissance Battalion, Jalalabad, Afghanistan 2012 |

*"Of all the senses, sight must be the most delightful."*

Helen Keller

**BLUF Box (Bottom Line Up Front)**

1. If there is head trauma, there is likely eye trauma. If there is eye trauma, there is likely head trauma.
2. Do not explore, irrigate, or debride a suspected open globe. If an open globe is suspected, place a *shield* on the eye and get them to the nearest ophthalmologist. Shield and ship.

(continued)

M.O. Oguntoye, MD (✉)
Kimbrough Ambulatory Care Center, Department of Vision and Hearing, Fort Meade, MD, USA
e-mail: morohunranti.o.oguntoye.mil@mail.mil

R.A. Mazzoli, MD, FACS
Education, Training, Simulation, and Readiness, DoD-VA Vision Center of Excellence, Bethesda, MD, USA

Surgery (Ophthalmology), Uniformed Services University of the Health Sciences, Bethesda, MD, USA

Ophthalmic Plastic, Reconstructive and Orbital Surgery, Madigan Army Medical Center, Tacoma, WA, USA

Madigan Army Medical Center, Department of Ophthalmology, Tacoma, WA, USA


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(continued)

3. There is never a reason to *patch* an eye in an emergency.
4. Do not attempt open globe repair.
5. There is rarely a reason for emergency enucleation.
6. Always avoid putting pressure on the globe, including an ultrasound probe.
7. A firm, proptotic globe is a surgical emergency, requiring immediate treatment with a lateral canthotomy and cantholysis.
8. A chemical injury is an ocular emergency requiring immediate copious irrigation to neutralize.

## Life, Limb, and *Eyesight*

You are the trauma surgeon for a CSH and you are patting yourself on the back for having effectively managed and evacuated the five soldiers injured in the most recent IED blast. As you walk back to your hooch, you go back over the injuries encountered today: massive head wound, pneumothorax, open abdomen, and traumatic leg amputation. Your team managed each of these injuries like a well-oiled machine, honed by months in the desert. It is a fair bet that at least one of your patients had an eye injury. It is also a fair bet that you probably missed it.

Eye injuries are common but often unrecognized on the battlefield, with ocular injuries being the fourth most common injury during Operation Enduring Freedom/ Operation Iraqi Freedom (OEF/OIF). The incidence of eye injuries has increased with every conflict, from 0.5% in the American Civil War to 13% during Operation Desert Shield/Desert Storm. The implementation of the mandatory use of polycarbonate antiballistic eye protection ("eye pro") has had a significant impact, dropping the incidence of eye injury to 6% from OIF/OEF. Nevertheless, eye injuries still occur, and, even when the eye injury is obvious, it is often managed incorrectly. A retrospective review of eye injuries in Afghanistan found only 39% of eye injuries were shielded (including 0% of avulsed eyes or those with orbit penetration), and only 20% of those that were shielded were shielded correctly, resulting in only 4% of eye injuries being treated properly (96% failure).

Eye injury is often missed because of its association with more attention-getting trauma. In one review, 85% of combat ocular trauma had other systemic injuries, the most common being traumatic brain injury (TBI) (66%), followed by facial injury (58%), extremity injury (44%), traumatic limb amputation (12%), abdominal injury (8%), thorax injury (7%), and pelvic injury (4%). While all of these injuries are significant and require treatment, it is at this point the phrase "life, limb, and *eyesight*" is invoked to remind you of the importance of the eyes in caring for the trauma patient.

## The Basics: Anatomy

The eyes occupy 0.1% of the total body surface area but comprise up to 13% of battlefield injuries. The eye is the brain and is notoriously unforgiving of injury and error. Therefore, ocular injuries require prompt evaluation and attention by ophthalmologists with the proper equipment. The first responder's role, then, is largely to prevent further damage while evacuating to the ophthalmic consultant. Understanding the anatomy of the eye is fundamentally important to understanding the different types of eye trauma and setting the foundation for further treatment.

## The Basics: Examination

An eye examination should be quick but should rule out any need for emergent intervention. If possible, determine the mechanism of injury and if the patient was wearing eye protection.

The first diagnosis to make is whether the globe is open or closed. If the globe is open, there is very little you need to do in the way of an eye exam short of checking vision and shielding the eye, and you should skip to the section titled "Open Globe." Signs of an open globe can be subtle but include a soft or irregular-appearing globe, an irregular or peaked pupil, hemorrhagic swelling of the conjunctiva (especially if 360°) preventing a view of the sclera, leakage of fluid seen upon staining with fluorescein (positive Seidel's sign), hyphema (blood in the anterior chamber), a shallow or deep anterior chamber (when compared to the uninjured eye), decreased eye movement, foreign body tract, and severe vision loss (Fig. 29.1). Any laceration on any part of the lid/eye that should otherwise be protected by eye pro should raise the suspicion of an open globe. When in doubt, treat the injured eye as an open globe: shield it and ship the person to the ophthalmologist.

**Fig. 29.1** Highly suspicious for open globe and should be treated as such: hemorrhagic swelling of the conjunctiva, periocular ecchymosis (mechanism), and limited extraocular motility

Once you have confirmed that the globe is closed, you can continue your eye exam. Each eye should be examined separately.

*Visual Acuity* Documenting visual acuity is more than an academic exercise; it is the eye's vital sign. It is the most accurate predictor of ocular injury severity as well as eventual outcome: the poorer the vision, the more severe the injury and the worse the outcome. Because many combat casualties are intubated close to the point of injury (POI), a rapid field evaluation of vision at the POI may be the only vision documented preoperatively. It does not take sophisticated equipment to perform: a Snellen chart, a handheld vision card, even determining if they can simply identify a badge, rank insignia, or uniform name tape at a certain distance gives valuable information about the patient's vision. You should check each eye separately and get the best visual acuity possible. The ability to discern any form of typeface is better than not being able to. Start with the Snellen chart, a handheld vision card, or any kind of printed text (including uniform name tapes). The smaller the font discerned, the better the prognosis. If the patient is not able to see "the big E" at the top of the chart or cannot read any size of text, this is not the end of the vision exam. Can they see how many fingers you are holding up? Visual acuity is count fingers (CF). Can they see you waving your hand? Visual acuity is hand motion (HM). Can they see a penlight shined into the eye? Visual acuity is light perception (LP). If they cannot see any light at all, the visual acuity is no light perception (NLP). Noting these visual acuities and at what distance (e.g., "hand motion at 2 feet") provides a wealth of information to the ophthalmologist receiving this patient. It also gives an idea of urgency of evacuation: the worse the vision, the higher the priority. A patient with decreased vision should trump the fracture for the final seat on the outgoing flight.

*Eyelids* Look for lacerations, particularly lacerations that may be full thickness and therefore indicate a globe injury. If the lids are tense, do not force them apart, but do gently retropulse the globe to determine if there may be a retrobulbar hemorrhage. In a retrobulbar hemorrhage, the lids may be open or closed, but they will be tense (see section "Retrobulbar Hemorrhage"). Look for foreign bodies in the fornices/inside of the eyelids. Look for singed lashes or chemical injuries to the lids that may indicate burns or chemical injuries to the eyes. Inspection of the eye itself should be very gentle. In the event swelling interferes with surface evaluation, you can fashion field expedient lid retractors from two paper clips to help separate the lids. Caution, however: use only very gentle force to elevate the lids and do not press on the globe or pull forcefully, as this may put dangerous pressure on the eye. Don't force eyelids open. It is better to suspect a significant eye injury, shield the eye(s), and ship to the ophthalmologist.

*Conjunctiva* Subconjunctival hemorrhage extending 360° around the cornea or extending posteriorly without a border is suspicious for an open globe and should be treated as such. White conjunctiva in an eye that has sustained chemical injury is equally concerning for extensive ischemic damage (see section "Chemical Injury").

*Globe* When possible, compare the injured eye to the non-injured eye. Look to see that the globe is well formed, not bulging forward or sunken in. If the globe is bulging forward, gently retropulse the eye and the fellow eye. If the injured eye has significantly more resistance to retropulsion, a retrobulbar hemorrhage should be suspected and requires immediate intervention (see section "Retrobulbar Hemorrhage").

*Extraocular Muscles* Have the patient look in the cardinal directions to ensure that the eyes move freely. If there is restriction to movement or the eye is sunken in, suspect an orbital fracture. Beware of the patient who becomes hypotensive, bradycardic, and/or nauseous when looking around—this could indicate a significant orbital fracture with muscle entrapment (causing an oculocardiac bradycardia/vagal reflex) requiring urgent ophthalmic or ENT intervention.

*Cornea* Examine for obvious foreign bodies. The patient may be wearing contact lenses, which should be noted for later removal by the ophthalmologist. Do not attempt to remove them, as laser-assisted in situ keratomileusis (LASIK) refractive surgery flaps can resemble contact lenses. A fluorescein exam with Wood's lamp should show no evidence of uptake or leakage. If there is uptake, suspect an abrasion or laceration. If there is leakage or pooling of clear fluid (positive Seidel sign), this is an open globe (see section "Open Globe").

*Anterior Chamber* Examine for symmetric depth in the injured and uninjured eye. Look for pooling of blood in the anterior chamber (hyphema), which indicates significant intraocular damage. Look for foreign bodies in the anterior chamber, indicating an open globe.

*Iris/Pupil* Look for reactivity to light. Look for irregularity of the pupil or the iris. If the pupil is peaked, look at the margins of the iris, as the iris will often be plugging a hole in the globe (Fig. 29.2).

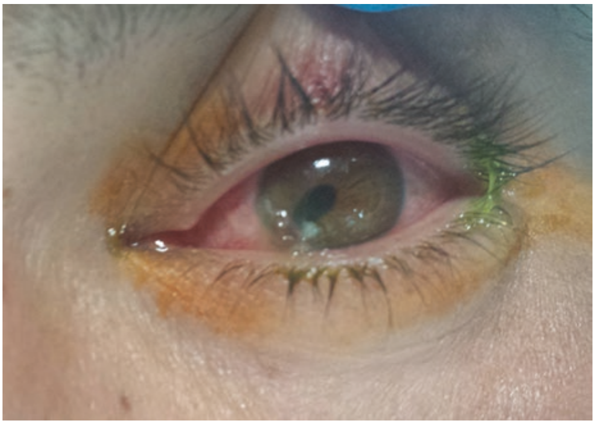

**Fig. 29.2** Open globe with peaked pupil. The peaked pupil points toward the corneal perforation, and the iris is plugging the wound. This eye should be treated as an open globe, a shield placed, intravenous antibiotics started, and the patient evacuated to the nearest ophthalmologist

*Orbit* Check for lid and soft tissue crepitus, bony pain and step-offs, and facial deformities. Check for numbness on the cheek, teeth, or forehead which can indicate orbital wall/floor/roof fractures.

## Open Globe

The good news is that, in the case of open globes, your first instinct when you see an eye injury is the correct one: *cover it up and do not touch it.* Do not irrigate, debride, excise, or reposit any tissue. You should obtain a visual acuity if possible, but do not force the lids open to do so. Do not attempt to measure the intraocular pressure (IOP) or do an ultrasound looking for foreign bodies (CT is better and you can't do anything about them anyway. Leave the ultrasound to the ophthalmologist). Cover it properly with a shield (see Shield vs Patch) and get the patient to the nearest ophthalmologist. Open globes should ideally be repaired within 24 h.

If the patient is conscious, give antinausea medications with any narcotics to prevent Valsalva or vomiting. Avoid maneuvers that may cause gagging (e.g., placement of a nasogastric tube in an awake patient), Valsalva (e.g., patient moving himself from litter to litter), or coughing. Obtain imaging (preferably an axial face and orbit CT scan with coronal reconstructions) to rule out concomitant injuries or unidentified retained foreign bodies. Give intravenous antibiotics within 6 h of injury, ideally fourth-generation fluoroquinolones, as they have the best intraocular penetration. Scheduled systemic/intravenous antibiotics should be continued until the patient reaches definitive ophthalmic care. Do not apply topical medications or ointments. If necessary, give a tetanus shot. The acronym FART is useful in remembering the tenets of managing an open globe: Fox shield, Antibiotics/Analgesia, Radiographic imaging, and Tetanus shot.

Other points to remember:

If the patient needs a pressure dressing on the head and it may cover the eyes, place shields over the eyes prior to wrapping the head. Similarly, protect the injured eyes with eye shields if you are operating on the head or neck, and there may be pressure placed on the eyes by the surgeon.

If there is a penetrating injury to the orbit or the globe, it is okay to place shields over both eyes if the patient will remain awake during transport. Moving the uninjured eye causes movement of the injured eye. Shielding both eyes decreases the ocular movement, potentially limiting secondary injury. Keep in mind that this will probably convert a self-ambulatory patient to a litter patient.

## Shield Versus Patch: *Always* the Shield, *Never* the Patch

These words are used interchangeably, but there is a difference. A shield is a rigid device placed over the orbit without putting pressure on the globe. The shield is placed so that its contact points with the face are at the brow/forehead and cheek. Placement of a rigid eye shield over the eye is critical to mitigating further damage until definitive care can be rendered. It is probably the single most important action taken by a non-ophthalmologist to treat an ocular injury. Appropriate shields include prefabricated plastic or metal shields (e.g., Fox shield), improvised eye shields such as the soldier's own eye pro, moldable splints (e.g., SAM® splints), or a modified Styrofoam/plastic cup (Fig. 29.3).

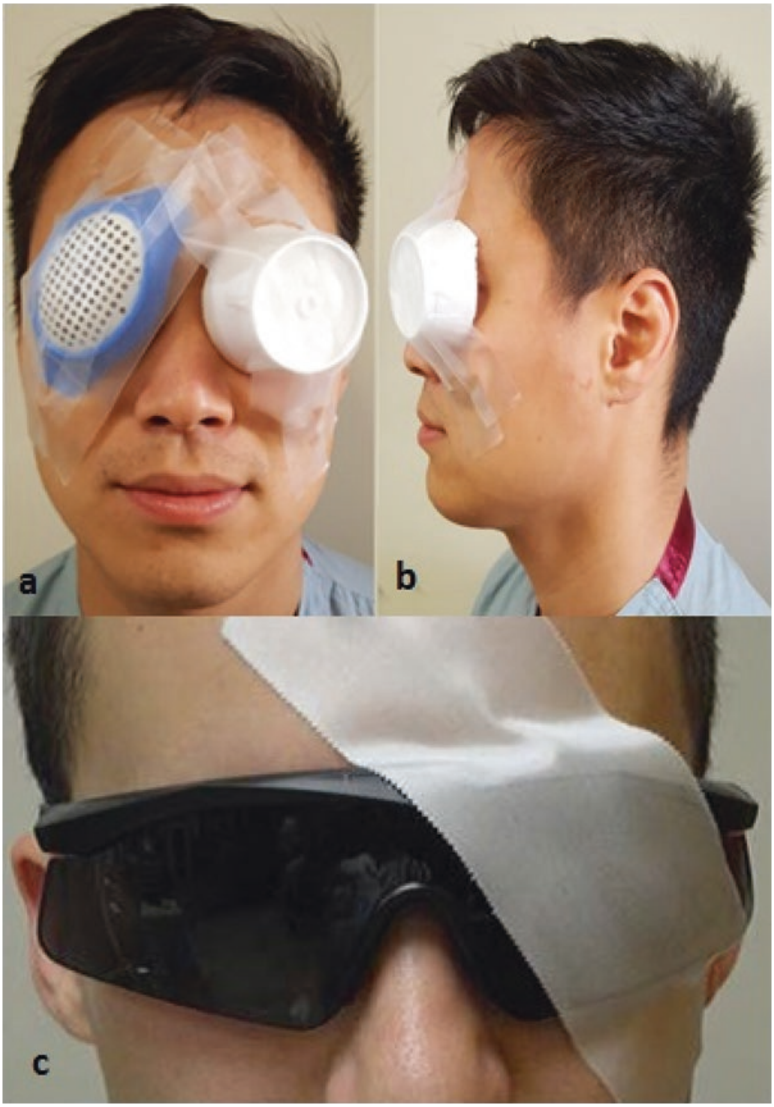


**Fig. 29.3** (**a**) Placement of rigid eye shield (*left*) and improvised shield made of Styrofoam cup (*right*). (**b**). Note that the shield is placed with the edges of the shield touching the forehead and cheek, there is no pressure on the globe, and there is nothing between the globe and the shield (i.e., no gauze). Tape should be placed securely, and completely cover the shield (not shown) so that no debris can get under the shield during transport. (**c**) Eye protection can also be used as a shield and taped in place as shown below

A patch is any occlusive material that has the potential to place pressure on the globe. This includes any dressings or gauze. A patch should be avoided in all eye injuries, including moist gauzes to "keep the tissue moist." Do not place any material between the shield and the globe as you prepare to transport this patient for definitive management.

## Bleeds and Burns

There are two eye injuries requiring immediate intervention: retrobulbar hemorrhage and chemical burns.

### Retrobulbar Hemorrhage

Retrobulbar hemorrhage is an orbital compartment syndrome that can rapidly lead to permanent vision loss if not identified and treated immediately. The retina's ischemic tolerance time is estimated at 90 min. A retrobulbar hemorrhage is a clinical diagnosis. A retrobulbar hemorrhage must be managed with timely and aggressive decompression using a lateral canthotomy and cantholysis *by the first provider that is able to perform the decompression*. When in doubt, perform the lateral canthotomy and cantholysis, as not performing it when it is needed will result in permanent vision loss. The procedure itself has little permanent morbidity and can be repaired if necessary at a later date.

The goal is to disinsert the lower eyelid sling from its periosteal attachments at the lateral canthus. The only two instruments needed are tissue forceps and blunt-tipped scissors. Local anesthetic and a hemostat can facilitate a smoother procedure. The canthotomy is performed by holding the palpebral fissure open with the thumb and index finger. You can apply local anesthetic at the lateral crus, numbing down to the periosteum of the lateral orbital rim. When numbing, be sure to orient the needle away from the globe, as any sudden movements could result in the needle piercing the globe (see section "Open Globe"). Place a hemostat at the crus for 10–20 s to provide hemostasis. Using scissors (blunt-tipped iris, Mayo, or tenotomy), make a cut through the lateral canthal junction of the upper and lower eyelids. Extend the incision laterally down to the orbital rim. Use the toothed forceps to grasp the lower eyelid at the inner edge of the incised canthus with traction oriented toward the ceiling. Place the scissors just beneath the skin and feel for the tendon, which will feel tough, like a guitar string. With the scissors oriented toward the toes, cut the lateral canthal tendon. As the cut tendon is released, the eyelid will fall away from the globe and be freely mobile. If the lower lid is not freely mobile, keep cutting until it is so. Do not expect a big gush of blood. If the lateral canthotomy and cantholysis is successful, the intraocular pressure should decrease within 15 min. Signs of reperfusion include an improved vision, a more reactive pupil, an increased extraocular motility, and a globe that is no longer tense to retropulsion (Fig. 29.4).

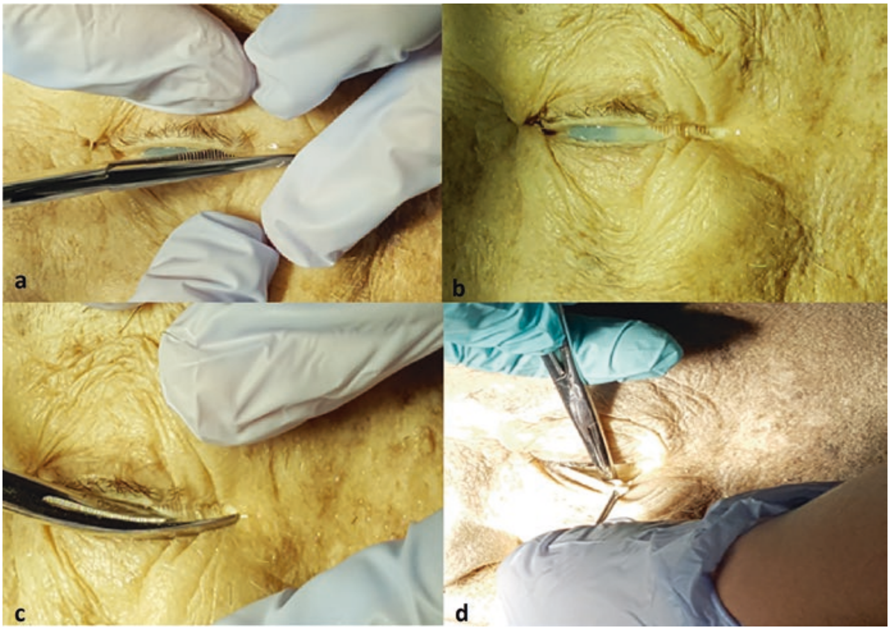

**Fig. 29.4** Key steps of a lateral canthotomy and cantholysis: (**a**, **b**). Use a hemostat to crimp the lateral portion of the patient's eyelid for 5–10 s. (**c**) Incise the skin with scissors laterally down to the orbital rim. (**d**) Retract the lower lid to expose and incise the inferior crus of the lateral canthus

Following a successful lateral canthotomy and cantholysis, additional measures to reduce the orbital pressure should be instituted, including applying ice packs to the orbit, elevation of the head, and administration of systemic analgesia and anti-emetics. IV diuretics such as acetazolamide or mannitol can be given to lower the intraocular pressure *after* the canthotomy and cantholysis has been completed.

## Chemical Injuries

*A Chemical Injury Is an Ophthalmic Emergency that Precludes Obtaining the Initial Eye Exam* Intervention with irrigation must be started immediately upon recognition of the chemical injury. As with chemical burns on any other part of the body, dilution is the solution to pollution. Alkaline materials cause more damage than acidic materials. Copious (liters) but gentle irrigation with any non-caustic fluid should begin as soon as the chemical injury is realized. If there is any suspicion of an open globe, the eye should still be irrigated, but tap water should be avoided as the irrigant (use saline instead). The pH (normal pH = 7) should be tested 5 min after cessation of irrigation to ensure that it is the pH of the eye and not the irrigant that is being measured. Measure it again after 15–30 min to confirm. Once the pH has neutralized, *then* a full eye exam should be conducted.

**Fig. 29.5** A nasal cannula can be attached to an IV bag to provide irrigation to neutralize a chemical injury

Topical anesthetic can be used to provide patient comfort, but it should not delay care. The eye should be held open, ideally using a lid speculum. Nasal cannula prongs positioned over the nasal bridge and attached to an IV solution bag is a very effective method of irrigating the eyes (Fig. 29.5). The fornices should be swept with a moistened cotton-tipped applicator to remove any debris. An IV bag of fluid run wide open into the eye provides the right amount of gentle irrigation and should be continued for at least 2–3 l of fluid. Once the pH is neutral, perform the full eye exam. Causes for concern include partial and full thickness burns to the surrounding eyelids, loss of eyelashes, decreased visual acuity, increased intraocular pressure, full thickness globe penetration/open globe, opaque cornea, and whiteness of the sclera near the cornea (limbal blanching).

## Traumatic Hyphema

A hyphema, the layering of red blood cells in the anterior chamber due to bleeding, can be the result of blunt or penetrating trauma. A hyphema may be very small, seen only with a microscope, or fill the entire anterior chamber with blood ("eight-ball hyphema"). Documenting the height of the hyphema at initial presentation is important, as there is a risk of rebleeding 2–7 days after the initial injury. Poor prognostic factors include sickle cell trait or disease, von Willebrand disease, hemophilia, rebleeding, and a history of glaucoma.

After conducting a full ocular exam and ruling out an open globe, the eye should be shielded, NSAIDS or aspirin should be avoided, and transport to an ophthalmologist should be arranged. If the patient has increased intraocular pressure (IOP > 24 mmHg), a topical beta-blocker may be administered. Systemic diuretics such as carbonic anhydrase inhibitors and osmotic diuretics should be avoided in sickle cell patients.

## Refractive Surgery

Laser-assisted in situ keratomileusis (LASIK), photorefractive keratectomy (PRK), and implantable collamer lens (ICL) as treatments for refractive errors have become force multipliers on the battlefield, obviating the need for gas mask inserts, prescription eyeglasses, contact lenses, and eye care supplies as part of the deployment packing list for a significant percentage of deployed personnel. It also decreases the risk of corneal ulcers, a potential ophthalmic emergency from poor contact lens hygiene, and unauthorized contact lens use that could warrant urgent evacuation (see section "Corneal Abrasion Versus Ulcer").

PRK and ICL have low likelihood of complications on the battlefield. In the case of PRK, once the eye heals, the eye is essentially the same structurally as a non-PRK eye. ICL, where effectively the lens correction is implanted within the eye, has a theoretical risk of dislocation, but this has, to date, not been documented in the combat environment, even in a documented case of a soldier involved in a grenade explosion.

The most feared complication with refractive surgery, flap dislocation, can occur in eyes that have had LASIK. The risk of flap dislocation is extremely low, with studies showing a rate of 0.085% among all Army soldiers. In the rare event that a LASIK flap becomes dislocated, the eye should be shielded and the person evacuated to the nearest ophthalmologist. Do not attempt to remove the flap, which can look disturbingly similar to a retained contact lens.

## Corneal Abrasion Versus Ulcer (Table 29.1)

"Wearing contact lenses in the deployed environment [is like] the cigarettes of the eyes. Extended wear becomes not only cigarettes but unfiltereds with a [chewing tobacco] chaser. The only thing that could make them worse is…topical anesthetic, which elevates the chaser to meth. There is no place for contact lenses in any sort of deployment. Period."—US Army ophthalmologist commenting on corneal ulcer that occurred in theater due to contact lenses.

It is important to distinguish between corneal abrasions and corneal ulcers. A corneal abrasion is a very common, minor injury that, while initially very uncomfortable, usually heals quickly even without any intervention. A corneal ulcer, while

**Table 29.1** Corneal abrasion versus corneal ulcer

| | Corneal abrasion | Corneal ulcer |
|---|---|---|
| History | Trauma | Contact lens use<br>Vegetable matter to the eye swimming in unclean water |
| Vision | Decreased | Decreased |
| Cornea | Clear | Opaque |
| Fluorescein | Irregular outline | Smooth outline |
| Topical anesthetic | Resolves pain | Pain persists |
| Photophobia | Yes | Yes |

similarly uncomfortable, is more serious. If left untreated, the ulcer can rapidly progress to corneal perforation, loss of vision, and loss of the eye.

They can present similarly, but a corneal abrasion will usually present with a history of some sort of eye trauma. If it is a large abrasion, the conjunctiva may be red and the eyelid may be swollen. Fluorescein staining and a Wood's lamp will highlight the epithelial defect, which often has an irregular surface. Topical anesthetic almost always completely resolves the pain (temporarily). Additional symptoms include decreased vision and photophobia. The ophthalmic exam should otherwise be normal. Topical fluoroquinolones eye drops QID, PO analgesia, and artificial tears for 5–7 days are the treatment of choice in the battlefield environment. Do not patch the eye. The abrasion should improve daily. Even with a corneal abrasion covering the entire cornea, the abrasion should be fully healed in 5–7 days.

*Topical Anesthetics Should Only Be Used for Diagnostic Purposes* Continued use of topical anesthetics is toxic to the cornea and can lead to permanent corneal scarring.

A corneal ulcer is often due to contact lens wear but can be seen when foreign bodies are not removed from the eye or with swimming in unclean water (amoebic ulcers). The history is often one of falling asleep in contact lenses, progressive pain with insertion and/or removal of contact lenses, poor contact lens hygiene, or recent episode of vegetable matter debris to the eye. The conjunctiva will likely be red and the eyelid may be swollen. The ulcer can often be seen as an opacity in the cornea without any staining, but fluorescein staining and a Wood's lamp may highlight the ulcer's smooth surface. Topical anesthetic usually does not resolve the pain (although it may lessen it). Additional symptoms include decreased vision and photophobia. In severe cases, the ophthalmic examination may reveal a hypopyon (pus in the anterior chamber). If the ulcer is small (<0.5 mm in diameter) and caught early, topical fluoroquinolones every hour until completely resolved are the treatment of choice in the battlefield environment. If vegetable matter is the etiology, there is concern for fungal etiology, and topical antifungals would be warranted. If the ulcer is large, is associated with hypopyon, is visually obstructing, or is due to vegetable matter, the patient should be placed on hourly topical antibiotics and evacuated to the nearest ophthalmologist as quickly as possible.

## Final Points

In one survey, 68% of people would rather lose a limb than lose their vision, and 67% would rather lose 10 years of their life than lose their vision [5]. Eye injuries are common and, in the trauma setting, commonly missed. With massive trauma and head trauma, the index of suspicion should be high that there is concomitant eye injury. If the globe is open, your job is easy—"shield it and ship it." If there is retrobulbar hemorrhage or chemical injury, it is up to you to preserve the patient's vision by immediate intervention. Remember, in trauma, it is life, limb, *and eyesight*.

## Civilian Translation of Military Experience and Lessons Learned

Robert A. Mazzoli

Medical treatment priorities are commonly cited as "life, limb, and sight," but most *survivors* re-prioritize the list to "life, *sight*, and limb." In the chaos of combat and mass casualty, however, the eye is often forgotten or overlooked, as attention is appropriately placed on more urgently life-threatening injuries. Nevertheless, it is precisely at these locations and points of care—close to the point of injury (POI)—that the ocular injury is most effectively mitigated. As MAJ Oguntoye points out in her text, the eye is notoriously unforgiving of injury and error. Early actions taken and not taken set the foundation for further care and can either enable successful repair or aggravate the injury sufficiently to seal an undesired outcome.

As military style polytrauma injuries become increasingly commonplace in the fabric of daily civilian life—whether the result of domestic terrorism, industrial accident, or natural disaster—lessons learned on the military battlefield can be directly applied to civilian care.

MAJ Oguntoye's chapter points out several tenets in the emergency, POI, pre-ophthalmic care of eye injuries that are universally applicable, whether in the streets of Fallujah or Boston. Many of these tenets are reflected in current military prehospital trauma care guidelines such as the Tactical Combat Casualty Care Guidelines (TC3 Guidelines) and the Joint Trauma System Clinical Practice Guidelines (JTS Guidelines), both of which outline essential actions for non-ophthalmic personnel. Fundamentally, these guidelines boil down to "Shield and Ship," reflecting simple actions that will most effectively mitigate an eye injury until definitively evaluated and treated by the ophthalmologist. But there is nothing new here. The tenet of shielding an eye injury is well established and is neither novel nor controversial nor exceptionally difficult; the problem and challenge lie in application and compliance.

Short of minimizing further damage to the eye in transport, there is little that the non-ophthalmologist can do (or should do) in terms of definitive treatment at the forward scene, and so his actions become very simple: shield and ship. Significant exceptions to this rule are the cases of chemical injury, in which immediate copious irrigation is required, and retrobulbar hemorrhage where immediate canthotomy/cantholysis can be sight saving. In that light, the roles of the non-ophthalmologist encountering an ocular injury are to (1) suspect an eye injury as a component of polytrauma, (2) stabilize the eye for transport, and (3) take steps to prevent further trauma. The single most effective action in accomplishing this is to ensure no pressure is placed on the eye by placing a rigid shield—not a gauze or patch—over it. The simple act of placing a $2.00 shield over the eye, whether the injury is penetrating or not, gives the ophthalmologist and the patient the best chance at salvaging the eye and vision. This simple precautionary move must be preserved at each echelon of care until the casualty reaches the ophthalmologist regardless of the number of exchanges, as permanent and irreversible damage can be caused at any stage of transition, including air evacuation. Lacking a commercially manufactured shield, anything that rigidly vaults over the eye from the brow to the cheek will work.

Success in this area depends largely on education, training, logistics, and communication. Education involves increased awareness of eye injuries and their unforgiving nature. For a high index of suspicion to be maintained, the nature of eye injuries—particularly in the context of head and neck injuries and systemic polytrauma—must be an integral component of universal military and civilian first aid and medical training courses. Concomitantly, management of ocular injuries must become a routine skills training station in the process of medical competency evaluation, whether in military or civilian settings. While literature is scant in this area, it is telling that only 4% of military eye injuries were appropriately or properly shielded at the point of injury, representing a 96% failure to properly mitigate a devastating wound. Few of us would accept a 96% failure rate as a reasonable “cost of doing business.” Nor should we. Yet, as bleak as those numbers may seem, civilian data may be even bleaker; in the wake of the Boston Marathon bombing of 15 April 2013, with numbers, rates, and types of eye injuries similar to the military’s combat experience and sophisticated facilities immediately available, *no eye shields were placed prior to evaluation by ophthalmology*, and only one shield was placed during the West, TX fertilizer plant explosion 2 days later. Clearly, education and training reflect a significant gap. Some improvement in this area is being made, as both TC3 and JTS guidelines have been adopted by civilian agencies such as the National Association of Emergency Medical Technicians (NAEMT) and incorporated into its curriculum and training.

An aspect of care that cannot be overlooked or undervalued is the role of logistics. It may be patently obvious, but shielding at the POI is accomplishable only if the shields are actually available at the POI. Surprisingly, such was not the case in the military until relatively recently, when a multiagency effort resulted in designating rigid eye shields as required components of POI aid kits. Civilian medical equipment suppliers have readily adopted these changes to their own inventories. Yet a persistent gap remains in civilian care, as many civil emergency response systems (EMS) do not require eye shields on ambulances as of this writing, essentially equipping our primary response personnel to fail. Again, in light of increasingly similar injuries, a question arises as to whether we are willing to admit this recognized shortfall as acceptable. Currently, multiagency, military-civilian efforts are underway nationally to remedy this deficit. But narrowing the logistics gap only reemphasizes the fundamental importance of education and training for awareness of recognizing the injury and properly treating it…. Now that I have a shield, what do I do with it?

A final component of proper care involves communicating between lower and higher echelons. The suspicion of an eye injury must be conveyed to each leg of transport, including care in the air, and the aforementioned precautions must be maintained at each exchange: if a shield is removed at one location to facilitate interval examination or a needed intervention, it must go back on prior to evacuation to the next level. Likewise, awareness of a potential eye injury must be conveyed to intervening surgeons, anesthetists, and nurses who may inadvertently place pressure on the eye during transfer from litter to litter, stretcher to OR table, mask anesthesia, or with a bi-coronal flap. Moreover, early communication with the ophthalmologist can help maximize efficiencies of care throughout the transport process.

A word should be said about checking vision as early as possible. Literature bears out that initial vision is the best predictor of final visual outcome; the better the vision, the better the prognosis, and the worse the vision, the worse the outcome. It is also an excellent barometer of injury severity; the worse the vision the graver the insult, and the greater the urgency for evacuation to definitive care. Again, it seems needless to state the obvious that this data is useful only if it is obtained. A common misperception, however, is that vision must be checked with an "official" eye chart, such as a Snellen chart of pocket card, neither of which will likely be available at the POI nor cared about, for that matter. The reality is that almost anything can be used to check vision quickly, and large leap estimations can be made and are acceptable; vision that is "on the chart" (i.e., Snellen acuity or equivalent) is better than being "off the chart" (i.e., counting fingers, hand motion, light perception, no light perception). The challenge comes in documenting vision that is "on the chart" in the absence of the chart. Again, almost anything will suffice; the aim is to document the ability to discriminate detail—the finer the detail, the better the acuity. One need not have a printed Snellen chart to accomplish this. Any typeface or text will do, including printing on the elastic Kevlar band (e.g., handprinted name or blood type), letters on uniform name tapes (e.g., "Can you read the letters of my name?"), rank insignia (e.g., "Can you see the rockers and chevrons on my rank?"), and unit patches (e.g., "Can you see the stars on the flag? Can you see the individual stripes?").

Finally, mention should be made of the transition from combat to peacetime and garrison activities. It is axiomatic but perhaps inevitable that the hard-learned lessons of combat are quickly forgotten in peacetime. Despite the best efforts of dedicated individuals to perpetuate these lessons learned into peacetime military training, history demonstrates a predictable loss of memory and competence, much of it due to the inescapable attrition of those same dedicated, experienced individuals. It is in this regard that the equally inevitable transfer of military knowledge to civilian care becomes even more critical, for it is in the civilian adoption of military experience that our gains are institutionalized and fed back into the military as "expected practice." It is therefore incumbent on all military medical personnel to champion that transition, whether as a careerist or not.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Initial care of ocular and adnexal injuries.

## Suggested Reading

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4. Weichel ED, Colyer MH. Combat ocular trauma and systemic injury. Curr Opin Ophthalmol. 2008;19(6):519–25.
5. Baush+Lomb Incorporated [Internet]. c2016[cited 2016 Aug 31]. Available from: http://www.bausch.com/ourcompany/recent-news/id/1461/7182012-wednesday#.V8eOLBEUXcs.

# Burn Care in the Deployed Setting

# 30

Gary Vercruysse

**Deployment Experience**

| | |
|---|---|
| *Gary Vercruysse* | Trauma Czar, 332d EMDG, Air Force Theater Hospital, Balad, Iraq 2008–2009 |
| | Mentor to the Czar and ICU Director, 455th EMDG, Craig Joint Theater Hospital, Bagram, Afghanistan 2010 |
| | Trauma Surgeon, Landstuhl Regional Medical Center, Landstuhl, Germany 2011 |

*Skin is the best dressing.*

Joseph Lister (1827–1912)

The incidence of thermal injury related to military operations generally equates to less than 10% of all combat injuries. Causes of severe burns include explosions, mishaps related to fuel and munitions, and non-tactical operations such as burning of waste and debris. Recent experiences in Iraq and Afghanistan have demonstrated that thermal burns are associated with other severe injuries such as fractures, closed head injuries, and severe soft tissue loss in approximately half of the patients injured by explosive mechanisms. This fact further emphasizes the great importance of treating the burn casualty as a trauma patient, assessing for life-threatening injuries aside from the burn itself.

Recognize that the rules of engagement with respect to survivability – namely, who is declared expectant – have changed during the past two to three decades. Rapid evacuation and transport is accepted as a major factor in the survival of combat

G. Vercruysse (✉)
Professor of Surgery, Director of Burn Services,
University of Arizona School of Medicine, Tucson, Arizona
e-mail: gvercruysse@surgery.arizona.edu


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casualties on the modern battlefield. The expedited evacuation with near-seamless intensive en route care (CCATT) has contributed to increased survival for many casualties, including burn patients. We have seen multiple military casualties with burns involving greater than 90% of their total body surface area (BSA) survive to return to the USA, and some ultimately return home. Hence, there is no longer an absolute extent of burn injury labeled as expectant. As a general rule, remember that most burn casualties do not succumb to their immediate burn wound, and consider any burn survivable to the point of being transported stateside to receive definitive care. However, local nationals will not be able to be evacuated to a US burn center, and only rudimentary burn care is available in the far forward setting. If there is no local burn care available, then a general rule of thumb is any full-thickness burn of >50% TBSA should be treated as expectant with comfort measures only.

**BLUF Box (Bottom Line Up Front)**

1. Burn casualties are, first and foremost, trauma patients; the burn injury is often times not immediately life threatening, whereas associated injuries may be.
2. Facial burns, burns >20% TBSA, and suspicion of inhalation injury warrant consideration for preemptive intubation.
3. Intubation of a patient is rarely emergent – there is usually time for completion of secondary survey prior to intubation.
4. Both over- and under-resuscitation may lead to morbidity in the burn casualty; avoid boluses of crystalloid whenever possible.
5. Releasing full-thickness eschar (escharotomy) may be life and limb saving; fasciotomies are rarely necessary unless compartment syndrome is present independent of burn injury (concomitant vascular or orthopedic injury).
6. Maximize available resources to keep the burn (trauma) patient warm.
7. Maximize every opportunity to prevent infection which represents one of the greatest threats to survival for the burn casualty.
8. Know your limitations. Burn care requires time, resources, and long-term care. If no local burn care is available, then you should consider treating local nationals with (full-thickness) burns >50% TBSA as expectant.

## Immediate Care in the Field (Tactical Combat Casualty Care)

Even before the surgeon lays eyes on a trauma patient, he or she may be asked to provide guidance or advice in the treatment of the combat casualty in preparation for staged evacuation. Intubation of patients with facial burns is rarely required immediately following injury, except in cases where the severity of the burn constricts the soft tissue around the mouth and nose so as to restrict the airway. One common error on the part of frontline medics in the initial treatment of burn casualties is the routine action of administering 2 liters of crystalloid whether it is indicated or not. This action can prove harmful, especially in a patient with burns isolated to the face and/or hands. The often excessive or unneeded crystalloid fluid simply contributes to edema of the burned body area while providing little or no systemic benefit. It is reasonable to simply initiate peripheral intravascular access and start crystalloid fluids at a maintenance rate for patients with smaller-size burns (less than 10% TBSA) or just hep-lock them until they arrive at a hospital facility. *Do not bolus IV fluids* when treating burn patients as this will lead to interstitial edema and does not contribute much to resuscitation other than morbidity.

First-line providers are encouraged to cover the burned tissue with a clean, nonadherent dressing and avoid the use of any topical cream or ointment if it is anticipated that the patient will be evacuated rapidly. Silver nylon dressing materials are generally not indicated as an initial burn dressing unless large areas of epidermis have been lost, in which case the silver nylon dressings work well to protect the underlying dermis during transport. Blisters may be left intact during transport as they provide an initial biological protective layer. Blisters may be drained or opened when their expansion leads to severe pain, such as in the case of burns to the palms of the hands.

Although it is desirable to place a urethral catheter very early following burn injury to follow urine output, placement of a suprapubic catheter in patients with burns to the *glans* penis or deeper is rarely, if ever, indicated. It is almost always possible to place a urethral catheter in even the most severely burned casualty if basic anatomy is considered and gentle debridement is performed.

## Acute Burn Care (In the Trauma Bay)

In general, approaching the burn patient as a trauma patient is the key to successful treatment and avoidance of missed injuries. While the burn is often the most dramatic (and distracting) injury, it is not immediately life threatening. These patients should be thoroughly evaluated like any other trauma patient, and in fact they probably warrant an even more detailed search for severe associated injury. One of the reasons that we don't see more burns in the combat setting is that modern blast devices are incredibly powerful and deadly. Most victims close enough to the blast to suffer thermal burns die at the scene, so those that make it to you should be assumed to have multiple external and internal injuries.

Assessment of airway and breathing includes ensuring that full-thickness eschar is not restricting ventilation. Full-thickness burns to the thorax can rapidly lead to respiratory acidosis from inadequate excursion which is rapidly remedied by the performance of thoracic escharotomies along the anterior axillary lines and other regions as indicated (Fig. 30.1). Circumferential extremity burns with any evidence of impaired distal perfusion should also prompt immediate escharotomy. Escharotomy, in contrast to fasciotomy, can be readily performed at the bedside using knife and/or electrocautery (Fig. 30.2). There is little if any added morbidity since the eschar will eventually be removed. If the burn is partial thickness (red dermis) but severe swelling mandates escharotomy, then sedation will be required.

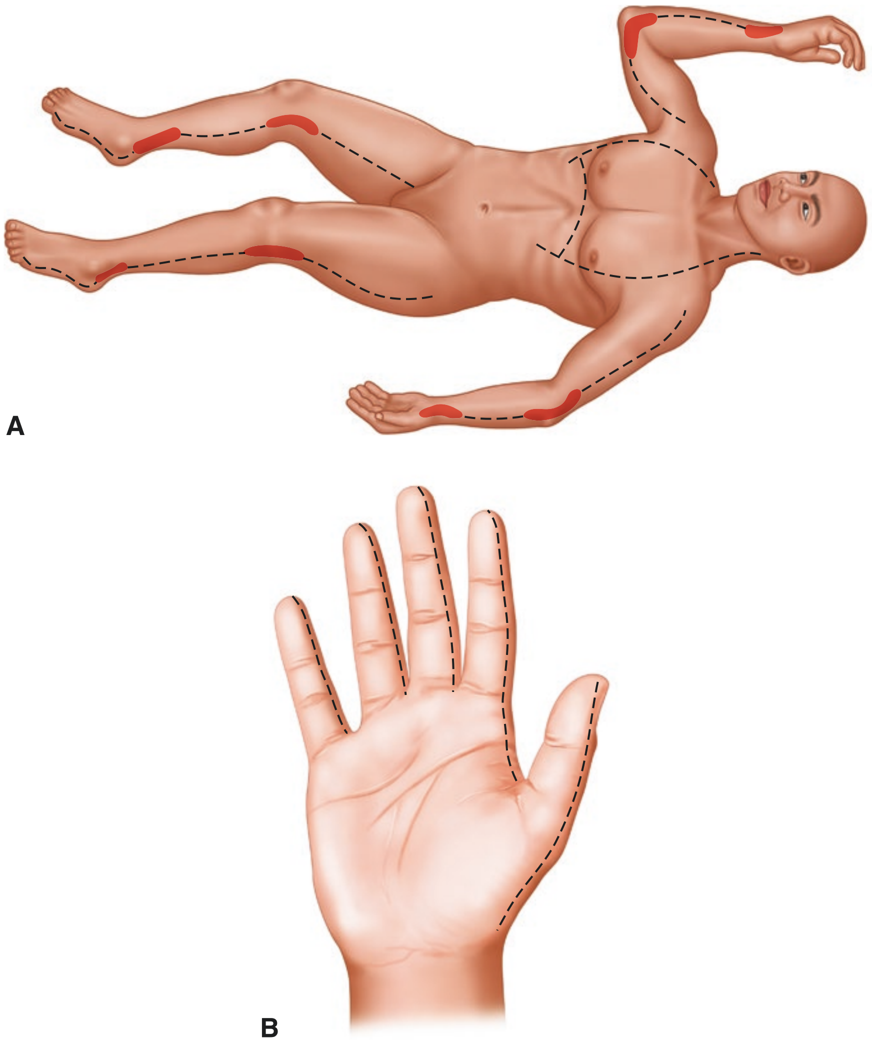



**Fig. 30.1** (**a**) Standard incision lines for burn escharotomies; (**b**) Marked incisions for performing digital escharotomies

If full-thickness burns require escharotomy, sedation may not be required. If escharotomy is to be done, try to refrain from making incisions on unburned skin. It is not required to follow the drawings exactly when making escharotomy incisions. If you have the choice between moving an incision to create an adequate escharotomy through burned skin and unburned skin, move the incision to save unburned skin.

Resuscitation remains one of the most challenging aspects of burn care. The morbidity of both over-resuscitation and under-resuscitation of the burn casualty is well described. Accurate resuscitation begins with an accurate assessment of the percentage of body surface area burned (Fig. 30.3). Remember that you should only count areas with partial- or full-thickness burns; superficial burns (i.e., sunburn) are

**Fig. 30.2** Escharotomies for circumferential burns of (**a**) the lower extremities and (**b**) the chest wall. Note the incisions are carried down to subcutaneous fat only; fasciotomy is not required. (**a**) (Courtesy of Walter L. Ingram MD, FACS)

excluded. Careful analysis of the process of burn resuscitation in the field has revealed the persistent difficulty in initiating and maintaining a consistent resuscitation across the spectrum of care and through the evacuation process. In an effort to simplify the process, Chung and colleagues developed the Rule of Ten as a tool for providers. The Rule of Ten provides an easy method of calculating the initial

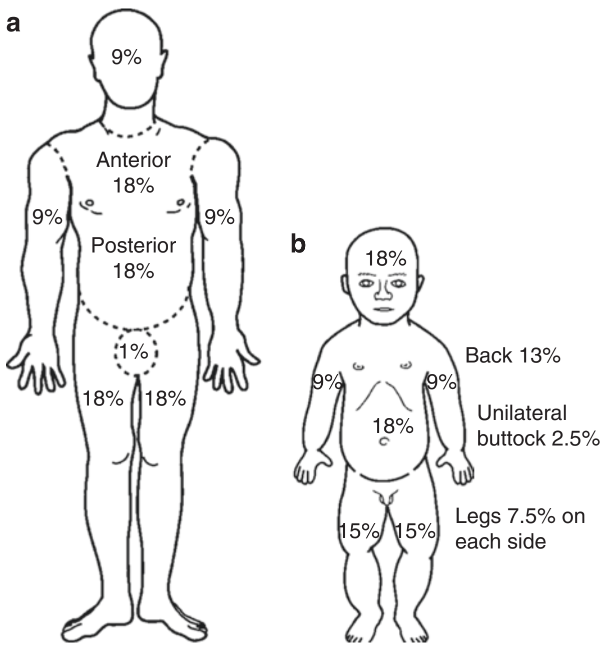
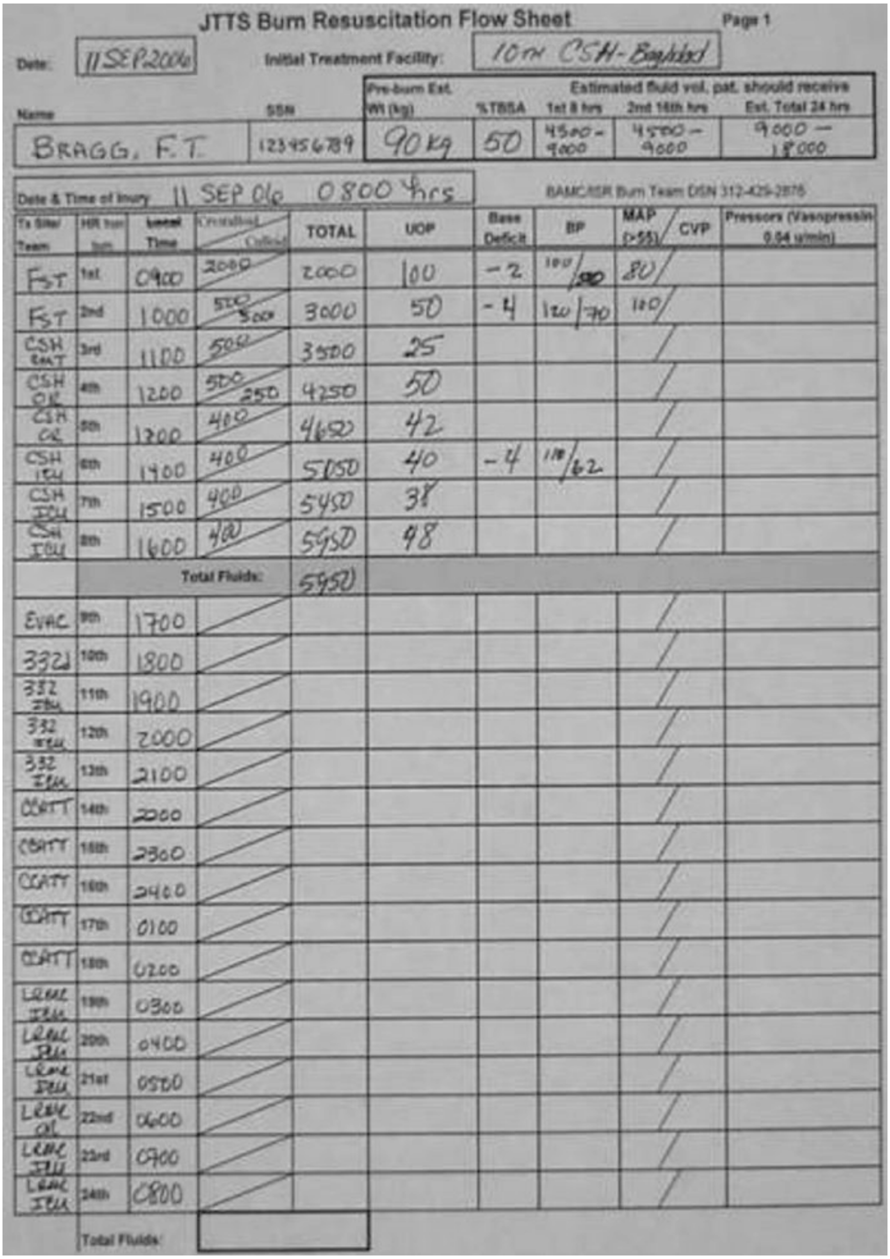



**Fig. 30.3** Charts for estimating the percentage of body surface area involved with partial- and full-thickness burns for adults (**a**) and children (**b**) (Reprinted from Burris et al., editors. *The Emergency War Surgery Manual*, 3rd revision. Washington, D.C: Borden Institute; 2004)

resuscitation fluid rate using the estimated burn size alone (utilizing the Rule of Nines). The initial fluid resuscitation rate, in milliliters per hour, is calculated by multiplying the total body surface area burned by 10 and is adjusted based upon the patient's response as measured by urine output with a target of 30–50 ml/h. This rule is for adult patients (40–80 kg). Modest increases or decreases in IV fluid rate less than 20% of the current rate are recommended to avoid unnecessary volume changes.

Rule of Ten: Multiple estimated burn size (%TBSA) × 10 to equal the *initial* rate of crystalloid resuscitation fluid. If the patient weighs more than 80 kg, add 100 ml of fluid per hour per 10 kg over 80 kg.

There are times when infusion with crystalloid is not adequate to achieve maintenance of adequate perfusion while avoiding the morbidities associated with hypervolemia. The addition of colloids such as 5% albumin may reduce the crystalloid requirements. In the multi-trauma patient, fresh frozen plasma (FFP) will provide very good colloid resuscitation in addition to correction of coagulopathy. After the initial 12 h of resuscitation, it is reasonable to run an FFP or 5% albumin drip at 50 ml/h in addition to crystalloid as necessary to maintain a perfusing blood pressure as measured by urine output (.5 ml/kg/h in adults, 1 ml/kg/h in children) after the first 12 h of resuscitation. This rate can be adjusted down in children as necessary. If hypotension related to burn shock persists despite aggressive fluid resuscitation, the use of low-dose vasopressin (not more than 0.04 u/min.) may be advised. High-dose vasopressin, norepinephrine, or other pressors are not advised as they shunt blood away from dermis, potentially increasing the burn penumbra. Recommendations regarding these and other adjuncts to resuscitation are provided as updates to the Joint Theater Trauma System (JTTS) Clinical Practice Guidelines which are readily available online (Fig. 30.4).



JTTS Burn Resuscitation Flow Sheet — Page 1

Date: 11SEP2006 — Initial Treatment Facility: 10TH CSH-Baghdad

| Name | SSN | Pre-burn Est. Wt (kg) | %TBSA | Estimated fluid vol. pat. should receive: 1st 8 hrs | 2nd 16th hrs | Est. Total 24 hrs |
|---|---|---|---|---|---|---|
| BRAGG, F.T. | 123456789 | 90 kg | 50 | 4500-9000 | 4500-9000 | 9000-18000 |

Date & Time of Injury: 11 SEP 06 0800 hrs — BAMC/ISR Burn Team DSN 312-429-2876

| Tx Site/Team | HR from burn | Local Time | Crystalloid / Colloid | TOTAL | UOP | Base Deficit | BP | MAP (>55) / CVP | Pressors (Vasopressin 0.04 u/min) |
|---|---|---|---|---|---|---|---|---|---|
| FST | 1st | 0900 | 2000 | 2000 | 100 | −2 | 100/50 | 80/ | |
| FST | 2nd | 1000 | 500 / 500 | 3000 | 50 | −4 | 120/70 | 100/ | |
| CSH EMT | 3rd | 1100 | 500 | 3500 | 25 | | | / | |
| CSH OR | 4th | 1200 | 500 / 250 | 4250 | 50 | | | / | |
| CSH OR | 5th | 1300 | 400 | 4650 | 42 | | | / | |
| CSH ICU | 6th | 1400 | 400 | 5050 | 40 | −4 | 118/62 | / | |
| CSH ICU | 7th | 1500 | 400 | 5450 | 38 | | | / | |
| CSH ICU | 8th | 1600 | 400 | 5950 | 48 | | | / | |
| | | Total Fluids: | | 5950 | | | | | |
| EVAC | 9th | 1700 | | | | | | / | |
| 332d | 10th | 1800 | | | | | | / | |
| 332 ICU | 11th | 1900 | | | | | | / | |
| 332 ICU | 12th | 2000 | | | | | | / | |
| 332 ICU | 13th | 2100 | | | | | | / | |
| CCATT | 14th | 2200 | | | | | | / | |
| CCATT | 15th | 2300 | | | | | | / | |
| CCATT | 16th | 2400 | | | | | | / | |
| CCATT | 17th | 0100 | | | | | | / | |
| CCATT | 18th | 0200 | | | | | | / | |
| LRMC ICU | 19th | 0300 | | | | | | / | |
| LRMC ICU | 20th | 0400 | | | | | | / | |
| LRMC ICU | 21st | 0500 | | | | | | / | |
| LRMC OR | 22nd | 0600 | | | | | | / | |
| LRMC ICU | 23rd | 0700 | | | | | | / | |
| LRMC ICU | 24th | 0800 | | | | | | / | |
| | Total Fluids: | | | | | | | | |

**Fig. 30.4** Joint Theater Trauma System burn flow resuscitation sheet. This document has begun at the initial point of care in the combat theater and is continued throughout the evacuation process

Treatment of the burn wound initially includes cleansing the skin with an antibacterial soap such as Hibiclens®. The application of topical antimicrobials such as silver sulfadiazine (Silvadene®) or mafenide (Sulfamylon®) cream is an effective method of decreasing the degree of skin colonization. More recently, the use of a silver nylon dressing (Silverlon®, Silverseal®) has found acceptance in the burn community due to their ease of application and documented effectiveness. One of the main advantages of using these materials in the military environment is the ability to place the wraps over multiple types of soft tissue wounds, including burns, and leave them in place with minimal maintenance during the evacuation process.

## Burn Critical Care (The ICU Phase)

Adults with burns involving more than 20% and children (<5 years old) or elderly adults (>51 years old) with burns more than 10% of their total body surface area (TBSA) should be admitted to an intensive care unit (ICU) environment due the multiple organ systems affected and need for close monitoring and intervention. Airway management, pulmonary toilet, and ventilator support are routinely required, especially when the patient has sustained inhalation injury associated with the burn. It must be remembered that inhalation injury is only suffered when patients are burned in a closed environment (in a house, in a car, in an MRAP vehicle). Scald burns, brush fires, and gasoline flash burns are not associated with inhalation injury even if the face is involved. Rarely, inhalation injury may be an isolated injury, but one that requires significant pulmonary support.

As facial edema progresses, protection of the soft tissue of the face while simultaneously securing the airway can be challenging. The RT and bedside nurse must ensure that any securing device or tie used to secure the endotracheal tube is tight enough to eliminate excessive movement, but not so tight as to cause injury. Alternative approaches to this problem also include stapling silk endotracheal tube tapes to the skin of the upper lip, using an umbilical tape harness, wiring of the ETT to a molar tooth using stainless steel wire, or early performance of a tracheostomy (Figs. 30.5 and 30.6).

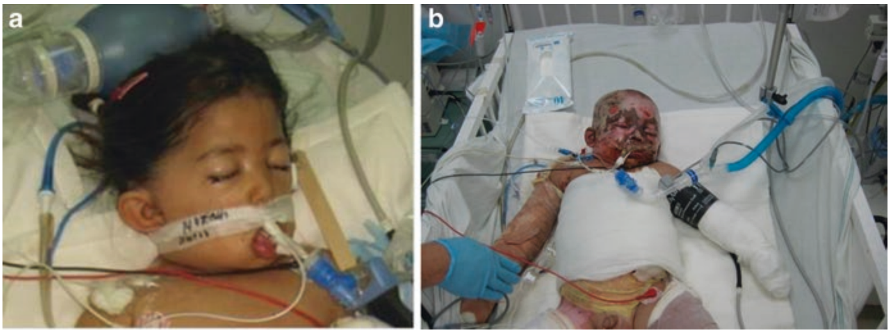


**Fig. 30.5** Two Iraqi children with facial swelling requiring intubation. The first child required intubation due to swelling from crystalloid resuscitation and the second due to severe facial burns. Both were managed with silk tape stapled to the skin over the upper lip (and a second layer of tape used to hide the staples)

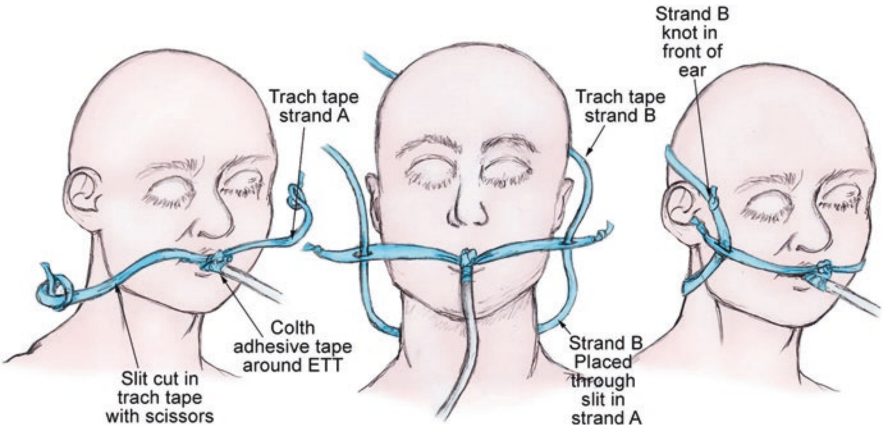



**Fig. 30.6** Method of using umbilical tape harness to secure an endotracheal tube when tape will not stick (Image reprinted with permission from Medscape Drugs & Diseases (http://reference.medscape.com/), 2016, available at: http://reference.medscape.com/article/934173-overview)

Bronchoscopy should be performed as early as possible after suspected inhalation injury (if possible) to assess the airways for evidence of smoke inhalation. During the early phases following injury, findings of edema, erythema, carbonaceous materials, and increased secretions are common. Later, evidence of airway sloughing, bleeding, and obstruction from mucoid plugs may be apparent. The use of nebulized heparin (5000 units q4 h with albuterol) may help reduce the incidence of airway plugging, especially during later phases when bleeding occurs as part of the regenerative process. Pulmonary toilet is essential during all phases of treatment. If a patient has inhalation injury, but is not hypoxic, has no obvious large burns requiring fluid resuscitation, is not going to require fluid resuscitation for other reasons, and is able to clear carbonaceous secretions, a trial of close observation is warranted as it is often better to allow the patient to cough up the secretions than to intubate the patient as this will be both less effective in accomplishing pulmonary toilet and use large amounts of valuable resources.

Resuscitation with crystalloid is an ongoing process for the first 24–48 h following burn injury and must be monitored carefully. Placement of an arterial catheter should be accomplished in the ICU if not previously performed in the trauma bay or operating room. The necessity for a central venous catheter is not absolute provided that redundant peripheral IV access is obtained. In fact, if a patient requires blood transfusions, or large volume resuscitation, large bore IV access allows for more efficient delivery of product than central access (Fig. 30.7). Tape or transparent adhesive strips do not adhere to burned skin, so IV access should be obtained in nonburned skin whenever possible. When required, IV access devices through burned skin may be sewn or stapled to the patient's denuded dermis. This point is especially important prior to transport of the patient where loss of IV access in flight may become life threatening.

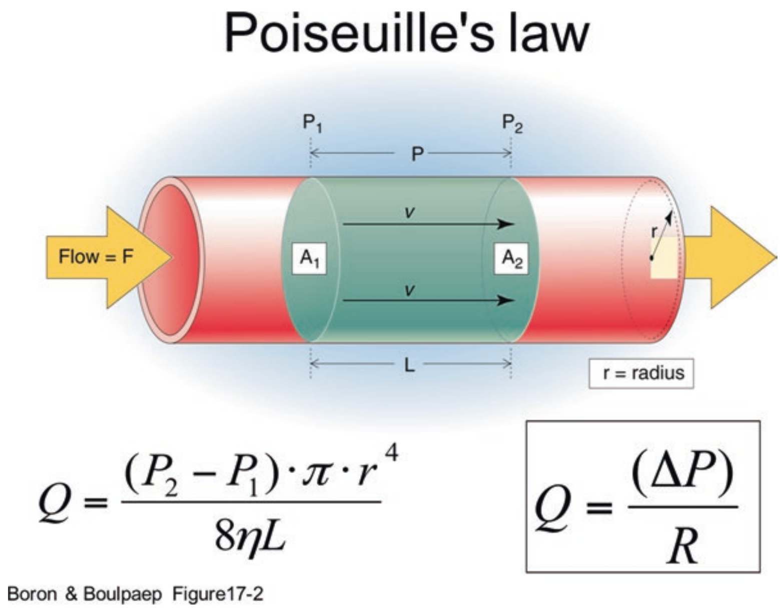



**Fig. 30.7** Representation of Poiseuille's Law demonstrating that short, fat lines are able to deliver fluid faster than long skinny IV catheters (Reprinted from Medical Physiology, Organization of the cardiovascular system, Boulpaep EL, 2017, with permission from Elsevier)

A nasogastric or orogastric tube should be placed early in the resuscitation phase of care to decompress the stomach, especially in the intubated patient being prepared for air evacuation. Securing the nasogastric tube with the use of cotton umbilical tape is preferred over other methods, and attention should be focused on preventing further soft tissue injury from the tie itself. Gastrointestinal prophylaxis with a proton pump inhibitor is strongly recommended. The use of empiric IV antibiotics for burns is not recommended; however, tetanus toxoid booster is very reasonable. In host nationals, tetanus immunoglobulin may be necessary in patients who have never been vaccinated. In the patient with multiple open wounds including open fractures and exposed joints IV antibiotics should be given as would any similar casualty without burns.

Abdominal compartment syndrome is of particular concern in this patient population. In addition to having severe thermal injury, many will have blunt or penetrating intra-abdominal injuries from blast effect or fragments. They also typically receive large volumes of resuscitation over the initial 48 h which increases the risk of developing a secondary abdominal compartment syndrome (ACS). ACS in the burn patient is usually not subtle; a rapid increase in ventilatory pressures coupled with decreased urine output and hypotension is typical and is easily confirmed with measurement of the bladder pressure. The knee-jerk response is usually crash laparotomy, but before reaching for the scalpel, you should consider several possibilities. Secondary compartment syndrome in these patients is often from accumulation of ascites, and this can be quickly confirmed with an ultrasound or a bedside peritoneal aspiration. Paracentesis or percutaneous drain placement will often resolve the problem without resorting to a highly morbid decompressive laparotomy. If the ACS is not due to ascites, then you need to consider the possibility that it is due to severe bowel edema (bad) or to a missed abdominal injury or newly developed abdominal catastrophe, such as dead bowel (worse). Decompressive and exploratory laparotomy should be performed but carries an overall poor prognosis. If a patient develops abdominal compartment syndrome, they are also at high risk of developing secondary extremity compartment syndrome and should be monitored closely for its development. If a striker devise is not available, an invasive arterial pressure monitor connected to a large bore needle may be used as a surrogate to confirm the diagnosis prior to fasciotomy.

## Areas of Special Interest (Face and Hands)

Improvements in combat equipment and uniforms, particularly body armor, have decreased not only penetrating injuries to the torso but thermal injury as well, resulting in sparing of the chest and back even when exposed to extremely high temperatures following an explosion. Likewise, increased use of ballistic eyewear has also reduced the incidence of burns to the periocular region. Unfortunately, the exposed nature of the face, hands, arms, and legs makes them more susceptible to burns, and combat burns frequently involve these areas.

When treating burns of the face, it is important to remember the priorities of trauma management, including airway protection. Although not usually immediate, intubation for airway protection may be required as fluid resuscitation is implemented. The burned tissues of the face, mouth, and tongue are prone to edema and can swell to the point of making orotracheal intubation impossible. It is therefore important to closely monitor the patient for evidence of edema and anticipate the need for intubation (or tracheostomy) before the situation becomes critical.

Hand burns are all too common among combat casualties, although the incidence appears to have decreased as command emphasis on glove wear has increased. Hand burns are associated with long-term disability, and efforts should be made to preserve hand function by minimizing edema with elevation and splinting the hands in a position of safety. Hand and digital escharotomies should be performed if necessary, and any large blisters that are limiting motion (across joint spaces) should be unroofed.

## Transport of the Burn Casualty

Key factors to consider when preparing the burn casualty for evacuation include the ability of the evacuation team to provide the necessary en route care (airway protection, ventilation, continued resuscitation, and pain control), environmental control, and soft tissue protection against further injury and infection. The timing of movement along the evacuation chain is also important to consider. If the option is available, it may be beneficial to complete the first 24 h of resuscitation prior to long-range evacuation. This ensures that this early phase of critical care is completed prior to moving the patient from the relatively controlled environment of the ICU to another staging base or aircraft. Normothermia remains a priority during transport. Working out a custom hypothermia prevention plan is strongly encouraged prior to transport.

## Keys to Success for the Burn Casualty Who Has Nowhere Else To Go

The US military is fortunate to have Critical Care Air Transport Team (CCATT) capabilities in combat theaters, which can safely and expeditiously transport a combat casualty from almost anywhere in the world back to a stateside tertiary treatment facility within 24–48 h in most cases. The deployed trauma surgeon, however, may find himself or herself facing one or more burn casualties who are not eligible for evacuation. These patients generally represent the population who are injured near a US field medical facility and present to you through one manner or another for definitive care. In the case of severely injured burn patients, the decision-making process as to whether to accept and treat the patient is relatively straightforward – you either decide to treat them or decide you are unable to treat them and then provide comfort care.

Recent US experience treating burn casualties in Iraq or Afghanistan who cannot be evacuated has led to clinical practice guidelines (CPG) citing 40–45% TBSA as the largest survivable burn size. There have been exceptions, most often involving pediatric patients or younger adults, who have survived somewhat larger burns largely due to the laudable efforts of a large team of providers who rallied their combined efforts and were not constrained due to overwhelming combat wounded during the time period.

Unlike civilian surgeons, the deployed surgeon must balance many competing priorities while providing care to US forces; coalition forces; national, regional, and local police; US and foreign contractors; host nationals; and prisoners of war (aka enemies of peace). Additionally, deployed surgeons must take into account that battle conditions may change abruptly necessitating "clearing" of the beds to accommodate newly wounded soldiers. For these reasons, wounded American and coalition forces and civilian contractors are continually evacuated to Europe via CCATT, local forces are transferred to local (non-American) military hospitals, and local nationals are given as much care as possible and transferred to local hospitals or home. When more capacity is needed to care for injured soldiers, every effort is made to find a local hospital to care for host nationals, (predictably without burn expertise) which will often result in mortality in non-American burn patients with critical needs at the time of transfer.

When providing definitive burn care in the deployed environment, one must remember that providing the same standard of care that one would in an American burn center will result in deaths as one cannot provide the same level of critical care, available blood is limited, dressing supplies are precious, infection control is rudimentary, supplemental nutrition may or may not be available, and deployed nurses and physical therapists may have variable to no burn experience. Despite these limitations, with determination, and adaptive care, acceptable burn care can be rendered. The key to acceptable care is not doing so much that the patient requires ICU care for prolonged periods of time. If you can resuscitate the patient and do wound care and grafting in small doses, often ICU level care is not necessary, even for large burns. Opportunities for innovation can be rewarding in and of themselves with the end result being a healed patient that will return to their community and speak well of their experience under American care.

When the surgeon – with the support and blessing of the medical unit leadership – decides to undertake the definitive treatment of a burned casualty, the following guidelines and recommendations are offered to assist you in providing the best care possible in what may be best described as suboptimal circumstances. What follows are general philosophies with regard to the definitive treatment of major burns in the deployed setting:

1. When a newly burned patient arrives, take them to the operating room ASAP. This will allow for maintenance of normothermia, adequate analgesia, and evaluation of the burn in a clean environment.
2. Change field lines as soon as possible to ensure the patient has clean lines placed in a relatively sterile environment.
3. Wash all wounds with soap and water or if available Hibiclens solution.
4. Note the size of the burn and try to determine which parts of the burn are superficial partial-thickness (pink and wet dermis), deep partial-thickness (less pink dermis that may be somewhat dry), and full-thickness (white dermis, leathery texture) burns.
5. Wrap with some form of antibiotic salve (silver sulfadiazine, Sulfamylon, bacitracin, or gentamycin ointment all work well) and Kerlix gauze.
6. Resuscitate the patient according to the Rule of Ten.
7. Rewash the patient with soap and water, or Hibiclens, and change the dressings every 24 h and note the evolution of the burn wounds.
8. Wait 2–3 days before making a decision as to grafting. (Partial-thickness wounds can heal on their own, and sometimes wounds that initially look good will look worse 72 h later and need grafting.)
9. Skin grafting is a surgical procedure essential to the survival of the burn patient who has deep partial- or full-thickness burns generally exceeding 20% TBSA. Many surgical specialties include the basic techniques of skin grafting as part of their training programs, but few surgeons perform these as part of their routine practice. Smaller-size burns may be amenable to primary excision and closure of the wound, particularly when the wound allows for an elliptical excision. Larger burns and those which involve full-thickness dermal injury generally require tangential excision of the burn and coverage with a split-thickness graft harvested from uninjured donor sites. Occasionally, a full-thickness skin graft may be required for smaller burns in cosmetically sensitive areas (i.e., face) (Figs. 30.8 and 30.9).

Once the burns have "declared" themselves, excise and graft small portions of full-thickness burn every 3 days until:

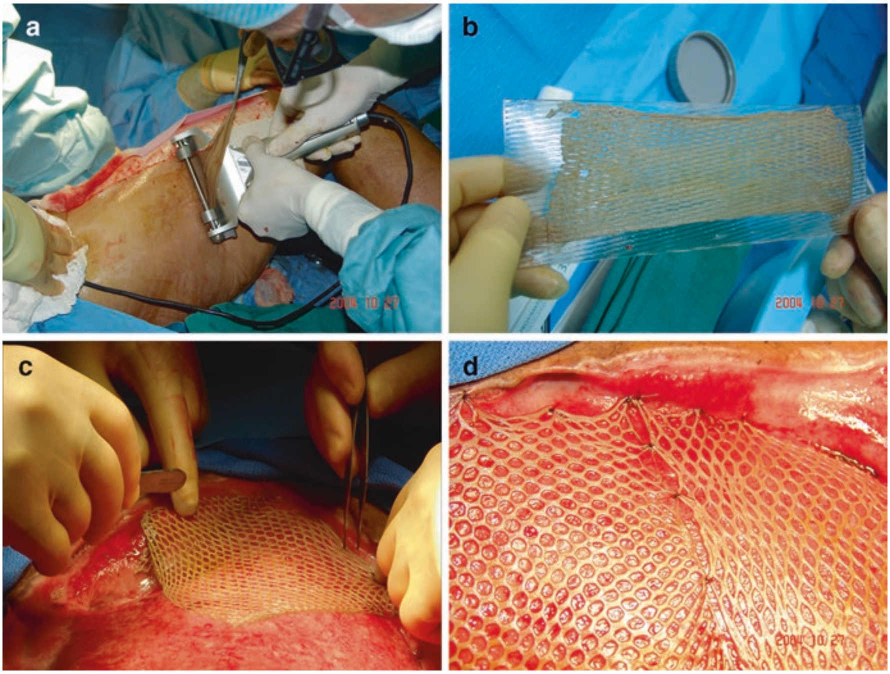


**Fig. 30.8** Split-thickness skin graft procedure. The skin graft is harvested from a donor site using a power dermatome (**a**) or manually. The graft is then meshed to increase the surface area it can cover (**b**) and applied to the wound bed (**c**). Multiple sheets of graft can be secured together and to skin edges with staples or absorbable suture (**d**)

A. All burn wounds are healing and all full-thickness sites are covered with graft. In this situation, the patient will not require critical care, will have full coverage, and can return to their community with clinic visits prn.
B. The patient no longer requires critical care (vent, IVF, abx), and wound care can be accomplished daily in an outpatient setting. In this circumstance, some full-thickness eschar will be allowed to separate from the patient. Under this separated eschar, either new skin will be present or a granulation bed. If a granulation bed is present, this can be grafted in a 2 or 3:1 fashion and will heal without further debridement. If no further grafting can be offered, this wound will eventually heal by secondary intention (contraction), which is not optimal and will lead to scarring and wound contracture, but the patient will live to undergo revisionary surgery at a later date.

In both of these situations, it is assumed that all partial-thickness burns will heal without grafting.

**Fig. 30.9** This Iraqi girl was admitted shortly after a large scald burn. She was intubated for pain control and expected swelling. She was resuscitated and on postburn day 3 taken to the OR for grafting of her chest and abdomen (legs were donor sites.) As she diuresed, she was extubated, and her back wound was allowed to "separate" as an outpatient. With aggressive feeding and daily dressing changes, she healed without further surgery and another ventilator course which saved valuable resources and freed up valuable hospital space

## Helpful Suggestions for Successful Burn Surgery in the Deployed Environment

1. When the decision has been made to debride and graft a burn, debride only full-thickness wounds. Leave all partial thickness wounds to heal with dressing changes.
2. Remember that blood is a precious resource. Wrap extremities tightly with an ace wrap to exsanguinate the extremity, and then use a tourniquet whenever possible prior to debridement. Preparation of the wound prior to excision includes cleansing with an antimicrobial cleanser such as Hibiclens. Excision of full-thickness burns may be accomplished by serial tangential passes of a knife or bladed instrument known by several names, to include Blair, Braithwaite, Humby, or Watson. This bladed instrument allows for tangential removal of the skin, and the ease and efficiency in using it is directly related to the experience of the operator. A power dermatome may also be used to excise burns; however, this process will require an ample supply of disposable dermatome blades, and the efficiency of the process will be related to the power of the dermatome. Alternatively, a bovie cautery may be used. This will often result in excision to the level of the fascia, but is very useful in minimizing blood loss when debriding wounds that are not located in areas amenable to tourniquets.
3. If the fat under the dermis is orange, or there is evidence of thrombosed vessels, excision will need to be taken to the level of the fascia. If graft is placed on questionable or dead fat, it will not survive.
4. If grafting to granulation tissue anywhere, wash with Hibiclens, rinse with NS, and then *lightly* rub with a 4 × 4 prior to grafting. You don't need to remove all granulation tissue prior to grafting. It has a great blood supply and will take grafts.
5. After extremity wounds have been debrided, spray with bovine thrombin, place Telfa Clear, dilute epinephrine-soaked Kerlix, ace wrap, and then release tourniquet. Wait 10 min, then take down gauze and stop any bleeding (there shouldn't be much.) For burns not located on extremities, the procedure is similar except that manual pressure is applied to the epinephrine-soaked Kerlix, and no ace wraps are used. Occasionally suture ligatures and electrocautery may be required after the wounds are unwrapped to help achieve hemostasis prior to placing the autografts.
6. Selection of donor sites is important when planning an operation (Fig. 30.10). I generally harvest skin from lateral thighs, anterior thighs, posterior thighs, lower abdomen, back, medial thighs, below knees (calf then shin), chest, and then anywhere else, in that order. Tumescent fluid (NS without epi) can be injected under skin to be harvested to make harvesting easier. Set dermatome to 10:1000 of an inch. Check depth of blade with bevel of #10 blade prior to use. Use mineral oil liberally. Use epi soln (1amp in 1 L NS) on a lap pad and apply to harvested area immediately after harvesting to stop bleeding. Xeroform gauze is inexpensive, is generally readily available even in remote locations, is easy to apply, and serves as an effective donor site dressing. With good nutrition, donor sites can generally be re-harvested in 10–14 days provided that healing is progressive.

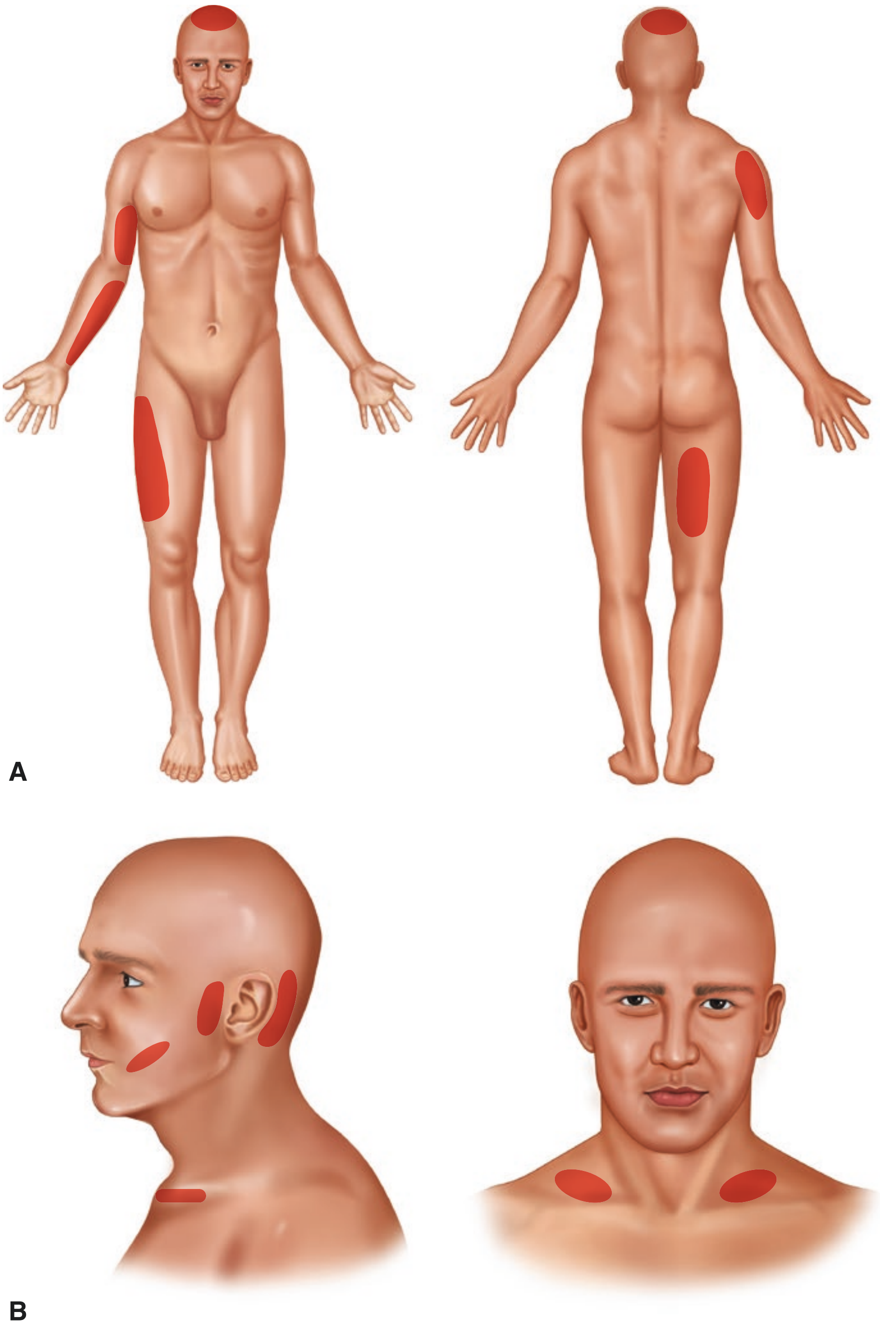



**Fig. 30.10** Donor sites for split-thickness skin grafts (**a**) and full-thickness skin grafts (**b**)

7. Securing of split-thickness autograft to the wound bed can be accomplished with the use of surgical staples, placed intermittently around the periphery of the graft as well as between the seams of adjacent grafts (see Fig. 30.8). Absorbable suture can be used in the same manner. The autograft must be protected during the early phases of engraftment. Dermanet® wound contact layer is a lightweight "veil" material which serves to protect the fresh graft yet allows for coverage with outer gauze or even negative pressure wound dressing. Dressings should typically be left in place for at least 72 h prior to "revealing" and inspecting the wounds.

## Special Circumstances

1. In cases of host national patients with superficial or deep burns of the dorsum of the hands, palms, or fingers or dorsum, soles, and/or toes of the feet, once initial debridement is done, often times these can be managed with a plastic bag dressing. This simple dressing is created by placing the hand or foot in a plastic bag containing Silvadene cream. The bag is then taped around the forearm or shank and can remain for up to a week. With time, the Silvadene will admix with perspiration and form a thick liquid that will bathe the hand or foot continuously. The advantage of this dressing is that it is less resource intensive than a daily dressing change and allows visualization of the healing burn as well as allowing the patient to do range of motion exercises as tolerated (Fig. 30.11).
2. If grafting of the face is required, sheet grafts have better cosmetic outcome and tend to have less contracture formation in the long term (Fig. 30.12).
3. In extreme cases of extensive full-thickness burns, amputation of the affected body part may be a necessary form of excision, especially if the injury appears to have destroyed the underlying tissue down to and including the bone. This situation is most commonly seen with high-voltage electrical burns.

Infection is the major factor associated with mortality of the burn casualty during the subacute phase of hospitalization. Patient survival is often directly related to the prevention, identification, and treatment of systemic infections associated with the burn wound. Additionally, the importance of implementing strict infection control practices for burn patients has implications beyond the individual patient. Many times the infections experienced by burn patients are multidrug resistant, thereby creating a pool of organisms which can be transferred to other patients in the hospital.

Burn centers capitalize on the importance of an interdisciplinary team to improve patient outcomes, and the deployed medical treatment facility is often able to utilize the same approach to care due to the cohesive and cloistered nature of the field hospital. Crucial to the effectiveness of the multidisciplinary team is the commitment and "buy in" from the individual members of the team. Recent experience gained by deployed US military medical units has confirmed this truth as units have rallied together to provide an unprecedented level of care for many host national civilian burn survivors who would have otherwise received little or no care.

**Fig. 30.11** Use of this "plastic bag dressing" allowed for range of motion exercises and daily inspection of the wound while using minimal supplies

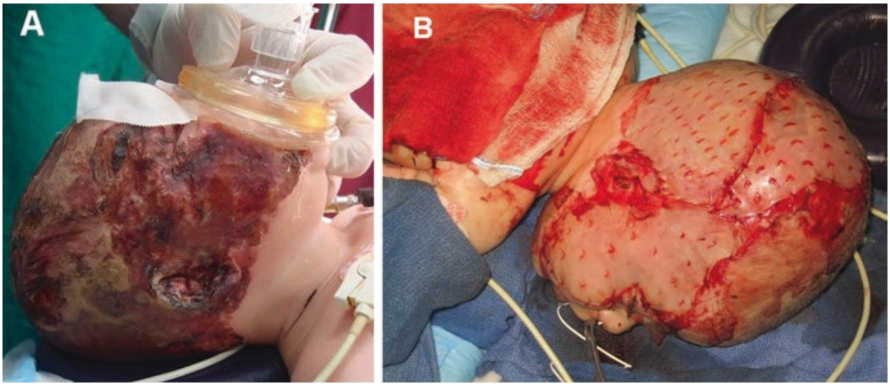



**Fig. 30.12** This Iraqi girl required extensive sheet grafting of her face after her parents used gasoline in a kerosene heater resulting in a large explosion and resulting fire. Initially cared for in an Iraqi facility, she came to us on postburn day 7. She was debrided to granulation tissue, and skin from her back was harvested and used for sheet grafting. Her ear was debrided to viable cartilage and closed primarily

## Final Points

Thermal injury can be devastating to the patient's entire homeostatic mechanism. Thermal injuries often affect multiple organ systems simultaneously requiring a comprehensive approach to acute management. Always remember that thermal injury is a form of trauma and when sustained from an explosion is often accompanied by other severe injuries which may be more life threatening than the burn itself. Infection control is a key factor for all burn patients.

Burn casualties benefit from early evacuation to a burn center where definitive treatment including surgical critical care and rehabilitation may be initiated by a multidisciplinary team. Early communication with the burn center is encouraged, and in the case of US military burn casualties, this can be accomplished easily by contacting staff at the USAISR Burn Center (see below), who are readily available to provide consultation and coordination for future evacuation. Remember that the incredible work of so many dedicated professionals has resulted in a system that is able to provide a continuum of state-of-the-art burn care for combat casualties. From the point of injury on a faraway battlefield all the way back to a stateside burn center, the outcome of these patients depends on you being a strong link in the chain of survival.

*US Army Institute of Surgical Research Burn Center.*

(210) 916-2876 or (210) 222-BURN

DSN (312) 429-2876

burntrauma.consult@us.army.mil

## Civilian Translation of Military Experience and Lessons Learned

**Key Similarities**

1. The care of US service members and coalition forces will almost always end in success with patient survival exceeding 90%.
2. Initial resuscitation, wound care, and transfer to CONUS burn centers closely parallel burn care within the USA.
3. As with any trauma patient, any burn patient must be treated for other life-threatening injuries (such as hemorrhage, intracranial injury, and fracture stabilization) prior to focusing on the burn.

**Key Differences**

1. Care of non-coalition forces and host nationals is very different from the care of burn patients in burn centers across the USA.
2. Survival of non-coalition forces and host nationals depends on optimizing limited resources and not doing “too much” burn care at one time.
3. Keys to survival in non-coalition forces and host nationals include adequate early resuscitation to reduce burn penumbra, allowing a burn to “declare” itself, adequate nutrition, and grafting full-thickness burn in small aliquots until healed.

Care of burn patients in war can be challenging. US and coalition forces have optimized triage, resuscitation, evacuation, and transport mechanisms that have allowed for the salvage of even the most burned (>90% TBSA) soldiers, airmen, sailors, and marines. Their care is very similar to the care of patients in the USA, and given that the vast majority are young and healthy at the time they are injured, they tend to do particularly well, even after suffering a major burn, in addition to other penetrating and blunt life-threatening injuries.

Particularly difficult is the burn care of non-coalition forces and host nationals (civilians). The reasons it is difficult to care for these individuals are multifold. Often, they are chronologically or metabolically very young or old. The prevalence of parasitic infections combined with a little to no protein diet ensures that they are always malnourished at baseline. Care that can be rendered by forward surgical teams is in competition with care given to US and coalition forces (primary mission) and is basic at best. Care given at the theater hospital level can be more extensive so long as the primary mission is met, but can be quite challenging. Survival in these patients depends upon several principles of care.

Firstly, these patients need to be managed as any other trauma patient. Do not focus on the burn. Once cavitary hemorrhage and fractures have been ruled out or ameliorated, the burn can be of primary concern. Secondly, if these patients have a major burn that is survivable, they need to be resuscitated adequately including ventilation when necessary. Thirdly, for the next several days, these patients will need dressing changes to determine if the burn is partial or full thickness. Fourthly, graft only full-thickness burns, in small aliquots so that they can be weaned from ICU care as soon as possible. This is particularly important because if the hospital needs beds, these patients will be moved to a host national hospital where burn care is not available and no ICU care is available and, if they have ICU needs, will likely die. Fifth, these patients need adequate nutrition. If they are not able to eat, they will need supplemental (nasogastric or nasoduodenal) feeds until they can eat to aid in wound healing. Finally, if a patient has more than a 50% TBSA full-thickness burn, and there are limited beds and resources, consideration for comfort care may be reasonable. I have personally cared for host national patients with burns that exceed 50% TBSA, and some have survived. I have also made several of them expectant upon admission. It is always a difficult decision. I would recommend it be made with the help of other medical professionals so that you can be sure that all potential avenues have been explored, and you can be as certain as possible that you are using sound judgment.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army/cpgs.html

1. Burn care.

# 31 The Pediatric Patient in Wartime

Lucas P. Neff, Philip C. Spinella, Kenneth S. Azarow, and Mubeen A. Jafri

**Deployment Experience**

| | |
|---|---|
| *Lucas P. Neff* | Staff Surgeon, Craig Joint Theater Hospital, Bagram, Afghanistan, 2013 |
| *Philip C. Spinella* | Medical Intensivist, 31st Combat Support Hospital, Baghdad, Iraq, 2004–2005 |

*Do what you can, with what you have, where you are.*

Arthur Ashe

*War is the only game in which it doesn't pay to have the home court advantage.*

Dick Motta

Just when you thought you were getting comfortable with combat trauma, an injured child rolls into your trauma bay. The pulse is 180 – can't remember if that's normal for this age or not. Don't have a small enough blood pressure cuff, but you think you might be feeling a femoral pulse. The nurses are frantically searching for IV access, and the ER docs are trying to figure out if they have a small enough endotracheal

L.P. Neff (✉)
David Grant Medical Center, Department of Surgery, Travis AFB, CA, USA
e-mail: lpneff@gmail.com

P.C. Spinella
Department of Pediatrics, Washington University in St. Louis, St. Louis Children's Hospital, Department of Pediatrics, St. Louis, MO, USA

K.S. Azarow • M.A. Jafri
Doernbecher Children's Hospital, Division of Pediatric Surgery, Portland, OR, USA


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**Fig. 31.1** Local children greeting a US military convoy in Iraq

tube to intubate. The flight medic had been bagging way too fast and the $O_2$ sats are tanking. The belly is hard as a rock. What's the dose of ketamine? Nothing can throw you off of your game like a severely injured child, and the smaller the child, the larger the difficulties and anxieties. The reality: You will see pediatric trauma. The mind-set: I will be prepared for pediatric trauma.

Throughout our nation's history, military physicians have endeavored to care for civilian casualties. Perhaps the most innocent and heartbreaking of these victims are children. Some of the most famous military surgeons of their time have documented their experiences in caring for children – whether after combat-related injury or accidental trauma – or for non-traumatic disease because no other option exists. Dr. Leonard Heaton took care of children that were injured as innocent bystanders at Pearl Harbor. Dr. DeBakey cared for injured children in the European Theater during World War II. Current and future conflicts have been and will continue to be no different (Fig. 31.1).

Recent data from our current conflicts in Southwest and South-Central Asia reveals that 5–30% of all inpatient beds in current combat operations were being filled by children. There are generally three routes of entry into a military care facility for children: as "collateral damage," "combatants" in an enemy encounter, or children brought in with surgical or medical disorders and cared for as part of a humanitarian effort. This chapter will deal with critical issues concerning children with traumatic injuries in an austere combat environment. In the civilian world, less is more. Nonoperative management of most pediatric trauma has become standard over the past 30 years. However, the setting and nature of wartime injuries often does not offer the combat surgeon the luxury of watching and waiting.

**BLUF Box (Bottom Line Up Front)**

1. You will encounter severely injured children of all ages, and you will have to manage them.
2. Pediatric trauma patients ARE just small adults – the primary evaluation and concerns are the same.
3. Ensure you have the basics on hand and labeled for easy access – pediatric peripheral and central IV catheters, endotracheal tubes, and nasogastric/urinary tubes. Almost everything else can be improvised.
4. A Broselow tape will be your best friend – have them in the ER, OR, ICU, and wards.
5. In the OR, focus on blood loss and heat loss. A few lap pads full of blood can be exsanguination in a child, and they will get cold if you don't use warming techniques.
6. Understand your Clinical Practice Guidelines and how they have been applied to kids in the past – no sense in reinventing the wheel.
7. Be ready to deviate from your normal methods of establishing vascular access.
8. Assume that every child is chronically malnourished and make definitive management decisions that will "fail well."
9. Be thinking about ultimate disposition of that child at the outset – make sure you are making decisions for the austere environment. That child will have to survive on the local healthcare economy long after you leave.

## Intravenous Access

Unlike the adult population, attaining two peripheral IVs can be an enormous challenge in some children, and central access may be technically easier. Have your best IV personnel (usually nurses and/or anesthesia providers) ready for any incoming pediatric casualties. Remember the scalp veins may be the easiest access in a baby. If this fails, then you have three options – central line, venous cutdown (usually saphenous vein), or intraosseous line. Current combat teaching is that an intraosseous placement is a safe and reliable method for access in children of all ages and should not take longer than 10 s to achieve. This maneuver is a standard part of pre-deployment war surgery courses. Don't blow it off. Know how and where to insert an IO. Intraosseous sites in infants and toddlers include the anterior tibia

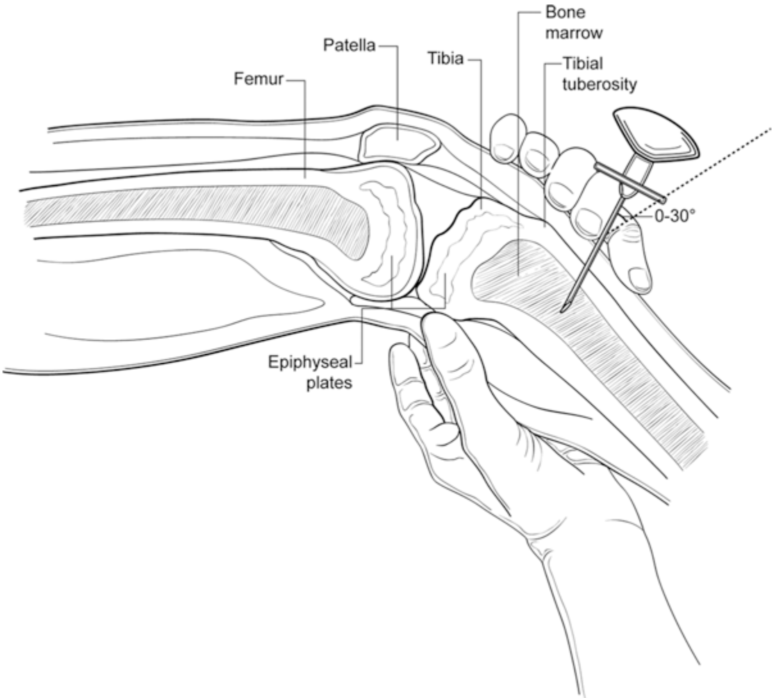


**Fig. 31.2** Technique for placement of an intraosseous catheter

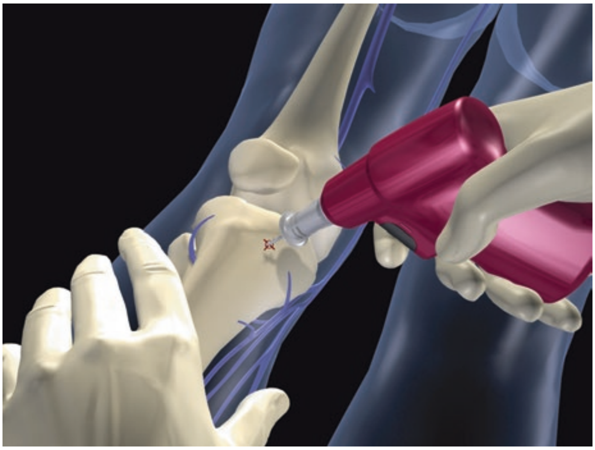

**Fig. 31.3** Placement of the EZ-IO catheter in the anterior tibia utilizing the included power drill (Image courtesy of Vidacare Corporation, San Antonio, TX)

below the tuberosity, distal femur, proximal humerus, iliac crest, and the sternum. *The anterior tibia should be your first choice* in children and the technique is shown in Fig. 31.2. If that fails, then try the anterior distal femur next. There are now several excellent military kits available for both children and adults, including the EZ-IO (Vidacare Corp.) system that uses a power drill for placement (Fig. 31.3).

If an intraosseous catheter kit is not available, a strong (18-gauge) short spinal needle may be substituted. You can use this catheter as you would any central line, but it should be removed within 24–48 h.

Femoral, subclavian, or jugular percutaneous access can be safely placed and act as longer-term access after the resuscitation. The use of ultrasound guidance has made central access technically easier and more reliable. In the emergency setting, the subclavian or femoral veins are easiest to access. However, it is true for all lines that the smaller the child, the higher the complication rates in the form of misplacement, pneumothorax, and hemothorax. In children less than 2 years old, you should avoid the femoral area if possible due to the risk of vein obstruction or devastating injury to the femoral artery. After all, misadventures in vascular access and an occluded SFA are the last things you need to be dealing with. Another good option in an emergency situation is a direct cutdown, but remember that these sound easier than they are. You need good lighting and exposure and wear magnifying loupes if you have them. Saphenous cutdown in the ankle is technically easier and faster than in the groin in children (Fig. 31.4), but both can be effectively used. Either EJ or IJ cutdowns are excellent options as long as the neck is available during the trauma resuscitation. Remember to remove the cervical spine collar if they don't have a mechanism that warrants having one in place – it just makes everything harder.

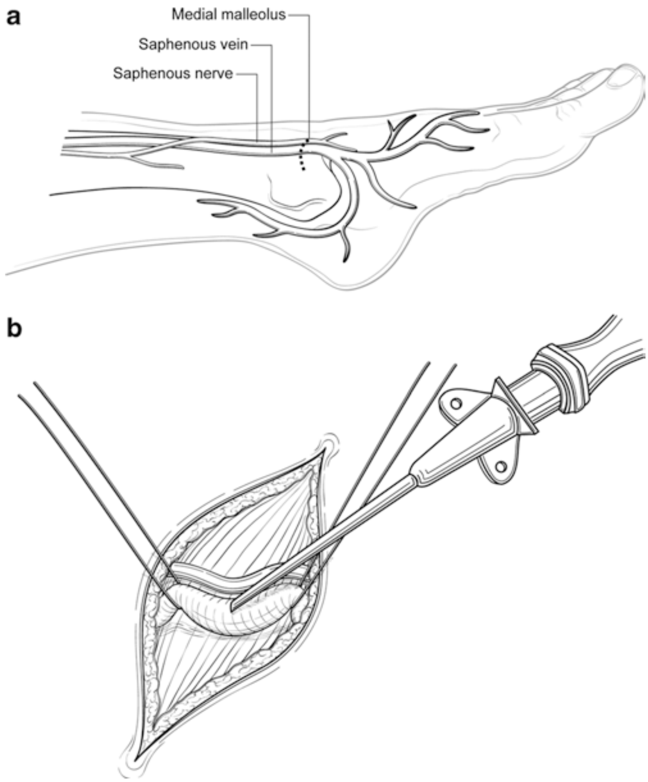


**Fig. 31.4** Technique for saphenous vein cutdown. (**a**) Neurovascular anatomy of the distal lower extremity. (**b**) proximal and distal control of the Saphenous vein is achieved with simple free ties placed around the vessel and allows the vein to distend enough to accept an angiocatheter

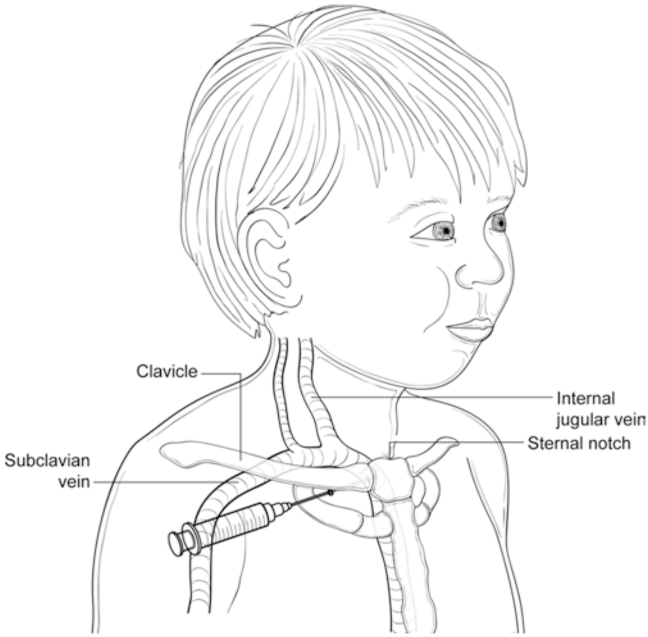


**Fig. 31.5** Technique for subclavian central line placement in infants and children

Technical considerations to enhance success at IV access include proper-sized angiocatheters, knowing the anatomy of the venous architecture, and knowing the developmental changes that occur throughout childhood. The use of predetermined-size algorithms to determine appropriate equipment sizes (Broselow© tapes) in the trauma bay is invaluable during a pediatric trauma resuscitation. Either too small (24 gauge in a child over 2 years of age) or too large (20 gauge in children under 1 year) will lead to failure and frustration. When in doubt, 22-gauge IV will be adequate for the distal saphenous vein of most toddlers and full-term infants. When dealing with percutaneous central venous access, there are several technical considerations to remember. The standard j-tip guide wires may not pass into the vein easily, and reversing the wire to use the straight end carries a risk of perforation. In these cases, the 0.018″ floppy-tipped wires and 20G introducer needles found in the 5Fr arterial access micropuncture kits are the perfect solution because they are essentially the same kits that are used for pediatric central venous access. The external jugular vein can be an excellent access point and requires only a superficial cutdown and careful placement technique. The most important advice with placement of these central lines is to use very slow and gentle motion of the needle to access the vein; otherwise, you will go through the back wall. For subclavian lines, make your skin puncture site more medial than you would for an adult, and direct the needle through the space between the clavicle and first rib. You will hit the larger subclavian/jugular junction or innominate vein much more reliably than trying for the mid or distal subclavian vein (Fig. 31.5). Small, rugged point-of-care ultrasound machines can be found in virtually every downrange medical treatment facility. They will prove to be an invaluable adjunct in vascular access.

## Special Considerations in the ER

The overall triage, evaluation, and resuscitation priorities are *the same* in children as they are in adults, but there are a few major anatomic and physiologic differences that need to be appreciated. Children have large heads and tongues as well as fore-shortened airways. This makes airway occlusion due to the tongue a much larger issue in the pediatric patient population. Bradycardia during intubation in children is well described, and you should either administer atropine (0.1–0.5 mg IV) during induction or have it standing by. The trachea is very short, making right mainstem intubation and inadvertent extubation very common events. Verify the correct position of the tube, and then SECURE it tightly. For children that have been crying or receiving bag-mask ventilation, while en route, the surgeon should be keenly aware of gastric distention and its cardiopulmonary effects. In a chaotic prehospital environment, there is risk of inappropriate ventilation (too fast and too much volume) by the providers that will distend the stomach and reduce the functional residual capacity. The resulting hypoxia and bradycardia may lead to a viscous cycle of more aggressive ventilation and cardiac arrest. In these situations, be mindful that gastric decompression may be a lifesaving maneuver – especially when things are going downhill in the trauma bay and not really making sense.

While the head and airway presents the most important anatomic consideration, the most important physiologic issue concerns estimating the degree of shock. Children are able to maintain blood pressure while significantly dropping cardiac output due to an enhanced heart rate affect and the tremendous elasticity/reactivity of their peripheral vessels. The result is that they will not drop their blood pressure until the last possible moment before cardiovascular collapse. Bradycardia is an ominous sign and usually indicates severe hypoxia or that arrest is imminent.

Evaluating the abdomen in a pediatric patient can be quite challenging, and supplemental imaging and/or surgical exploration should be performed when indicated in all trauma patients. Ultrasound images are typically excellent in children but may be compromised by gastric or bowel distension and patient motion. In adults, the FAST exam is used to identify hemoperitoneum or pericardial fluid in the hypotensive patient to guide the next step in management. Given the ability to maintain vascular tone, the absence of hypotension doesn't mean that pediatric patients don't have a surgical abdomen. Consider an initial FAST exam even if they seem "metastable" and then decide on surgery versus additional imaging (CT) or observation. CT is the gold standard for identifying abdominal injuries and should be used liberally if there has been abdominal trauma. Discuss a protocol with your radiologist to minimize radiation exposure while still obtaining adequate images. A missed injury is much more of a concern than a theoretical increase in cancer risk decades later. Screaming children will usually have significant gastric distension which can mimic an acute abdomen. If you haven't already done it, place an NG tube and repeat your exam.

The management of pneumo- and hemothorax is similar to adults, with two additional challenges. The first is selecting an appropriate-sized chest tube. Very small tubes are fine if you only have air to evacuate, but larger tubes (at least 20 French) should be used to evacuate blood. The second challenge in placement is tube location. For infants and small children, it is physically impossible to put your finger or even a Kelley or tonsil clamp into the pleural space to assist in directing the tube during insertion. Most small tubes come with malleable trocars with a sharp chamfered tip to assist in placement; I recommend removing the trocar if you are not familiar and comfortable with it. If using the trocar, a cutdown technique is still advisable as most surgeons are far more familiar with that method than the percutaneous chest tube placement. To assist with accurate placement, pull the trocar back 1 cm so that the sharp point is located within the tube and then perform cutdown on top of the rib as normal. The trocar now functions as a stylet and adds rigidity and can then be used as a steering mechanism to guide the tube into any part of the thoracic space desired. Keep in mind that it is still possible to injure the lung or mediastinal structures during tube placement.

Over the last several years, many pediatric trauma centers have adopted massive transfusion protocols that are similar to those used in adults. A 1:1:1 ratio of PRBCs to FFP to platelets is becoming standard, despite the fact that there isn't really any good data to suggest that it is beneficial in children. Nevertheless, it makes intuitive sense and is generally accepted. Providers caring for injured kids must be aware that the volumes used in creating these ratios are not in "units" of blood product like the adult studies describe. The volumes for children are all weight-based and calibrated in cubic centimeters. As an estimate 80 cc/kg is considered one total blood volume in a child. Remember that while 200–400 cc blood loss in an adult is not of major concern, in a small child, this can be exsanguination. *Pay attention to your blood loss, including lap sponges, and don't get behind!* Begin by administering products in boluses of 10 cc/kg for both packed red blood cells and plasma. Platelets can be administered at 10–15 cc/kg or one single donor unit per 10 kg of body weight. In the exsanguinating and coagulopathic child, Factor VIIa can be administered at a dose of 90–120 mcg/kg, with one to two repeat doses as needed. Thinking "outside the box" with whole blood, cryoprecipitate, and TXA is also necessary. The only two prospective studies to compare whole blood to components have been performed in children, and both indicated improved outcomes with whole blood. A retrospective series of tranexamic acid (TXA) given within 3 h after injury for severely injured children did suggest a survival benefit. No adverse complications from TXA were reported. There are no weight-based TXA dosing guidelines for these situations. Simply administer 1 g over 10 min and then another gram over 8 h.

The indications for tourniquet use are the same in children as in adults. The CAT tourniquet is the most commonly fielded extremity tourniquet used by US forces. It can be adjusted to fit children and should be thought of early in the course of care to minimize blood loss. Attempt to remove the tourniquet and restore perfusion as soon as possible. An understanding of the exact time that the tourniquet was applied is essential to avoid nerve injury, deep venous thrombosis, compartment syndrome, and the possibility of limb loss.

Performing invasive or painful procedures on injured children often requires sedating agents. If there is any doubt about the airway, the safest approach is to intubate and then administer sedation as needed. In the child who does not require intubation, ketamine is a fast-acting hypnotic that provides excellent short-term sedation for procedures such as laceration repair or fracture reduction/stabilization (dose 1–1.5 mg/kg IV, 4 mg/kg IM). We recommend giving a low dose of benzodiazepine also to minimize emergence agitation. Ketamine in children is a potent sialogogue; the use of atropine or glycopyrrolate can help decrease excessive oral secretions.

## Special Considerations in the OR

Preparing the trauma OR for infants and children is critical. While keeping the patient warm is essential for all trauma patients, infants are particularly susceptible to their environment. This is where the increase in surface area to body size for infants really comes into play. If not controlled for, the resultant hypothermia not only leads to coagulopathy but will result in cardiorespiratory insufficiency due to the enormous increase in metabolic demand required by the body to maintain a normal temperature. Bear huggers and warming devices are very useful; however, often there is no substitute for keeping the room as warm as possible regardless of how uncomfortable it may be for the surgeon and OR personnel. Do not expose the child until you are ready to prep and drape.

Incisions in small infants and toddlers can be challenging. The standard midline incision for trauma laparotomy is always safe and can be utilized to achieve exposure for any part of the abdomen. However, exposure for certain areas can be improved by avoiding the midline approach. Injuries to the liver, spleen, kidney, and retroperitoneum can be more easily approached via a supraumbilical transverse incision in children under 2. The downside of this incision occurs as children get older; the pelvis becomes more difficult to reach. If the nutritional status of the patient is in question, it is best to err on the side of the transverse incision as the incidence of dehiscence and evisceration is less. Appropriately sized self-retaining retractors also greatly assist with exposure. Many standard self-retaining systems have pediatric and infant attachments to allow the procedure to take place on any OR table.

Intraoperative management of specific injuries is very similar to that utilized in adult trauma. Solid organ salvage depends upon the physiologic circumstances and degree of injury that the patient has sustained. Never compromise patient safety in order to preserve the spleen, but a more aggressive approach to splenic preservation in children under 12–14 years old is warranted – especially given the fact that prompt treatment of future post-splenectomy infections is unlikely in the host nation healthcare system. If you are in damage control mode or the patient is unstable, take the spleen. If the patient has a severe associated brain injury, it is also better to remove the spleen rather than risk subsequent rebleeding and hypotension. Otherwise, you can proceed with a splenorrhaphy procedure based on the injury type. Fully mobilize the spleen to the midline for control and to assess the injury. The simplest, all-purpose method is to wrap the spleen with an absorbable mesh. An alternative technique is to form the mesh into a bag and use a purse string suture to close the “mouth” of the bag around the hilar vessels. If you don’t have mesh, you can harvest a large square of peritoneum from the abdominal wall or use omentum to plug the laceration or wrap the spleen. Fortunately, the thicker capsule of the spleen in children allows better purchase for sutures. A similar mesh wrap technique can be applied to liver injuries after full hepatic mobilization as described for adults. Ensure that post-splenectomy vaccinations are given prior to discharge or transfer – do not wait 2 weeks or some other arbitrary interval!

You should also consider an attempt at splenic preservation with isolated injury to the pancreatic tail that requires a distal pancreatectomy. This should be limited to stable patients with no other major injuries or physiologic disturbance. The technical difficulty of this procedure is in peeling the pancreas off of the splenic vein. You will encounter multiple small branches that require clips or ligation, and take great care to avoid excess manipulation or narrowing of the splenic vein. Transect the pancreas first, and then work from proximal to distal to free it from the vein. If you encounter significant bleeding or injure the splenic vein, then just proceed with splenectomy.

The remainder of abdominal injuries should be managed similar to the adult patient. Watch your operative time and perform temporary closure as a damage control measure or if a second-look operation is indicated. Monitoring for abdominal compartment syndrome is more difficult in children due to their pliable abdominal walls. Children will demonstrate minimal physiologic changes as the abdominal pressure rises until it hits a critical point, which will be followed by rapid and severe decompensation. Significantly rising abdominal pressures should prompt early intervention even without the classic signs of full-blown compartment syndrome.

Vascular injuries can also be managed in damage control fashion with selective ligation or the use of shunts and eventual plan for autologous vein construction after the child stabilizes. As with tourniquet use, the management of a vascular injury or mangled extremity should prompt serious consideration for decompressive fasciotomy. This is especially true for intubated or preverbal children that cannot vocalize the clinical indicators of increasing extremity compartment pressures. At the bedside, the more generic indicators of agitation, anxiety, and increasing analgesic requirements (the “three As”) are likely to be seen. Maintaining a high index of suspicion and having a low threshold to perform a thorough and complete release of all fascial compartments in the affected extremity is essential. This involves standard volar and dorsal incisions of the forearm and the medial and anterolateral incisions of the lower leg. Dress the incisions with vacuum-assisted closure devices to facilitate eventual closure, to minimize painful dressing changes, or to prepare the wound for possible skin grafting.

When resuscitation is complete and it is time to go back to the OR for continued surgical management or definitive reconstruction, your management decisions should be guided by this basic assumption: all of these children are chronically malnourished before injury and even more so after injury. Deciding on how to definitively manage a patient will be much different than a US combat casualty. A thoughtful approach is necessary to provide a good long-term solution. This is especially true for limb salvage and creation of stomas or enteral feeding access. Consultation with host nation medical providers that can give insight into the cultural attitudes and living conditions and healthcare system “outside the wire” will help surgeons make definitive management decisions that will benefit the patient and their family in the short and long term (Fig. 31.6).

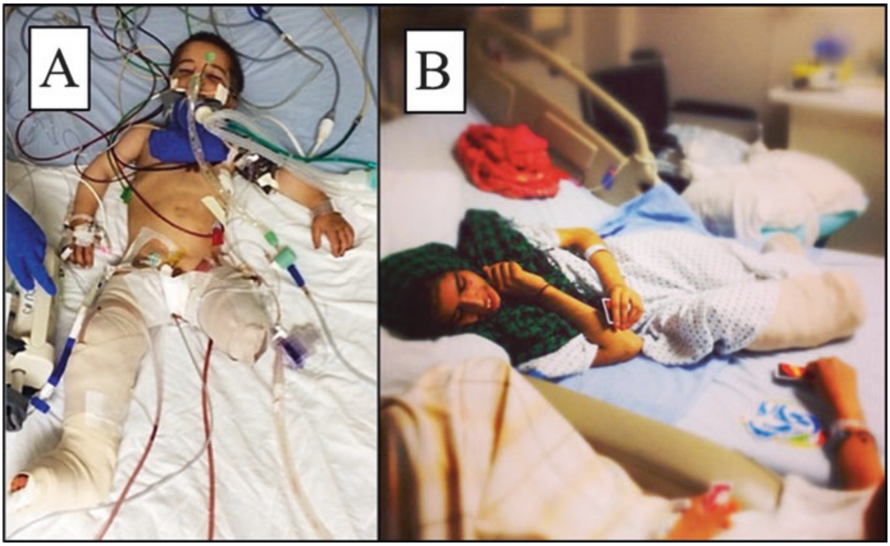


**Fig. 31.6** Afghanistan is one of the most heavily landmined countries in the world. Children are often the victims. (**a**) A 3-year old treated at a deployed military treatment facility. (**b**) A young Afghan teenage female with bilateral below-knee amputations recovers in the US military hospital

## Special Considerations in the ICU

The principles of mechanical ventilation in children are the same that are practiced in adults. The goals are to provide an adequate amount of oxygenation and ventilation to meet the child's metabolic needs while minimizing ventilator-induced lung injury. This often means the goals of oxygenation and ventilation are not to achieve "normal" partial pressures of oxygen and carbon dioxide but instead practicing permissive hypoxemia and hypercarbia. This concept is similar to "damage control surgery" and as such has been referred to as "damage control mechanical ventilation." In general these permissive or damage control principles allow for the $pO_2$ to decrease to the 50–60 Torr range as long as there is no clinical evidence of ongoing oxygen debt or shock evidenced by increasing lactate and allow the $pCO_2$ to increase to the 50–90 Torr range as long as the arterial pH remains above 7.2. Target a tidal volume of 5–7 ml/kg and provide enough PEEP to achieve an open lung strategy with higher respiratory rates to compensate for lower tidal volumes. The only ventilator settings that are age specific are the *respiratory rate and the inspiratory time*. The appropriate rate may be between 30 and 40 breaths/min for neonates and infants, which requires the inspiratory time to range between 0.5 and 0.6 s. It is important to understand that there are no limits to ventilatory pressure in children. If a child needs additional PEEP or tidal volume, it should be applied. If the prone position is used in a child, it is extremely important to secure the airway and all vascular access when turning the child. If the child has a critical airway, it is reasonable to secure the tube to the child's teeth with wires to prevent excessive movement or dislodgment.

Since the diameter of a child's airway is smaller, they do become obstructed more easily. Additional pulmonary toilet measures are often needed. In addition to frequent chest physical therapy, nebulized mucolytics such as N-acetylcysteine, DNase, and 7.5% hypertonic saline with albuterol may be required. Another useful method of clearing an endotracheal tube of thick secretions is to use a 1:1 volume mixture of saline and bicarbonate solution to lavage and then suction the airway. The base solution is able to break up the thick secretions and allows for airway clearance with suctioning.

The approach to septic shock is different than in adults since the response to overwhelming infection is altered. The majority of children develop cold shock, (decreased myocardial contractility with reflexive increased systemic vascular resistance) rather than warm shock (decreased vasomotor tone). After the initial rapid volume resuscitation with crystalloids, dopamine or epinephrine at beta agonist doses are initiated to improve contractility. For children in cold shock with adequate intravascular volume, afterload-reducing agents such as dobutamine or milrinone can be used. For children who are in catecholamine-resistant septic shock, hydrocortisone should be added (2–5 mg/kg/day either divided in q4–6 h dosing or as a continuous infusion).

All sedatives available for adults can be used in children. The only agent that needs special attention is propofol. Propofol infusion syndrome causes a fatal metabolic acidosis and is also associated with cardiac dysrhythmias, renal failure, rhabdomyolysis, and elevated bilirubin. It has been associated with the use of propofol in children with higher doses and *when used for days*. If alternative agents are not available for deep sedation, these propofol risks must be communicated to all staff caring for the child, and frequent monitoring for acidosis is required.

The etiology of seizures in children that are evacuated to a combat support hospital after an acute injury is likely to be related to traumatic brain injury or as a consequence of hypoxic ischemic injury. Hypoglycemia, hyponatremia, and other electrolyte disturbances should always be immediately ruled out as the cause of seizure. The differential diagnosis should also include meningitis, epilepsy, hypertension, and drug ingestion or overdose. A rapid-acting benzodiazepine such as lorazepam (0.1 mg/kg IV) or diazepam (0.2 mg/kg IV) should be administered intravenously as a first-line therapeutic agent if continued tonic-clonic seizure activity persists beyond 1 min. If the seizure persists beyond several minutes, repeat dosing of rapid onset benzodiazepines is indicated. If seizures recur or persist in the minutes that follow infusion of first-line agents (benzodiazepines), second-line therapy is indicated. Second-line agents include intravenous administration of phenytoin (18–20 mg/kg), fosphenytoin (15–20 mg/kg), or phenobarbital (15–20 mg/kg). If phenytoin is administered, the rate should not exceed 1 mg/kg/min due to the risk of fatal dysrhythmias.

As with adults, the initiation of nutrition as early as possible will lessen the intense catabolism seen in children after extreme physiologic stress. Considering the endemic protein-calorie malnutrition and vitamin/mineral deficiencies in these countries, there is virtually no nutritional buffer. Enteral feeding is preferred, but not always an option. Depending on the care environment, parenteral nutrition may be available and provide a bridge over several days until the gut can be used. Even with maximum attention paid to nutritional optimization, expect delayed wound healing and slower recoveries than you would normally anticipate.

## Humanitarian and Non-trauma Care

One of the most rewarding aspects of providing surgical care in austere environments is being able to positively impact the health of the local community. In addition, the fastest and most effective way to win the "hearts and minds" of the local population is to care for their children. Despite what you may be told about this not being "your mission," it is an important and near-universal function of the deployed physician. However, you must always strike a balance with your primary mission (military trauma care) and your capabilities. This cannot be overstated: irrespective of your clinical capabilities, the deployed surgeon must be thoughtful about the environment that you will send these children out into (Figs. 31.7 and 31.8).

Although you may be able to do an incredibly complex reconstructive procedure, the required rehabilitation and follow-on care may not be available. Thus, sometimes a simpler but less optimal plan may be better than what you would typically consider the "gold standard." For example, a child is brought in with a large

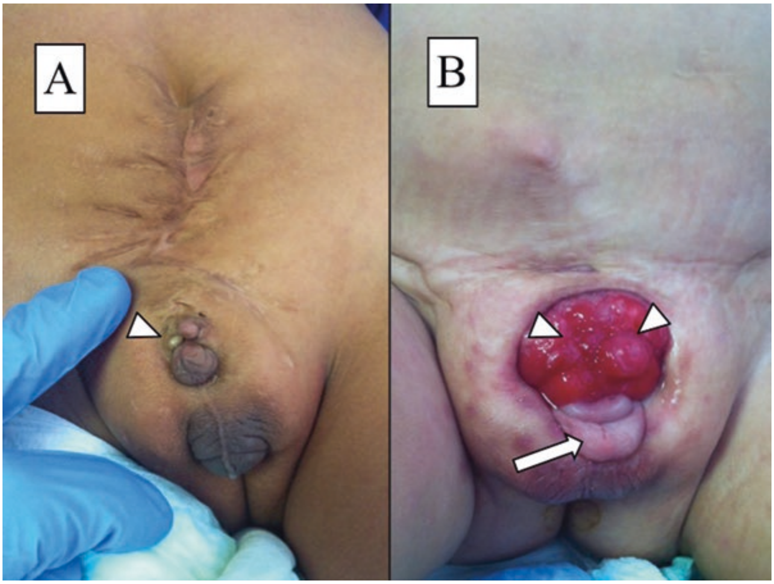


**Fig. 31.7** (**a**) A 7-year-old Afghani with ambiguous genitalia vs. microphallus (*arrowhead*) and incontinence following a bladder exstrophy repair in Pakistan at 6 months of life. Karyotype analysis was performed at a USAF hospital in Germany demonstrated XY sex chromosomes. This facilitated genetic counseling with the parents. No surgery was offered. (**b**) A 4-year-old Afghani child with previous failure of bladder exstrophy and epispadias (*arrow*). The ureteral orifices were visible (*arrowheads*)

**Fig. 31.8** Neonate with myelomeningocele (*arrowhead*) and encephalocele (*arrow*) brought to a military treatment facility for evaluation. No treatment was offered

abdominal mass and hematuria. This is obviously a Wilms' tumor. To resect this would be easy, but if chemotherapy and appropriate follow-up are not available, the surgery will be not indicated. The mortality of this child will not change and the surgery will only take away a portion of what time this child has left. Understanding that your deployed hospital is simply a "North American bubble" in an environment with very little supporting healthcare infrastructure can help guide decisions.

On the other hand, there are multiple interventions that you can perform that will transform the life of a child and their family. Figures 31.9, 31.10, and 31.11 demonstrate several of these performed by military surgeons in the current Iraq and Afghanistan conflicts. The amount and extent of humanitarian pediatric care provided by countless military surgeons, physicians, nurses, and technicians has contributed immensely to the health of these communities and to the overall mission. This is an often underreported and underappreciated function of the combat physician that you should understand and prepare for. These are the cases and patients that help to make the experience of wartime medicine more bearable and that will stay in the hearts and minds of all involved for life.

Recent reports out of Afghanistan indicate that ophthalmology and otolaryngology procedures have the lowest complication rates. Yet, the majority of them require more than one time under general anesthesia. In contrast, elective neurosurgical procedures have the highest complication rates – and those tended to present much later. These complications occurred well after the operative surgeon and team have redeployed back home. To the extent that you can, chose the types of patients and

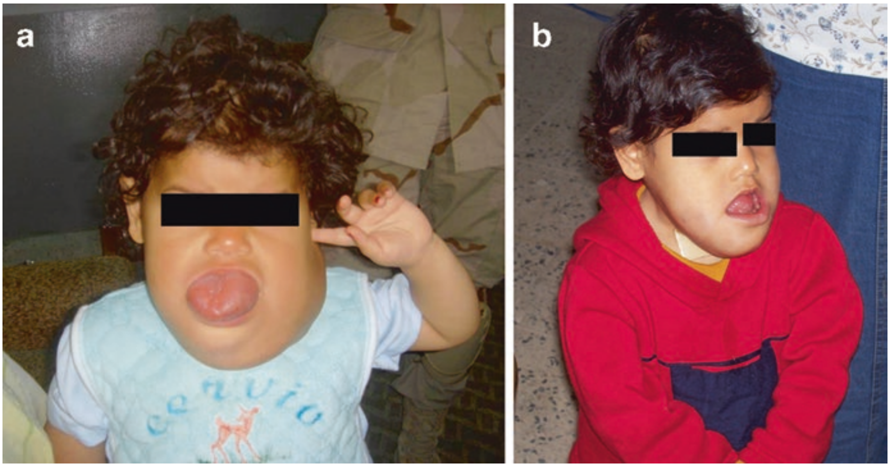


**Fig. 31.9** (**a**) Iraqi child with craniofacial deformity and cystic lymphangioma of tongue requiring liquid feeds and tracheostomy. (**b**) The same child after undergoing resection of facial tumor by Air Force surgeons and subsequent hemiglossectomy by Army surgeons. She was able to begin regular diet and removal of the tracheostomy

procedures that do not have a long management tail. You will leave, but your replacement may not have the same skill set, interest level, or operation tempo to finish what you started.

As with emergency surgery for children, the deployed surgeon must understand that he/she is evaluating a child that has some degree of chronic malnutrition. An awareness of that fact can guide preparation for surgery and surgical planning. Leveraging whatever resources you can to get patients ready for surgery is advisable (Fig. 31.12).

Finally, you must coordinate carefully with the leadership of the hospital, nursing staff, and other physicians (especially the anesthesia provider) to get adequate top cover and ensure that everyone is on the same page before taking on an elective care patient. Because the medical "rules of engagement" for elective humanitarian care in austere locations are highly situational, you must be communicating with your leadership to make sure the current operational tempo and mission can support pediatric surgery (Fig. 31.13). As with civilian humanitarian surgical missions, the US military places an emphasis on procedures and therapies that are low risk, can be performed quickly, require limited follow-up, and do not undermine the host nation medical system.


**Fig. 31.10** (**a**) Iraqi child with meningomyelocele who presented to an Air Force facility. (**b**) The same child after undergoing surgical repair by Air Force surgeons. (**c**) Child with major burns undergoing excision and skin grafting at an Air Force facility

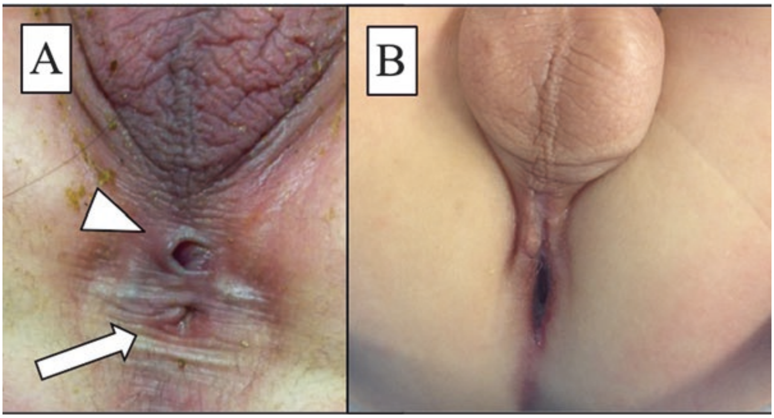


**Fig. 31.11** (**a**) A 3-year-old male with imperforate anus with perineal fistula (*arrowhead*) and well-formed anal dimple (*arrow*). (**b**) 4.5 months post-OP after serial anal dilations. A board-certified pediatric surgeon participated in the operation

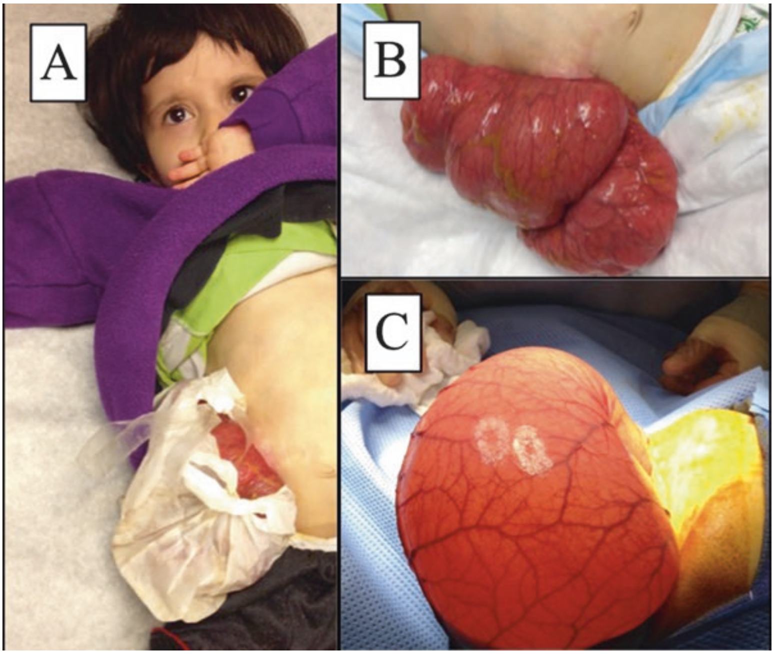


**Fig. 31.12** (**a**) A severely delayed and syndromic 9-year-old female with chronic abdominal distention and massive ileocolonic prolapse (**b**) who presented to the deployed medical treatment facility with a diagnosis of Hirschsprung's disease and diverting loop ileostomy. During laparotomy for planned stoma revision, she was found to have massive gastric distention (**c**) from malrotation with obstructing Ladd's bands. The stoma was closed, intestinal continuity restored, and gastrostomy created

**Fig. 31.13** An ad hoc ethics committee in a deployed medical treatment facility is convened to discuss the current medical rules of engagement for elective humanitarian care

## Civilian Translation of Military Experience and Lessons Learned

Kenneth S. AzarowMubeen A. Jafri

### Strategy

For those of us who care for injured children in the United States, there are several aspects of care that we often take for granted. First and foremost is that we generally have an unobstructed means of transportation to facilitate transfer of patients to higher levels of care. This fact alone makes the nonoperative management of solid organ injuries more difficult as children cared for in combat zones may not be able to be transferred out to a facility with a robust blood bank or appropriate monitoring equipment. Medical supplies including medications, blood products, and medical devices are more readily available at home, and most importantly caring for these children is our primary mission. For the deployed surgeon, caring for children is usually a secondary humanitarian mission. As a result, while nonoperative management of solid organ injuries has become standard practice in the civilian world, the same may not be true in a combat zone. Observing a child in a monitored setting for several days followed by minimal activity for several weeks utilizes resources that either may not be available or simply may not be sparred depending upon the operational climate of the theater.

### Diagnosis

As far as diagnosis is concerned, we have a huge advantage in a civilian environment. The use of imaging does become easier to obtain as more resources are available. CT scans and MRIs may be possible to obtain depending upon one's location when deployed, whereas they are commonplace in the civilian trauma center. Something that has been changing in our civilian centers is the emerging use of ultrasound (FAST exams) in the acute pediatric trauma setting. Depending upon the deployed setting, it may be the only imaging modality available. In addition, the use of diagnostic laparoscopy is also becoming more commonplace in civilian pediatric trauma centers to avoid nontherapeutic laparotomies and often intervene on minor injuries in stable patients.

## Intra-op

Despite all these differences, once a decision is made to operate, the actual resuscitation and operative management is remarkably the same regardless of the environment. We have adopted many lessons from our military experience. Massive transfusion protocols for children frequently consist of balanced ratios of PRBC/platelets/FFP being 1:1:1. The general rarity of this occurrence has left the data lacking compared with the robust adult literature, but study is ongoing. The use of antifibrinolytics such as tranexamic acid has also become popularized in injured children. Many of the same pitfalls and challenges presented by Drs. Neff and Spinella exist in our civilian trauma centers as well. For instance, IV access can be a challenge regardless of location. The use of interosseous access remains common in emergent situations. Within the OR, properly sized instrumentation is another luxury that we take for granted. Pediatric vascular clamps for instance may not be readily available for deployed surgeons who often need to rely on the use of Rummel tourniquets for vascular control. The decision to perform a damage control laparotomy is virtually identical as the outcomes of those children can be improved regardless of the environment. Likewise, the decision to decompress an abdomen for compartment syndrome is not dependent upon location.

## Post-op/ICU

Once a child is postoperative, a variety of cardiopulmonary support strategies are vastly increased outside of a deployed situation. The ability to change ventilators and modes of ventilation and offer cardiac assistance when needed simply does not exist in most deployed situations. Otherwise, the physiologic parameters and strategies to address these parameters regarding specific injuries are identical.

## Elective Surgery, Follow-Up, and Outcomes

The availability of certain specialized resources is the biggest and most obvious distinction between the civilian world and the deployed care of injured children. Access to future care may also be limited for noncombatant children, making the need for definitive care prior to discharge an important consideration. This would include the judicious utility of long-term drains, temporizing stents, external fixators for orthopedic injuries, and even stomas for bowel and rectal injuries when they can be avoided. The elective return to the OR several months after injury and complicated medical care including long-term parental nutrition, antibiotics, and wound/stoma care are often luxuries we take for granted. Safe care must always be a priority, but the routine use of temporizing measures or fecal diversion has become the exception in the care of injured children in civilian practice, and it may be extended to the care of children that may never have access to the level of expert care that they receive after initial injury in combat areas.

Children have accounted for 5–10% of hospital admission over the last two decades of conflict. Despite the expenditure of significant resources for the care of children in combat settings, mortality is significantly higher than pediatric hospitals in the United States. Little information is available about long-term outcomes. Our commitment to the care of these children, though, remains a priority for deeply rooted ethical and moral reasons. The lessons learned on the battlefield have directly improved our care of children in areas where experience is limited including damage control, massive transfusion, explosive injuries, and multisystem trauma. The sharing of knowledge and technique between these two environments will continue to improve the overall care we deliver to this most vulnerable population.

# Part III

# Postoperative Principles and Miscellaneous Topics

# The Combat Hospital ICU

# 32

Kevin K. Chung and Matthew J. Eckert

**Deployment Experience**

| | |
|---|---|
| *Kevin K. Chung* | Chief, Intensive Care Unit, 86th Combat Support Hospital, Ibn Sina, Baghdad, Iraq, 2008<br>Director, Joint Combat Casualty Research Team, Bagram, Afghanistan, 2012 |
| *Matthew J. Eckert* | Trauma Surgeon, Camp Bastion Role 3 Hospital, Helmand, Afghanistan, 2012–2013<br>USSOCOM Surgical Support, Iraq, 2014–2015<br>USSOCOM Surgical Support, Horn of Africa, 2015<br>USSOCOM Surgical Support, Iraq, 2016 |

*Everything in war is very simple. But the simplest thing is difficult.*

Carl von Clausewitz

K.K. Chung (✉)
Brooke Army Medical Center, Department of Medicine, Fort Sam Houston, San Antonio, TX, USA

Uniformed Services University of the Health Sciences, Bethesda, MD, USA
e-mail: kevin.k.chung.mil@mail.mil

M.J. Eckert
Uniformed Services University, Madigan Army Medical Center, Department of Surgery, Tacoma, CA, USA


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**BLUF Box (Bottom Line Up Front)**

1. Putting the *right* people with the *right* training with the *right* experience in the *right* place at the *right* time is 90% of the battle. Wherever you are going, make sure you have the right people.
2. An ICU team of nonsurgical intensivists, medical subspecialist, experienced ICU nurses, respiratory therapists, PharmD, and dieticians are trauma surgeon force multipliers.
3. A scaled multidisciplinary team approach, leveraging some or all mentioned in #2, elevates and optimizes trauma care.
4. There are many different ways to do things. Your way is not the only way.
5. Minimize polypharmacy as much as possible. And go through your pharmacy inventory when you arrive – you will *not* have all of the ICU meds you are accustomed to having at home.
6. Minimize iatrogenic complications. If you don't have to do something, don't do it.
7. Bundles and guidelines are great. But remember that every patient is different. Apply an individualized approach to care.
8. Routine daily checklists can be helpful if succinct and efficient (Fig. 32.1).
9. You are not always going to have the right equipment. Be prepared to improvise.
10. Wash your hands and make others wash their hands. The more austere the environment, the more important this is.

## Introduction

You have just finished your morning team ICU rounds on a mix of nine critically injured US and host-nation trauma patients. A tenth US casualty with multiple gunshot wounds to the chest and abdomen rolls in after a damage control laparotomy. He had become pulseless in the ED trauma bay during his initial evaluation, so he underwent an emergency thoracotomy and aortic cross clamp and was immediately taken to the OR while undergoing multiple blood transfusions. In the OR, he received over 40 units of products (PRBCs, FFP, PLTs, Cryo, whole blood) as well as a dose of tranexamic acid (TXA). The liver is packed and the abdomen left open with wound VAC placement. The patient is on high-dose Levophed and epinephrine and acidotic. Post-op ROTEM looks like a champagne flute.

This patient scenario is just one example among the many critically ill patients commonly encountered in a combat support hospital setting where robust surgical capabilities exist. In order to optimize care and resultant outcomes, it is necessary to maximize capabilities in this setting to have it match the quality of care delivered at any busy trauma center with a Level 1 American College of Surgeons designation. As such, a multidisciplinary team approach with the right people with the right

**DAILY GOAL SHEET TO BE FILLED OUT BY ALL TEAMS FOR ALL PATIENTS IN THE ICU.**
**ICU QA/QI.**

ICU Room# Code Status: Allergies: ______________________

Date: ___________ Primary Service: ICU GS/Trauma CT Vascular Other:
Attending: ___________________

| | | | | |
|---|---|---|---|---|
| Is the Universal Consent Signed? | **(Consent?)** | Y | N | NA |
| Have all of the bedside nurse questions been addressed? | **(NQ's?)** | Y | N | |
| Have all the patient's questions been addressed? | **(PQ's?)** | Y | N | |
| Is the patient on a ventilator? | **(Ventilator?)** | Y | N | Trach |
| Spontaneous Breathing Trial Performed? | **(SBT?)** | Y | N | NA |
| Sedation holiday performed? | **(DSH?)** | Y | N | NA |
| Is the Head of the bed >30 degrees? | **(HOB >30?)** | Y | N | NA |
| Is Oral Care being performed every six hours? | **(Oral Care?)** | Y | N | NA |
| Is the patient receiving PUD prophylaxis? | **(PUD?)** | Y | N | NA |
| Is the patient receiving DVT prophylaxis? | **(DVT?)** | Y | N | NA |
| Are day/night cycles adhered to? | **(Day/Night?)** | Y | N | NA |
| Can the patient be mobilized? | **(PT/OT?)** | Y | N | NA |
| Have Restraints been ordered if necessary? | **(Restraints?)** | Y | N | NA |
| Can any central lines or other devices be removed? | **(Lines Out?)** | Y | N | NA |

If so, which one(s): ______________________________

| | | | | |
|---|---|---|---|---|
| Was the ECG Reviewed? | **(ECG?)** | Y | N | NA |
| Was nutrition addressed? | **(Nutrition?)** | Y | N | NA |
| Was a bowel regimen addressed? | **(BMs?)** | Y | N | NA |
| Was skin care/pressure ulceration addressed? | **(Skin?)** | Y | N | NA |
| Were the medications reviewed? | **(Meds?)** | Y | N | NA |

Starting: ______________________________

Stopping: ______________________________

**Daily I/O goal is: Positive Negative Even**

**What is the patient's greatest safety risk??**
______________________________

**What is being done for the patient that cannot be done in a lower level of care?**
Technology (i.e. ventilator) ☐
Monitoring (frequency or invasiveness) ☐
Interventions (intensity) ☐

**Today's Big 3 Goals:**

1)______________________________

2)______________________________

3)______________________________

Name:___________
Reg # ___________
SSN:___________
Enter info or place pt sticker here

**Fig. 32.1** Sample daily goal sheet that should be used every day for every ICU patient. The details of the sheet can be adapted to each unique setting in the deployed environment training and experience needs to be applied. This team is naturally led by a trauma surgeon and complemented by a multidisciplinary mix of providers experienced in the care of critically ill patients.

## A Team Approach

A multidisciplinary team approach is widely considered to be best practiced in the care of complex critically ill trauma patients. Our goal is to deliver the same level of care available at any premier trauma center around the world. It is important to understand that this capability should be scalable. A larger and more diverse team may need to be assembled the busier and more complex the patients. In a less busy setting where both the volume and acuity of patients are not high, assembling a robust team may not be necessary. Given that the vast majority of combat hospital admissions are trauma related, the most appropriate type of individual to lead this multidisciplinary team would naturally be a surgeon specifically trained and board certified in trauma and/or acute care surgery and appointed as the trauma director. The trauma director oversees the entire trauma program ensuring that the highest quality of surgical and critical care is delivered throughout the hospitalization from presentation to discharge. It is also important to appoint a medical director of ICU. Although it is feasible to assign the duties of the ICU medical director to the trauma director, a separate individual is preferred in a busy combat hospital. Best practice is to appoint a physician who is fellowship trained in critical care of trauma and surgical patients. Physicians obtain subspecialty fellowship training in critical care via multiple pathways. The most common are through general surgery, anesthesia, internal medicine, and emergency medicine. Although a critical care-trained surgeon can easily take on the role of the ICU director, a nonsurgical subspecialist is preferred so that all available surgeons are available to operate. It is also important to note that internal medicine-trained intensivists have two separate pathways for critical care subspecialty training: pulmonary critical care and straight critical care medicine. Most pulmonary critical care physicians practice in a pulmonary and internal medicine-focused environment with very little trauma and surgical patient interaction, while critical care medicine physicians, like anesthesia and emergency physicians, typically practice regularly in surgical, burn, and trauma ICUs. Thus, the specific skill set, experience, and philosophy may differ from one type of intensivist to another.

Perhaps the most important member of the ICU care team is the bedside registered nurse. It is imperative that bedside registered nurse has critical care training and has at least some trauma critical care experience. Certification as a Critical Care Registered Nurse (CCRN) is preferred but not required for staffing although it is the opinion of the author that it should be. The head nurse of the ICU should be the most experienced CCRN willing to jump in at the bedside to assist at a moment's notice. The head nurse should also be experienced with appropriate staffing of busy ICU with a focus on the maintenance of nursing competencies among critical care staff, especially for support of procedures not routinely performed (such as intraventricular drain management, renal replacement therapy, burn care, etc.).

**Table 32.1** Multidisciplinary ICU team composition

| |
|---|
| Trauma director (trauma surgeon) |
| Medical director (trauma/acute care surgery, CCM, anesthesia CC, pulmonary/CC, or EM/CC) |
| Head nurse |
| Bedside nurse (CCRN preferred) |
| Respiratory therapist (CRT or RRT) |
| Clinical pharmacist (PharmD preferred) |
| Registered dietician |
| Other subspecialists if available (ID, hematology, nephrology) |

*CCM* critical care medicine, *CC* critical care, *EM* emergency medicine, *ID* infectious disease, *CCRN* critical care registered nurse, *PharmD* doctor of pharmacy, *CRT* certified respiratory therapist, *RRT* registered respiratory therapist

Respiratory therapists are vital to the multidisciplinary team. All respiratory therapists should attend daily rounds with the team and have a constant presence in the ICU. The medical director of the ICU should be in complete synch with the respiratory therapists regarding ventilator management philosophy and overall respiratory care. Once this relationship of trust is established, great respiratory therapists can attain significant degrees of autonomy, allowing the intensivists to focus on other matters in the care of the critically ill.

Combat hospitals typically have an inpatient pharmacist on staff. Given the complexity and acuity of combat-related trauma patients, the inpatient pharmacist needs to be an integral part of the ICU team and attend rounds on a regular basis. Appropriate drug dosing and identification of drug-related adverse events and interaction are crucial for optimal care in the ICU.

An inpatient registered clinical dietician should also be an integral part of the ICU team. An important principle in the care of trauma patients in the ICU is optimizing the conditions for wound healing and overall organ health. Optimizing nutrition is often the centerpiece of that principle.

Overall, superior care of the trauma patients can be achieved by leveraging the expertise that can exist across multiple disciplines. Prepositioning key providers from each of these disciplines in a combat hospital setting is 90% of the solution that will allow for optimal outcomes (Table 32.1).

## ICU Models

Various ICU models exist in the civilian setting depending on the type of ICU. For example, most medical ICUs operate as a “closed” ICU where the ICU team is the admitting service and subspecialists do not typically engage in direct patient care regardless of where the patient came from. Alternatively, many surgical ICUs operate as an "open" ICU, whereby the admitting surgeon maintains primary responsibility of the patient, while ICU physicians are strictly consultants and participate only when invited. In the combat hospital ICU, the best model is a "semi-closed" or "hybrid" ICU. In this type of structure, the primary surgeon maintains responsibility of the patient but defers most ICU-related care to the ICU team who assumes care of every patient in the ICU. Ideally, it is important for the primary surgeon to take part in multidisciplinary rounds when able, to be able to contribute to important aspects of care. For those not so infrequent non-trauma or nonsurgical patients who get admitted to the ICU, the ICU team and ICU medical director should assume complete responsibility of the patient until the patient is transferred out of the ICU.

During active combat operations in Iraq and Afghanistan, there has been significant variation in the way that combat hospitals have run their ICUs. The following are a few examples:

## Ibn Sina Model

The primary Army combat hospital during the peak of combat operations in Iraq was located in Baghdad, Iraq. Organic Army combat support hospital units were augmented regularly with various subspecialists. The chief of trauma oversaw the trauma service consisting of various general surgeons as well as surgical subspecialists. A separate ICU director was appointed, often a nonsurgical intensivist (pulmonary critical care or critical care medicine physician) who worked alongside an additional "intensivist equivalent" (cardiologist or nephrologist) who received on both pre-deployment and on-the-job training to assist in the ICU. The call schedule typically had the ICU director alternate 24 h beside ICU call duties with the "intensivist equivalent." On occasion, a surgical intensivist would be thrown into the call schedule for a three-person rotation. The ICU functioned like a "semi-closed" model where the chief of trauma, surgeons, and the ICU team met for daily multidisciplinary rounds.

## Balad/Bagram Model

The primary Air Force theater hospitals both in Iraq (Balad) and Afghanistan (Bagram) operated a slightly different model for the ICU. A clear hierarchical model was established, whereby the "trauma czar," a relatively senior trauma fellowship-trained surgeon, assumed responsibilities as the chief of trauma, all surgical services, ICU, and the wards. Nonsurgical intensivists were not organic to this model. Instead, general internists and other internal medicine subspecialists, all with virtually no trauma experience and variable degrees of ICU experience, were assigned to the ICU. While some rotating ICU internists could have some experience and even be trained in critical care, this model was completely reliant on the “trauma czar” to dictate ICU care 24/7. Most internist rotators only received limited “just-in-time” pre-deployment training supplemented by on-the-job training and didactics lead by the “trauma czar” in order to mitigate for their lack of experience and trauma competency. This is the *least* desirable model to optimize ICU outcomes in a combat hospital setting in the opinion of the author.

## Kandahar Model

Perhaps the most robust US-based combat hospital ICU care was delivered through the Navy model in Kandahar, Afghanistan. This model also appointed a “trauma czar” who oversaw all trauma-related operations to include ICU care. However, the ICU was staffed by at least three nonsurgical intensivists. In this model, the category of “intensivist” was broadened to allow pediatric intensivists as well as neonatologist to serve in these roles. Thus, day-to-day management of the ICU always involved a fellowship-trained intensivist or a pediatric/neonatal intensivist with highly transferable skills. Daily rounds were led by the “trauma czar” with ICU staff and all surgical staff present.

## Camp Bastion Model

Arguably the most ideal ICU model for combat hospital ICU care is the Camp Bastion model. The combat field hospital at Camp Bastion, Afghanistan, was led by the UK and staffed jointly by the British and the USA. In this hospital the ICU was staffed entirely by nonsurgical fellowship-trained adult intensivists. British intensivists were mostly anesthesia trained, while US intensivists were pulmonary or straight critical care trained. Prior to deployment, all those deploying with the hospital underwent a 2-month simulation exercise in the UK to drill workflow and build cohesive teams. As such, the ICU benefited from this training exercise as all ICU staff (physicians, nurses, respiratory therapists) became familiar with each other and knew what to expect prior to going “live.”

## Ideal Model

The ideal US-based ICU model should take a page out of the Camp Bastion model. Future ICUs must be staffed with physicians who are fellowship trained as intensivists with experience caring for trauma patients. This would ideally include at least one fellowship-trained trauma/critical care surgeon who will bring the most experience in terms of managing major trauma ICU patients. If this asset is not available, then it is critical to have the staff trauma surgeons at that facility involved in ICU rounds and developing comprehensive plans of care in concert with the

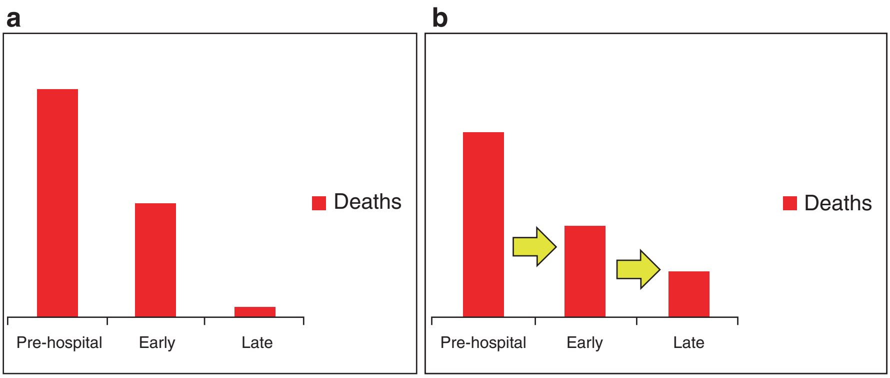


**Fig. 32.2** (**a**, **b**) The traditional trimodal distribution of trauma deaths. The deaths in the third peak are mostly due to sepsis and multi-organ failure. Recent advances in the care of trauma patients are likely to impact the first two peaks whereby sicker patients survive deeper into the hospitalization. Hence, the third peak will predictably be higher

medical intensivists. Nurses trained in critical care with experience caring for trauma patients should staff the ICU. If the individual services (Army, Navy, Air Force) lack the capacity to staff these ICUs appropriately, staffing should be coordinated jointly with all services contributing to the pool of available providers. In short, the staffing model should mirror the level of care delivered at the premier trauma centers in the USA.

## Organ Support

Critically ill patients are defined by the presence of life-threatening conditions that place them at high risk of developing organ failure. As such, a fundamental role of ICU care involves the prevention and/or management of organ failure. Over the last two decades, advances in the management of combat trauma patients have resulted in a decrease in early deaths due to hemorrhage. As such, patients with more severe injury are surviving deeper into their hospitalization. Among all deaths that occur after trauma, those who survive the pre-hospital and early hospital period often succumb to sepsis and multi-organ failure. Thus, as sicker patients survive deeper into the hospitalization, the larger the pool of patients who are at high risk of organ failure becomes. As such, the trimodal distribution of death after trauma will likely see a higher third peak (Fig. 32.2). In turn, the more patients there are who develop organ failure, the greater the number of patients with severe organ failure that will challenge any robust ICU capability. In short, the combat ICU of the future will be full of very sick patients, requiring a robust capability in order to optimize survival.

## Lung Support

It is vital that the combat hospital ICU maintains a state-of-the -art capability in order to deliver the same quality of care delivered at the most robust ICUs around the world. Thus, mechanical ventilators must have the capability to be able to deliver a variety of modes to include those that may be considered rescue modalities (i.e., airway pressure release ventilation or bi-level). Depending on the expected operational tempo, the ability to initiate and transport patients on extracorporeal membrane oxygenation (ECMO) must be considered as a desirable capability. It has become clear that a role exists for the initiation of ECMO in the management of trauma patients with severe lung failure. In our limited experience, lives have been saved when ECMO was available and initiated in a timely manner. The author suspects that many potentially salvageable lives were probably lost due to the absence of this capability. However, the challenge is that this skillset is still not ubiquitous among critical care providers due to the fact that ECMO is typically offered in only a few specialized centers around the world. In fact, only one Department of Defense facility (Brooke Army Medical Center, BAMC) currently offers ECMO, and this capability is relatively new. Thus, the expectation that ECMO could be delivered safely and competently in every combat support hospital may be unrealistic. Still a strategy is needed to be able to safely and rapidly deliver this therapy the few times it may be required. During the last two decades, the Landstuhl Acute Lung Rescue Team was strategically positioned in Germany and launched a number of times to various locations in Iraq and Afghanistan. This capability has recently been retired due to low operational tempo. The codification of a global ECMO response team based out of BAMC is currently being considered.

## Renal Support

Given that patients with major trauma often suffer from ischemia-reperfusion injury with resultant acute kidney injury, electrolyte disturbances (hyperkalemia), and metabolic derangements (acidosis), a capability to institute renal replacement therapy (RRT) is a must. The emerging frequent use of retrograde endovascular balloon occlusion of the aorta (REBOA) will likely increase the prevalence of these disturbance needs even further. The most combat deployable RRT modality is continuous renal replacement therapy (CRRT) due to a variety of reasons to include relative simplicity and the availability of premixed sterile solutions. All intensivists should be trained, competent, and credentialed to be able to prescribe and manage patients on CRRT. More importantly, nursing staff must be trained and competent in running the CRRT machines. This capability has allowed for immediate stabilization of patients with severe metabolic derangements while optimizing patients prior to evacuation out of theater. Feasibility and sustainability of CRRT in a theater hospital setting have already been established. Collectively, we must ensure the need for this capability is not lost when planning for future conflicts.

## Practical Considerations

1. Remember that all supplies and medications (i.e., fluids, blood, drugs, ventilators, procedure kits) are a limited resource in the combat environment. You must pay close attention to careful resource allocation.
2. Don't pull chest tubes and other drains before aeromedical evacuation.
3. Keep things simple by minimizing polypharmacy.
4. Keep things as efficient as possible. Admission order sets, notes, and ICU rounds need to be seamless. You don't have time inefficiencies.
5. Remember that throughput is one of your priorities. Get patients stabilized and out of your ICU as soon as you are able. You need to save your beds for those who really need it.
6. Be aware of what's happening in the ED and OR. The ICU needs to prepare just like the OR does when you anticipate a big case.
7. Rest when you are able. You are no good in the ICU if you are exhausted.
8. During mass casualty scenarios, expect that approximately 10% of all casualties will require ICU admission. Admissions will occur in waves. Expect the sick ones to come in after the first couple of waves.
9. You will treat enemy combatant on a regular basis. Treat them with the same dignity and respect as other patients.
10. You will treat pediatric patients. You will *not* be optimally supplied for pediatric ICU care, so improvisation and adaptability are key!

## Intensive Care Is Not a Place

Although the bulk of this chapter has described combat ICU care at the larger and more robust facilities such as a combat support hospital or an Air Force Theater Clearing Hospital, many patients will require critical care to be started at more forward and robust facilities such as a Role 1 aid station or a Role 2 forward surgical team (or equivalent). This typically would include intubation and ventilator management, massive transfusion, pain and sedation management, and initiation of neurocritical care and intracranial pressure control for severe brain injury. This type of ICU-level management can and *must* be started as far forward as possible, even though it is outside of a typical ICU environment and very rarely directed by a physician who is board certified in critical care.

At a typical Role 2 facility, there will be no formal ICU, but one or more beds are designated for post-op and critical care patients. The required staffing at a Role 2 does *not* require an ICU-trained physician, but will typically include at least one nurse with ICU experience, as well as a general surgeon and an anesthesia provider. At this level, the ICU care focuses on stabilization and then transfer to a higher level of care as soon as practicably possible. High-quality basic critical care can be delivered in even this environment and is enhanced through mentoring and feedback from the "experts" at the Role 3 receiving facility and through

**Fig. 32.3** A frontline ICU is established in a very austere environment by simply grouping critically injured patients together in proximity to the available highest level of provider care and equipment

familiarization with the relevant Joint Theater Trauma System Clinical Practice Guidelines (listed below). Although the sequence and settings for the delivery of critical care to the severely wounded solider may vary from the front lines back to the Role 3 facility and then onto aeromedical evacuation by a CCATT (Figs. 32.3, 32.4, and 32.5), the quality of the care should be high throughout the initial treatment and evacuation phases.

## Final Thoughts

Quality delivery of care in a combat hospital ICU is vital to optimizing overall survival for the combat injured. The overall goal should be to deliver the same capability and level of care that exists in the most sophisticated and high-volume trauma centers worldwide. This is only possible by ensuring the ICU is staffed and equipped commiserate with the anticipated operational tempo with the right people and the right equipment. Our military sons and daughters deserve nothing less.

**Fig. 32.4** A more "mature" intensive care unit established in a fixed structure at the combat support hospital level (Ibn Sina Hospital, Baghdad, Iraq)

## Civilian Translation of Military Experience and Lessons Learned

Matthew J. Eckert

**Key Similarities**

1. The multidisciplinary intensive care unit team is the hallmark of modern critical care, led by specialty-trained critical care physicians.
2. Bundled pathways, practice guidelines, and protocolized management help ensure that the details of complex critical care are not overlooked during periods of high unit census, increased acuity, and staff turnover or that these practices become provider dependent.
3. Multisystem organ support with the goal of reestablishing homeostasis in the body remains the underling concept in critical care.
4. Critical care is a practice, *not* a place.

**Fig. 32.5** Full ICU-level care and interventions are able to be delivered during air evacuation by the Air Force Critical Care Air Transport Teams (CCATT)

**Key Differences**

1. Civilian ICUs are more likely to have a greater depth and variety of subspecialty consultants available to assist the primary ICU attending.
2. Extensive resources such as mechanical ventilators capable of salvage modes of ventilation, ECMO, hemodialysis, and seemingly endless pharmacy options are frequently found in civilian ICUs.
3. The civilian ICU patient is much more likely to have chronic medical conditions that may greatly influence the complexity of illness and level of support required.
4. While the combat ICU faces immense challenges in patient acuity, most patients are rapidly evacuated to a higher level of care. The civilian ICU may care for critical patients over prolonged periods, through numerous rounds of organ failure and/or complications; thus, throughput becomes secondary to completion of care in the civilian world.

In this chapter Dr. Chung provides a concise and timely description of the contemporary practice of critical care medicine across the recent conflicts in Iraq and Afghanistan. The descriptions of ICU team compositions and particularly the strengths and weaknesses of various ICU models in numerous combat support hospitals attest to the fact that no two ICUs are identical, in military or civilian hospitals, but some function better than others. Dr. Chung's emphasis upon a multidisciplinary approach, scalable in size based upon patient volume and acuity, and a team emphasis are key principles for any critical care setting.

Civilian critical care practice spans a wide spectrum of resource availability from community and critical access hospitals to major university settings. Many university medical centers today have numerous subspecialty ICUs organized around a particular body system or specialty of medicine. Huge multidisciplinary medical teams provide around-the-clock care utilizing cutting-edge monitoring equipment and the newest and best treatments and medications, with seemingly endless options for a patient's failing organs. Despite the obvious differences at the surface between the combat support hospital ICU and the major medical center ICU, the principles of critical care medicine are the same, regardless of location.

One of the key concerns in any ICU setting is ensuring clear, timely communication and continuity of care. Dr. Chung describes the challenges in managing numerous critically injured patients and the constant planning and consideration of interventions and treatments in the face of impending evacuation from the combat zone. While evacuation is likely to be less of a concern in the civilian ICU, continuity of care and communication among multiple consultants and teams contributing to the overall care of the patient represents a continuous challenge. Development of electronic communication tools, checklists, patient tracking mechanisms, and formalized rounds and meetings between contributing services are required to avoid iatrogenic injury and ensure all team members have a similar plan of care in mind. Even with all of these mechanisms to help ensure adequate communication, frequently details are missed and complications or derailments in efficiency occur, hence the importance of a supervising critical care professional who is overall responsible for coordinating care and adjudicating decisions in management when divergent opinions arise.

While the combat ICU may face resource limitations routinely, the civilian ICU often has the opposite problem: endless resources and a compelling desire to "do everything and anything possible." Despite the increased relevance and consciousness of cost and resource utilization, civilian ICU patients frequently enter a pipeline of seemingly endless interventions, moving from one treatment to another, even if the possibility of a functional recovery is slim. Defining goals of care in the civilian ICU help the medical team, patient, and family achieve the most effective, efficient, and humane care possible. These considerations are more pertinent to the patient with chronic or end-stage medical conditions but may be relevant to any patient with an overwhelming burden of injury or disease.

Finally, one unique and rarely discussed concern in any ICU is the emotional, mental, and physical effects that burden ICU staff, particularly in periods of high acuity and volume. Often, ICU nurses, physicians, and team members will suppress the stress, anxiety, and emotional effects as long as possible, placing their own health last. The "health" of the team must remain a concern, despite our altruistic intentions, or else collective detrimental effects can bring down the effectiveness of the ICU team. Frequently, the supervising intensivist is blind to the early signs of stress in the team or individuals or in himself or herself. The routine presence of a pastoral care professional can provide an objective evaluation and be an essential member of the team when stress begins to accumulate. Recognizing the signs of these effects is critical before the development of interpersonal conflict, communication breakdown, compassion fatigue, loss of attention to detail, and serious self-harm. The overall goal is the health of the patient, but without a healthy multidisciplinary team, that goal cannot be achieved.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Acute respiratory failure.
2. Catastrophic care.
3. Management of pain, anxiety, and delerium.
4. Nutritional support.
5. Ventilator associated pneumonia.

## Suggested Reading

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# Postoperative Resuscitation

# 33

Richard Nahouraii, Martin Schreiber, and Andrew C. Bernard

**Deployment Experience**

| | |
|---|---|
| *Martin Schreiber* | 228th Combat Support Hospital, Tikrit, Iraq (FOB Speicher), OIF 3 (2005), Joint Theater Trauma System Director, Bagram AB, Afghanistan OEF (2010), 932nd FST FOB Shank, Afghanistan OEF (2014) |
| *Richard Nahouraii* | 14th Combat Support Hospital, Bagram AB, Afghanistan, Role 3 Multinational Medical Unit (Canadian Forces), Kandahar AB, Afghanistan, OEF 7 (2006) |
| | 86th Combat Support Hospital, 745th Forward Surgical Team, Tallil, Iraq (COB Adder/Ali AB), al-Amarah, Iraq (Camp Sparrowhawk/FOB Garry Owen), OIF 7–9 (2008) |
| | 352nd CSH FOB Salerno Afghanistan OEF 12 (2012) |
| | 946 FST Camp Dahlke Afghanistan ORS (2016) |

*"A good heart and kidneys can survive all but the most willfully incompetent fluid regimen."*

Mark Ravitch (1910–1989)

R. Nahouraii
Duke-Lifepoint Conemaugh Memorial Medical Center, Department of Surgery, Johnstown, PA, USA

M. Schreiber (✉)
Oregon Health and Science University, Department of Surgery, Division of Trauma, Critical Care and Acute Care Surgery, Portland, OR, USA
e-mail: schreibm@ohsu.edu

A.C. Bernard
University of Kentucky Hospital, Department of Surgery, Lexington, KY, USA


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**BLUF Box (Bottom Line Up Front)**

1. Damage control surgery and resuscitation occur simultaneously. Failure to stop hemorrhage precludes successful resuscitation.
2. Patients lose blood in the field. The traumatically injured combatant in shock needs whole blood or a combination of components as close to whole blood as possible, not crystalloid.
3. Beware of the CVP. It is usually calibrated and measured incorrectly and, even when done correctly, shows little ability to predict preload and volume responsiveness.
4. A patient with a normal blood pressure and good urine output may still have compensated shock. Trending serum lactate in combination with base deficit is the best way to assess oxygen delivery and consumption and hence determine if resuscitation is succeeding.
5. In the post-damage control, ICU patient who is failing resuscitation, has ongoing bleeding, and has occult tissue ischemia must be strongly considered. Take the patient back to the operating room.
6. Over-resuscitation is as bad as or worse than under-resuscitation – stop when goals are met to avoid the "dry-land saltwater drowning" syndrome.
7. Develop a general approach and philosophy to resuscitation goals and methods that everyone agrees on. Make it easy and make it as automatic as possible.

## Introduction

You have just completed a major damage control operation with significant blood loss and ongoing resuscitation. As the patient rolls through the ICU doors, you are asked to write orders for the nurses to begin the postoperative care phase. You may or may not have an "intensivist" available to help you. Having a clear vision and plan for performing and monitoring the postoperative resuscitation is critical to avoid the twin evils of under-resuscitation and over-resuscitation. In combat surgery this is particularly critical as you often have to hand the patient off to the nurses or another physician and return to the ER or OR. Having a general approach or "philosophy" to resuscitation that the nurses, surgeons, and other physicians agree with and understand can make this process much smoother and less confusing.

## Principles of Combat Resuscitation

The concepts of postoperative resuscitation and damage control surgery are inextricably linked in the combat environment. Presented with the critically injured patient, the surgeon in a combat environment must rely upon the guiding concepts of

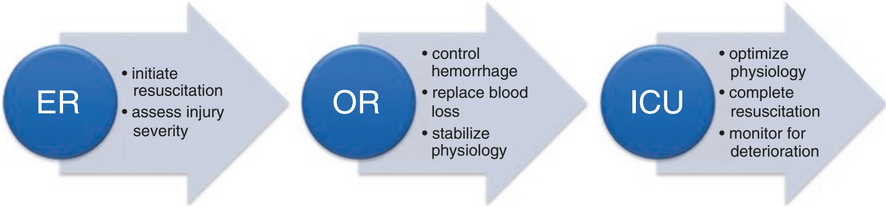


**Fig. 33.1** The trauma resuscitation process can be seen as a continuum of care rather than fragmented episodes, beginning in the prehospital and emergency room (*ER*) and proceeding through the operating room (*OR*) and intensive care unit (*ICU*) phases

damage control surgery: stopping hemorrhage and controlling contamination. Definitive operations with anatomic reconstruction are delayed. Resuscitation and the restoration of normal physiology are the objectives, accomplished in the intensive care unit and aimed at either correcting or preventing the lethal triad of hypothermia, metabolic acidosis, and coagulopathy. Furthermore, resuscitation is a dynamic process, often occurring over hours or days, after injury. Combat resuscitation should be viewed as a continuum of care as outlined in Fig. 33.1.

The goals of therapy in the ICU after damage control surgery are well defined: (1) correct metabolic acidosis, (2) restore normothermia, (3) reverse coagulopathy, and (4) ensure adequate oxygen delivery and consumption. The components of the lethal triad act synergistically. Hypothermia and acidosis exacerbate coagulopathy by impairing clotting factor function. Each of the clotting factors is a protease that has enzyme kinetics dependent on an optimal pH and temperature. All three components of the triad must therefore be addressed simultaneously. The cornerstone of resuscitation in hemorrhagic shock (and the focus of this chapter) is ensuring adequate oxygen delivery by restoring an adequate circulating volume. Since the prior edition of *Front Line Surgery*, damage control resuscitation strategies utilizing plasma/platelets/PRBCs in a 1:1:1 ratio have been shown to improve early survival and reduce death from exsanguination compared to a 1:1:2 ratio in the PROPPR Trial published in 2015. Resuscitation is dynamic, and the goal is not merely to replenish circulating volume and restore oxygenation but to do so in a guided fashion, avoiding the complications of over-resuscitation. Indeed, fluid administration should be guided by the concept of volume responsiveness. Volume responsiveness refers to an increase in stroke volume of at least 10–15% after a fluid challenge of 250–500 mL or a passive leg raise. It should be noted that in normovolemic healthy patients, a volume challenge (increase in preload) will result in an increase in stroke volume, representing a reserve cardiac output capacity. Increasingly recognized is the need to prevent overloading with infused volume of any type; such overloading ultimately leads to tissue edema and more importantly pulmonary edema in the form of extravascular lung water (Fig. 33.2). In short, the goal of volume resuscitation is euvolemia: volume overloading with its attendant negative side effects is to be avoided.

Inherent to assessing volume responsiveness is the ability to measure cardiac output, preferably noninvasively. Various devices utilizing differing principles for the indirect measurement of cardiac output are available in the modern intensive

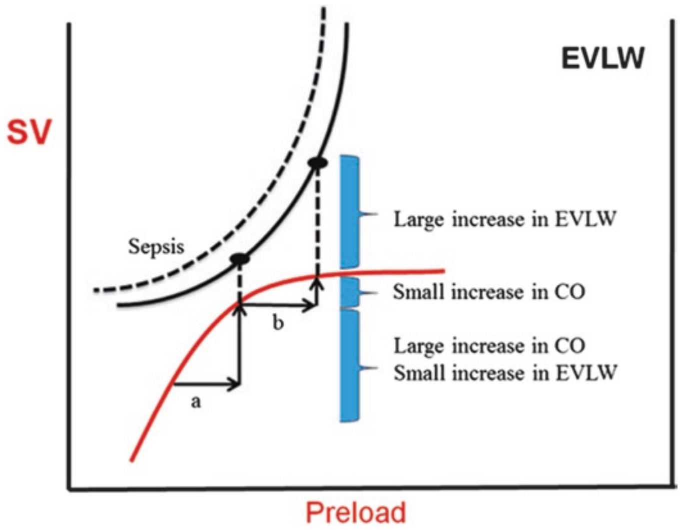


**Fig. 33.2** Graph showing that initial fluid boluses result in increased cardiac output (*CO*) and only small increases in extravascular lung water (*EVLW*), but further boluses produce minimal improvement in CO, but large increases in EVLW (Reproduced from Evidence-Based Critical Care, Fluid Responsiveness and Fluid Resuscitation, 2014, Marik PE. With permission of Springer)

care unit. They vary not only in the principles underlying their cardiac output measurements but also in their level of invasiveness. See Chap. 35 for a detailed discussion of monitoring devices, options, and applicability in the combat environment. Remember that no monitoring device can replace careful bedside assessment and good clinical judgment based on analysis of all of the available data. Do not go chasing some value on a monitor that does not agree with the rest of your assessment just to "normalize" the value.

A basic portable ultrasound and an anesthesia ventilator with end-tidal CO2 monitoring are available at all levels of surgical care throughout CENTCOM, including all far-forward GHOST (Golden Hour Offset Surgical Team) missions accompanying US Special Forces units. Facility with basic cardiac ultrasound views should allow static determinations of hypovolemia during resuscitation. Specifically, the parasternal long-and short-axis views (PLAX and PSAX, respectively) can provide nonquantitative information about volume status and global cardiac function during resuscitation. Additionally, although not validated in prospective studies, a subxiphoid inferior vena cava view (SIVC) can assess IVC size and collapsibility during ventilation, providing some information regarding volume status. In the PLAX and PSAX views, left ventricular walls that touch during contraction are indicative of hypovolemia (ejection fraction >70%). On SIVC viewing, a decrease in IVC diameter with respiration of 75% or more indicates hypovolemia; 15% or less variation with respiration, determined quantitatively via M-mode, represents normovolemia. Again, the limitations of IVC collapsibility, especially during mechanical ventilation, remain an area of active investigation.

As previously described, the devices currently available to measure cardiac output and hence determine volume responsiveness are not available in the forward environment of the GHOST or even many Role 3 medical facilities. However, the availability of end-tidal CO2 (EtCO2) monitoring may provide some information regarding volume responsiveness, at least under stable ventilatory conditions. Recent studies have demonstrated that increases in EtCO2 of ≥5% after passive leg raise predict fluid responsiveness. One such study demonstrated that a passive leg raise-induced increase in EtCO2 of ≥5% predicted an increase in cardiac index of ≥15% (i.e., fluid responsiveness) on subsequent volume challenge (500 mL of normal saline infused over 30 min) with sensitivity of 71% and specificity of 100%. Moreover, changes in arterial pulse pressure were unable to predict fluid responsiveness in the same patients. When combined with echocardiographic assessments of left ventricular filling and IVC collapsibility, EtCO2 changes in response to volume challenges should enable the forward deployed surgeon to make informed decisions regarding initial and ongoing postoperative fluid resuscitation needs.

## What Fluids Should I Use? When Do I Give Blood Products?

ATLS guidelines recommend the initial administration of 1–2 L of lactated Ringer's solution (LR) or normal saline (NS) followed by an immediate assessment of the response of the arterial blood pressure as the preferred initial resuscitation maneuver in hemodynamically unstable patients. The goal is to differentiate patients into one of three categories: responder, transient responder, and nonresponder. If after the initial 2 L of crystalloid the patient fails to respond or transiently responds but then again develops hypotension, blood is transfused. Accordingly, several points regarding this approach and its application to the combat environment deserve mention.

The ATLS is geared toward blunt trauma, and the target audience is primarily those inexperienced in trauma or "amateurs." You are not an amateur and should not approach trauma with a generic and basic algorithm. Do not spend 30 min in the emergency department with a critically injured patient trying to infuse liters of crystalloid to determine if the patient is a "responder" or trying to get the blood pressure up to some arbitrary level. In combat trauma this will get you way behind the power curve at the least or a dead patient. Combat trauma patients that are stable and mentating do not need any initial large fluid volumes, particularly cold crystalloid solutions. The vast majority of patients with compensated or uncompensated shock on presentation need resuscitation in tandem with operative intervention, and this resuscitation should start and end with blood products.

If you resuscitate postoperatively with standard crystalloid solutions (normal saline), you may see several adverse effects due to the large sodium and chloride loads. The most immediate clinical consequence of this iatrogenic hyperchloremic metabolic acidosis is to confound the interpretation of blood gas pH and base deficit values obtained during the resuscitation. In the worst case, a persistently decreased pH or base deficit could be misinterpreted as ongoing hypoperfusion and treated with further volume expansion, thereby exacerbating the problem. This effect will be worse with normal saline compared to a more balanced solution like lactated Ringer's (LR).

There are currently no data to support the use of colloids over crystalloids for the resuscitation of hemorrhagic shock. Colloids are generally more expensive than crystalloid, and they may be associated with negative effects. Starch solutions such as Hespan® may induce coagulopathy at high (>20 mL/kg) doses. Albumin, which is frequently used for post-trauma resuscitation, is a human product with attendant potential infectious risks. Hextend® is composed of 6% hetastarch in a balanced electrolyte solution. Its infusion has been shown, in a prospective randomized study, to result in reduced blood loss and coagulopathy in patients undergoing large elective surgical procedures compared to Hespan® (which is hetastarch in normal saline). While Hextend® is currently used in the field for Tactical Combat Casualty Care largely due to its ability to restore intravascular volume with smaller quantities than crystalloid, its role in the trauma bay or ICU is limited.

Another common misconception in the ICU is the practice of ordering "maintenance fluids." This is a ward medicine concept designed for a euvolemic patient to replace normal daily losses. Your ICU patient will be either volume depleted or volume overloaded, particularly immediately after a major surgical procedure. Do not write for maintenance fluids simply out of habit, as this is ineffective for volume expansion and deleterious in the overloaded patient. Give bolus therapy as needed, or hold fluids and allow the overloaded patient to equilibrate.

Before beginning your postoperative resuscitation, the first step is determining whether it is even required. Review the operative record for fluids/blood products given and blood loss, as well as the extent of injuries and procedures performed. Discussion with the surgeon directly will be the best way to get a sense of whether ongoing fluid losses or bleeding is expected. Obtain immediate labwork to establish a baseline for the hematocrit, platelet count, coagulation panel, and lactate or base deficit. Examine drains, tubes, and wounds for ongoing blood loss. In combat trauma, your postoperative resuscitation fluid of choice for hypotension and/or coagulopathy is blood products in a 1:1:1 ratio or whole blood. A simple rule of thumb is to administer red blood cells until you have a stable hematocrit of at least 25 and plasma until the INR is less than 1.8. In addition to correcting coagulopathy, plasma is an excellent early resuscitation fluid with colloid volume expansion properties.

## How Do I Tell if I Am Winning or Losing the Battle? What Is the Best Endpoint?

After damage control surgery and damage control resuscitation have controlled hemorrhage and contamination, the goal of resuscitation is to restore adequate tissue oxygenation by normalizing intravascular volume. The questions of when adequate oxygenation and intravascular volume have been achieved are not straightforward. When traditional parameters of resuscitation such as systolic and mean arterial blood pressure, heart rate, and urine output have normalized, up to 85% of severely injured patients may still have inadequate oxygen delivery, a state known as compensated shock. Attempts to guide resuscitation toward supranormal values of oxygen delivery, oxygen consumption, and cardiac output have met with limited success. It appears that patients who achieve supranormal levels of oxygen delivery have a better survival than those who cannot achieve these levels, but no evidence exists that attempting to attain such levels directly improves survival, and supranormal resuscitation has been associated with abdominal compartment syndrome and an increased incidence of organ failure. Oxygen delivery is a function of cardiac output, hemoglobin, and oxygen saturation. Therefore, options for improving oxygen delivery include increasing cardiac output, transfusing blood, or increasing oxygen saturation.

Since volume resuscitation is the primary means to improving cardiac output, various hemodynamic monitoring endpoints have been advanced as guides to resuscitation. Central venous pressure (CVP), pulmonary artery occlusion pressure (Ppao, often incorrectly referred to as pulmonary capillary wedge pressure), and more advanced volumetric measures of preload such as right ventricular end-diastolic volume index (RVEDVI) and global end-diastolic volume index (GEDVI) have been studied. With the exception of CVP, these require specialized equipment and/or training not present in most forward deployed facilities. Dependence on the CVP should be limited. Even when it is measured and interpreted correctly (from waveforms, not from the mean pressure displayed on the monitor) in a ventilated patient with no active expiration and reasonable levels of PEEP, the CVP does not appear to reliably predict volume status or volume responsiveness. The trending of CVP is a more useful tool than individual measurements, as there is a wide variation in baseline CVP between patients. Use CVP as one additional data point in your algorithm and not as a primary factor directing management decisions. Chap. 6 describes a useful technique for bedside ultrasound assessment of the size and collapsibility of the vena cava which can provide a real-time assessment of CVP and volume status.

The best and most feasible markers of resuscitation adequacy should be obtainable without specialized equipment, and they should be easy to interpret. Metabolic parameters show the most usefulness in assessing resuscitation from shock. The arterial base deficit, serum lactate, and central venous oxygen saturation (CvO2) are all readily available measures from standard blood-gas analyzers. Although they assess oxygen delivery and tissue hypoxia globally and not regionally, they provide the most consistent measures of shock severity and resuscitation response. Serum pH is a useful measure but is too easily influenced by respiratory factors and renal function to provide a reliable pure marker of tissue perfusion.

The arterial base deficit is an easily obtained and widely used measure in trauma. Investigators have demonstrated that the initial base deficit on presentation correlates with survival, and trends in the base deficit predict the success or failure of resuscitation. A base deficit of 5 mmol/L or greater is a marker of severe injury and should prompt further assessment and intervention. It is important to understand that you are using the base deficit as a surrogate for lactate, but several factors can disrupt the correlation between these two measures. These include hyperchloremic acidosis from saline overload, alcohol intoxication, and acidosis secondary to renal failure. In these situations, an elevated base deficit may have little or no prognostic significance.

Due to these limitations of the base deficit, lactate has become favored as the best biochemical marker for its specificity and predictive value. Although initial lactate values have been shown to correlate with outcome, lactate trends over time correlate better with survival. If you have the ability to check lactate levels, obtain one immediately postoperatively and then every 4–6 h during the early resuscitation. Your goal is normalization of the lactate level (<3 mmol/L) within 24 h, which predicts a greater than 90% survival. Failure to correct the lactate level within 48 h is associated with a mortality of 80–100%. The lactate clearance time will also predict postoperative complications such as infection: lactate normalization within 12 h is associated with a 10–15% infection rate, while normalization beyond 24 h is associated with a markedly increased (>60%) incidence of infection. Lactate clearance remains the most convenient and readily attainable indicator of resuscitation especially in the forward environment, where point-of-care testing devices are available and allow determination of lactate levels along with arterial blood gas measurements. Normalization of lactate levels within 24 h predicts greater than 90% survival. Since the last edition of *Front Line Surgery*, the concept of adequate lactate clearance as a predictor of mortality and as a major endpoint of resuscitation in critically ill patients has been questioned, with critics averring that elevated lactate levels result from increased aerobic metabolic flux from physiologic stress, labelling the phenomenon stress hyperlactemia. However, a recent systematic review of 96 studies (14 of which were specifically in trauma patients) demonstrated a consistent association between serial lactate measurements and response to therapy across the different studies with differing types of patient populations, with only five studies concluding no predictive association of lactate clearance with survival. Of note, given the rapid patient evacuation times (on the order of hours) with GHOST missions, trending of lactate levels over 24–48 h is unlikely to occur. However, the relatively slow changes in lactate concentration imply that measurements every 1–2 h are likely adequate. Combined with arterial blood gas measurements, lactate trending is a readily available and simple method for the forward surgeon to assess the direction of resuscitation and adjust therapy accordingly.

Measurement of the central venous oxygen saturation (CvO2) is being increasingly utilized in a variety of ICU populations, including trauma and major surgery. Obtain a venous blood gas from the central venous catheter. The CvO2 is the oxygen saturation value (not the pO2, which is a common mistake), and normal values are in the 65–80% range. This measure reflects the adequacy of tissue oxygen delivery and the amount extracted, with levels below 65% indicating inadequate delivery. If the CvO2 is less than 65%, then a stepwise approach is initiated to maximize the key factors in oxygen delivery. First, optimize the intravascular volume status and ensure the hematocrit is at least 25. If the CvO2 remains low, then transfuse to get the hematocrit to ≥30. Ensure that the oxygen saturation is as close to 100% as possible. If the CvO2 remains low, then the next culprit is the cardiac output. Although cardiogenic shock is less common in the average young trauma patient, it can be seen with major chest trauma, arrhythmias, or sepsis. A cardiac inotrope such as dobutamine or norepinephrine should be started and then assess for any improvement in CvO2. This is often a trial and error process, but it should be done in an orderly and rapid manner. Figure 33.3 outlines a basic algorithm to approach the early postoperative resuscitation.

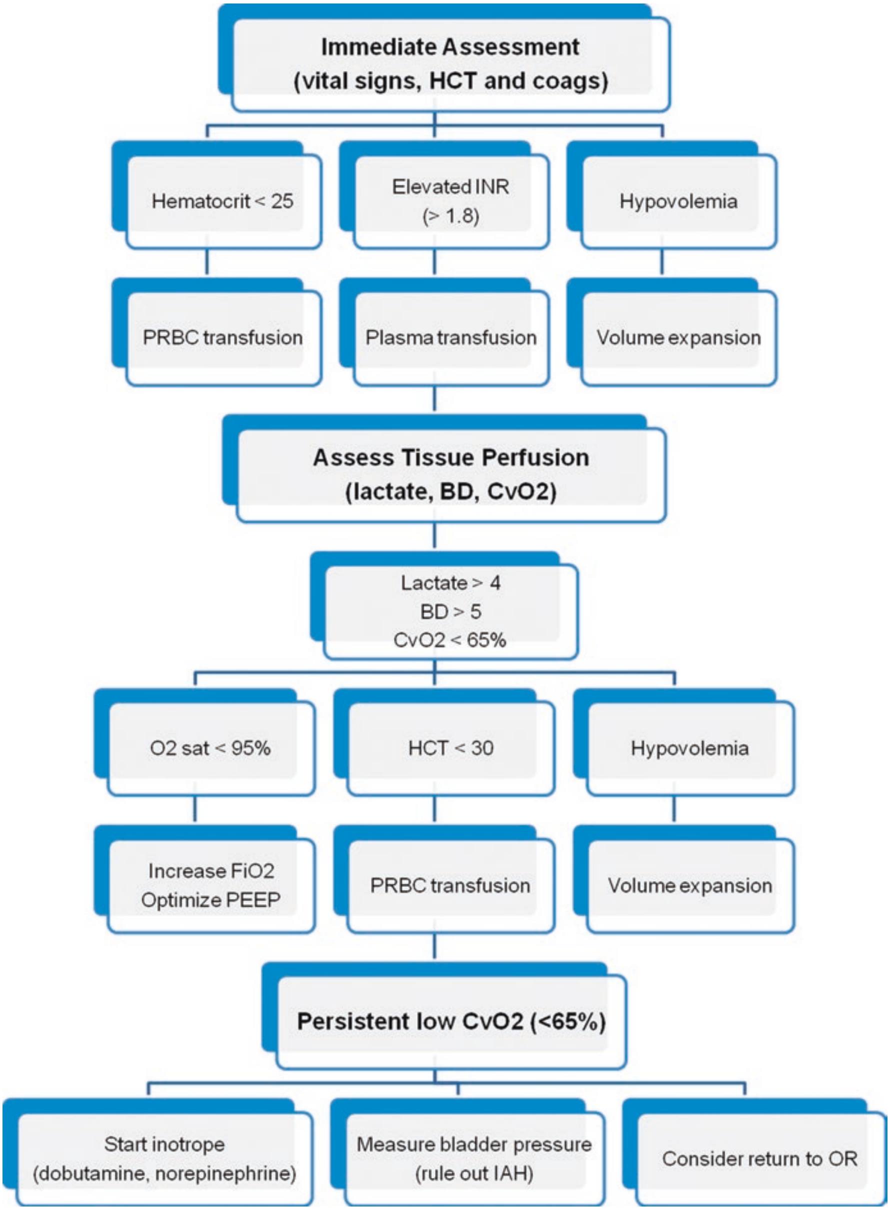


**Fig. 33.3** Example of a postoperative resuscitation algorithm based on physical examination, vital signs, and routine laboratory parameters. *INR* international normalized ratio, *FiO2* fraction of inspired oxygen, *IAH* intra-abdominal hypertension (pressure >20 mmHg)

One of the least discussed aspects of postoperative resuscitation is the role of pressor agents. Standard surgical teaching is that there is no role for early pressor use, and resuscitation should focus on volume administration, followed by more volume. There is growing interest in the efficacy of earlier introduction of pressor agents for hypotension during resuscitation. It is now appreciated that the early response to major trauma is not purely due to volume depletion but also represents a variety of factors including vascular permeability, cardiac dysfunction, and resistance to naturally produced catecholamines and vasopressin. It would therefore make sense that pressors could be of benefit in maintaining perfusion and in avoiding overzealous crystalloid administration. There is also accumulating animal data that early pressor use in hemorrhagic shock markedly improves survival compared to volume and blood resuscitation alone. Pressor agents may also contribute to hemorrhage control by vasoconstriction and redistribution of blood flow. In the patient with refractory hypotension despite an adequate volume load (particularly those with associated brain injury), we recommend initiation of a balanced pressor agent (norepinephrine, dopamine), while resuscitation is continued and other causes (i.e., recurrent hemorrhage) are addressed.

## Who Does Not Need Resuscitation?

One of the hallmarks of expertise in postoperative resuscitation is the ability to identify patients who do not require any resuscitation or even require immediate volume removal. The easy (and often expected) practice is to continue large volume fluid administration until every last number has normalized or is supranormal. Withholding fluids in the early postoperative period is often criticized or looked upon as heresy, but this is pure dogma. If the surgeon and anesthesia provider did their job well and there is no ongoing contamination or bleeding, then the patient will often arrive to the ICU fully resuscitated or even overloaded. As described above, you must rapidly establish a baseline assessment of the patient's status based on the injuries and operations performed, vital signs, urine output, and laboratory parameters. If the measures of tissue perfusion and adequate oxygen delivery are normal (lactate <2, base deficit <5, central venous O2 sat >70%), then there is little that you can improve by adding additional fluid. You will best serve the patient by minimizing unnecessary fluids and closely follow these parameters every 2–4 h to adjust your plan. You will be rewarded with decreased incidences of organ failure and abdominal compartment syndrome and faster times to extubation.

## When Do I Need to Go Back to the OR?

As resuscitation proceeds, following conventional parameters such as the blood pressure and urine output in conjunction with lactate and base deficit will be important. The hematocrit will also help guide resuscitation but less so than the other variables as hematocrit is affected by both loss of red cell mass and infusion of fluids. As urine is produced and the lactate and base deficit normalize in the face of continued hemodynamic stability, the resuscitation may be assumed to be progressing well, and fluid administration should be minimized. Increasing lactate, increasing base deficit, decreasing CvO2, or hemodynamic instability should induce a rapid and aggressive search for ongoing hemorrhage and devitalized tissue or ischemia. Wounds should be examined for evidence of devitalized tissue, and the extremities should be assessed for vascular integrity. Ongoing cavitary hemorrhage or hemorrhage into extremity compartments may be difficult to assess. Chest tube output may not adequately reflect hemorrhage due to clotting, so function of the chest tube should be assessed and a chest x-ray obtained to evaluate for retained hemothorax. Suspicion of uncontrolled intra-abdominal hemorrhage is an indication for exploration. Evidence of ongoing bleeding that persists despite adequate efforts to treat coagulopathy mandates an immediate return to the OR to control the source. Failure to do so will ultimately lead to catastrophe, and no amount of blood, plasma, or recombinant factor VIIa will salvage a patient who languishes in the ICU when they belong in the operating room.

A final point regarding the problem of traumatic coagulopathy bears mentioning. Since the last edition of *Front Line Surgery*, research into trauma-induced coagulopathy has yielded insights into the physiology and management of this condition. Unfortunately, in the most forward locations, some of the cornerstones of preventing trauma-induced coagulopathy, namely, damage control resuscitation with plasma, platelets, and packed red blood cells (PRBCs) in a 1:1:1 ratio or whole blood, along with the increasingly popular use of viscoelastic measuring devices, are logistically constrained. The prevention and treatment of trauma-induced coagulopathy in forward locations necessarily depend on an adequate supply of packed red blood cells and fresh frozen plasma. In combination with administration of tranexamic acid, the administration of PRBCs and FFP in a 1:1 ratio is still the cornerstone of hemostatic resuscitation when forward deployed. Blood product refrigeration units such as the AccuTemp AX56L (formerly HemaCool) and the Golden Hour Box allow the storage of PRBCs and FFP far forward, subject to resupply requirements. Particularly with GHOST missions, whole blood drives are not tactically feasible; hence platelet repletion is not a therapeutic option at present. The resolution of coagulopathy is itself an endpoint of hemostatic resuscitation, and at most Role 3 hospitals in theater viscoelastic point-of-care methods for hemostasis testing such as rotational thromboelastometry (ROTEM) (TEM International GmbH, Germany) are available. Point-of-care cartridge-based PT/INR measurements however are the only method of coagulation testing elsewhere in theater. As such, the surgeon will need to adhere to a strict 1:1 ratio of PRBCs to FFP. Although complex and in need of further study, the limitations of SLTs to guide hemostatic resuscitation must be kept in mind and highlight the importance of maintaining a 1:1 ratio of PRBCS to FFP particularly when limited to only POC standard laboratory tests to assess hemostatic response.

## Final Thoughts

You should think of the resuscitation as a continuous line that begins in the prehospital setting and continues through the ER, OR, and into the ICU (see Fig. 33.1). Therefore, understanding what has been already done and where your patient is now will guide your postoperative resuscitation plan. Always be cognizant of the morbidity of excess administration of cold, dilutional, and acidotic solutions – i.e., standard crystalloids. This all too common occurrence of "dry-land saltwater drowning" is now easily avoided with modern resuscitation principles. Be smart, be aggressive, and be focused

**Key Similarities**

- Resuscitations often change hands in civilian practice, so directions and transitions of care have to be clear and accurate.
- Over- and under-resuscitation can occur and are equally bad.
- Those failing resuscitations are probably bleeding.
- Goals are the same – resolve acidosis and restore normothermia, coagulation, and oxygen delivery/consumption.
- Blood products should be the primary postoperative resuscitation fluids.
- Base deficit and lactate are the overall best measures of resuscitation.

**Key Differences**

- A myriad of monitoring tools are available which can tempt the provider into focusing too heavily on numbers and devices rather than examining the patient, assimilating information, and making decisions.
- Misguided use of albumin is more common in the civilian trauma resuscitation because the civilian environment is not as resource-limited.

on the important variables to achieve an effective combat resuscitation.

## Civilian Translation of Military Experience and Lessons Learned

Andrew C. Bernard

Civilian postoperative resuscitation follows the same principles as those outlined by Dr. Schreiber. This includes resolving acidosis and restoring normothermia, as well as restoring normal coagulation and normal oxygen delivery/consumption. All of these goals are sought simultaneously and on a continuum as in the military environment, but the fragmentation inherent in US trauma systems creates discontinuity and unique challenges in achieving this goal. Continuous resuscitation can be more, not less, difficult in the civilian setting.

Resuscitative fluid choice and volume has gained much attention, and the ATLS now supports a smaller initial fluid bolus and earlier assessment of whether the patient has ongoing hemorrhage. "Hypotensive resuscitation" is taught in the ATLS and in our training programs and has been practiced more in the last decade. But the most appropriate population and situation for "hypotensive resuscitation" are still unclear. Historically the blunt-injured patient with a possible head injury facing a long transport time was thought not to be a candidate for hypotensive resuscitation, while the penetrating-injured patient in a major trauma center with a very short door-to-OR time was thought to be ideal. But recent evidence from the original proponents of hypotensive resuscitation questions the superiority of this resuscitation strategy over a more standard blood pressure target (MAP =65 mmHg). In the average emergency department (ED) in the USA, the initial fluid will and still should be crystalloid. More important is what happens after the crystalloid bolus. The characteristics of nonresponders, transient responders, and responders indicate the likelihood of ongoing bleeding and dictate the next fluid to be used. Non- and transient responders in the emergency department need blood. In postoperative resuscitation, blood component therapy is even more likely to be the best choice. Fresh whole blood remains impractical and of questionable benefit in the civilian setting. The recently published PROPPR Trial demonstrated that a balanced hemostatic resuscitation with a plasma/platelet/RBC ratio approaching 1:1:1 will produce more survivors at 24 h than a lower ratio of plasma and platelets to RBC (1:1:2 or lower).

Colloids have no more benefit in civilian postoperative resuscitation than in military resuscitation. But because the civilian environment is resource-rich, albumin use is much greater. Most civilian surgeons would be surprised to find out how much albumin is administered to their trauma patients by anesthesia and by their less-informed but well-intentioned residents and staff. We have admonished our teams for giving too much crystalloid, so they sometimes turn to albumin as an alternative. A quick look at one's hospital pharmacy data, searched by attending name or by service, will be eye opening to many surgeons and serve as a basis for reducing unnecessary and expensive albumin use. Albumin does nothing to enhance urine output and only contributes to accumulation of extracellular fluid, rather than preventing it.

Monitoring resuscitation in the civilian setting is best done with eyes, ears, hands, and basic laboratory tests, just as in the military setting. However, a myriad of monitoring systems are available and thus are used and misused. Base deficit and lactate are the best overall measures of resuscitation. Just as in the military setting, they should be obtained immediately upon arrival in the postoperative care area and trended until normal, an endpoint best reached within 24 h. CVP is notoriously inaccurate for all the same reasons articulated by Dr. Schreiber. The primary value of a central line is to administer blood and to monitor central venous oxygen saturation as an indirect measure of oxygen delivery. Despite recent criticism of continuous venous oxygen saturation as a resuscitation target in the critically ill septic patient, tissue oxygenation remains the fundamental physiologic goal in ICU patients, especially those who are injured and bleeding. The question one should ask oneself at the bedside is how best to measure oxygen delivery. Tissue oxygen saturation can be measured noninvasively via near-infrared spectroscopy and predict blood product requirement and need for surgery. Aside from measuring oxygenation via lab tests and tissue saturation, all other resuscitation tools measure plasma volume or flow. Cardiac and/or caval ultrasound is perhaps the most popular new method of assessing volume status, but it is highly user- and image-dependent. Analysis of the arterial waveform in ventilated patents can be used to assess volume responsiveness, but this has not been tested in trauma, is interpreter-dependent, and requires arterial cannulation and mechanical ventilation. Measures of plasma volume and arterial waveform amplitude still only measure one component (stroke volume) of one component (cardiac output) of the oxygen delivery equation, *not* whether the tissues are actually receiving and consuming oxygen adequately.

Vasopressors should not be necessary for most trauma victims, and Dr. Schreiber's admonition is equally true in the civilian trauma ICU: failure of a patient to respond appropriately to resuscitation is most often a sign of ongoing hemorrhage that warrants reoperation or some other intervention for hemorrhage control. However, select patients in whom bleeding is not severe, and are more neurologically injured, will benefit from vasopressor use for limited intervals during early resuscitation. Established scientific evidence to support vasopressors in bleeding patients is still lacking, and no randomized prospective data support their use.

"Saltwater drowning" occurs in civilian trauma resuscitation with equal or greater frequency than in military settings because modern resuscitation paradigms germinated in theaters of war take time to establish themselves as standards across the US civilian data support a ratio of less than 1.5:1 for crystalloid: RBCs in reducing MOF, ARDS, and abdominal compartment syndrome though not all authors agree that crystalloids are such the culprits they have been portrayed to be. Civilian surgeons are, however, catching on to fluid restriction. Temporary closure of the abdomen after trauma is less common today as a result. Abdominal compartment syndrome has become uncommon compared to the past.

Civilian resuscitation should follow the same principles as it does in the hands of our military colleagues. Careful transition of care out of the operating room; liberal use of blood components until temperature, coagulation, acidosis, and oxygen delivery normalize; high index of suspicion for ongoing bleeding; consistent and systemic use of the reliable resuscitation targets like serum lactic acid; and avoidance of over-resuscitation are the fundamental principles. We in the civilian setting must not let our ready access to a myriad of monitoring devices and too many unnecessary adjuncts like albumin cloud our judgment, distract us, and simply inflate the cost of good trauma care.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Damage control resuscitation.
2. Fresh whole blood transfusion.
3. Frozen blood.

# TEG/ROTEM-Driven Resuscitation in Trauma

**34**

Hunter B. Moore, Eduardo Gonzalez, and Ernest E. Moore

*A pint of sweat saves a gallon of blood.*

General George S. Patton

**BLUF Box (Bottom Line Up Front)**

1. "Stop the bleeding" requires mechanical (surgical) control and physiologic normalization of the coagulation system.
2. Coagulation is a cellular mediated process that is dependent on both tissue factor-bearing cells and platelets and soluble coagulation proteins.
3. Viscoelastic assays provide as much information as five conventional clinically based assays.
4. Viscoelastic assays should be employed only in patients with concerns for active bleeding.
5. Blood for viscoelastic assays should be collected in a citrated tube to prevent clotting before the assay can be performed.
6. A rapid TEG and EXTEM ROTEM assay will provide the quickest results and thus are optimal in the actively bleeding patient.
7. A prolonged rapid TEG ACT (>128 s) or a prolonged EXTEM CT (>80 s) is an indication for plasma transfusion in an actively bleeding patient.
8. A shallow rapid TEG angle (<65°) or a small EXTEM A10 (<30 mm) is an indication for cryoprecipitate/fibrinogen transfusion.
9. A small rapid TEG MA (<55 mm) or small EXTEM MCF (<45 mm) is an indication for a platelet transfusion.
10. A high rapid TEG LY30 (>5%) or low EXTEM IL30 (<70%) is an indication for consideration of administering an antifibrinolytic.

H.B. Moore • E. Gonzalez (✉)
University of Colorado Denver, Department of Surgery, Denver, CO, USA
e-mail: hunter.moore@ucdenver.edu; eduardo.gonzalez@ucdenver.edu

E.E. Moore
Denver Health Hospital, Department of Surgery, Denver, CO, USA


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Personalized medicine employs diagnostic testing to target the optimal care for the individual patient. While the extremes of individualized care can be seen in oncology in which genotyping of malignancies guides chemotherapy, trauma patients do not provide the liberty of weeks to determine their definitive treatment plan. As a result, in trauma, algorithmic rapid decision-making is common, as timely intervention is critical. This is particularly true in actively bleeding patients. To combat bleeding, empiric ratios of red blood cells (RBCs), plasma (FFP), and platelets are used in massive transfusion protocols to deliver blood-based resuscitation in a timely fashion. However, blood product transfusions are not without risks. A balance of judicious blood product utilization while not falling behind on a hemostatic resuscitation is critical. Clinical judgment and laboratory assessment work synergistically to correct bleeding. Hemostasis is achieved by both mechanical (surgical) interventions and a physiologically intact coagulation system.

Trauma patients most commonly present to the hospital with a coagulopathy caused by a combination of their tissue injury and hemorrhagic shock, which can be identified by a prolonged international normalize ratio of prothrombin time (INR). However, an INR only identifies a patient who has a potential coagulopathy and does not determine the patient's specific derangement in coagulation. It is now appreciated that trauma patients present to the hospital with a spectrum of coagulation abnormalities. These coagulation deficits can be related to endothelium, platelets, coagulation factors, fibrinogen, red cells, and neutrophils. To appreciate the full-potential coagulation abnormalities of a trauma patient, at least five traditional clinical coagulation tests would be required (INR, PTT, platelet count, Clauss fibrinogen assay, D-dimer). Alternatively, the same information can be provided by a single viscoelastic assay.

Viscoelastic assays have been used clinically to analyze coagulation abnormalities for over half a century, although interest in their implementation to guide trauma care is relatively recent due to improved and reliable equipment. These tests provide actionable results within minutes and can provide a complete coagulation profile in just over an hour. While the output of a viscoelastic assay may appear daunting, there are only four variables to remember (ACT, angle, MA, and LY30 for TEG; CT, A10, MCF, and LI30 for ROTEM), each of which is associated with a specific intervention. This enables an individualized approach to resuscitation based on the dominant coagulation abnormality while implementing an algorithmic approach to deliver targeted blood products during resuscitation. Prospective data indicates that viscoelatic based resuscitation in trauma patients undergoing massive transfusion can reduce mortality by 50%.

When you are confronted with an actively bleeding trauma patient, there is one priority, stop the bleeding. This requires two interventions: mechanical control and normalizing the coagulation system. Goal 1 to stop mechanical bleeding will be the most labor intensive, and steps toward normalizing coagulation can be as simple as ordering a single assay to personalize blood-based resuscitation efforts to target the coagulation deficiencies of the patient's specific bleeding phenotype. While ongoing studies are arguably needed before global adoption of viscoelastic assays to guide resuscitation, the output of these assays can be easily interpreted and currently provides the only level 1 evidence of a transfusion strategy to reduce mortality in massively bleeding trauma patients. The objectives of this chapter are to provide the reader with a rationale for using these assays from a basic science standpoint, a framework for understanding viscoelastic assays, and an overview of the important indices from these assays to guide resuscitation and discuss how to clinically implement a viscoelastic assay in a trauma center.

## Coagulation Is Not as Simple as an INR: The Cell-Based Model of Hemostasis

Enzymatic pathways taught during medical school do not accurately assess the functional coagulation system. When considering coagulation assessment, plasma-based tests are designed to measure individual coagulation factor deficiencies (e.g., hemophilia) or therapeutic anti-coagulation such as an international normalized ratio of prothrombin time (INR) or partial thromboplastin time (PTT). These long-standing assays have their clinical roles in assessing coagulation status, but have several important limitations when addressing the needs of the bleeding trauma patient. First, these assays partition coagulation as they have separated the cellular component of blood. Second, these assays were designed to measure coagulation factor deficiencies, not global coagulation which included platelets, fibrinogen, and fibrinolysis. And finally, INR and PTT cannot be used to assess hypercoagulability. Whole-blood assays not only include the same proteins that these assays assess but also include the cellular components which are central in the generation of hemostatic clots. The importance of assessing coagulation with its cellular components has been highlighted by the work of Hoffman and Monroe [1], in which cell-based interactions coordinate hemostasis. The following is a brief overview of cell-based hemostasis, where, for a more complete appreciation of the complexities of hemostasis, readers should refer to reference [1].

Hemostasis begins with *initiation*. Cells lining the extravascular space contain tissue factor (TF). TF is a potent activator of coagulation and in the presence of smaller-sized coagulation factors (II, VII, IX, X, IX, and XII) that exist in both extra- and intravascular compartments. However, additional large coagulation proteins (e.g., vWF, VIII,) and platelets are confined to the intravascular space. This partition prevents intravascular thrombosis while priming the outside of blood vessels to clot if injury occurs (Fig. 34.1). When blood vessels are injured (Fig. 34.2), the release of large intravascular coagulation proteins and platelets interact with a TF-rich environment, causing the initiation of coagulation with the first generation of thrombin.

*Amplification* of coagulation is dependent on platelets. There are numerous additional enzymatic reactions that regulate this process, but ultimately when platelets bind to an area of injury, coagulation begins to rapidly proceed. This process is thought to be mediated by the dual activation platelets from both collagen (binding site of injury) and thrombin (local initiation of coagulation). This leads to platelet aggregation and assembly of coagulation factors. Platelets orchestrate the thrombin burst resulting in clot *propagation* by localizing coagulation factors on their surface.

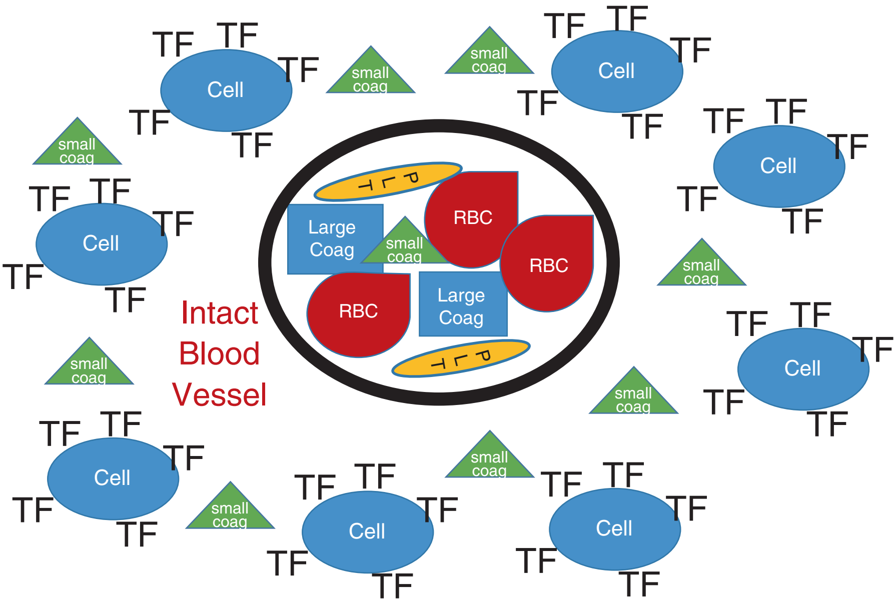


**Fig. 34.1** An intact blood vessel and the partitioning of coagulation. Within the blood vessel, larger molecular weight coagulation factors (VIII and von Willebrand Factor) are confined to the intravascular space and cannot leave the blood vessel unless damage occurs. The same is true with platelets. Additional smaller molecular weight coagulation factors (II, VII, IX, X, XI, and XII) can freely diffuse in and out of the blood vessel and can interact with tissue factor-coated cells. This creates a primed procoagulant environment around the blood vessel. By partitioning the coagulation factors and platelets, minimal coagulation will occur inside the blood vessel under healthy conditions. *TF* tissue factor, *PLT* platelet, *Large Coag* larger molecular weight coagulation proteins, *Small Coag* smaller molecular weight coagulation factor, *RBC* red blood cell

This results in high levels of thrombin cleaving fibrinogen and strengthening the forming hemostatic plug, which is further strengthened by fibrin cross-linking from factor XIII. These critical interactions between platelets and coagulation factors are key to appreciate when interpreting the results of conventional coagulation assays, as both an INR and PTT have excluded the critical platelet component.

## What Is a Viscoelastic Assay?

During coagulation, blood transitions from a liquid to a solid state (thrombosis) and will naturally degrade back to a liquid (fibrinolysis). These changes can be assessed using viscoelasticity. Viscoelasticity is a composite measurement of viscosity and elasticity quantified by a force causing a deformity. A simplified analogy is mixing cement with a stick. As the cement hardens, the force required to push the stick increases. This increase in force represents the transition of the cement from a liquid to a solid. Therefore, the force required to move the stick in the hardening cement is

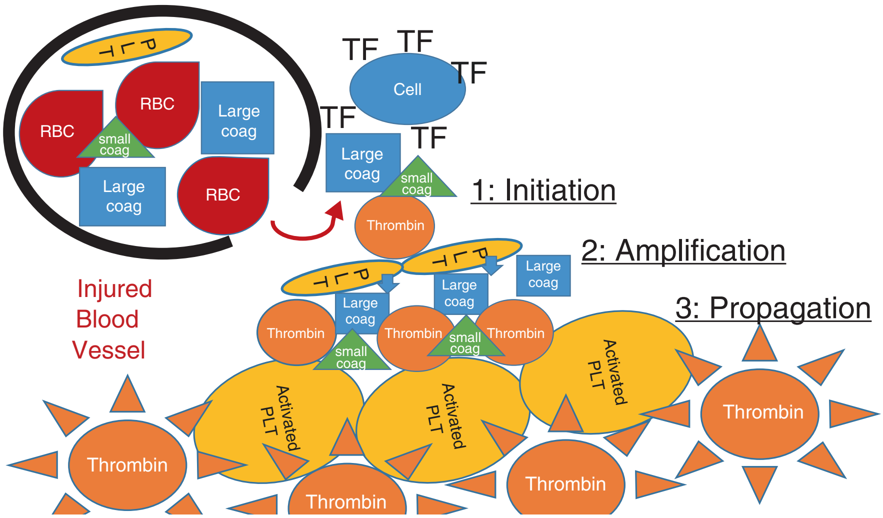


**Fig. 34.2** Blood vessel injury and cell-mediated hemostasis. Large coagulation factors and platelets have leaked into the extravascular space. The once separated large coagulation factors can now interact with tissue factor-bearing cells and small coagulation factors to generate a small amount of thrombin. Thrombin is the active enzyme in coagulation that cleaves fibrinogen into fibrin which forms a clot. This represents clot *initiation* (*1*). Platelets begin to aggregate around the injured vessel and in the presence of thrombin and other activating factors release additional coagulation factors (e.g., V) that increase thrombin generation. This phase of coagulation is known as *amplification* (*2*). During amplification a larger amount of thrombin is generated, and platelets take on an activated form from receptors on their surface that are activated by thrombin and extracellular matrix proteins. These activated platelets form a scaffold of phospholipid membrane that enables a large thrombin generation known as the "thrombin burst" and causing the third phase of coagulation, *propagation* (*3*). This cell- and protein-based interactions emphasize the importance of assessing coagulation from a whole-blood standpoint. Assays that partition coagulation require careful interpretation as they neglect to account for these interactions. This represents the first half of coagulation known as thrombosis. The second phase of coagulation is fibrinolysis in which the clot breaks down, which is a natural physiologic process to prevent clot occluding the blood vessel. *TF* tissue factor, *PLT* platelet, *Activated PLT* platelet that has been activated by thrombin and extracellular matrix proteins, *Large Coag* large molecular weight coagulation factor, *Small Coag* smaller molecular weight coagulation factor, *RBC* red blood cell

a crude quantification of the viscoelastic strength of the cement over time. This is an overly simplified explanation of how these machines which, which involves physics beyond what a clinician needs to interpret a viscoelastic assay.

The most common methodology to cause deformity of blood (the stick in the cement) is with a pin and cup. Thrombelastography (TEG) uses a rotating cup to deform blood, while ROTEM uses a rotating pin in a stationary cup. Additional methodologies can be used, but are beyond the scope of this chapter. As blood transitions from a liquid to solid state, the shear strain created by polymerizing fibrin and platelet aggregation (increasing viscosity) is transmitted to the device.

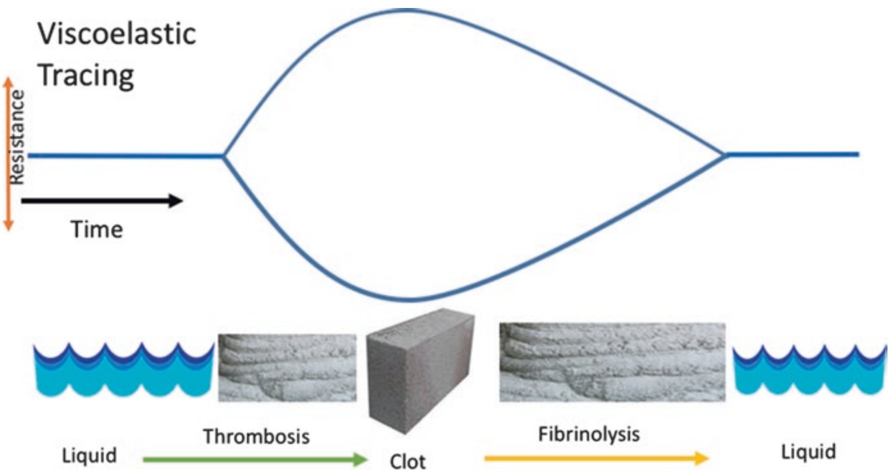


**Fig. 34.3** Phases of the viscoelastic assay. This figure represents the viscoelastic readout as blood transitions from a liquid to a solid (thrombosis) and back to a liquid state (fibrinolysis). In viscoelastic assays the *Y* axis represents time and *X* axis represents resistance (relative clot strength). In the figure, the liquid form of blood is associated with a single line. As coagulation initiates the line splits. The larger the split between the lines, the higher the viscoelastic resistance is generated from the clot. These lines will continue to split until the clot forms its maximum strength. This represents thrombosis. The clot will then begin to degrade overtime in a process known as fibrinolysis. As the strength of the clot begins to decrease, the lines come closer together. Once the clot has returned back to the liquid state, the lines have now intersected and represent a single line

Resistance is then quantified by the machine, which is visualized on a display as a single line splitting into two (Fig. 34.3). The distance between the two lines is proportional to viscoelastic resistance transmitted from the clot. This resistance is measured over time until the clot forms its maximum strength, represented by the two lines reaching their maximum amplitude and distance apart. This concludes the clot formation aspect of the device. After this point, the clot begins to lose strength through fibrinolysis, via cleavage of fibrin. The two lines' amplitudes decrease, and are quantified over time. The end result of a viscoelastic assay is an hourglass-shaped tracing, which has numerous properties that can be calculated to approximate abnormalities of the different components of coagulation.

## What Type of Blood Tube Is Optimal for Running a Viscoelastic Assay?

Blood samples run on viscoelastic assays can be stored in citrate (light blue top), heparin (green top), and no anticoagulant (white top) vacuum-sealed containers. Manufacturers have specific recommendations on the timing between blood sample draw and time to run assay. Heparin-based TEGs are primarily used in cardiovascular surgery and will not be further discussed in this chapter, although may be useful when treating patients with vascular injuries who require systemic heparinization.

In the acute setting of trauma, a citrated sample or non-anticoagulant tube can be used. Despite concerns that running a citrated blood sample early after blood draw can alter results, this methodology is favored to guarantee that the patients' assays can be completed. Non-anticoagulant blood sample is problematic, particularly during emergency department evaluation, as a significant amount of samples is coagulated before they could be assayed. While in a healthy individual a non-anticoagulated sample can sit for over 5 min before coagulation begins, the majority of trauma patients will have a primed coagulation system and initiate clot formation much sooner. This is particularly true if the blood sample is obtained as the first tube of collected blood, as it can contain TF-bearing cells from the puncture of the surrounding venous tissue. In the research setting, the first ml of blood after venous puncture is always discarded to reduce the risk of TF contamination.

The location of the blood draw is also relevant when interpreting TEG results. Arterial blood samples tend to be more hypercoagulable than venous samples. As early arterial blood draws may be challenging in hypotensive trauma patients, it is the authors' recommendations to rely on venous blood draws when possible. In the more stable patients, while a fresh venous stick would be ideal, existing arterial and central venous catheters can be used for blood sampling. When trending the effects of blood products during resuscitation, it is optimal to not alternate between blood sampling sites. In the end, the differences between sampling sites may be more of an academic argument, as patients who are clinically hypocoagulable will likely demonstrate abnormalities regardless of the blood draw source.

## Activation of TEG/ROTEM-Based Assay

Whole-blood generation of clot can be initiated through various mechanisms. The two classic pathways of coagulation are the intrinsic and extrinsic activators. Hemostasis in reality is driven by both of these pathways that do not act in isolation of each other. However, activation of blood with different agonists can produce different results with viscoelastic assays, which needs to be taken into clinical consideration. Extrinsic pathway activation is typically via tissue factor, while intrinsic, also known as contact, pathway, is activated through kaolin. ROTEM has simplified the naming of their assays as EXTEM for tissue factor-based activation and INTEM for kaolin-based activation. TEG uses both tissue factor and kaolin in the rapid TEG (rTEG) to expedite clotting and uses a kaolin TEG (kTEG) for intrinsic activation.

The decision for running the specific assay is dependent on the clinical scenario. For example, the time to obtain clotting indices in an rTEG to guide resuscitation is 10 min quicker than kTEG due to rapid activation of the clotting. Therefore, an rTEG is optimal for use in hemodynamically unstable patients in both the emergency department and operating room. Unlike an INR and PTT, viscoelastic assays detect hypercoagulability. Detection of hypercoagulability in the intensive care unit is better assessed with a kaolin-activated assay. kTEG also demonstrates that the majority of trauma patients have elements of hypercoagulability on presentation to the hospital, which is not appreciated with rTEG. This could be attributable to saturating the activation of the coagulation system with supraphysiologic levels of tissue factors. The authors routinely use rTEG to guide blood product transfusions and kTEG to guide antiplatelet therapy in the intensive care unit for post-injury deep venous thrombosis prophylaxis. An important caveat of differences between ROTEM and TEG parameters is that despite assays targeted to specific coagulation pathways, the composition of the reagents in these assays is not the same, and thus indices are not interchangeable.

## Viscoelastic Indices' Correlation to Coagulation Abnormality

Viscoelastic indices are correlated to specific abnormalities of the coagulation system. However, assumptions are made that these processes are independent of each other to guide resuscitation, but the reality is that these variables are representative of interdependent processes occurring at the same time. In both TEG and ROTEM, regression analysis of specific indices correlates with fibrinogen (clotting factor) versus platelet contribution to clot formation. Interestingly, platelets are believed to contribute 80% of the ultimate clot strength. Despite the existing limitation of these assays, reproducible results can be determined in both TEG and ROTEM to predict patients at risk of massive transfusion and guide resuscitation of specific blood products. Abnormalities of the manufactured reported normal limits of TEG (Table 34.1) and ROTEM (Fig. 34.4) can be used as relative indications for blood product transfusion. However, the optimal threshold for transfusions based on readout of these assays in trauma is yet to be defined. The following sections describe the anatomy of these viscoelastic assays (Fig. 34.5) and association with blood product use.

### Transition from Liquid to Solid State: Plasma

As previously described blood transitions from a liquid to solid phase and indices measured by the viscoelastic assays correlate to particular components of coagulation. The initial transition from liquid to start of solid phase is in theory representative of the patient's coagulation factor status. Patients on systemic anticoagulation with heparin for bypass surgery will form a flat line and no evidence of clot, unless

**Table 34.1** Manufacturer recommended normal limits of TEG 5000 device

| Reagent/assay | Specimen type | TEG ACT (sec) | R (min) | Angle (degree) | MA (mm) | LY30 (%) |
|---|---|---|---|---|---|---|
| Kaolin | Whole blood | n/a | 4–9 | 59–74 | 55–74 | <7.5 |
| Kaolin | Citrated | n/a | 5–10 | 53–72 | 50–70 | <7.5 |
| RapidTEG | Whole blood | 86–118 | 22–44[a] | 64–80 | 52–71 | <7.5 |
| RapidTEG | Citrated | 78–110 | 17–38[a] | 66–82 | 54–72 | <7.5 |

*sec* seconds, *min* minutes, *mm* millimeters
[a]seconds for rapid TEG R time

## ROTEM® Reference values

| test name (reagent) | CT (s) | CFT (s) | α Angle | A10(mm) | A15(mm) | A20(mm) | A25(mm) | MCF(mm) | CLI 30(%) | ML (%)2) |
|---|---|---|---|---|---|---|---|---|---|---|
| INTEM | 100-240 | 30-110 | 70-83 | 44-66 | 48-69 | 50-71 | 50-72 | 50-72 | 94-100 | < 15 |
| HEPTEM | *Comparison with INTEM. A better clot quality in HEPTEM as compared to INTEM indicates the presence of heparin or heparin-like anticoagulants in the sample.* | | | | | | | | | |
| EXTEM | 38-79 | 34-159 | 63-83 | 43-65 | 48-69 | 50-71 | 50-72 | 50-72 | 94-100 | < 15 |
| APTEM | *Comparison with EXTEM. A better clot formation with ap-TEM® or APTEG-S when compared to ex-TEM® is an early sign of hyperfibrinolysis.* | | | | | | | | | |
| FIBTEM | n.d | n.d | n.d | 7-23 | n.d | 8-24 | n.d | 9-25 | n.d | n.d |
| | *MCF <9 mm is a sign of decreased fibrinogen or disturbed clot polymerisation. MCF > 25 mm is a sign of elevated fibrinogen levels (which may lead to a normal EXTEM or INTEM in spite of thrombocytopenia).* | | | | | | | | | |
| NATEM | 300-1000*) | 150-700 *) | 30-70 *) | | | 35-60 *) | | 40-65 *) | 94-100 *) | < 15 *) |

**Fig. 34.4** Manufacturer recommended normal limits for ROTEM delta device

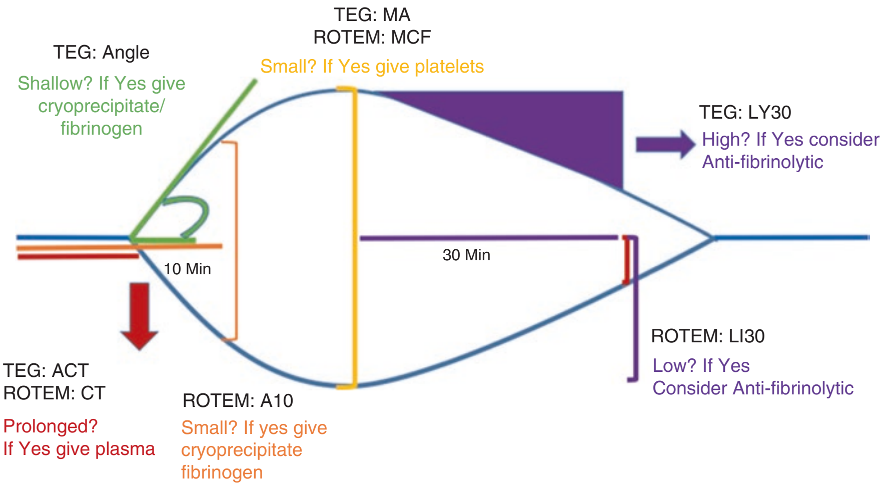


**Fig. 34.5** Anatomy of the viscoelastic assay for rTEG and EXTEM ROTEM. This figure represents the different actionable indices from both a rapid TEG and EXTEM ROTEM assay. While there are numerous outputs that both TEG and ROTEM provide, there are four major variables which can be used to guide resuscitation. (1) rTEG ACT or EXTEM CT. A prolonged ACT or prolonged CT is an indication for a plasma transfusion in an actively bleeding trauma patient. (2) rTEG angle or EXTEM A10. A shallow angle or small A10 is an indication for cryoprecipitate/fibrinogen transfusion in an actively bleeding trauma patient. (3) rTEG MA or EXTEM MCF. A small MA or MCF is an indication for a platelet transfusion in a trauma patient. (4) rTEG LY30 or EXTEM IL30. The LY30 represents the percent of the clot that has degraded 30 min after MA. IL30 represents the percent of the clot strength remaining 30 min after MCF. A high LY30 or low IL30 is an indication for considering an antifibrinolytic in an actively bleeding trauma patient. *ACT* activated clotting time in rTEG, *CT* coagulation time, *A10* amplitude at 10 min, *MA* maximum amplitude, *MCF* maximum clot firmness, *LY30* lysis at 30 min, *IL30* lysis index at 30 min

their blood is run in a specialized heparinase assay (heparinase cup TEG or ROTEM hepTEM), reversing the effects of this anticoagulant. Prolongation of this initial time, after eliminating the effects of exogenous heparin, indicates a patient likely to benefit from a plasma transfusion to replete their coagulation factors. The name of this indices varies by company and type of activator used.

The R time is the measurement of this initial phase of coagulation in kTEG. R time represents the time required from the baseline tracing to split and achieve an amplitude of >2 mm. While TEG will also record the actual split time (time when the initial line splits into two lines), the R time is more reliable as small air bubbles can artificially shorten the split time, in a sample with a normal R time. The R time in rTEG is described as an activated clotting time (ACT). Since the ACT is available in minutes before these other assays, the utility of using a kTEG in emergent situations is of limited value. However, these slower assays may be useful for the detection of hypercoagulability early after injury.

ACT is the first actionable data from rTEG. The time to obtain ACT is within minutes, and in an attempt to normalize the distribution of data, the actual time is converted to an artificial number called the ACT. ACT in TEG is not the same as point-of-care Hemochron® ACT tests and should not be used interchangeably. The optimal threshold for plasma transfusion based on ACT remains to be validated by prospective data, but appears to be 128 s. A markedly prolonged ACT (>140) is indicative of additional dysfunction of both platelets and fibrinogen and is an indication for transfusing cryoprecipitate and platelets before obtaining additional TEG indices in a hemodynamically unstable patient. It is important to take into context that the rapid TEG uses supraphysiologic levels of tissue factor. This should evoke rapid clot formation in a patient with a functional coagulation system, and the delayed onset of activation of a clot in severely injured trauma patient in this setting should generate immediate concerns (particularly if it exceeds 200 s in authors' personal experience).

The ROTEM comparable variable is called the coagulation time (CT). CT is not commonly used as a transfusion threshold. This may be attributable to transfusion practice differences between the United States and Europe. European trauma centers more often use ROTEM and often employ the A5 and A10 (amplitude of clot after 5 and 10 min after CT) as the first indices to guide resuscitation with fibrinogen replacement (discussed below). The rationale for using these variables is they serve as surrogates for predicting maximum clot firmness in an expedited fashion in trauma patients. However, in an early plasma-based resuscitation strategy, a CT > 79 s in an EXTEM can be used as a transfusion trigger for a plasma transfusion.

## Clot Strengthening: Fibrinogen

After the clot has transitioned to its solid state, the rate at which it strengthens can be quantified by the rate required to reach maximum clot strength. To expedite the time to achieve this result without waiting for the clot to reach its maximum strength, a tangential line to the curve generated by the growing clot that passes through the 2 mm deflection point creates an angle to the baseline tracing. The resulting angle between the two lines is called alpha or angle in both TEG and ROTEM. An angle of less than 65° has been proposed to be the threshold for cryoprecipitate transfusions in trauma patients using rTEG. ROTEM angle has also been correlated to fibrinogen dysfunction following trauma, but its utilization to guide fibrinogen repletion is less common. The preferred methodology of guiding fibrinogen replacement with ROTEM is with an EXTEM A10 < 30 mm. Additional kinetic parameters exist for TEG and ROTEM called the K time and clot formation time (CFT), but are rarely used clinically to guide resuscitation, although they correlate with coagulopathy and massive transfusion.

## Maximum Clot Strength: Platelets

The maximum clot strength called the maximum amplitude (MA) in TEG and maximum clot firmness (MCF) in ROTEM represent the ultimate clot contribution to hemostasis. An MA of less than 55 mm has been used as a transfusion threshold for platelets in trauma. An MCF < 45 mm that has been identified can also be used as a threshold for platelet transfusion. However, the European thresholds for ROTEM-based platelet transfusions are more stringent and are dependent on a low platelet count (<50,000) and confirmation of a low MCF or A10. Most of the published transfusion triggers in ROTEM-based hospitals use platelet count to guide platelet transfusions. These trans-Atlantic differences in transfusion practice represent the confusion associated with the use of viscoelastic assays during resuscitation. The decision to use MCF to guide platelet resuscitation therefore is thus hospital dependent.

## Fibrinolysis: Tranexamic Acid

Both ROTEM- and TEG-based assays have been used to detect increased fibrinolysis in trauma patients, which has been associated with massive transfusion and mortality. TEG quantifies the amount of fibrinolysis 30 min after MA (LY30). ROTEM quantifies fibrinolysis as the percent decrease in clot strength after MA at 30 min (LI30, which is comparable to the TEG CL30 variable (not commonly reported clinically)). These indices can also be measured at 60 min. While it is believed that the goal-directed antifibrinolytics should be used in patients with excessive fibrinolysis, recent retrospective data has failed to identify a survival advantage. At the moment, there are several multicenter randomized trials underway to address this issue. Furthermore, investigation of fibrinolysis following acute injury has identified that the majority of patients have impaired fibrinolysis (fibrinolysis shutdown) within an hour of injury, which is associated with increased mortality [2]. These data suggest that antifibrinolytics such as tranexamic acid (TXA) should be used selectively, but the optimal patient population is yet to be defined. However, antifibrinolytic administration, with or without the guidance of a viscoelastic assay, should not be given more than 3 h after injury, as this has been associated with increased mortality in the CRASH-2 study. The authors use a TEG LY30 > 5% as an indicator to use TXA in actively bleeding trauma patients. An LI30 in ROTEM <70% can also be used as a threshold to consider TXA.

## Rationale for Goal-Directed Resuscitation

Trauma-induced coagulopathy is not the result of a specific definable etiology. Unique phenotypes of coagulation abnormalities after injury have been identified by principal component analysis using plasma-based assays and viscoelastic testing. While a high injury severity and hypotension drive coagulopathy identified by an increased INR, the reason that these patients continue to bleed is multifactorial. Coagulation-based assessment of bleeding has been predominantly descriptive and associated with massive transfusion or mortality, and previous research has failed to delineate if patients were actually bleeding to death from their coagulopathy or if they were bleeding to death from their injury. While there is enthusiasm for empiric high ratios of plasma to red blood cells in bleeding patients based on the military experience in Iraq, the most recent randomized control trial in the United States did not demonstrate an overall survival advantage when using empiric high ratios of plasma and platelets to red blood cells [3]. Retrospective studies suggest individualized resuscitation with TEG is superior to fixed ratios in massively bleeding patients.

The evidence for TEG-guided resuscitation has been validated prospectively in a randomized control trial of patients at risk of massive transfusion [4]. Mortality was reduced to 19% in the TEG-based resuscitation group compared to the standard of care group (36%) based on intention to treat. Of note, by the end of the trial, the treating surgeons preferentially unblinded the study to obtain TEG results to guide resuscitation, and the survival benefit-based was even greater with TEG (18% vs. 40% mortality). TEG-guided resuscitation did not result in less red blood cell transfusions compared to the standard of care group, but resulted in patients receiving less platelets and plasma. While the exact mechanism leading to a survival advantage is not known, this study indicates the importance of goal-directed resuscitation. Since the publication of this study, the authors have adopted an initial empiric 2:1 ratio of red blood cells to plasma in patients meeting activation of our massive transfusion protocol, followed by rTEG-guided resuscitation for additional blood products (Fig. 34.6). Multicenter validation of these findings is warranted before global adoption of this protocol, but due to the large survival advantage appreciated at our trauma center, rTEG-guided resuscitation is the standard of care.

ROTEM-directed resuscitation algorithms also exist. As previously mentioned due to differences in transfusion practices, there are different strategies employed to achieve hemostasis based on ROTEM indices which also emphasize a functional fibrinogen assay to guide fibrinogen replacement, PCC, and tranexamic acid (Fig. 34.7). Using ROTEM vs. TEG is based on hospital/surgeon/anesthesia preference and local transfusion practices. While results between TEG and ROTEM are not interchangeable, both are useful in identifying coagulopathy and transfusion requirements.

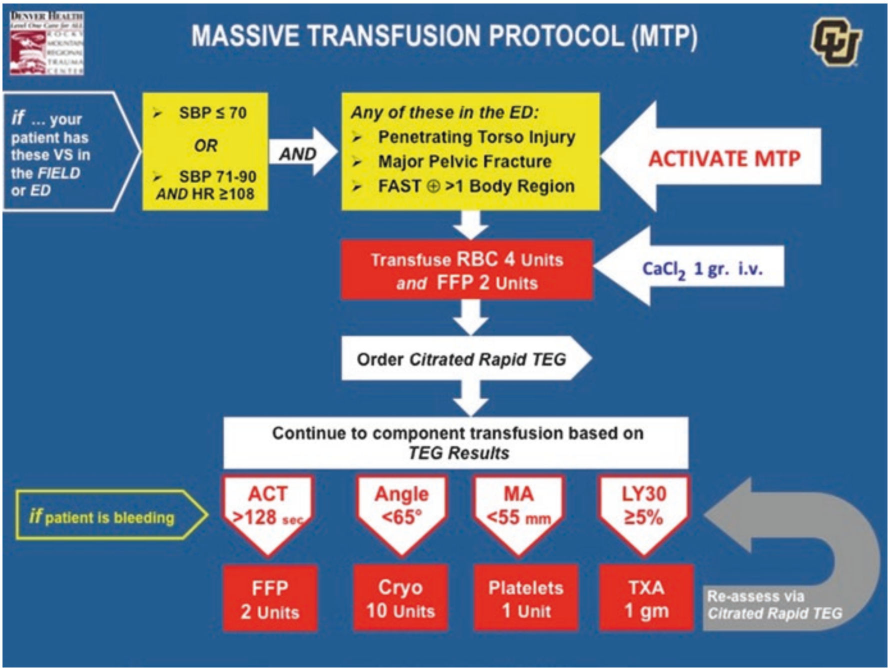


**Fig. 34.6** Massive transfusion protocol for Denver Health Hospital in the United States. This figure represents an American-biased resuscitation strategy using rTEG for goal-directed resuscitation

## Using Viscoelastic Assays in the Clinical Setting

Viscoelastic assays require additional logistic efforts. Current viscoelastic assays require a trained technician to run blood samples and must be performed in a timely fashion to get actionable results. In most cases this requires 24 h coverage of a technician capable of running these assays. However, new-generation TEG (6 s) and ROTEM (sigma) devices are beginning to get their federal approval for clinical use and have an automated process requiring minimal training to perform these assays. The potential for a point-of-care portable assay performed prehospital, in the emergency department, and in the operating room is exciting.

There are currently no standard transfusion thresholds agreed upon for TEG and ROTEM in trauma, although there are many recommendations in the literature. The authors have recently published their transfusion triggers for rTEG-based resuscitation based on an analysis of high-level trauma activations and blood product requirements and comparisons to large healthy volunteer study [5]. It is imperative for centers that use viscoelastic assays to have agreed upon threshold for transfusions. Prior studies in non-trauma patient populations have had mixed results in regard to the success in using viscoelastic assays to reduce blood loss and mortality. The common theme of

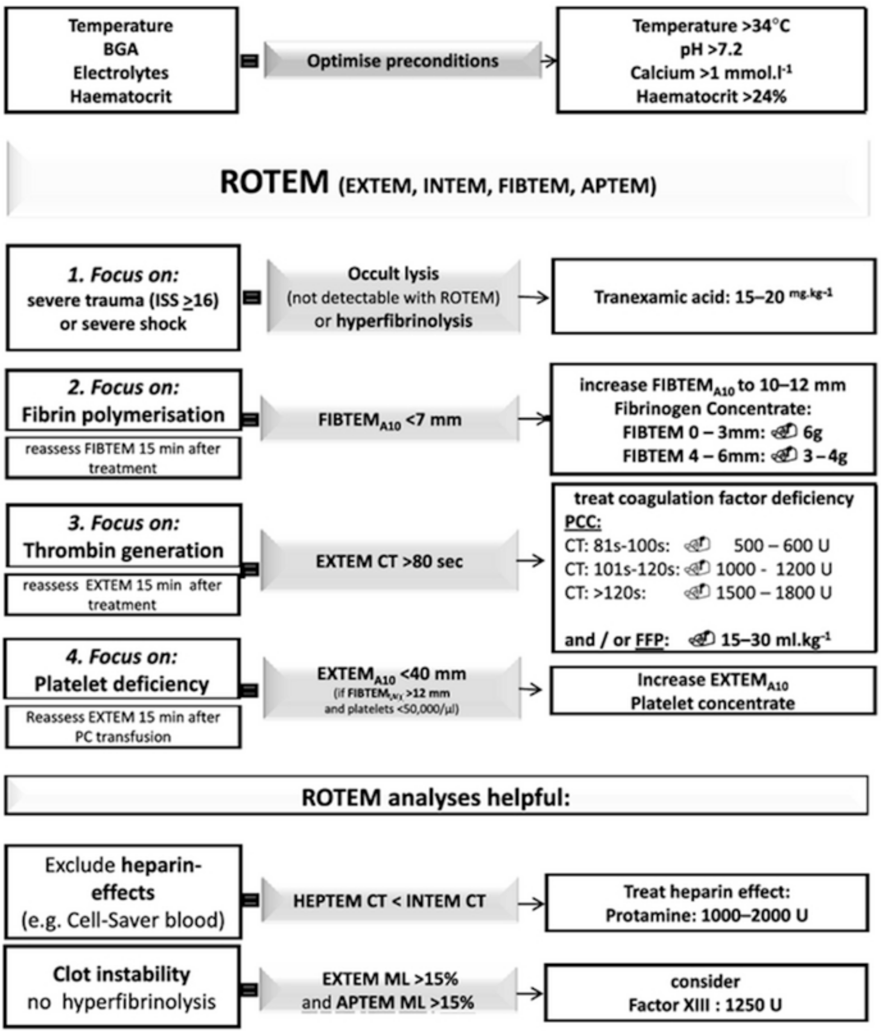


**Fig. 34.7** Massive transfusion protocol for AUVA Trauma Center in Austria. This figure represents a European-biased resuscitation strategy using ROTEM for goal-directed resuscitation (Reprinted from Schöchl et al. [6], with permission from John Wiley and Sons)

the studies which demonstrated an advantage with implementing viscoelastic assays was a clearly defined algorithm to give blood-specific products based on predefined thresholds. All centers adopting viscoelastic testing should have agreements between the blood bank and trauma service for these specific transfusion targets.

While there are a large number of indices that these devices report, keeping resuscitation efforts simple is an important component to clinical implementation. Reporting variables that are associated with specific blood products is logical. The authors use four variables during resuscitation to guide resuscitation. These include

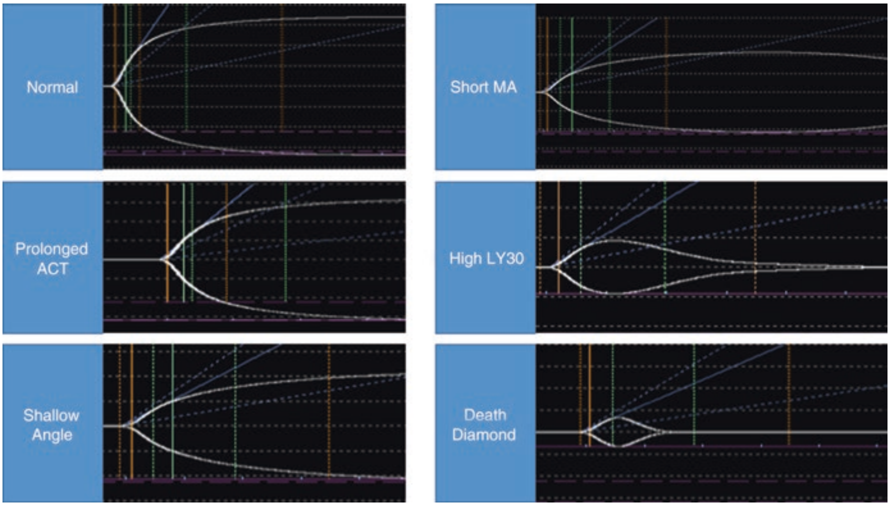


**Fig. 34.8** Visualization of different TEG patterns. This figure represents a spectrum of coagulation abnormalities appreciated in trauma patients after injury. The panel on the upper left represents a relatively normal-appearing TEG after trauma. Each subsequent panel represents an rTEG abnormality associated with one of the four previously mentioned indices to guide transfusion. The final panel in the lower right represents the death diamond, which is a pan-coagulopathic patient with an extremely high amount of fibrinolysis

ACT, angle, MA, and LY30. Important to clinical implementation is having a real-time tracing of the viscoelastic curve displayed to the trauma surgeon and anesthesiologists during resuscitation efforts. Specific TEG can be appreciated earlier than the numeric output of these devices and can expedite blood product administration. Figure 34.8 demonstrates the different TEG patterns associated with different coagulation deficiencies. The last tracing is representative of the "death diamond" viscoelastic tracing which is associated with 100% mortality in a moderately sized clinical study.

The most important component of viscoelastic assays is to have a plan for how and when they will be used. There is no benefit of performing a viscoelastic assay in trauma patients who are hemodynamically stable with no risk of active bleeding. Our current practice is to obtain an rTEG in all trauma activations or patients in whom a massive transfusion protocol has been activated. We repeat testing after the appropriate blood products have been administered. This continues until the patient has clinically stopped bleeding. This practice results in obtaining one TEG roughly every hour, or more frequently if the patient is massively bleeding.

Purchasing a viscoelastic assay will not in itself save lives. As a trauma community as a whole, we struggle with blood-based resuscitation efforts. In a recent survey of 125 level I and II trauma centers in the United States, 98% reported having a massive transfusion protocol, yet the indications for activating this protocol were only based on a validated score system 7% of the time. In this survey, a coagulation test was only routinely measured a third of the time, and a viscoelastic assay was only available in 9% of centers, yet over a quarter continued to use activated factor VII and more than half of these centers used tranexamic acid. In Europe, similar concerns about a lack of consensus for guiding resuscitation in bleeding trauma patients exist. Thus, there is a desperate need for research to understand the fundamental mechanisms driving TIC and clinical trials to determine the optimal timing and composition of blood component therapy.

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# Monitoring

# 35

Jay A. Johannigman, Alec C. Beekley, and Timothy A. Pritts

**Deployment Experience**

| | |
|---|---|
| *Alec C. Beekley* | Staff Surgeon, 102nd Forward Surgical Team, Kandahar Airfield, Afghanistan, 2002–2003 |
| | Chief of Surgery, 912th Forward Surgical Team, Al Mussayib, Iraq, 2004 |
| | Staff Surgeon, 31st Combat Support Hospital, Baghdad, Iraq, 2004 |
| | Director, Combat Casualty Research Team, 28th Combat Support Hospital, Baghdad, Iraq, 2007 |
| *Jay A. Johannigman* | Deputy Commander, 332nd EMEDDS, Talil Air Base, Iraq, 2003 |
| | CCATT Team Member, Balad Air Base, Balad, Iraq, 2005 |
| | Deputy Commander, 332nd Air Force Theater Hospital, Balad, Iraq, 2006 |
| | Trauma Czar, 332nd Air Force Theater Hospital, Balad, Iraq, 2008 |
| | DCCS; Craig Joint Theater Hospital, Bagram Afghanistan, 2010 |
| | Deployed surgeon; Craig Joint Theater Hospital, Bagram Afghanistan 2012 |

J.A. Johannigman (✉)
Surgical Critical Care and Acute Care Surgery, University Hospital, Cinicinnati, OH, USA

Department of Surgery, Cincinnati, OH, USA
e-mail: Jay.johannigman@uc.edu

A.C. Beekley
Thomas Jefferson University Hospitals, Paoli Hospital, The Lankenau Hospital, Division of Acute Care Surgery, Division of Bariatric Surgery, Philadelphia, PA, USA

T.A. Pritts
University of Cincinnati Medical Center, Department of Surgery, Cincinnati, OH, USA


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*An increasing worship of an instrument for its own sake sometimes leads to enslavement by it.*

David Seegal

**BLUF Box (Bottom Line Up Front)**

1. No monitor can or should replace your eyes, ears, hands, or brain.
2. Young casualties demonstrate robust physiologic defense mechanisms and will defend blood pressure and pulse to the point of complete cardiovascular collapse.
3. "Compensated" shock may often be more accurately termed "unrecognized" shock.
4. The standard monitors available – pulse oximetry, electrocardiography, arterial lines, and central venous pressure – provide valuable but limited data.
5. Evaluation of shock and resuscitation should focus on parameters that reflect the adequacy of cellular oxygen delivery.
6. Pulse, blood pressure, and urinary output are notoriously unreliable indicators of adequacy of resuscitation – particularly in the young casualty.
7. There is not a single "best" endpoint of resuscitation.
8. Pulse volume variability is a quick and reliable means of estimating potential response to volume administration.
9. Base deficit, lactate, venous oxygen, and saturation are reliable indicators of resuscitation.
10. Correction of coagulopathy is a valuable indicator that your patient is doing well.
11. Several novel technologies (e.g., NIRS $StO_2$, CRI, closed-loop resuscitation, and oxygenation) show promise and have been introduced into the combat setting; they should not replace your physical exam skills and judgment.

## Introduction

During a discussion I was having about near-infrared spectroscopy (NIRS)-derived tissue oximetry, an expert surgeon who has written a lot about NIRS asked, "If we could have the perfect patient monitor, what would it look like? It would be non-invasive. It would be continuous. It would be reliable. It would be inexpensive, so you could use it repeatedly on anyone and everyone. It would tell us information that we couldn't figure out on our own. And it would not only tell us that something was wrong, it would tell us WHAT was wrong ( and with sufficient advance warning) so we'd know what to do about it."

All current monitoring devices – even the new, high-tech ones – fall short of this ideal. The monitors you will have in theater will provide you with raw data, but it


**Fig. 35.1** Ubiquitous portable monitoring unit used in deployed Army surgical units. Continuous electrocardiographic tracings, pulse oximetry, temperature, and respiratory rate are standardly displayed. This particular monitor also reveals end-tidal $CO_2$ monitoring in an intubated patient

will still be up to you to put various pieces of data together with the appearance of the patient to determine what is wrong with the patient and what needs to be done. Monitors are tools and looking magnifying glasses; the art of medicine is in the interpretation. There is no single lab, test, monitor, or device that can tell you what is wrong with a patient and what to do. No monitor can replace your eyes, hands, brain, and judgment. With that in mind, the follow-on lesson is that the establishment of monitors, particularly invasive ones, should never take priority over the interventions necessary to save a patient. The words, “We’re just going to get another central line and a-line in him, and then we’ll go to the OR,” should not come out of your mouth. Central lines or a-lines are almost never the intervention that saves a bleeding trauma patient’s life. Nor should monitoring delay the execution of life-saving interventions.

Although heart rate and blood pressure may be inadequate to gauge resuscitation, they are frequently sufficient as a triage tool to separate those that need immediate operation from those that do not. The character of the radial pulse and a simple GCS motor score can fairly reliably separate the “sick” from the “not sick.” This is particularly true if keen attention is paid to other nonmeasurable clinical signs (skin color, mental status, obvious physical signs of injury, etc.). Rapid point-of-care testing (INR, base deficit, lactate and Hgb) can provide confirmatory data. Invasive continuous monitoring is almost never required for this initial decision process. Typically, a simple pulse oximeter, electrocardiographic, and respiratory rate monitor are rapidly established and provide adequate continuous data for patients needing transfer from the trauma bay to the OR or CT scan (Fig. 35.1). All surgical units will have this basic monitoring capability. The other standard monitors available at the forward surgical team and combat support hospital include arterial lines and central venous pressure. More advanced continuous monitors, such as continuous central venous saturation, intracranial pressure, near-infrared spectroscopy-derived tissue oxygenation, and noninvasive cardiac output monitors, will only be available at selected facilities.

## Pulse Oximetry

The ubiquitous pulse oximeter device consists of a light source and a detector that fits around the finger, toe, or earlobe. It passes visible (red) and infrared spectrum light through the tissues and, based on values programmed into the device, can detect the different amounts of red and infrared light that are absorbed or transmitted through oxygenated and deoxygenated hemoglobin in the blood vessels. The percentage of oxygenated blood can be calculated automatically by the device. The pulse rate is also displayed.

Several problems or conditions can cause the pulse oximeter to provide faulty readings. Patients in profound shock, elderly patients (particularly those with vascular disease), and patients with very cold extremities may have poor perfusion of their digits, and the oxygen saturation may be falsely decreased and/or pulse rate may not be detected. Please remember to develop a prejudice in the trauma bay that the reason the oximeter is not working is more often related to *SHOCK* and hypoperfusion than to defective equipment. The authors have all too often watched precious time wasted as multiple probes/monitors are placed on the patient in shock in an effort to troubleshoot equipment rather than troubleshoot the patient in shock. It is critically important that you look at not only the number being displayed on the monitor but also the waveform. You will frequently see false values of 95–100% saturation displayed when there is no discernible waveform.

For the combat environment, the relevant things to remember are that the pulse oximeter may be unreliable in casualties in profound shock – and in these cases, the value of the pulse oximetry should not be decisive anyway. The fact that the pulse oximeter cannot detect a pulse IS a decisive finding. Casualties may also have profound hypothermia, even in the hot desert; others may have cold weather exposure as well. Finally, casualties are sometimes trapped in burning vehicles or buildings and may have a carbon monoxide exposure. All of these scenarios may affect the accuracy and reliability of the pulse oximetry reading.

## Electrocardiography/Telemetry

Electrocardiographic monitoring is also standard for combat casualties and is available in most medical units, all surgical units, and aeromedical units. There are essentially no downsides to continuous monitoring of electrocardiographic tracings, and most trauma bay personnel get used to rapidly applying these to casualties. Unfortunately, the data obtained from these tracings are somewhat limited, at least from the standpoint of rapid decision-making in trauma. The cardiac telemetry monitors do not provide much additional information aside from heart rate, particularly in young, otherwise, healthy casualties. There are instances where older foreign national patients, contractors, and even soldiers may suffer cardiac ischemia, and these monitors can be useful in that setting. The monitors are also useful for easy, continuous monitoring in the intensive care unit and are standard in ICUs throughout the world. One key point is if your patient suddenly becomes asystolic, check that the leads have not fallen off or the cable has become disconnected before you crack the chest open.

## Central Venous Pressure

Continuous monitoring of central venous pressure (CVP) is available in most surgical units, but the utility to reliably determine volume status and monitor resuscitation is limited. The administration of fluids prior to establishing hemorrhage control remains of very questionable value. The administration of sedation, analgesia, medications, antibiotics, and sufficient sedation to initiate anesthesia for surgery may often be accomplished via the intraosseous route. If adequate large-bore peripheral IV access has already been established, central line placement is not a valid reason to delay taking the patient to the OR. Central lines can be placed by anesthesia personnel while the surgeons operate. Once the central line has been established *in the appropriate setting*, the best monitoring data it will provide is through intermittent assessments of the central venous oxygen saturation.

One of the biggest fallacies in critical care that continues to be taught and practiced is that central venous pressure is an accurate reflection of ventricular preload. While this looks reasonable on diagrams, the reality is that this is an "estimate of an assumption about a surrogate." The lack of correlation between CVP and volume status has been proven in multiple studies, even among healthy volunteers where the relationship between end-diastolic volume and CVP should be the most reliable. While it may have some use at the extremes of measurement (complete volume collapse or massive volume overload), CVP IS NOT AN ACCURATE OR RELIABLE REFLECTION OF INTRAVASCULAR VOLUME! This is so important that it bears repeating. CVP IS NOT AN ACCURATE OR RELIABLE REFLECTION OF INTRAVASCULAR VOLUME (got it?). Changes in CVP can just as easily reflect changes in patient position, monitor position, respiratory pressures, and most importantly ventricular compliance. Intubating a patient and placing them on positive pressure ventilation to include PEEP will always elevate CVP while simultaneously impeding central venous return and cardiac filling volume. This truism explains the often observed paradox of the freshly intubated trauma patient who demonstrates an elevated CVP and concomitant hypotension. The higher the airway pressure, the higher the CVP and the lower the venous return. This patient needs fluids, not Lasix. The compromise of venous return effected by airway pressures may also explain why trauma patients placed on APRV early in their resuscitation (prior to adequate volume restoration) display more hypotension than patients on conventional ventilation.

The measurement of CVP is also highly user and interpreter dependent; we have found that drastic CVP changes more often reflect a nursing change of shift or recalibration of transducers than they do fluid shifts. You will be much better off using some of the alternative measures for assessing volume status outlined in this chapter and in Chap. 6 (Ultrasound in Combat Trauma).

## Venous Oxygen Saturation

The term mixed venous oxygen saturation ($SvO_2$) refers to the hemoglobin saturation of blood in the proximal pulmonary artery. Central venous oxygen saturation ($CVO_2$) refers to the hemoglobin saturation in the superior vena cava (or other central vein). They are not identical because of the consideration of the return of highly desaturated blood at the level of the coronary sinus. When oxygen *supply* provided by the cardiopulmonary system is insufficient to meet the bodily/cellular oxygen *demand*, there is a resultant increase in oxygen extraction at the tissue level. This state of increased extraction is manifested by a decrease in the venous oxygen content. Monitoring of venous oxygen content therefore serves as a shorthand of the equity between oxygen supply and oxygen demand. Shock is, in its most basic understanding, a mismatch of oxygen supply and demand.

Traditionally the monitoring of venous oxygen saturation has required the placement of a pulmonary artery catheter in order to obtain sample(s) from the pulmonary artery ($SvO_2$). The logic of this approach recognizes the variability and sampling error that may be introduced by the contribution of cardiac return via the coronary sinus. The contribution of the effluent of the coronary sinus is significant and may (or may not) be accounted for by a central venous line. This anatomic and physiologic consideration is the basis for the traditional use of $SvO_2$ as the correct measurement of venous oxygen saturation (requiring full admixture of venous blood in the right ventricle) for truly representative sampling of venous oxygen content.

A number of recent studies have attempted to identify a correlation between mixed venous saturation (pulmonary artery catheter) and central venous saturation (CVP line). These studies have reached alternative conclusions regarding the absolute correlation between individual observations of $SvO_2$ and $CVO_2$. However, what can be concluded from these studies is that although individual observations may vary, the *trend* in $SvO_2$ closely approximates the trend in $CVO_2$ and may be used as an accurate surrogate (Fig. 35.2). The author recommends the use of $CVO_2$ (via central venous sampling) as a means of tracking the direction and trend of an ongoing resuscitation. Most combat casualties with significant injuries will have a central line placed in anticipation of needs for resuscitation and transport by the CCATT team. The availability of CVP lines in combat casualties affords the opportunity for frequent and simple sampling of the trend in $CVO_2$ as a means of monitoring the progress of an ongoing resuscitation. Limited studies in the setting of hypovolemic shock (animals and humans) have demonstrated the utility of monitoring venous saturation as a marker of the severity of shock as well as its subsequent resolution during resuscitation. To date, there has not been a prospective study examining the efficacy of venous saturation as an endpoint of resuscitation in trauma patients. A study completed in medical patients did demonstrate that the use of $CVO_2$ is a valid endpoint of resuscitation capable of altering mortality and superior to standard goals. In the setting of trauma patients, positive trends in the resolution of venous desaturation have been demonstrated to be associated with improved survival. It is the authors' belief that monitoring of venous saturation ($SvO_2$ or $CVO_2$) is much

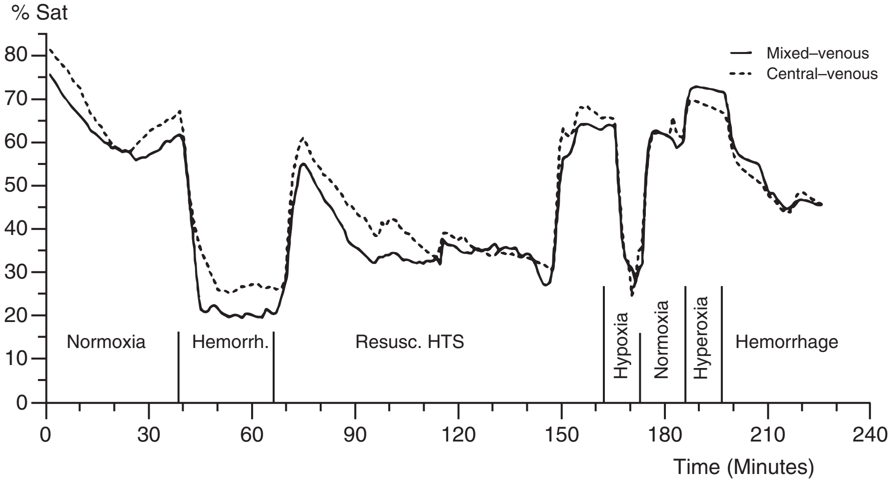


**Fig. 35.2** Strong correlation between mixed and central venous oxygen saturation across a variety of physiologic extremes (Reprinted from Chest, 95(6), Konrad Reinhart, Tobias Rudolph, Donald L. Bredle, Lutz Hannemann, Stephen M. Cain, Comparison of Central-Venous to Mixed-Venous Oxygen Saturation During Changes in Oxygen Supply/Demand, 1216–1221, copyright 1989, with permission from Elsevier)

more reliable and meaningful than the oft-quoted standards of heart rate, blood pressure, and urinary output. This is especially true in the young and otherwise healthy combat casualty. In addition to helping guide your resuscitation, this data can also prevent the other cardinal sin: over-resuscitation. If you have an isolated abnormality (tachycardia, low blood pressure, borderline urine output) but your $CVO_2$ and other markers (hematocrit, lactate) are reassuring, then you do not have to chase the abnormality with more volume resuscitation.

## Pulmonary Artery Catheters

Although some combat support hospitals may actually stock a few of these devices, there are very limited applications for their use in the combat setting. The most common use of pulmonary artery catheters in forward surgery has been as an improvised embolectomy catheter or occlusion catheter for vascular repairs in the operating room. The patients are predominately young, healthy men and women who happened to suffer severe penetrating trauma. There is rarely any confusion about their cardiac function, and volume status may be assessed by other means. If you happen to be in a unit that stocks these devices, keep in mind that in addition to the device, their use requires specialized monitors and skilled intensive care nurses. Finally, there is no quality data to support pulmonary artery catheter use in trauma patients – if anything, it may be harmful because of misleading data. If you do have these available and do use them, then you should always follow these basic principles:

(1) level the device and read your numbers from the waveform, not from the averaged numbers on the monitor; (2) repeat your measurements several times to ensure consistency; and (3) do not use it as a "wedgometer"; among all of the data provided by this device, the filling pressures are less accurate and useful than the volume indexes (cardiac index, stroke volume index) and getting a true mixed venous oxygen saturation ($SvO_2$). If you truly want a real-time assessment of cardiac function, output, filling, and major pathology, then an echocardiogram is a far more reliable tool. A rapid and limited transthoracic echocardiogram is relatively easy to learn and to perform (see the "Ultrasound", Chap. 6) and will typically provide much more reliable and functional information than a pulmonary artery catheter.

## Arterial Lines

Arterial lines have substantial utility in the treatment of combat casualties – *as long as their placement does not delay transfer to the OR.* The preferred sites for placement are in the radial arteries, but if you are struggling or fail at the wrist, don't hesitate to place a femoral arterial line. Brachial arterial lines and other end arterial lines have been associated with potential ischemic complications – they should be avoided if other alternatives are available and removed as soon as possible if they are used. Establishment of an arterial line allows second-to-second monitoring of blood pressure and withdrawal of blood specimens for standard labs, arterial blood gas, and lactate levels. Adequacy of resuscitation cannot be directly gained from the arterial line tracing, but the trend may at least be able to tell you if you are headed in the right direction.

A quick word is in order regarding the accuracy of arterial line versus blood pressure cuff for the measurement of mean arterial pressure. As with any other technology, the use of an arterial line to constantly monitor blood pressure relies on the inherent accuracy of the system. There are multiple reasons that a properly placed arterial line may overestimate blood pressure to include transducer position and line resonance. The addition of arterial line extension tubing to the standard monitoring tubing set creates the potential for resonance or "ringing" of the system which impairs the accuracy of the electronic algorithm by which the monitor deduces mean arterial pressure. It is important to assure that the arterial line and a properly fitted blood pressure cuff are correlating before committing to important interventions based upon arterial line monitoring.

Over the recent years, there has been increasing attention directed to utilizing arterial waveform analysis as a means of estimating cardiac performance. It has long been recognized that the character of the central vascular pressure waveform (aortic root pressure) provides significant information regarding stroke volume. A number of companies and investigators have focused on the opportunity to utilize the pulse profile of the arterial line (positioned peripherally in the radial or femoral artery) to derive information on stroke volume variability as a surrogate to stroke volume and, in turn, end-diastolic volume.

As an example, the Vigileo monitor (Edwards Lifesciences LLC, Irvine, CA) uses input from a high-fidelity arterial line to estimate the cardiac stroke volume


**Fig. 35.3** The Vigileo monitor (Edwards Lifesciences LLC, Irvine, CA) extracts data from a radial artery catheter (*arrow*) to provide reliable estimates of stroke volume (*SV*), cardiac output (*CO*), and stroke volume variability (*SVV*)

(and thus cardiac output), which can be combined with standard blood gas data to estimate oxygen delivery and consumption. A second-order analysis of the same data can examine the variations in the cardiac stroke volumes during the respiratory cycle and provide an estimate of the intravascular volume status (Fig. 35.3). The continuous nature of this data makes it ideal for both point assessments and for assessing the response to resuscitation and other interventions. Beware: As stated above the accuracy of this technology relies on a “high-fidelity arterial line” as a platform for intense computational mathematics. Any situation which degrades the fidelity of the signal – the patient bending their wrist and kinking the catheter, air bubbles in the pressure line, and change in transducer positioning – degrades the signal fidelity and, therefore, may compromise the information delivered.

Since the first edition of this chapter, there have been continued investigations into the utility of pulse volume variability. The Compensatory Reserve Index (CRI) uses a small wrist cuff and finger sensor to monitor pulse volume variability and to predict cardiovascular decompensation. This process has demonstrated significant accuracy in the laboratory and is currently being put through clinical field testing to evaluate its merits. It remains to be seen whether this or other novel technologies will prove themselves reliable and hardy enough to provide useful information in the austere far-forward setting. However, the noninvasive nature and ease of use of these newer generations of devices make them attractive options for use in the deployed ICU setting.

## Assessing Volume Status: The Holy Grail

The inventor of the device that can provide a quick, easy, and ACCURATE bedside estimate of intravascular volume will be a wealthy person indeed. For most combat casualties in the early phases of resuscitation, there will not be much mystery; they require repletion of intravascular volume. The greater challenge is understanding when adequate volume has been restored in order to avoid the hazards of excessive resuscitation. As previously mentioned, CVP may be notoriously misleading as an index of intravascular or end-diastolic volume(s). Utilizing ultrasonography to visually assess the inferior vena cava at the level of the diaphragm (size and respiratory variation) may provide more useful clinical information than measurement of intermittent CVP.

The recognized physiologic phenomenon of respiratory variability in hemodynamics may be used at the bedside to evaluate volume status even without an ultrasound. The augmentation of venous return produced by spontaneous inspiratory effort results in concomitant variations in filling volume of the heart. In turn, varying end-diastolic volume produces varying stroke volume that may be observed in any number of physiologic waveforms at the bedside. In the setting of intravascular volume depletion, this variability is particularly pronounced and a reliable indication of a patient who will have a favorable response to therapies that augment intravascular volume (fluids, blood, plasma, etc.). In the intubated patient, there is a similar swing in ventricular filling volume that is impacted by the respiratory cycle. In this setting, venous return is impeded during inspiration and the positive intrathoracic pressure effected by mechanical ventilation (exactly opposite the effect of spontaneous respiration). The astute clinician may gain an enormous amount of insight regarding volume status by simply standing at the bedside and observing the monitor for pulse variability with an understanding of how the respiratory cycle (or mechanical ventilation) impacts on venous return and filling volume of the heart.

Pulse volume variability may be readily observed at the bedside through observation of arterial line waveform pulse variability. This variability can be more readily identified by slowing the sweep speed of the arterial waveform tracing. This maneuver creates a relative trend function that makes pulse volume variability easier to detect. The Vigileo monitor (discussed above) attempts to provide an objective estimate of this variability. The variability in pulse volume may also be observed in the tracing of the pulse oximeter (Fig. 35.4).

A similar technique that is gaining wider acceptance is the passive leg raise maneuver. This is done by moving the patient from the standard ICU bed-rest

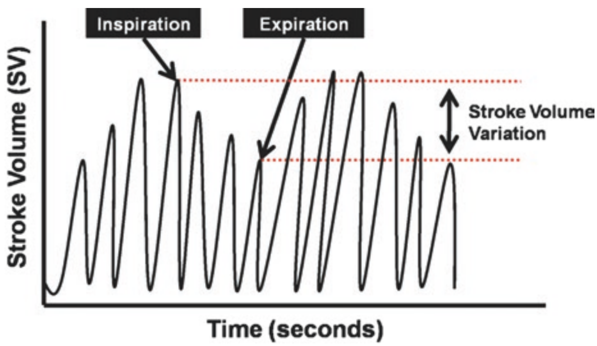


**Fig. 35.4** Stroke volume variation with the respiratory cycle during mechanical ventilation. A variation of greater than 10–15% accurately predicts that the patient will be responsive to volume infusion

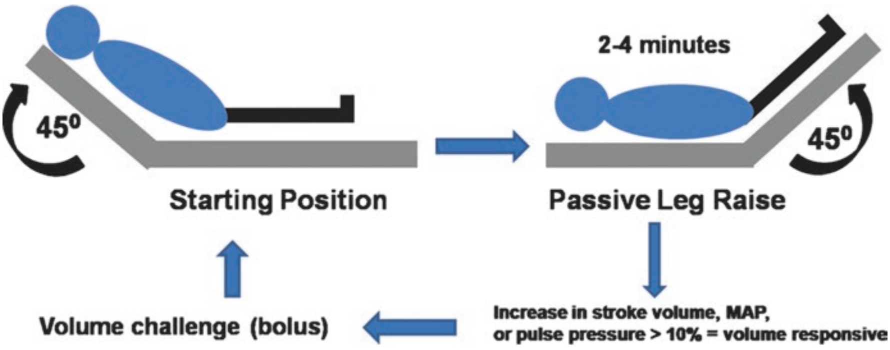


**Fig. 35.5** The passive leg raise (PLR) test for volume responsiveness. If the selected hemodynamic parameter improves by greater than 10% with PLR, then a volume challenge is administered. The test can be repeated to assess response

position (with 45° head elevation) to supine with the legs elevated to 45° (Fig. 31.5). In "volume-responsive" patients, this should result in significant improvement in central hemodynamics, with minimal change in euvolemic or volume-overloaded patients. The bad news is that traditionally this required a specialized probe to measure aortic flow or transthoracic echocardiography. The good news is that this technique has now been validated using the simple bedside measures of either mean arterial pressure (MAP) or pulse pressure (difference between systolic and diastolic pressure). As shown in Fig. 35.5, if your measure improves by greater than 10% (volume responsive), then you can proceed with a fluid bolus and then reassess. If the response is less than 10%, you can assume that the intravascular volume status is fine and look elsewhere.

## Intracranial Pressure Monitors (ICP)

Neurosurgical assets are usually centralized in a combat theater, and patients requiring evaluation and intervention are typically evacuated to these locations. If you are located at one of these centers, it will be important to gain familiarity with the placement and interpretation of ICP monitors. Chapter 24 provides a description of the options and techniques for placing these devices.

When interpreting the values displayed by an ICP monitor, it is important to consider several factors, including the current ICP level, the trend in ICP, and the ICP in relation to the mean arterial pressure. Cerebral perfusion pressure (MAP-ICP) should be maintained greater than 60 mmHg. An ICP elevated above 15 is a cause for concern, and any ICP above 20 or any rapidly increasing ICP should prompt immediate evaluation and intervention. In addition to the ICP value, additional important clinical information may be gained from examining the ICP waveform. Figure 35.6 shows a normal ICP waveform and several abnormal examples. Progressive elevation of the P2 peak (tidal wave) in relation to the P1 peak indicates

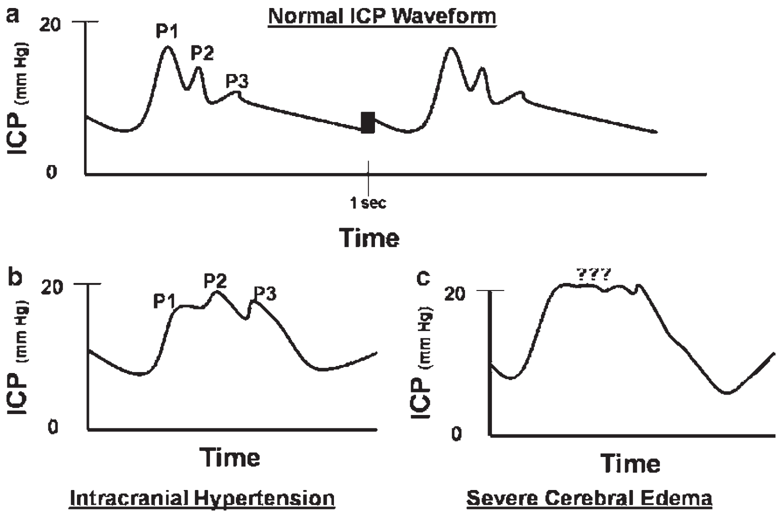


**Fig. 35.6** (**a**) A normal ICP waveform has three peaks of decreasing amplitude, *P1* (pulse wave), *P2* (tidal wave), and *P3* (dicrotic wave). (**b**) Increased amplitude of the tidal wave (*P2*) is seen with rising ICP and loss of cranial compliance. (**c**) Diffuse cerebral edema indicated by loss of the characteristic triphasic ICP waveform

decreasing cranial compliance and may predict refractory intracranial hypertension (Fig. 35.6b). Diffuse cerebral edema and loss of compliance are typically reflected by a rounding or "monotony" of the waveform, with loss of the three distinguishable peaks (Fig. 35.6c). This is an ominous sign which typically indicates a poor prognosis in the absence of an identified and reversible cause (i.e., epidural hematoma).

## Monitoring for Shock and Adequacy of Resuscitation

Shock is defined as inadequate oxygen delivery at the cellular level. In order to resuscitate a patient and eliminate shock, it is appropriate to evaluate parameters that relate to the adequacy of oxygen delivery as endpoints of resuscitation. There is no single endpoint that has proven to be unequivocally predictive of shock, but all prove to be more reliable than the simple measures of heart rate, blood pressure, and urinary output. It is the responsibility of the clinician to understand the strengths and weaknesses of the various parameters utilized to assess adequacy of cellular oxygen delivery. Chapter 30 provides an in-depth discussion of specific "endpoints" of resuscitation. The reader should not expect to emerge with a simple formula, device, or parameter to guide resuscitation but rather should derive a balanced foundation of how assessment of adequacy of cellular oxygen delivery is a complex yet potent patient care tool. The EARLY recognition and correction of shock will require collection of multiple traditional parameters (base deficit, lactate, venous oxygen concentration, and INR) combined with solid clinical judgment. The ability to assess for shock may be variable based upon the medical and laboratory technology available at the deployed location.

The remainder of this chapter will introduce several novel monitoring technologies for assessing shock and guiding resuscitation that you may encounter now or in the near future in the deployed setting. This includes near-infrared spectroscopy-derived tissue oximetry, heart rate and R–R variability, and closed-loop ventilation and resuscitation. These parameters are evaluated in the context of a progressive resuscitative paradigm that monitors the patient's progress and physiologic response to therapy.

## Correction of Coagulopathy

Traditional discussions of endpoints of resuscitation fail to include correction of coagulopathy as a targeted endpoint. The significant negative contribution of coagulopathy to the "lethal triad" (hypotension, hypothermia, and coagulopathy) has been demonstrated in numerous publications from the theater. Early correction of coagulopathy is an important component of damage control resuscitation. Data derived from OIF and OEF has demonstrated the utility of thromboelastography as a more accurate means of measuring the adequacy of the coagulation cascade. TEG machines have been available in theater, and the clinician must familiarize themselves with the displayed information and the interpretation of the TEG curve (see Chap. 34 on viscoelastic testing).

It is yet to be established with evidence-based studies, but the authors also believe that correction of coagulopathy will be a valuable and predictive endpoint for resuscitation. It is already established that patients who arrive to the trauma bay coagulopathic are at an increased risk of mortality. It remains to be seen whether the early correction postoperatively of coagulopathy will favorably impact outcome and mortality.

## Advanced Continuous Monitors

New technology is constantly being introduced into the combat environment. Which technology and how it may be applied to the advantage of the casualty remain to be answered.

The Vigileo monitor has already been described and is one of several devices that provide cardiac and volume data through analysis of the standard arterial pressure waveform. Near-infrared spectroscopy (NIRS)-derived tissue oxygenation (StO2) has been studied in Iraq and in Afghanistan. The NIRS is based on technology similar to an oximeter to measure oxygen saturation of hemoglobin. In the case of NIRS, the waveform utilized has the ability to penetrate skin and detect the oxygen saturation of an underlying tissue bed (muscle). The oxygenation of the peripheral muscle bed has been shown to reflect global perfusion, and the early studies suggest it is as good

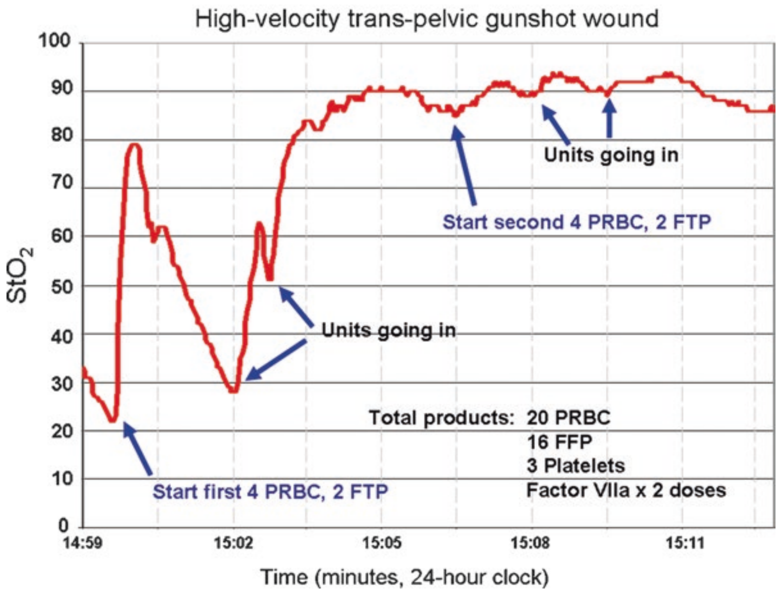


**Fig. 35.7** Graph of near-infrared spectroscopy (NIRS)-derived tissue oxygenation ($StO_2$) data from a combat casualty in Baghdad. The $StO_2$ data provided early recognition of initial severe injury, operative hemorrhage, and then the adequacy of the postoperative resuscitation

as base deficit at detecting shock but has the advantage of being continuous and noninvasive (Fig. 35.7). Keep in mind that like base deficit, NIRS $StO_2$ values must be used in the context of a casualty's overall progression. It is also important to recognize that the current $StO_2$ technology uses a sensor placed on the thenar eminence. The changes observed by the placement of the device in this location may be skewed by peripheral vasoconstriction during shock, hypothermia, and/or limb ischemia.

NIRS $StO_2$ may have additional utility in the detection of regional ischemia or compartment syndrome in extremity injuries after vascular repair (Fig. 35.8). Although the data are still being collected, the devices show some promise as potentially allowing early identification of vascular graft failure, compartment syndrome, and extremity ischemia.

Other technologies continue to be explored and are yet to be fielded. These will be briefly mentioned so that the reader may be aware and monitor their development.

Continuous monitors which can rapidly assess changes in pulse pressure and beat-to-beat variability in the heart rate (or R–R interval variability) have been deployed for continuous data stream collection on casualties for later analysis. Power spectral analysis is applied to the standard EKG tracing to assess the relative parasympathetic and sympathetic activity that is present and thus the adequacy of autonomic compensation to the traumatic injury or insult. Preliminary data with this technology indicates that it may identify patterns that predict adverse outcome or death, primarily higher parasympathetic modulation and lower sympathetic modulation after injury. This could provide invaluable data from far-forward triage

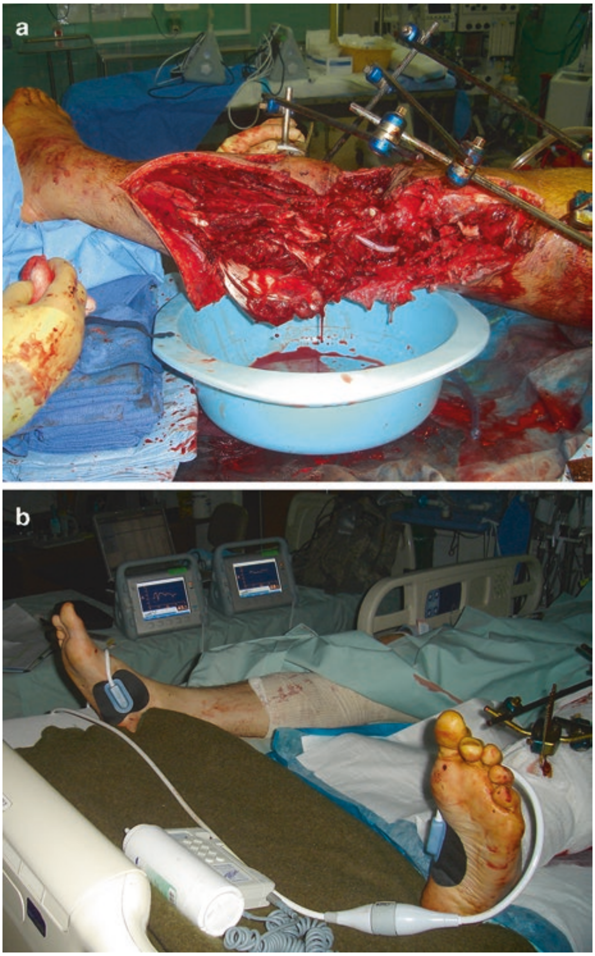

**Fig. 35.8** (**a**) Casualty with severe left lower extremity wound and vascular repair. (**b**) The same patient postoperatively with near-infrared spectroscopy (NIRS)-derived tissue oxygenation ($StO_2$) monitors placed on the injured extremity and on the uninjured extremity as a continuous monitor for graft thrombosis or compartment syndrome

decisions all the way through to definitive operative care and postoperative monitoring. However, the reliability and accuracy of these newer measures remains to be demonstrated, particularly in the incredibly demanding and punishing climate of modern combat operations.

## Closed-Loop Systems

Several standard monitors have been attached to elegant software programs to create a "closed-loop" system to guide critical decisions and interventions during resuscitation. Currently a closed-loop oxygenation system for mechanical ventilation is in civilian clinical trial as final phase before application. This system (integrated into the currently military transport ventilator) monitors oxygen saturation of the casualty via an integrated pulse oximeter. The algorithm allows for continuous, independent titration of oxygen concentration to maintain the casualties' oxygen saturation between 94 and 98%. Previous clinical trial with this algorithm demonstrated fewer hypoxic events and a net oxygen savings of almost 40%.

Similar closed-loop resuscitation programs have been created to adjust the IV fluid rate based on the patient's urine output and other vital signs. The Army ISR developed and now has commercialized a similar (decision assist) program for the resuscitation of the burn casualty.

These technologies, while still being perfected, have been demonstrated to conserve resources and limit excessive administration of therapeutic agents (oxygen and fluids). They may be particularly useful in more austere settings where physician resources are limited or during MASCAL situations where personnel resources are overwhelmed. However, it must be emphasized that any of these systems will only be as good as the algorithms that guide them and the accuracy of the monitoring inputs that they utilize.

## Summary

It is imperative that the deployed clinician understands that no single device, laboratory value, or study can replace his or her faculties and judgment. Monitoring devices and labs may provide useful data, but that data must be incorporated with all the other pieces of clinical data – a single data point should rarely, if ever, be acted on alone. The clinician should know the monitors available in his unit and the specific strengths and weaknesses of these particular devices and technology. There will be no shortage of new devices and technologies introduced with promises of providing "the answer" to all of your clinical dilemmas. As of now, none of these can outperform the astute and experienced clinician at the bedside, integrating the important data points and filtering out the rest to best serve the wounded soldier.

## Civilian Translation of Military Experience and Lessons Learned

Timothy A. Pritts

**Key Similarities**

- No single laboratory value or device can replace the judgment of an experienced clinician.
- The diagnosis and treatment of partially compensated shock is a significant challenge.
- Standard monitors provide useful data, but it is the interpretation and actions taken that define the utility of ANY monitor.
- Technology will continue to make rapid advances, and the medical community must take advantage of this "golden age" in biotechnology.

**Key Differences**

- Weight and size of monitoring devices are of primary concern in the deployed setting but secondary concern in civilian hospital care.
- In addition, device function in extremes of weather, harsh conditions, and during ground or helicopter transport is a prime concern in the military setting.
- The military setting patient population skews more toward the younger and healthier cohorts, versus the increasing amount of elderly trauma victims in the civilian setting.
- Elderly patients may not mount an adequate cardiovascular response after hemorrhage and thus are inherently more challenging to monitor effectively.

In this chapter, Drs. Beekley and Johannigman discuss several aspects of monitoring the physiological status of trauma patients. If it existed, the ideal civilian and military patient monitor would be lightweight, noninvasive, and reliable and would provide continuous information in a way that would allow providers to determine if something was wrong as well as guidance as to how to correct physiological derangements. Unfortunately, the ideal patient monitoring system remains elusive in both the civilian and military settings.

The principal lesson from the chapter is that the best single monitoring device continues to be the brain of an experienced clinician. Several technological adjuncts are useful (and should be utilized in many settings), including pulse oximetry, electrocardiography, central venous pressure determination, central venous oxygen saturation, pulmonary artery catheterization, arterial lines, and intracranial pressure monitors (for patients with head injuries). Advanced monitoring systems, such as near-infrared spectroscopy, can provide more detailed data concerning a patient’s status through analysis of arterial pressure waveforms or tissue oxygenation status, but the data must still be integrated, interpreted, and acted upon by the clinician in order to improve patient care.

Determining volume status at the bedside remains a significant challenge. As the authors point out, in the early phases of resuscitation from hemorrhage shock, the solution is almost always to give more volume. In both civilian and military settings, it is useful to determine intravascular volume status as the resuscitation progresses. Measurement of central venous pressure, while commonly performed in the surgical intensive care unit, cannot be used to reliably determine preload or the potential hemodynamic response to further volume infusion. Pulmonary artery catheterization, while previously liberally used in the civilian setting to guide resuscitation, is less commonly used in civilian ICUs today. We feel that the best current method of determining volume status in our ICU is transthoracic echo. In the civilian setting, we have the luxury of 24 h access to this test as well as a physician skilled in its interpretation. While this is not practical in austere environments, both focused echocardiography and bedside ultrasound have been shown to be reliable and effective in assessing intravascular volume status in a method that is adaptable to austere environments. These techniques allow estimation of intravascular volume status in an efficient, reliable, and reproducible manner.

Determination of the patient's shock status as well as monitoring resuscitation from shock is difficult in both the civilian and military settings. Traditional vital signs, including heart rate, blood pressure, and urine output, are valuable in identifying the patient with severe shock but may underestimate the physiological derangements of patients in compensated or partially compensated shock states. Identification of the physiologically "near-normal" patient is especially important with young trauma patients, who may maintain relatively normal vital signs until they reach the point of physiological collapse, as well as the elderly, who due to beta-blockade or cardiac disease may not become tachycardiac as shock progresses. As the authors discuss, determination of central venous oxygen saturation (with a central line) or mixed venous oxygen saturation (with a PA catheter), combined with arterial blood gas analysis, can provide useful data concerning the ratio of whole-body oxygen demand to oxygen delivery and help determine patients who are currently in shock. Additional helpful laboratory values include base deficit and serum lactate. Each of these is obtainable in virtually all care environments, and trends can be followed over time. When using lactate levels to guide a resuscitation, the provider must be aware that lactate clearance frequently lags the clinical picture by several hours and is also affected by hepatic function. Other strategies that have been employed in the clinical setting to guide resuscitation include gastric or rectal pH monitoring to determine the acid/base status of the viscera. Although they showed promise in clinical trials, these techniques have not become widely employed in either the civilian or military settings.

As Drs. Beekley and Johannigman point out, there is ample room for future improvement in monitoring of the trauma patient. One potentially exciting innovation is the use of arterial line-linked devices to continuously determine cardiac function parameters, including cardiac stroke volume, cardiac output, and estimates of intravascular volume status (Vigileo monitor, Edwards Lifesciences, Irvine, CA). These monitors are now in use in civilian ICUs but require a high-fidelity arterial line, which may potentially limit their utility in austere environments, especially during strategic or tactical critical care transport. Advanced versions of basic monitors, such as the Tempus Pro (RDT, Huntsville, AL), provide telemedicine capabilities and are entering into use in military and civilian settings.

The next generation of patient monitors will likely include decision support tools to offload busy clinicians. One such monitoring platform includes software to display and analyze patient data in real time and offers clinical decision support tools to maximize clinical use of available patient data (Decisio Health, Houston, TX). This platform is currently in use in a limited number of US civilian intensive care units but has the potential for widespread adaptation to austere environments as well. An additional step in patient care monitoring systems is to make them autonomous – that is, the device monitors the patient and then guides interventions based on the clinical data. Currently these systems include closed-loop control of oxygenation (currently in multicenter clinical trials) and decision support for burn resuscitation. These technological advances will have broad military and civilian applications and offer the opportunity to fine-tune aspects of resuscitation and trauma care.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Acute respiratory failure.
2. Catastrophic care.
3. Damage control resuscitation.

## Suggested Reading


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# 36 Ventilator Management: A Practical Approach to Respiratory Failure in Combat Casualties

Anita A. Shah, Paul B. Kettle, and Alexander S. Niven

**Deployment Experience**

| | |
|---|---|
| *Anita A. Shah* | Pulmonary/Critical Care, Medical Director of Intensive Care Unit, 14th Combat Support Hospital, Bastion Hospital, Helmand Province, Afghanistan, 2012–2013 |
| *Alexander S. Niven* | Theater Consultant, Pulmonary/Critical Care, Chief, Critical Care, 47th Combat Support Hospital, Mosul, Iraq, 2006 |

**BLUF Box (Bottom Line Up Front)**

1. Lung injury and acute respiratory distress syndrome (ARDS) are common in battlefield casualties and are usually multifactorial in origin.
2. Blast lung injury is a common contributing mechanism to respiratory failure.
3. Management of blast lung injury is similar to other etiologies of ARDS, and the prognosis is excellent if patients survive their initial injuries.
4. Endotracheal intubation and mechanical ventilation should be initiated early in casualties with altered mental status or respiratory insufficiency, especially prior to transport.

(continued)

A.A. Shah (✉) • P.B. Kettle • A.S. Niven
Madigan Army Medical Center - Pulmonary Critical Care Service, Department of Medicine Tacoma, WA, USA
e-mail: anitashah4@gmail.com


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(continued)

5. Early application of positive end expiratory pressure (PEEP) is essential to maintain adequate lung recruitment and gas exchange.
6. Mucus plugs, pneumothorax, and decreased lung compliance are common in combat casualties. A deliberate approach to mechanical ventilation troubleshooting is essential to accurately and rapidly address these problems.
7. Low tidal volume ventilation ($\leq$ 6 cc/kg) improves mortality in ARDS. Airway pressure release ventilation (APRV) is the primary mode employed in theater to manage refractory hypoxic respiratory failure.
8. To minimize barotrauma and volutrauma, try to minimize the rate, tidal volume, and time on positive pressure ventilation.
9. Permissive hypercapnia and moderate acidosis (pH > 7.2) are acceptable in the treatment of ARDS and should not prompt increases in rate or tidal volume.
10. Routine access to high-level salvage modalities for hypoxemic respiratory failure (jet ventilation, inhaled nitrous oxide, etc.) is not available; thus, proper patient and ventilator management is critical.
11. Veno-venous (VV) extracorporeal membrane oxygenation (ECMO) to treat refractory hypoxemic respiratory failure may be available on a limited basis.

The survival of combat casualties from the point of injury to definitive medical care has significantly improved over the last decade. Survival is >95% for casualties who survive their initial injury and are evacuated to definitive care. This improvement can be credited to several factors, including advances in body armor, an improved skill set of prehospital personnel, the presence of forward surgical teams, the availability of surgical and critical care assets in austere environments, and deployment of an increased number of soldiers skilled in basic and advance trauma life support. Early and effective management of battlefield casualties can be successful when the basic principles of prehospital, trauma, and critical care are maintained throughout the entire medical evacuation process. A critical care-trained physician may not be available to treat casualties; thus, all deploying physicians should be familiar with principles of respiratory failure and standard ventilator management.

The most common mechanisms of battlefield injuries vary from blast injuries (due to improvised explosive devices [IED], rockets and mortar attacks) to gunshot wounds (GSW). Prior studies have demonstrated that casualties of blast injuries have a higher prevalence of multiple injuries, specifically of the head and extremities. Due to the blast effects, the lungs are one of the most commonly injured organs. As a result, intubation for airway protection and mechanical ventilation to manage respiratory failure is often necessary. Even when the lungs are not directly injured, these patients may develop severe pulmonary failure due to their associated injuries, massive transfusion and resuscitation, thermal injuries, or even inhalational effects of various substances including weaponized chemical agents such as chlorine. The purpose of this chapter is to provide a practical overview to the management of respiratory failure in these patients and to discuss the logistics, management, and troubleshooting of the mechanical ventilator in this population. In addition to the traumatically injured patient, you may be frequently called upon to manage patients with a variety of nontraumatic illnesses or pathology that require intubation and mechanical ventilation, and having a good grasp of the principles of basic mechanical ventilation and ventilator management will serve you well in any deployed setting.

## Which Combat Casualties Need Mechanical Ventilation?

The indications for intubation and mechanical ventilation are the same for all patients, including battlefield casualties. Broadly, the indications for intubation include the inability to oxygenate or ventilate, the inability of a patient to protect their airway, increased work of breathing, a decreased level of consciousness (specifically a Glasgow Coma Scale [GCS] < 8), and multiple injuries in which future surgical management or ongoing resuscitation is anticipated (Table 36.1). The combat environment frequently forces providers to rapidly evacuate patients to a

**Table 36.1** Combat injuries for which intubation and mechanical ventilation are indicated

| |
|---|
| *Airway protection* |
| Decreased level of consciousness (GCS < 8) |
| Significant head trauma, cognitive dysfunction following blast injury |
| Airway trauma, obstruction |
| Craniofacial, neck injury with risk for airway compromise (consider surgical airway) |
| Significant secretions or blood in the airway |
| *Inability to oxygenate or ventilate* |
| Thoracic, lung injury |
| Flail chest, pneumothorax (despite management with tube thoracostomy) |
| Penetrating thoracic injuries |
| Respiratory distress, oxygen requirements following blast injury |
| *Increased intracranial pressure (ICP), herniation syndrome* |
| Airway protection, hyperventilation to decrease ICP |
| *Multiple injuries with anticipated surgical management* |
| Injuries requiring massive transfusion |
| Thoracic, abdominal, large soft tissue injuries |
| >1 proximal amputation |
| Hypotension, hypothermia on presentation |

**Table 36.2** Causes of ARDS in combat casualties

| |
|---|
| *Early* |
| Systemic inflammatory response following multi-organ trauma |
| Aspiration, chemical pneumonitis |
| Thermal, inhalation injury |
| Transfusion-related acute lung injury (TRALI) |
| Blast lung injury (BLI) |
| Fat emboli (long bone fractures) |
| *Late* |
| Ventilator-associated pneumonia (VAP) |
| Ventilator-associated lung injury (VALI) |

higher echelon of care. Often this is required immediately upon initial stabilization which makes patient monitoring, identification of progressive clinical deterioration, and definitive airway management difficult. Given this, it is important to determine if patients with significant head, neck, or chest trauma would benefit from securing a definitive airway (endotracheal intubation or surgical airway) and initiating mechanical ventilation prior to transport.

## Respiratory Failure in Combat Casualties: The Role of Blast Lung Injury

The lung is one of the most frequently injured internal organs when suffering a blast injury. ARDS and respiratory failure in severely injured combat casualties are common. ARDS was redefined in 2012 and is currently categorized using the "Berlin criteria," which is primarily based on the degree of hypoxemia as measured by the ratio of the $PaO_2$ to the $FiO_2$. Using this system, mild ARDS is characterized by a P/F ratio of 200–300, moderate by a ratio of 100–200, and severe by a ratio of less than 100. Patients will also have bilateral opacities on chest x-ray (which are non-cardiogenic or atelectatic in etiology) or worsening respiratory symptoms within 1 week of the clinical insult. The etiology of ARDS in combat casualties is usually multifactorial and can be divided into early and late causes (Table 36.2).

Of the common causes of ARDS listed in Table 36.2, blast lung injury (BLI) and its sequela are the least familiar to deploying providers. BLI has been reported to be present in 70% of civilian victims of terrorist violence and is likely even more prevalent in the combat environment. Because its onset can frequently be delayed and its radiographic presentation is variable, it is difficult to determine the true prevalence of BLI in the critically injured combat casualty or to differentiate its contribution from other potential etiologies.

**Table 36.3** Sequela of blast lung injury

| | |
|---|---|
| *Immediate* | |
| | Respiratory disturbance (rapid, shallow breathing or transient apnea <30 s) |
| | Pulmonary hemorrhage and edema secondary to ruptured alveolar capillaries |
| | Hypoxemia |
| | Pneumothorax |
| | Pneumomediastinum |
| | Air embolism |
| *Delayed* | |
| | Progressive hypoxemia due to ventilation perfusion mismatch |
| | ARDS |
| | Persistent pneumothorax |
| | Alveolo-venous fistula |
| | Broncho-venous fistula |

Of the four categories of blast injury (primary, secondary, tertiary, and quaternary), the lung is most vulnerable to primary blast injury. Lung manifestations include barotrauma (pneumothorax, pneumomediastinum) due to gross thoracic deformation, hemoptysis and pulmonary contusion due to alveolar disruption, and intraparenchymal hemorrhage within the lung. These injuries are caused from the blast wave traveling through the body armor and human tissue and releasing energy in any area where there is a gas-liquid interface. The released energy causes disruption of the epithelial cells and vascular structures in the thoracic cavity leading to both immediate and delayed effects (Table 36.3). The damage caused by the blast wave is related to the proximity of the victim to the blast site and is amplified in closed spaces. It is important to be aware that casualties from an indoor blast are more likely to have airway and/or lung injuries which may take up to 12–24 h to manifest.

The classic clinical presentation of BLI is the triad of respiratory distress, hypoxemia, and perihilar "bat wing" pulmonary infiltrates; however, this triad is infrequently seen. Hypoxia is the most common finding and may develop after the first few hours of injury. Other common manifestations of primary blast injury include tympanic membrane perforation, bowel contusion and perforation, brain axonal injury, and myocardial contusion.

Secondary blast injury, to the lungs, can be caused by weapon fragments and other debris scattered at high velocity by an explosion. While body armor generally protects victims from fragmentation injuries, it does not prevent primary blast injury. Tertiary blast injuries are caused by the blast wave throwing victims against a stationary object. Finally, quaternary injuries of the lung include inhalational burns from fires or heated gas or crush injuries that occur from structural collapse that follows an explosion.

## Management of Lung Injuries and Respiratory Failure

### Initiation of Mechanical Ventilation

Successful management of respiratory failure in a combat environment will largely depend on the level of expertise of the provider and available resources. Most deployed units will not have the depth or breadth of ventilator management experience as a stateside facility. The management of respiratory failure requires a multidisciplinary approach to include an experienced physician, respiratory therapist, and nurse. If your facility is not appropriately staffed with providers and does not have the appropriate resources, early evacuation to a higher level of care is the highest priority after initial stabilization. Initial ventilator settings will depend on the capability of the available ventilator. Advanced modes of ventilation can be utilized based on the ventilator's capability, the patient's lung mechanics, other associated clinical conditions, and the experience and comfort of the medical staff.

Table 36.4 lists the capabilities of four common mechanical ventilators used in the combat environment. Prior to deployment, medical providers should identify the specific in-theater ventilators and oxygen supplies that will be available. Additionally, it is important to ensure that respiratory therapists and biomedical maintenance technicians have received the necessary training to ensure proper equipment operation and a consistent supply of oxygen.

### Lessons Learned from an Experienced Critical Care Physician

1. An unlimited continuous supply of oxygen may not be available in all deployed medical facilities. Check your units supply and method of refilling or resupplying for oxygen when you arrive. It is CRITICAL information for you to know.
2. Patients with acute respiratory failure are time and resource intensive and should be evacuated to a tertiary care center stateside as quickly as possible.
3. Advances in transport ventilators have increased the survival of combat casualties from the point of injury to definitive medical care.
4. While mechanical ventilators used in CSHs are capable of advanced settings such as bi-level or APRV, other adjuncts used in hypoxemic respiratory failure (inhaled nitric oxide, proning) are typically not available.
5. The use of continuous corticosteroids or paralytics may not be practical in patients with multiple combat injuries.
6. VV ECMO is available on a very limited basis. It can take 12–24 h for an ECMO team to arrive from the United States or Germany into the theater to cannulate and evacuate the patient.
7. Host nation casualties that cannot be evacuated out of theater pose a challenge as they utilize a significant amount of resources (bed space, blood products, ventilator resources, man power) for an extended period of time.

**Table 36.4** Commonly available mechanical ventilators and their capabilities

| Type | Description |
|---|---|
| Impact™ 754 Eagle | Compact transport ventilator<br>Internal or external power; typical battery life 2–4 h., recharging time 12–14 h<br>Modes: AC, SIMV, CPAP modes<br>Settings: Ventilation rate, inspiratory time (or 1:2 I:E ratio default), tidal volume, $FiO_2$, high and low pressure control, PEEP (maximum 20 cm $H_2O$)<br>Alarms: Low pressure/disconnect, high pressure, PEEP not set, alarm mute, external low power/fail, battery low/fail, apnea (activates in AC and SIMV modes)<br>Additional features: Sigh breaths, PEEP, plateau pressure, manual breath trigger, automatic apnea backup rate<br>Display: Peak, mean inspiration pressure display; set and delivered tidal volume<br>Side effects: Hypoxia due to ventilator malfunction, pneumothorax from overpressure<br>https://www.aarc.org/wp-content/uploads/2014/11/02-754OM.pdf |
| VersaMed™ *i*Vent 201 | Compact ventilator with expanded functions<br>Internal or external power, battery life 2–4 h<br>Modes: AC (volume or pressure control), SIMV, adaptive bi-level, CPAP, PSV<br>Settings: Ventilation rate (80 bpm max), inspiratory time, flow, pressure, tidal volume or pressure target (80 cm $H_2O$ max), $FIO_2$, PEEP (maximum 40 cm $H_2O$), trigger sensitivity, pressure support (60 cm $H_2O$ max)<br>Additional features: Adjustable rise time, 100% $O_2$ suction, easy exhale, sigh breath parameters, adaptive flow, adaptive time, back up apnea ventilation<br>Alarms: High/low RR, high/low minute volume, low VT, apnea, high/low $FiO_2$, leak<br>Display: Airway pressure, total breath rate, I:E ratio, exhaled tidal volume, exhaled minute volume, peak flow, inspiratory time, electrical power source, battery level<br>http://www.eacampos.pt/fotos/editor2/equipamento/Ventilador_UCI.pdf |
| EMV + ™ 731 | Compact transport ventilator<br>Internal or external power, internal battery life 10 h, recharges to 90% in 2 h<br>Modes: AC, SIMV +/− PS, CPAP (invasive and noninvasive) +/= PS<br>Settings: Ventilation rate (1–60 bpm), flow (0–100LPM at 40cm$H_2O$), tidal volume or pressure target, inspiratory time (0.3–3 s), I:E 1:1 to 1: 99.9, $FiO_2$, PEEP<br>Additional features: Peak inspiratory pressure, trigger sensitivity, $O_2$, input pressure, all weather device<br>Alarms: Airway high and low pressure limit, BPM high and low alarm, LED status<br>Display: HR, $SpO_2$, $FiO_2$, PIP, VT, BPM, mode, minute ventilation<br>http://www.infiniti.se/upload/Bruksanvisningar/Impact/IMP_UM_EN_906-EMVP-02%20EMVCommercial.pdf |

(continued)

**Table 36.4** (continued)

| Type | Description |
|---|---|
| Drager™ Evita XL | Advanced, multifunctional ventilator<br>Internal or external power; limited battery life<br>Can provide invasive and noninvasive ventilation<br>Modes: AC (CMV), SIMV, IPPV, MMV, PCV, PSV, CPAP, APRV, ILV, PPS modes<br>Settings: Ventilation rate, inspiration time, flow, and pressure, tidal volume or target pressure, $FIO_2$, PEEP, pressure support, rise time for inspiratory pressure, trigger sensitivity, alarms<br>Additional features: plateau pressure and auto-PEEP measurement, automatic tube compensation, integrated $CO_2$ monitoring, noninvasive mask ventilation, smart care™, lung protection package<br>Alarms: High/low airway pressure, high/low expired minute volume, apnea alarm, high spontaneous breathing frequency, high/long inspired $O_2$ concentration, high gas temp, $SpO_2$, $EtCO_2$<br>Display: Multiple graphic waveforms for patient-ventilator synchrony; peak, mean airway pressure; minute volume; $O_2$ concentration; breathing frequency; lung mechanics; multiple others<br>http://www.medex.su/catalogue/anaesthesiology/resusciators/EvitaXL/EvitaXL.pdf |

8. Prolonged weaning from mechanical ventilation, of host nation casualties, without a disposition plan can be difficult and may not be practical.
9. An interdisciplinary approach, with experienced providers, is necessary for the successful management of respiratory failure in a resource-limited environment.

## Equipment and Planning

All respiratory therapists and biomedical technicians should receive specialized training to operate and maintain transport ventilators, the portable oxygen generating system (POGS), and the expeditionary deployable oxygen concentrator system (EDOCS) model 120.

Oxygen delivery in a combat zone can come from more than one source and may require logistic coordination and training. For example, a facility may have an on-site EDOCS with backup POGS and an emergency compressed cylinder stock level to provide redundancy in the event of equipment and/or supply line failure. Proper maintenance of this system is critical, and the stock of oxygen stores should be monitored on a daily basis. Additionally, a strict system should be implemented to ensure proper labeling of equipment and segregation of empty and full oxygen cylinders.

## Maintenance

While the "EAGLE" 754 IMPACT ventilator is the most commonly used transport ventilator, the types and models of ICU ventilators can widely vary in theater. The ability to obtain replacement parts for ventilators is an important issue. Maintaining a backup stock of parts and ensuring that equipment is stored in the appropriate environment will ensure appropriate functioning. For example, the "EAGLE" 745 IMPACT ventilator has a lead-acid internal battery which, in normal conditions with proper maintenance, has a 1 year lifespan. However, the battery can quickly lose efficiency in hot climates. Ventilators should be stored in a temperature-controlled environment when not in use, and a properly trained biomedical technician should verify the battery's age and condition before placing a ventilator into service. All "standby" ventilators should be continuously plugged in to maintain a full charge. Placing a high priority on battery maintenance for ventilators and other transport equipment will minimize the risk of in-flight equipment failure and improve patient safety.

## Patient Care

Clinical practice in a combat zone is often limited by available resources and provider experience. Developing sound fundamental practices, utilizing evidence-based guidelines, and developing deployment standard operating procedures will help providers achieve a high level of patient care.

Air evacuation: Staffing air evacuations with inexperienced providers may be unavoidable and poses significant challenges. Providers should be prepared to treat patients of all ages and be able to manage a wide variety of medical and surgical conditions.

Sight and hearing are very limited in a rotary-winged aircraft; therefore, maximizing patient monitoring with continuous ECG, blood pressure, pulse oximetry, and end-tidal $CO_2$ monitors when available is very helpful. If monitoring systems fail, you should manually check for pulses and chest rise and fall. All transport vehicles should be equipped with a bag valve mask, suction, oral airway, and advanced airway equipment. The ability to secure endotracheal tubes for patients with facial burns and trauma is also crucial. Having several types of ETT securing devices on board minimizes the risk of a lost airway during transport. Take an organized approach to stocking equipment. Additionally, be familiar with and know how to troubleshoot all equipment and their connections.

Mucus plugging is common in dry desert environments, especially in the pediatric population. Heat moisture exchangers may not be sufficient enough to prevent mucus plugging; therefore, it is important to use heated humidifiers for any patient who is likely to remain intubated for more than 24–48 h.

As mentioned previously, initial ventilator settings will depend on the ventilator's capability and provider expertise. Trauma casualties sustain a significant physiologic

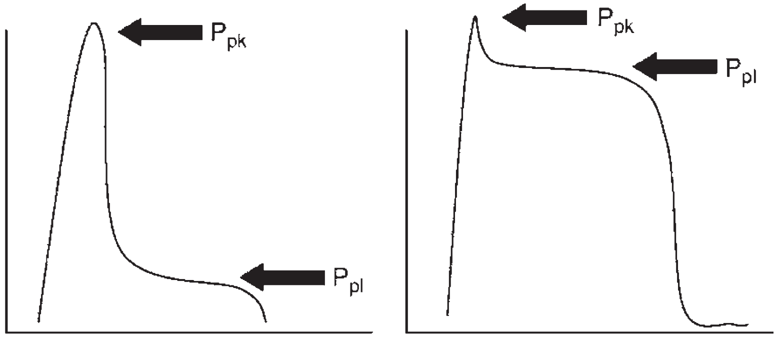


**Fig. 36.1** Measurement of the plateau pressure is performed during an inspiratory pause maneuver and provides an estimate of the pressure transmitted at the level of the alveoli. *Ppk* peak inspiratory pressure, *Ppl* plateau pressure. Graphic demonstration of a large peak to plateau gradient, seen in the setting of bronchospasm, mucus plugging, or a kink in the endotracheal tube (*left*). A small peak to plateau gradient (*right*), which may be seen in the setting of decreased lung compliance (i.e., ARDS), a large pleural effusion or tension pneumothorax, or abdominal compartment syndrome

insult and are at risk for rapidly progressive lung injury. These patients have a very high-energy expenditure and would benefit from minimizing their work of breathing and allowing the ventilator to maximally control gas exchange. This can be achieved by initiating the patient on a fully assisted mode of ventilation (assist control). Typical ventilator settings include a respiratory frequency of 12–15 bpm and a tidal volume of 6–8 cc/kg, to equal a minute ventilation of 8–10 L/min. Tidal volumes can be reduced as needed to maintain a plateau pressure < 30 cm $H_2O$ with small increases in respiratory rate to maintain an appropriate minute ventilation (Fig. 36.1; use peak pressure if plateau pressure is not available). All patients should be placed on an initial $FiO_2$ setting of 1.0 but rapidly weaned to an $FiO_2$ that will maintain a $SpO_2$ level > 93%. The PEEP can be increased by increments of 3–5 cm $H_2O$ to keep the $FiO_2$ < 0.6. See Table 36.5 for some ventilator adjustment pearls.

Trauma patients can present with a wide variety of injuries which present unique challenges when it comes to managing the ventilator. Below are some clinical pearls to help with specific aspects of ventilator management:

- Neurotrauma: Patients with head trauma should be ventilated with the goal of maintaining adequate oxygenation and a normal $CO_2$ level. This allows for optimal cerebral perfusion. Hypercarbia should be avoided as it can lead to cerebral vasodilation and elevations in ICP. Hyperventilation to a target $pCO_2$ of 28–30 mm Hg causes cerebral vasoconstriction and can be useful to acutely reduce elevated ICP. This measure should only be used as a short-term therapy while definitive measures to reduce ICP are attempted. Minute ventilation should slowly be decreased following definitive ICP intervention to restore adequate cerebral perfusion. The ICP should be monitored closely through this entire process.

**Table 36.5** Ventilator adjustment tips and pearls

| |
|---|
| *General approach* |
| Consider every ventilator-delivered breath as potentially causing injury to the lungs |
| Use the lowest possible ventilator settings to minimize lung injury |
| If the patient meets criteria, perform daily spontaneous breathing trials and extubate whenever possible |
| Pulmonary function and compliance are dynamic – reevaluate ventilator settings frequently |
| Avoid “chasing” the blood gas – don’t make ventilator changes just to get “normal” numbers |
| Dys-synchrony (“fighting the ventilator”) will often respond to ventilator adjustments. Minimize sedation and paralysis when possible |
| *Oxygenation* |
| Use as much oxygen (up to a $FiO_2$ 1.0) as you need initially to avoid hypoxia |
| Avoid prolonged periods of high $FiO_2$ – use PEEP and other adjuncts to wean $FiO_2$ to 0.3–0.4 |
| A $PaO_2$ of 60–80 is acceptable |
| Hypoxia = mucous plugging, pulmonary embolus, ventilator problem, or ARDS |
| Adjustable factors that drive oxygenation are PEEP, $FiO_2$, and mean airway pressure |
| *Ventilation* |
| Accept elevated $pCO_2$ levels as long as the pH is above 7.2 |
| Acute and large changes in $pCO_2$ = pulmonary embolus, cardiac event, ventilator malfunction |
| Adjustable factors that drive ventilation ($pCO_2$) are respiratory rate and tidal volume |
| Respiratory acidosis may be a response to a metabolic alkalosis (and vice versa) – correct the metabolic process and respiratory process will usually correct itself |

- ARDS: Lung protective ventilation with low tidal volumes ($\leq$ 6 cc/kg) and goal plateau pressures <30 cm $H_2O$ should be utilized and have been shown to reduce mortality in ARDS by almost 9%. This ventilator strategy also reduces ventilator-associated lung injury. Lung protective ventilation should be combined with a high PEEP strategy to improve oxygenation.
- Barotrauma: High levels of PEEP can lead to persistent air leaks if patients have a bronchopleural fistula. These patients may benefit from a lower PEEP and higher $FiO_2$ strategy to maintain adequate oxygenation.
- Flail chest: Patients with multiple contiguous rib fractures may have significant mechanical dys-synchrony. Higher PEEP levels can theoretically improve pain from mechanical dys-synchrony; however, it has been shown that patients have a larger benefit from early use of a thoracic epidural for pain control.
- Abdominal compartment syndrome: An increase in intra-abdominal pressure can lead to impaired diaphragmatic excursion, a progressive increase in peak inspiratory pressure with a minimal peak to plateau pressure gradient, increased intrathoracic pressure, and impaired venous return. Beware of the possibility of this syndrome in all trauma patients.

## Troubleshooting Common Ventilator Problems

### Hypercapnia and Respiratory Acidosis

Hypercapnia occurs when $CO_2$ production increases without a corresponding increase in alveolar ventilation and there is decreased alveolar ventilation, decreased minute ventilation, or an increase in alveolar dead space. Sudden increases in dead space can be attributed to massive pulmonary embolism, a leak in the ventilator circuit, or other more severe cases of ventilation/perfusion mismatch.

A systematic approach should be used when faced with unexpected hypercarbia. First, check the patient's minute ventilation. If there is a significant decrease in minute ventilation, check the ventilator settings to ensure no inadvertent changes have been made. Next suction the patient, remove any mucus plugs, and obtain a CXR to evaluate for new significant intrathoracic abnormalities. If these steps do not reveal an adequate explanation, evaluate for developing sepsis (with increasing metabolic demand resulting in increased $CO_2$ production) and pulmonary embolism.

Respiratory acidosis is a common complication of lung protective ventilation. Permissive hypercapnia is acceptable in ARDS patients unless there is concomitant head trauma causing significant elevations in ICP. There is no significant evidence that suggests elevated levels of $CO_2$ cause adverse clinical effects, but permissive hypercapnia should only be tolerated as long as the pH can be maintained >7.2. pH levels <7.2 can result in decreased effectiveness of vasopressor therapy and an increased risk of arrhythmia in critically ill patients. Bicarbonate infusions can be used to maintain a pH >7.2, but beware that bicarbonate can worsen acidosis if the minute ventilation is inadequate. Alternative agents such as THAM can also be used but may not be available to you depending on your deployed setting and pharmacy supplies. If the pH is above 7.2 and there is no associated severe brain injury or concerns about elevated intracranial pressure, then do not start making ventilator adjustments just to lower the $pCO_2$. There is no benefit in trying to normalize the blood gas. Doing so, may cause additional harm and ventilator-induced lung injury.

### Hypoxemia and ARDS

Hypoxemic respiratory failure is a common problem on the battlefield. Patients with severe or rapidly progressive hypoxemia should be prioritized for early evacuation to a higher level of care. Early evacuation will help avoid a potentially dangerous situation where transport personnel are unable to oxygenate patients at altitude.

The differential diagnosis of hypoxemic respiratory failure in combat casualties is listed in Table 36.6. The most common cause of persistent hypoxemic respiratory failure in combat is ARDS. The management of ARDS has been discussed at length above. The management of refractory hypoxemic respiratory failure is difficult even in modern US hospitals and can be even more challenging in resource-limited environments. Many of the salvage therapies commonly used to treat refractory

**Table 36.6** Common causes of hypoxemic respiratory failure in combat

| |
|---|
| Pneumothorax |
| Pulmonary embolism |
| Obstructive lung disease exacerbation (asthma, COPD) |
| ARDS (see Table 36.2) |
| Congestive heart failure |
| Mucous plugging |

hypoxemic respiratory failure (inhaled nitric oxide, inhaled prostacyclin, proning) are not available in combat environments. Management of these patients will largely depend on the available resources and provider experience (Fig. 36.2).

Any patient requiring high levels of oxygen and a PEEP ≥10 cm $H_2O$ after initiation of mechanical ventilation may require a longer period of mechanical ventilation. If possible, these patients should be expeditiously evacuated to a higher level of care. There is not an upper PEEP limit; however, PEEP levels of >15–20 cm $H_2O$ can increase intrathoracic pressure sufficiently enough to decrease venous return and cause hypotension.

If your patient is failing on a conventional mode of ventilation, then salvage therapy should be attempted. The most common salvage ventilator mode is APRV, a pressure targeted mode of ventilation that keeps the lungs inflated for the majority of the respiratory cycle. Based on the settings, the ventilator will periodically "release" pressure for a fraction of a second before returning to its previous pressure setting. This "release" also allows for adequate ventilation (Fig. 36.3). A unique feature of APRV is that the circuit allows the patient to spontaneously breathe over this set waveform, which provides increased minute ventilation, further improvements in alveolar recruitment, and improved patient comfort. Standard initial ventilator settings using this mode are a high pressure ($P_{\text{High}}$) of 30 cm $H_2O$, a low pressure ($P_{\text{Low}}$) of 0 cm $H_2O$, a time at the high pressure ($T_{\text{High}}$) of 3.5 s, and a time at the low pressure ($T_{\text{Low}}$) of 0.8 s with an $FiO_2$ of 1.0. Further improvements in oxygenation can be achieved by increasing the $P_{\text{High}}$ and/or $T_{\text{High}}$. A common mistake is increasing the $P_{\text{Low}}$ thinking that this is equivalent to adding PEEP. In general, the $P_{\text{Low}}$ should be zero. Due to auto-PEEP, from a short exhalation time, the $P_{\text{Low}}$ will not actually reach zero and alveolar collapse should not occur. Early and aggressive implementation of APRV can frequently obviate the need for further salvage strategies for refractory hypoxemic respiratory failure.

In a patient with severe or rapidly worsening ARDS, a short course of neuromuscular blockade can improve patient ventilator synchrony and reduce metabolic oxygen demands, thereby improving oxygenation. Generally, cisatracurium is the neuromuscular blockade of choice and is given as a continuous IV infusion.

Another potential salvage strategy is prone positioning, which increases effective ventilator pressure transmission to the lungs and improves ventilation perfusion matching by prone positioning the patient. Prone positioning is effective, but it is extremely labor intensive and can be dangerous in unskilled hands due to the risk of inadvertent device removal and inadequate protection of sensitive pressure points.

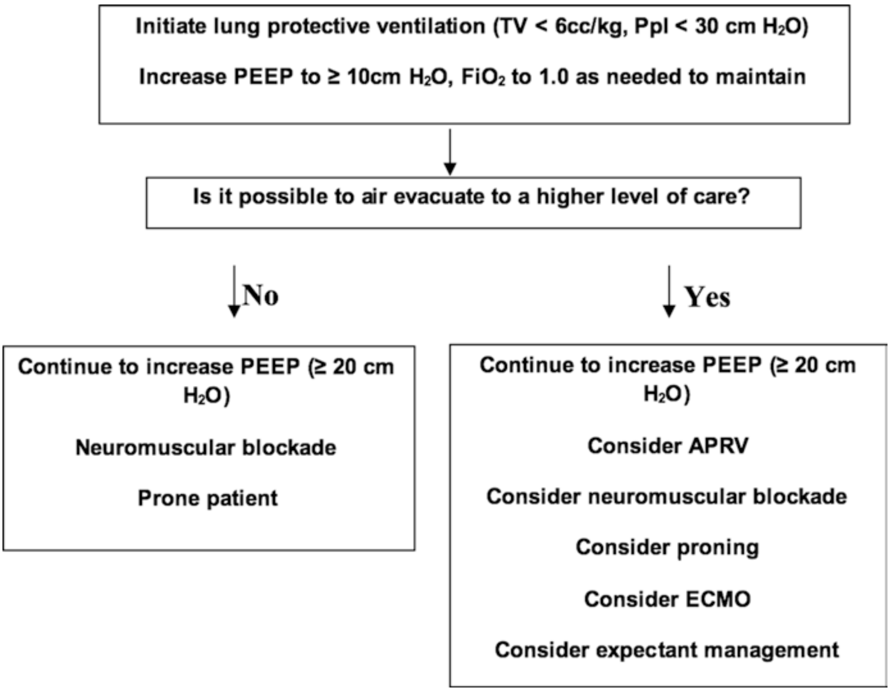


**Fig. 36.2** Algorithmic approach to ARDS with refractory hypoxemia in combat trauma patients

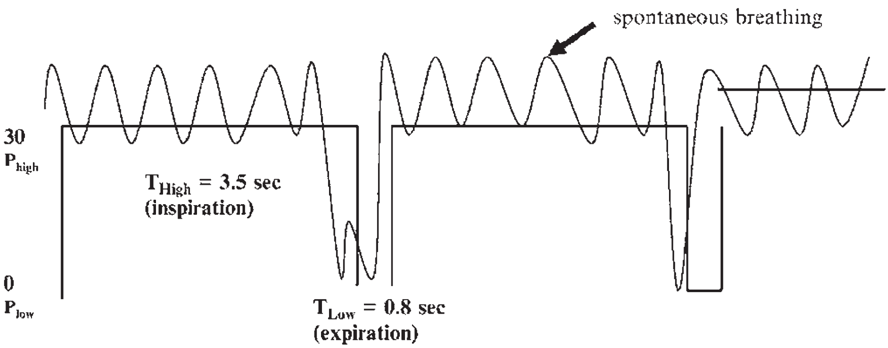


**Fig. 36.3** A pressure/time curve demonstrating the APRV mode in a spontaneously breathing patient

Using a specialized proning bed is the optimal way to perform proning; however, these specialty beds are generally not available in an austere environment. A modified version of proning can be attempted by simply turning the patient over in bed, but as previously stated, great care must be taken to ensure all lines and tubes are secured, and the patient is adequately padded while proned. If proning is attempted, it should be done with the use of a proning protocol. The mortality benefit of proning has been demonstrated in severe ARDS when performed for 16 h/day. Providers can attempt a short trial of proning for 2–6 h twice daily. If the patient remains stable with the trial, an alternating cycle of proning for 4–6 h intervals can then be attempted. Document the improvement in the P/F ratio for each proning cycle and cease proning when the degree of improvement in P/F ratio in the prone position has decreased (less than 10–20%). Only prone relatively stable patients as you will not have access to their chest for CPR or other emergent interventions.

If an ECMO team from the United States or Germany is available to transfer the patient from a combat hospital, this option should be utilized. The ECMO team generally consists of a critical care physician, surgical intensivist, an ICU nurse, and a respiratory therapist. Currently, ECMO is only provided by an ECMO transport team operating out of San Antonio Military Medical Center. They are available to pick up patients, on a limited basis, from the theater of operations. They can be contacted via DSN 312-429-BURN (2876). The acute lung rescue team which was created in 2005 at Landstuhl Regional Medical Center is currently not operational. Patients should be managed expectantly if they fail all above salvage therapies, and they are either too unstable for ECMO or ECMO is not an available therapy.

## Final Points

Advances in trauma care and improved training of medical personnel have increased the survival of patients injured on the battlefield. Early intubation and mechanical ventilation are essential and, when employed correctly, can support the majority of patients from the point of injury through to recovery. Advances in transport ventilators has allowed for sicker patients to be safely transferred out of combat environments. Advanced modes of mechanical ventilation are generally only available at CSHs, and salvage therapies beyond APRV are limited. The use of ECMO in the combat environment for patients with severe hypoxemic respiratory failure is very exciting and promising, but its utility is still limited due to the lack of available resources. Providing mechanical ventilation on the battlefield can be complicated and requires coordination and training utilizing a multidisciplinary team of providers, respiratory therapists, nurses, and biomedical technicians to ensure seamless, continuous care. With appropriate education, resources, and effective teamwork, even the most critically ill patients can survive from the point of injury to definitive care.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Acute respiratory failure.
2. Catastrophic care.
3. Ventilator-associated pneumonia.
4. Inhalation injury and toxic industrial chemical exposure.

## Suggested Reading

5. American College of Surgeons Committee on Trauma. Advanced Trauma Life Support (ATLS) student course manual. 9th ed. Chicago: American College of Surgeons; 2012.
6. ARDS Definition Task Force, Ranieri VM, Rubenfeld GD, Thompson BT, Ferguson ND, Caldwell E, et al. Acute respiratory distress syndrome: the Berlin definition. JAMA. 2012;307(23):2526–33.
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# 37 Practical Approach to Combat-Related Infections and Antibiotics

Heather C. Yun and Clinton K. Murray

**Deployment Experience**

| | |
|---|---|
| *Heather C. Yun* | Intensivist and Infectious Disease Consultant, Craig Joint Theater Hospital, Bagram Air Field, Afghanistan, 2011 |
| *Clinton K. Murray* | Senior Medical Officer, Medical Company, 1st Infantry Division, 1st Brigade Combat Team, 101st Forward Support Battalion, Ar Ramadi, Iraq, 2003–2004 |
| | ID/Infection Control Subject Matter Expert In-theater Review of Role 2 and 3 US, Coalition and Afghanistan National Facilities, CENTCOM, 2012 |
| | Team Leader, Graduate Medical Education Subject Matter Expert In-theater Consultant to Afghan National Army ID/Preventive Medicine Residency Training Program, CENTCOM, NATO Training Mission-Afghanistan (NTM-A), Kabul, Afghanistan, 2013 |
| | Expeditionary Surgical Assessment Team-Forward Surgical Team/Golden Hour Off-Set Treatment-Mission Review, Special Operations Command, Afghanistan, 2015 |

*"Every operation in surgery is an experiment in bacteriology."*

Berkeley Moynihan (1865–1936)

H.C. Yun (✉) • C.K. Murray
San Antonio Military Medical Center, Department of Medicine, Fort Sam Houston, TX, USA
e-mail: heather.c.yun.mil@mail.mil



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**BLUF Box (Bottom Line Up Front)**

1. Evacuate to surgical care as soon as possible.
2. Aggressively debride wounds with the removal of all necrotic tissue and foreign bodies easily reached except in the eye, brain, and spine.
3. Irrigate wounds until clean with normal saline or sterile water without additives under low pressure (less than 14 PSI).
4. Deliver antibiotics within 3 h of injury; avoid overly broad spectrum antibiotics and minimize duration; antibiotic activity should reflect the most contaminated site; IV infusion of antibiotics is preferred.
5. Give tetanus immunoglobulin and toxoid as appropriate.
6. Obtain cultures only when there is clinical evidence of infection.
7. Extremity wounds should undergo delayed primary closure; skin should not be closed if there is a colon injury or extensive devitalized tissue due to excessive infectious complications.
8. If no evacuation at 3–5 days, consider closing wounds if no evidence of infection.
9. Forward hospitals are breeding grounds for resistant bacteria. It is not the soil or the projectiles or the water; assume it is your facility! Standard infection control procedures reduce infection rates even in austere environments.

## Introduction

Infections have complicated the care provided to those wounded in war throughout recorded history. During Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF), approximately one-third of casualties developed an infectious complication, and sepsis was the fourth most common cause of reversible mortality. Infectious risks associated with combat-related injuries include those from initial wound contamination and from nosocomial infections associated with long-term care. The latter often involve multiple drug-resistant bacteria (multidrug-resistant organisms (MDROs)) such as the gram-negative bacteria *Acinetobacter baumannii* (primarily associated with injury in Iraq), *Pseudomonas aeruginosa*, extended spectrum beta-lactamase-producing *Escherichia coli* and *Klebsiella pneumoniae* (commonly found after injury in Afghanistan), and the gram-positive bacteria methicillin-resistant *Staphylococcus aureus* (MRSA). Invasive fungi also emerged in the Afghanistan theater of operations as a significant cause of wound infections.

The most comprehensive treatment strategies for managing combat-related injury infections can be found in the 2011 Guidelines for Prevention of Infections Associated with Combat Trauma. These were developed as an update to the earlier 2008 guidelines and were endorsed by the Surgical Infection Society and the Infectious Diseases Society of America. These highlight strategies for infection prevention with different injury patterns, with evidence-based weighting of recommendations. The suggestions provided in this chapter for preventing and treating combat-related infections are obtained from those guidelines along with current recommendations by the Tactical Combat Casualty Care (TCCC) committee and published as Joint Theater Trauma System Clinical Practice Guidelines. Of note, the recommendations are not for managing nosocomial infections. In addition, it is vital to recognize the importance of infection control – even in a combat setting – and that it begins during the initial stages of stabilizing a patient. Overall, surgeons should aim to replicate standard US surgical care with dedicated operating rooms, good hand hygiene, wear of clean scrubs with hats and shoe covers in the OR, cohort of long-term vs rapidly evacuated patients, protocols for disinfection and/or sterilization of patient care equipment, and appropriate environmental cleaning.

The primary method to prevent the development of infection in penetrating trauma is rapid surgical evaluation and management without relying on antimicrobial therapy to "sterilize" the wound. This is a lesson that has been repeatedly relearned since antibiotics have been available on the battlefield. Treatment strategies vary by anatomical location; however, overall treatment strategies include an emphasis on irrigation, debridement, antimicrobial therapy, coverage of wounds, and stabilization of underlying bony structures. Other interventions of secondary importance include minimizing blood transfusion, controlling hyperglycemia, minimizing hypothermia, and providing adequate oxygenation. In addition, antibiotic stewardship/control programs should be put in place in the combat zone to limit duration and spectrum of antimicrobial agents. It is critical to get the entire hospital team involved in infection control measures and to understand that "appropriate" antibiotic use often means narrowing the coverage or stopping antibiotics altogether.

## Prevention of Infection

### Care at Point of Injury (Level I)

Initial care provided in the combat zone near or at the time of injury should emphasize the safety of the patient and the personnel caring for the patient, controlling hemorrhage, and stabilization of breathing and airway per TCCC guidelines (available online at http://www.naemt.org/education/TCCC/guidelines_curriculum). Wound care at this point consists of wound coverage with sterile bandage and stabilizing bony structures with rapid evacuation to a surgeon as soon as is feasible. If evacuation to surgical care is expected to be longer than 3 h, antibiotics should be provided to the casualty as soon as possible (Table 37.1). The selection of these agents is based on spectrum, ease of administration, stability, and storage limitations. These antibiotic recommendations are not applicable to patients who can be rapidly removed from the battlefield or to those who have reached care at

**Table 37.1** Antimicrobial therapy for the prevention of infection in combat-related trauma during the care of casualties under tactical situations when evacuation is expected to be delayed (>3 h), as suggested by the Tactical Combat Casualty Care Committee

| Injury | Preferred agent | Alternate agent | Duration |
|---|---|---|---|
| Point-of-injury/ delayed evacuation Expected delay to reach surgical care | Moxifloxacin 400 mg PO × 1 dose. Ertapenem 1 g IV or IM if penetrating abdominal injury, shock, or unable to tolerate PO medications | Levofloxacin 500 mg PO × 1 dose. Cefotetan 2 g IV or IM q12 h if penetrating abdominal injury, shock, or unable to tolerate PO medications | Single-dose therapy |

Tactical Combat Casualty Care (TCCC). The three phases of TCCC in which these antibiotic choices apply are "Care Under Fire" which is the care rendered by the medic or first responder at the scene while still under effective hostile fire, "Tactical Field Care" which is care rendered by the medic once no longer under effective hostile fire and medical equipment is still limited, and "Combat Casualty Evacuation Care" which is the care rendered once the casualty has been picked up by evacuation vehicles but has not reached a higher level of care including a Battalion Aid Station (BAS) or forward surgical team (FST)

established medical facilities such as a battalion aid station (BAS) or combat support hospitals (CSH). Based on mission, oral moxifloxacin has been placed into some personal medical kits (the Improved First Aid Kit or IFAK; these also hold individual use items such as tourniquets, bandages, and pain medications) along with medic/corpsman medical kits.

## Professional Medical Care Without Surgical Support (Levels I and IIa)

Care at a BAS (level I) is typically provided by a physician assistant and/or a general medical officer with no patient-holding capability. Patients were evacuated from these facilities within 1–2 h of injury in Iraq, with slightly longer delays early during the conflict in Afghanistan. In 2009, a mandate for prehospital evacuation times of <60 min further reduced this to an average of 43 min in the years since. Although enhanced casualty care can be provided, the primary goal for most injuries is stabilization and evacuation to a surgeon within 6 h of injury. Primary wound management consists of hemostasis, wound irrigation, and removal of gross contamination. Wounds should be bandaged with a sterile dressing and underlying bony structures stabilized to prevent further injury. Antibiotics, typically intravenous, should be given within 3 h of injury (Table 37.2). The agent of choice should reflect the injury site requiring the broadest spectrum of bacterial activity, avoiding excessively broad empiric antimicrobial therapy. Tetanus immunoglobulin or toxoid should be given as indicated. It is acceptable to leave small, retained metal fragments in soft tissues; however, x-ray evaluation is necessary to adequately determine location and extent of injury.

**Table 37.2** Selection and duration of antimicrobial therapy for the prevention of infection in combat-related trauma

| Injury | Preferred agent(s) | Alternate agent(s) | Duration |
|---|---|---|---|
| *Extremity wounds (includes the skin, soft tissue, bone)* | | | |
| Skin, soft tissue, no open fractures | Cefazolin, 2 g IV q6–8 h | Clindamycin (300–450 mg po, or 600 mg IV q8h) | 1–3 days |
| Skin, soft tissue, with open fractures, exposed bone, or open joints | Cefazolin, 2 g IV q6–8 h[a] | Clindamycin 600 mg IV q8h | 1–3 days |
| *Thoracic cavity* | | | |
| Penetrating chest injury without esophageal disruption | Cefazolin, 2 g IV q6–8 h | Clindamycin (300–450 mg po, or 600 mg IV q8h) | 1 day |
| Penetrating chest injury with esophageal disruption | Cefazolin, 2 g IV q6–8 h, plus metronidazole 500 mg IV q8–12 h | Ertapenem 1 g IV × 1 dose or moxifloxacin 400 mg IV × 1 dose | 1 day after definitive washout |
| *Abdomen* | | | |
| Penetrating abdominal injury with suspected/known hollow viscus injury and soilage, may apply to rectal/perineal injuries as well | Cefazolin, 2 g IV q6–8 h, plus metronidazole 500 mg IV q8–12 h | Ertapenem 1 g IV × 1 dose or moxifloxacin 400 mg IV × 1 dose | 1 day after definitive washout |
| *Maxillofacial* | | | |
| Open maxillofacial fractures, or maxillofacial fractures with foreign body or fixation device | Cefazolin, 2 g IV q6–8 h | Clindamycin 600 mg IV q8h | 1 day |
| *Central nervous system* | | | |
| Penetrating brain injury | Cefazolin 2 g IV q6–8 h Consider adding metronidazole 500 mg IV q8–12 h if gross contamination with organic debris | Ceftriaxone 2 g IV q24h. Consider adding metronidazole 500 mg IV q8–12 h if gross contamination with organic debris. For penicillin allergic patients, vancomycin 1 g IV q12h plus ciprofloxacin 400 mg IV q8–12 h | 5 days or until CSF leak is closed, whichever is longer |
| Penetrating spinal cord injury | Cefazolin 2 g IV q6–8 h. ADD metronidazole 500 mg IV q8–12 h if abdominal cavity is involved | As above. Add metronidazole 500 mg IV q8–12 h if abdominal cavity is involved | 5 days or until CSF leak is closed, whichever is longer |

(continued)

**Table 37.2** (continued)

| Injury | Preferred agent(s) | Alternate agent(s) | Duration |
|---|---|---|---|
| *Eye wounds* | | | |
| Eye injury, burn, or abrasion | *Topical*: erythromycin or bacitracin ophthalmic ointment QID and PRN for symptomatic relief<br>*Systemic*: no systemic treatment required | Fluoroquinolone one drop QID | Until epithelium healed (no fluorescein staining) |
| Eye injury, penetrating | Levofloxacin 500 mg IV/PO once daily. Before primary repair, no topical agents should be used unless directed by ophthalmology | | 7 days or until evaluated by a retinal specialist |
| *Burns* | | | |
| Superficial burns | Topical antimicrobials with twice daily dressing changes (include mafenide acetate or silver sulfadiazine, may alternate between the two), silver-impregnated dressing changed q3–5 days, or Biobrane | Silver nitrate solution applied to dressings | Until healed |
| Deep partial-thickness burns | Topical antimicrobials with twice daily dressing changes, or silver-impregnated dressing changed q3–5 days, plus excision and grafting | Silver nitrate solution applied to dressings plus excision and grafting | Until healed or grafted |
| Full-thickness burns | Topical antimicrobials with twice daily dressing changes plus excision and grafting | Silver nitrate solution applied to dressings plus excision and grafting | Until healed or grafted |

[a]These guidelines do not advocate adding enhanced gram-negative bacterial coverage (i.e., addition of aminoglycoside or fluoroquinolone) in type III fractures

## Care with Surgical Support (Levels IIb and III)

Surgical care provided in the combat zone is available at Level IIb facilities (forward surgical teams), which are designed for damage control surgery and short-term holding of patients, and level III facilities (combat support hospitals) which provide tertiary referral care in the combat zone. Although casualties should be evaluated by a surgeon within 6 h of injury, there is no requirement for surgery to occur within that time window.

There is no indication for pre- or post-procedure microbial cultures at initial surgery. Even at subsequent debridement, unless there is gross evidence of infection, wound cultures do not adequately predict subsequent infections or infecting pathogens. Inappropriately obtained wound cultures may lead to unnecessary courses of antibiotics, even broad-spectrum ones.

Aggressively debride wounds at initial surgery. Skin should rarely be closed due to excessive infectious complications. For abdominal injuries, debride all nonviable solid and hollow viscera and drain most solid organ (i.e., liver and pancreas) injuries. Small wounds to a hollow viscus may be primarily repaired. The combat surgeon should be appropriately apprehensive with destructive colon injuries that require resections and anastomosis. Diversion should be considered in cases of colon injuries that require resection, particularly in the multiple injured or transfusion-requiring patients. Appropriate antibiotics (see Table 37.2) should be administered perioperatively, but the common practice of continuing them for days in cases of gastrointestinal injury is of no benefit, and likely harmful. Perioperative antibiotics in general are for 24 h; after that antibiotic use should be based on standard infectious indications.

Certain injuries, notably the eye, spine, and brain, have a higher associated morbidity with immediate surgical intervention by an untrained subspecialist that outweigh the infectious complications, limiting benefits of immediate debridement. Whenever possible, evacuate these patients to a facility with ophthalmologic and/or neurosurgical expertise.

Irrigate wounds copiously. For extremity injuries, 3 L of fluid are typically used for type I fractures, 6 L for type II fractures, and 9 L for type III fractures. For other wounds the recommendation is irrigation until the wounds are “clean,” which is typically 6 L for abdominal injuries. The recommended irrigation fluids are normal saline or sterile water, but potable water is acceptable with delivery under low pressure (typically less than 14 PSI). Recent tissue and microbiologic data has implicated the use of high-pressure irrigation systems (i.e., pulse lavage) in delayed wound healing and higher rates of wound infection.

Give antibiotics as soon as possible following injury and intravenously within 3 h of injury. Use agents that should cover the pathogens likely to be contaminating the wounds at the time of injury; these may include normal cutaneous and enteric flora such as *S. aureus*, *E. coli*, and alimentary tract anaerobes. You should *not* direct initial antibacterial activity at multidrug-resistant organisms (MDROs) such as *A. baumannii*, *P. aeruginosa*, and *K. pneumoniae* as they are not typically recovered in the wound at the time of injury. Given the low number of MRSA infections, along with research which favors drainage over antibiotics as the primary therapy of MRSA skin and soft tissue infections, empiric MRSA therapy with vancomycin is rarely necessary. Agents should be active against the injury that requires the broadest spectrum of bacterial activity. There are data that suggest the use of broad-spectrum antibiotics often leads to the development of subsequent infection with resistant pathogens. In addition, research from the United Kingdom indicates even penicillin-based regimens are adequate for extremity injuries, though intravenous amoxicillin-clavulanate (which covers methicillin-susceptible *S. aureus*, while penicillin does not) was primarily used by the British for their war injured in recent conflicts. The duration of antibiotic therapy should be minimized as indicated in the Table 37.2. Prolonged therapy has been shown to worsen outcomes. Antibiotics should not be used just because the wound is “open” or because a drain, including a chest tube, remains in place. The role of topical antimicrobial therapy is clear for burn patients. Antibiotic impregnated beads for open fractures may be an appropriate therapy for personnel not being evacuated out of the combat zone who will also have an appropriate follow-up. Their role is not clear for US personnel being evacuated 1–3 days after injury. Burn patients do not require systemic antibiotics unless there is evidence of infection or if antibiotics are indicated for treatment of other injuries. Systemic antifungal prophylaxis is not indicated, although dilute Dakin’s solution can be used through an instillation vacuum-assisted closure (VAC) device in high-risk wounds.

Combat wound management includes delayed primary closure for extremity wounds; however, injuries to the face and brain require early closure of the mucosal lining or dura to decrease infections. VAC has been shown to be effective for personnel not being evacuated out of the combat zone when used in extremity and abdominal injuries. Localized soft tissue infections that are adequately opened and drained (or undergoing VAC therapy) do not require prolonged antibiotics unless there are systemic manifestations of infection.

The stabilization of underlying bony structures helps prevent subsequent infections. External fixation is recommended for extremity wounds; however, there are infectious complications with percutaneously placed pins necessitating close clinical monitoring.

Patients requiring splenectomy should receive immunization against encapsulated organisms (e.g., *Haemophilus influenzae*, pneumococcal and meningococcal vaccines), ideally at 14 days of injury as this provides optimal immune reconstitution. However, you are better off administering vaccinations while the patient is under your control rather than counting on someone else to do it further along the evacuation chain. This was borne out in a study evaluating the effects of a clinical practice guideline directing vaccine administration in theater, which improved delivery of the vaccines with no adverse impact on outcomes. Administer them prior to discharge from your facility. Also, advise the patient about seeking immediate medical attention for any signs of symptoms of infection and the need for routine influenza and pneumococcal vaccinations.

## Care of Personnel Not Evacuated Rapidly Out of the Combat Zone

There is a large non-US patient population receiving damage control surgery and definitive therapy without evacuation to higher levels of care. Manage these patients according to criteria based upon nosocomial (not community-acquired) infections after admissions of greater than 72 h. These patients may be at significant risk for MDRO colonization and infection due to prolonged admission, especially if

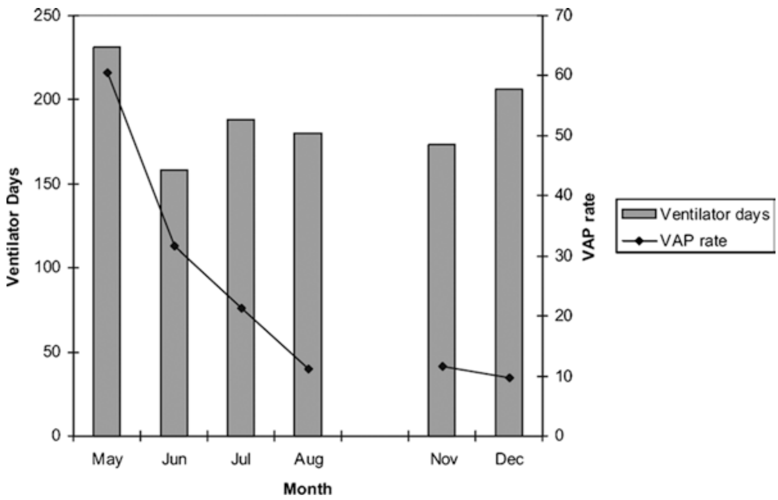


**Fig. 37.1** Graph showing the sharp decline in rates of ventilator-associated pneumonia (*line with circles*) at the Air Force Theater Hospital (Balad, Iraq) after the implementation of a targeted infection control program. The VAP rate is expressed as the number of infections per 1000 ventilator days (Reprinted from The Journal of Trauma and Acute Care Surgery, Ventilator-associated pneumonia in a military deployed setting: the impact of an aggressive infection control program, 2008, 64(2), Landrum M, Murray C. With permission from Springer)

aggressive infection control procedures are not followed. In the combat zone, evaluate these patients for signs and symptoms of infection and culture for bacteria appropriately. Therapy should be pathogen specific based upon culture results and antibiotic resistance testing if available. Direct empiric therapy by the facilities antibiogram, which should be updated regularly.

Implement comprehensive management strategies for the prevention of nosocomial infections as is done in US military treatment facilities. This should include infection control procedures and aggressive antibiotic control programs. Every facility, no matter the size, should have at least a designated infection control officer (typically as an additional duty) and preferably an infection control committee. The designated infection control officer should have some related training prior to deployment, and courses have been developed for just this purpose. The number one priority for infection control basically always has to be hand hygiene. This is because (1) people are uniformly bad at doing it without significant prompting, (2) it reduces the risk for both colonization and infection from all organisms and for all clinical infections, and (3) it is highly evidence based. It is also cheap and easy to implement. Alcohol-based handrub should be at the bedside of every patient. Remember the simple but high-yield interventions such as hand hygiene surveillance, traffic control in high-acuity areas (intensive care unit, burn units), and the checklist approach to daily goals in the ICU (Chap. 29). It needs to be easy for people to do the right thing and hard for them to do the wrong thing. Fig. 37.1 shows the impact that a simple targeted program of awareness and infection control had on

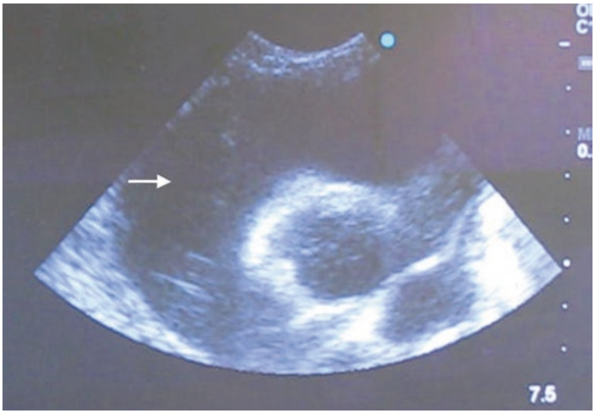

**Fig. 37.2** Echocardiogram of a 3-year-old Afghani female evaluated at a US forward surgical team for severe dyspnea. A massive pericardial effusion with tamponade was diagnosed and surgically evacuated. The final diagnosis was tuberculous pericarditis

the rates of ventilator-associated pneumonia at the Air Force Theater Hospital in Iraq. Similar results were achieved at Craig Joint Theater Hospital in Afghanistan. This can be accomplished in combat hospitals!

## Zebras in the USA May Be Horses in a Combat Zone!

Although you may think that your only mission will be providing care to traumatically injured US service members or coalition nation forces, you will typically also care for a large number of host nation service members (police, military, etc.) and civilians who are injured in battle. In addition, deployed medical units have not infrequently been called upon to provide medical care for local nationals with a variety of acute or chronic conditions. It is important to understand the differences in diseases that are prevalent and endemic to that particular country or geographic area and particularly the types of common infectious diseases and how they may present or may alter the treatment of a coexisting injury or illness. An in-depth discussion of all of the infectious diseases and their implications to different combat zones around the globe is beyond the scope of this chapter, but the important points or principles for the deployed physician/surgeon are:

1. Preparation for your deployment should include a review of the infectious diseases that are common to that area. There are multiple military publications and flash cards available for every area of operation that cover this material.
2. Never forget TB! Tuberculosis is the "great masquerader" and should be on any differential for problems where you cannot identify one of the typical underlying causes, or one that is failing to respond to usual therapy (Fig. 37.2).
3. Parasitic infection/infestation should be a baseline assumption in most underdeveloped regions and again should be on your differential. Traumatic bowel injuries, particularly in children, with associated spillage of parasitic worms were not an uncommon event in Iraq and Afghanistan.

4. Consultation with a military infectious disease specialist is readily available by email or telephone and should be used liberally in these situations to assist with diagnosis and also with the optimal therapeutic plan.
5. Don't forget malaria – for you or your patients. Persistent fever with no identified source despite extensive workup should prompt consideration of malarial infection. And "take your prophylaxis" if deployed to an area where malaria is endemic.

## Civilian MASCAL and Disaster Events

Combat trauma is often unique in terms of mechanisms of injury, site of care, and the number of patients requiring care simultaneously. However, parallels exist in civilian trauma care, particularly in the context of intentional violence as well as natural disasters generating mass casualties. Both may involve high-energy traumatic injuries, heavily contaminated wounds, unexpectedly large numbers of patients, and austere environments of care. Civilian disaster contexts are often at a relative disadvantage considering the chaos typical after large-scale events and the frequent problems with command and control, logistics, security, and the lack of staged levels of care or opportunities for evacuation by air or ground transportation. There are few civilian guidelines which specifically address such circumstances, aside from recommendations for postexposure prophylaxis against blood-borne pathogens after suicide bombings. However, the microbiology of infectious complications after natural disaster-related trauma frequently mirrors that seen in combat casualties. Gram-negative pathogens, frequently MDRO, predominate, especially later after international transport, suggesting nosocomial origins. In events with water exposures, additional potential pathogens including *Vibro* and *Aeromonas* species, among many others, may present early and aggressively. Additionally, invasive fungal infections have been increasingly reported after natural disasters, including tornadoes, tsunamis, and earthquakes. Rather than nosocomial pathogens, molds found in wound infections are typically related to displacement from their natural habitat in soil and vegetation. However, they are more likely to be found as part of a polymicrobial infection, frequently also involving nosocomial MDR bacteria. Atypical mycobacterial infections can also be found after injuries with substantial environmental contamination, particularly after suboptimal debridement, and usually present weeks or months after injury.

As in prevention of infections after combat injury, in these instances, "the best antibiotic is good surgery." This is true whether the environment of care is a Boston hospital after a terrorist attack or a Haitian clinic after an earthquake. Our BLUF recommendations are not specific to context. Rapid surgical evaluation remains the first priority, with aggressive debridement of wounds and removal of most easily reached foreign bodies, and irrigation with appropriate and available fluids, including potable water if sterile water or saline is unavailable. While tetanus has not been seen in (highly immunized) US military personnel injured in recent conflicts, it can a be major concern in austere environments where the population may be incompletely immunized, surgical evaluation of heavily contaminated wounds is delayed, and septic conditions exist on initial presentation. Liberal use of tetanus immunoglobulin and immunization should be encouraged.

Finally, infection prevention and control must be considered as part of standard, basic trauma care regardless of context. It is common in these scenarios to see any attempt at infection control dropped, especially in the early phases. This is a grave mistake that will exact a toll later on in the patient's course. Trauma patients in general are at higher risk for healthcare-associated infections, including wound infections, pneumonia, and bloodstream infections, than nearly any other demographic, and the literature clearly shows that these infections have serious implications in terms of mortality, success of limb salvage, quality of life, and many other clinically relevant measures. While zero infections may not be attainable in these contexts, the status quo is just not acceptable. There is no reason to suspect that this experience will be any different after a civilian natural disaster or mass casualty scenario.

## Final Points

Despite the fact that bombs and bullets are the most common images associated with war casualties, infection will be one of the top three causes of death in any combat medical facility. These common complications of combat-related injuries necessitate a multifaceted approach to management including irrigation, debridement, coverage of wounds, and stabilization of underlying bony structures. Use antimicrobial therapy as an adjunct to these strategies; do not rely upon antibiotics to sterilize a wound. Tailor antibiotics to the injury site, avoid overly broad-spectrum coverage, and use the agents for a limited period of time after initial injury. If a patient develops a nosocomial infection, choice of antibiotics should be dictated by the recovery of a pathogen associated with the infection and its resistance pattern. Fundamental to preventing subsequent infections with MDRO is aggressive infection control strategies in and out of the combat zone. Be a leader in infection control and management, and encourage others by your example.

**Disclaimer:** The views expressed are those of the authors and do not necessarily reflect the official views of the U.S. Army Office of the Surgeon General, the Department of Defense or the Departments of the Army or the Air Force.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Blunt abdominal trauma, splenectomy, and post-splenectomy vaccination.
2. Infection prevention in combat-related injuries.
3. Invasive fungal infections in war wounds.
4. Ventilator-associated pneumonia.

# Patient Transfer, En Route Care, and Critical Care Air Transport Team (CCATT)

# 38

Raymond Fang

**Deployment/Operational Experience**

General Surgeon, 379th Expeditionary Medical Group, Al Udeid Airbase, Qatar, 2003–4

Trauma/Critical Care Surgeon, 332nd Expeditionary Medical Group, Balad Airbase, Iraq, 2007

CCATT Physician, 10th Expeditionary Air Evacuation Flight, Ramstein AB, Germany, 2007–08

Deputy Commander for Clinical Services, Task Force Medical-East, Bagram Airbase, Afghanistan, 2012–13

Trauma Surgeon, Landstuhl Regional Medical Center, Landstuhl, Germany, 2004–7

Associate Trauma Medical Director, Landstuhl Regional Medical Center, Landstuhl, Germany, 2007–9

Chief, Trauma Program, Landstuhl Regional Medical Center, Landstuhl, Germany, 2009–11

*When in desperate need of evacuation, the approach of a rescue helicopter breaks down all cultural and language barriers.*

Michael Hampson

R. Fang (✉)
Air Force Center for Sustainment of Trauma and Readiness Skills, University of Maryland Medical Center, R Adams Cowley Shock Trauma Center, Baltimore, MD, USA
e-mail: rfang@umm.edu


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**BLUF Box (Bottom Line Up Front)**

1. Understand that casualty movement through increasingly capable levels of care is a hallmark of the modern combat casualty care system. Three distinct categories of patient movement occur in the operational environment: CASEVAC, MEDEVAC and AE.
2. Educate yourself on the concepts of Tactical Combat Casualty Care so that you can educate prehospital personnel, both medical and nonmedical, and provide constructive feedback.
3. Know the CASEVAC, MEDEVAC, and/or AE plans for your location to include transport platforms, en route medical personnel, and destinations for your location.
4. Plan for the worst-case scenario. Anticipate potential complications and mitigate risk. MEDEVAC and AE mission success is primarily determined by actions before the transport, not during it.
5. Confirm lines of communication with the PECC/PMRC supporting your location prior to your first MEDEVAC/AE. Early dialog facilitates patient and mission preparation.
6. Learn from each patient you evacuate so that you can improve the process for the next patient.
7. Consider patient transfer as if it were a surgical procedure. Weigh the real risks of movement against the benefits of arrival at the next destination. In some cases, a delaying evacuation is the better decision.
8. If possible, every military surgeon should fly on a patient transport mission to truly understand the setting, capabilities, and limitations. This is particularly true for helicopter transport.

## Incident Summary

A 25-year-old soldier was on dismounted foot patrol when an improvised explosive device detonated, showering only him with metallic fragments. He sustained multiple penetrating wounds to his lower extremities resulting in pulsatile, bright red bleeding from a large wound to his left thigh with underlying bony deformity. While most of his squad mates secured the site, others tended to him according to *Tactical Combat Casualty Care* guidelines. Direct pressure was immediately placed upon the wound until a tourniquet could be placed to control the bleeding. He was loaded onto a standard HumVee and transported to a predetermined helicopter landing zone. A HH-60M Black Hawk manned by Army Combat Flight Medics (Callsign: DUSTOFF) was launched to transport him to a Role II military medical facility for initial resuscitative trauma care.

The casualty arrived to the Role II facility 67 min after injury. He was evaluated by an Army Forward Surgical Team (FST) and underwent external fixation of his left open femur fracture and vascular shunting of his lacerated left superficial femoral artery. The FST also performed left four-compartment calf fasciotomies. He was resuscitated primarily with packed red blood cells and plasma. Postoperatively, he remained intubated and was transported by an Air Force Tactical Critical Care Evacuation Team member on a HH-60 M to the regional Role III facility, an Air Force Theater Hospital.

At the Role III facility, the casualty underwent definitive, reversed saphenous vein interposition graft reconstruction of his left superficial femoral artery and repeat washout and debridement of his left thigh wound. He was extubated without complication. Less than 48 h post-injury, the casualty was evacuated from the combat zone on a C-17 Globemaster attended to by an Air Force Critical Care Air Transport Team for a 6-h, 3200-mile intercontinental flight to the regional Role IV evacuation hub.

The effective movement of casualties through increasingly capable levels of care is a hallmark of the modern combat casualty care system (Fig. 38.1). In contemporary military operations, surgical capabilities are ideally positioned as far forward as possible to provide resuscitations and urgent lifesaving hemorrhage control. Minimal patient-holding capacity necessitates "patient throughput" to recover capability for subsequent casualty care (Fig. 38.2). While surgeons are

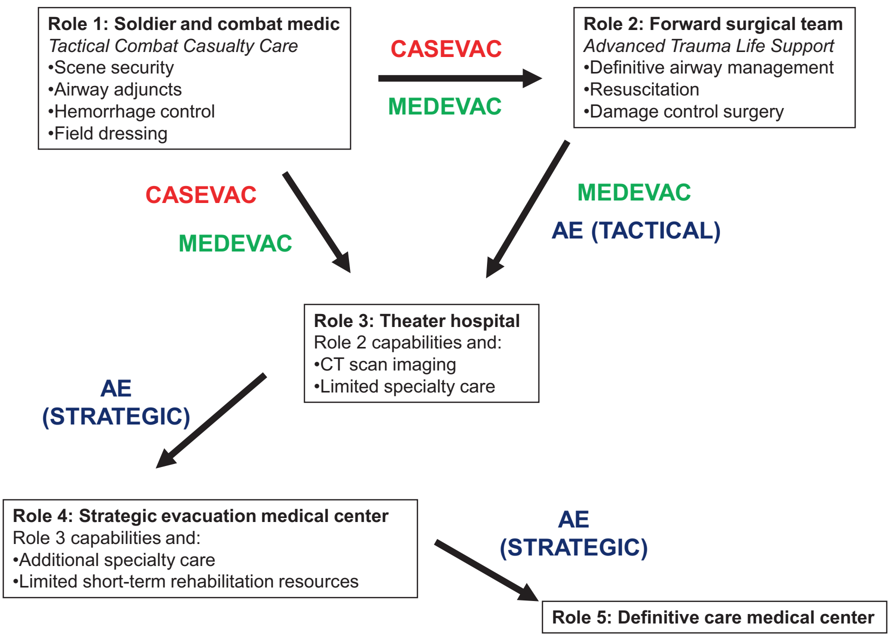


**Fig. 38.1** Patient transfer between roles of care


**Fig. 38.2** Role II facility layout. A Role II facility may consist of just three essential clinical work areas with limited patient-holding capacity. Timely "patient throughput" is essential to recover capability for subsequent casualty care

generally not deployed as en route care providers, surgical judgment in the planning for and execution of patient transfers is paramount for patient safety and mission success. Transport is an extremely dangerous process for a casualty, and a heroic surgical save can be quickly negated by a simple, unanticipated problem arising during transport. The three distinct categories of patient movement occurring in the operational environment are presented in the preceding vignette with each offering opportunities for surgical input.

## Casualty Evacuation (CASEVAC)

*CASEVAC*: Evacuation of Casualties from the Point of Injury to the Deployed Medical System by Nonmedical Personnel

**Definition** *CASEVAC* [casualty evacuation] – *The movement of casualties by nonmedical personnel aboard vehicles of opportunity for initial transport to the military medical system. Casualties transported in this manner may not receive proper en route medical care nor be transported to the appropriate medical treatment facility (MTF) to address their medical condition.*

Initial care of a wounded soldier following a traumatic event will be performed by other soldiers immediately available at the point of injury and not necessarily dedicated medical personnel. Prehospital care in a hostile, tactical environment is guided by the recommendations of the multidisciplinary Committee on Tactical Combat Casualty Care (TCCC) to accomplish the objectives of (1) treating the casualty, (2) avoiding further harm to the casualty and caregivers, and (3) preserving combat mission integrity. Contemporary Combat Medic (MOS: 68 W) and Combat Lifesaver training emphasizes TCCC concepts. The three phases of TCCC are (1) care under fire, (2) tactical field care, and (3) tactical evacuation care.

The tactical evacuation phase of care occurs when the casualty is moved from the potentially hostile, austere point of injury toward a more secure location for staging and subsequent care. The mode and timing of evacuation will vary widely, occurring either when the main force exfiltrates from the objective or as a separate component of the operation. Pre-mission planning is essential to identify available vehicles, destinations, and routes of travel within the area of operations for casualty evacuation. Ideally, medical equipment and/or personnel can be pre-positioned to support the operation: dressing supplies, junctional tourniquets, supplemental oxygen sources (oxygen generator or concentrator preferred over compressed gas cylinders as less explosive hazard), and hypothermia prevention measures. If possible, a Combat Medic or Combat Lifesaver should accompany all casualties. Combat Medics are trained to provide emergency medical interventions, whereas Combat Lifesavers are soldiers trained to provide enhanced first aid. CASEVAC degrades military mission capability by diverting resources from the fighting force, but it may be the only option when the hostile threat level is high or dedicated medical assets are not otherwise available.

TCCC saves lives. In 1998, the 75th Ranger Regiment under the command of COL Stanley McChrystal focused on four training priorities termed the "Big Four": (1) marksmanship, (2) physical training, (3) small unit tactics, and (4) medical training. TCCC training was incorporated into programs of instruction, training exercises, and contingency planning for all Rangers. An analysis of Ranger casualties sustained from 2001 to 2010 in combat action supporting Operations Enduring Freedom in Afghanistan and Operation Iraqi Freedom was published by Kotwal et al. in 2011. Substantial prehospital care was provided by nonmedical personnel. Despite sustaining more severe injuries, the Rangers' killed in action and died of wound rates were lower than the overall US military's rates (10.7 vs 16.4%, $p = 0.04$ and 1.7 vs 5.8%, $p = 0.02$). Of the 32 total fatalities, none were judged to have been potentially survivable through additional prehospital medical intervention.

TCCC is not Advanced Trauma Life Support (ATLS) exported to a prehospital setting, and there is some conflicting instruction between the two philosophies, particularly in the combat setting. In a review of combat-related US military deaths occurring between 2001 and 2011, Eastridge et al. retrospectively identified that 23% of deaths were potentially survivable under ideal conditions. They found that 90% of deaths occurred prior to arrival at a medical treatment facility and that 92% of deaths resulted from hemorrhage. Thus, hemorrhage control is paramount in TCCC and is the first priority, even ahead of airway and breathing management. Because cervical spine injuries are rare and cervical collars are often unavailable in the combat setting, cervical spine immobilization is de-emphasized in TCCC. It is not the purpose of this chapter to detail all TCCC concepts. Open-access educational materials are available for download at the National Association of Emergency Medical Technicians' website for all three phases of TCCC, and surgeons receiving patients from a TCCC environment must educate themselves on these concepts. Real-world, prehospital care is not routinely practiced within the in-garrison military medical system so for most military personnel, training alone acts as a surrogate for true, hands-on clinical experience. Surgeons should proactively seek to provide TCCC-appropriate education as well as timely, constructive feedback whenever possible to prehospital personnel, both medical and nonmedical. These efforts are always highly appreciated.

*DUSTOFF* – "**D**edicated **U**nhesitating **S**upport **T**o **O**ur **F**ighting **F**orces."

## Medical Evacuation (MEDEVAC)

*MEDEVAC*: Evacuation of Casualties by Medical Personnel on Dedicated Evacuation Platforms

**Definition** *MEDEVAC* [medical evacuation] – *The movement of casualties by dedicated, standardized medical evacuation platforms, with medical professionals who provide the timely, efficient movement and en route care of the wounded, injured, or ill persons from the battlefield and/or other locations to medical treatment facilities.*

If dedicated medical evacuation platforms (ground and/or air) are available, casualties should be evacuated on these vehicles to ensure they receive proper en route medical care both from the point of injury and during inter-facility movement. Military MEDEVAC platforms and crew are categorized as non-combatants and identified as such by visible display of a Red Cross. For this reason, MEDEVAC assets may not be able to retrieve casualties in a high hostile threat environment. Due to distances and hazards of ground travel in Iraq and Afghanistan, the majority of both battlefield and inter-facility MEDEVAC transfers were executed by US Army Combat Flight Medics (MOS: 68WF) flying in versions of the UH-60 Black Hawk helicopter (Fig. 38.3). The HH-60 M is the MEDEVAC-specific version of the UH-60 Black Hawk helicopter. The HH-60 M offers six patient litter positions, cabin climate control, oxygen generation capability, as well as other built-in medical support systems. In other operational theaters, both military and nonmilitary MEDEVAC platforms may be utilized depending on availability. It is critical that

**Fig. 38.3** UH-60 Black Hawk MEDEVAC Platform

**9 Line MEDEVAC Request**

**Line 1.** Location of the pick-up site.
**Line 2.** Radio frequency, call sign, and suffix.
**Line 3.** Number of patients by precedence:
A – Urgent (within 2 hours)
B – Urgent Surgical (within 2 hours)
C – Priority (within 4 hours)
D – Routine (within 24 hours)
E – Convenience
**Line 4.** Special equipment required:
A – None
B – Hoist
C – Extraction equipment
D – Ventilator
**Line 5.** Number of patients:
A – Litter
B – Ambulatory
**Line 6.** Security at pick-up site:
N – No enemy troops in area
P – Possible enemy troops in area (approach with caution)
E – Enemy troops in area (approach with caution)
X – Enemy troops in area (armed escort required)
* In peacetime - number and types of wounds, injuries, and illnesses
**Line 7.** Method of marking pick-up site:
A – Panels (color)
B – Pyrotechnic signal
C – Smoke signal
D – None
E – Other
**Line 8.** Patient nationality and status:
A – US Military
B – US Civilian
C – Non-US Military
D – Non-US Civilian
E – EPW
**Line 9.** NBC Contamination:
N – Nuclear
B – Biological
C – Chemical
* In peacetime - terrain description of pick-up site

**Fig. 38.4** 9 Line MEDEVAC Request

surgeons know the MEDEVAC plan supporting their operational location prior to their first casualty to include the response times and the potential limitations of the vehicles and the medical attendants. The following discussion primarily focuses on inter-facility MEDEVAC by military rotary wing aircraft.

MEDEVAC is requested by transmission of a “9 Line MEDEVAC request” (Fig. 38.4) to the supporting Patient Evacuation Coordination Cell (PECC) or equivalent theater operations center. Administrative support staff usually performs this task, but surgical input is important to ensure that the request accurately reflects the patient prioritization and the need for any special equipment (or medical personnel). Priorities for MEDEVAC movement are urgent (within 2 h), priority (within 4 h), routine (within 24 h), and convenience. Prioritization influences the mission planning, so be careful not to increase mission risk with unwarranted urgency. Depending on where the aviation assets are based, MEDEVAC missions may also offer opportunities to request delivery of consumable supplies such as blood products, medications, and even sterile surgical instrument sets from the higher echelon of care.

Prerequisites for Army Combat Flight Medic training include rank of E-4 or above, 1-year experience as a Combat Medic, current Class 3 Flight Physical and National Registry of Emergency Medical Technicians-Basic (NREMT-B) level certification. Training is a 5-week course designed to train these enlisted personnel to conduct pre-MEDEVAC treatment, to load/unload patients in MEDEVAC aircraft, and to stabilize/treat patients in flight. Following retrospective analysis of battlefield MEDEVAC patient outcomes in Afghanistan showing improved casualty outcomes with higher, civilian-standard flight medic training, the Army is currently elevating the Combat Flight Medic's skill baseline to the EMT-paramedic level service-wide. However given the rarity of prehospital evacuation and inter-facility transfers performed by the Military Health System outside the deployed environment, how to acquire clinical currency for these specialists remains to be determined. Well trained and motivated, a Combat Flight Medic's first real-world casualty transport may be the one shared with you.

MEDEVAC between Role II and Role III facilities in Iraq and Afghanistan of mechanically ventilated, critically ill and injured casualties posed a challenge to Combat Flight Medics who are generally without formal critical care training or experience. At times, physicians or nurses from the sending Role II facilities accompanied these patients to provide monitoring and care during transport. It should be anticipated that these essential medical personnel are then potentially lost from their deployed facilities for several days, and their absences degrade the facility's capabilities until their return. In 2010 to remedy these situations, the US Army created a team of critical care nurses to embed within the aviation companies to provide en route critical care during inter-facility transport. The US Air Force created the Tactical Critical Care Evacuation Team (TCCET) to similarly meet this requirement (Fig. 38.5). TCCETs are three-person teams comprised of (1) an emergency medicine or critical care physician, (2) a certified nurse anesthetist, and (3) an emergency department or critical care nurse. The team can be employed either as a complete team, in pairs, or as individuals tailored to specific mission needs. If deployed, both the US Army en route critical care nurses and US Air Force TCCETs are theater MEDEVAC assets, but these capabilities may not be available at all locations at all times.

At times, en route MEDEVAC care may be limited to patient vital sign monitoring and fluid and medication administration. Impediments to care during MEDEVAC include cramped quarters with limited physical patient access, low light or "blackout" environment, noise and vibration, and lack of ready access to equipment and supplies. Litter positioning within the platform may allow access only to one side of the

**Fig. 38.5** Inter-facility TCCET MEDEVAC mission (Photo courtesy of Maj. Rod Fontenette)

patient, the other side obstructed by the sidewall of the vehicle. To prevent hypothermia, casualties are generally bundled in blankets and strapped to the litter with minimal exposed skin to lose heat. During hazardous flight conditions due to enemy threat or weather conditions, medical personnel may need to remain belted in their seats for mission safety. For operational security, these missions frequently fly at night under low/red light conditions obscuring visual assessments of patients. Noise and vibration hinder communication with patients, eliminate the ability to auscultate breath sounds, and prevent recognition of audio patient monitor alarms. Thus, the most crucial care provided during MEDEVAC occurs during premovement preparation to optimize the casualty for transport by minimizing the risk that any interventions will be required during the mission. Otherwise if the condition of a casualty deteriorates and emergency measures are required, the vehicle might have to be stopped to render care, which otherwise may not realistically be possible until reaching the planned destination.

Surgeons share the responsibility of preparing casualties for MEDEVAC transport while keeping the potential worst-case scenario in mind. Extubation of a casualty during flight can be a catastrophic event. If postoperative patients can be safely extubated with a period of observation to ensure airway patency and breathing adequacy prior to movement, this may be the safest course of action. Otherwise, endotracheal tubes must be well secured and pharmacologic paralysis should be avoided to allow the possibility for spontaneous breathing. Small, asymptomatic pneumothoraxes should be decompressed to eliminate the risk of tension physiology developing during transport; many attempts at needle decompression outside the MTF for tension physiology do not successfully enter the pleural space. Chest tubes and all surgical drains must be well secured to prevent inadvertent removal during the mandatory, multiple patient litter transfers. Secure, redundant intravenous access should be acquired with central venous access preferred in the more severely ill and injured casualty to ensure reliable routes for fluid and medication administration. Accessible hemorrhage must be controlled prior to facility departure; blood components may be given for MEDEVAC administration for continued resuscitation. Extremity fractures should be immobilized by splinting or external fixation to reduce pain and blood loss, although sedation and increased analgesia will usually be needed to tolerate painful stimulation from movement and vehicle vibration. Even in hot climates, hypothermia is a risk of rotary wing flight and preventative measures are required. Learn from each casualty that you evacuate by seeking feedback from the MEDEVAC providers on how future casualty preparation could be improved.

Two nonconventional MEDEVAC platforms utilized by coalition forces in Afghanistan are Air Force Pararescue (para-jumpers/PJs) and the United Kingdom's Medical Emergency Response Team (MERT). PJs are not medical personnel and are tasked to conduct search and rescue operations in both peacetime and combat environments. As combatants, their aircraft is an armed and armored UH-60 derivative, the HH-60G Pave Hawk. PJs are trained to the EMT-paramedic level and can respond to MEDEVAC requests in more hostile settings than conventional MEDEVAC. They are uniformly outstanding first responders and flight medics and can be counted on to safely transport and to initiate lifesaving therapies in the critically injured combat trauma patient. However, all current standard and most nonconventional modes of medical evacuation on the battlefield in the US system do not include a physician on the crew. They generally follow the "scoop and run" philosophy that emphasizes minimal prehospital interventions and focus on rapid transport to an appropriate Role II or Role III facility. In contrast to this approach is the UK MERT platform that has been employed primarily in Afghanistan for transport to the UK Role III facility. The MERT is an eight-person team that focuses on rapid casualty movement to the Role III facility but is also staffed and equipped to perform higher-level interventions during evacuation. The medical contingent includes an emergency medicine physician, an emergency room nurse, and two medics; four soldiers provide security for the team. MERT brings emergency room capabilities to the point of injury so that evaluation and resuscitation can begin even before the casualty arrival to the medical facility. Their capabilities include initiating blood product transfusion, performing bedside surgical procedures (e.g. chest tube, airway, and central line placements) and even performing a resuscitative thoracotomy during transport. There is significant ongoing discussion and analysis regarding the pros and cons of this model, and this could potentially be adapted by the US military for future use.

"AE forces can operate as far forward as aircraft are able to conduct air operations, across the full range of military operations, and in all operating environments." *Air Force Instruction 11-2AE, Volume 3* Aeromedical Evacuation (AE) Operations Procedures [15 August 2014]

## Aeromedical Evacuation (AE)

*AE*: Evacuation of Casualties by Air Force Fixed-Wing Aircraft by Aeromedical Evacuation Crews

**Definition** *AE* (aeromedical evacuation) – *The regulated movement of casualties by United States Air Force fixed-wing aircraft with en route care provided by trained aeromedical flight crews which may include Critical Care Air Transport Teams. Missions may be either intra-theater (tactical/Role II to Role III) or inter-theater (strategic/ Role III to Role IV).*

Aeromedical evacuation is a component of the Air Force's core mission of Rapid Global Mobility. AE includes both tactical movements within a theater of operations as well as strategic movements between theaters of operations with patients cared for by trained AE flight crews. No dedicated AE airframe exists within the Air Force inventory since the retirement of the C-9A Nightingale. AE missions are flown on "aircraft of opportunity" so that any Air Force cargo, passenger, or tanker aircraft can be rapidly configured for patient transport. AE requires that a location is capable of receiving fixed-wing aircraft with the C-130 Hercules operable even from rough dirt strips. It is critical that surgeons know the AE plan supporting their location prior to their first casualty to include anticipated response times and potential limitations of the aircraft and the medical attendants. In some regions, civilian AE companies may be contracted to provide support in lieu of military assets.

AE should be considered a medical intervention. Analogous to the decision to take a patient to the operating room, the risks and benefits of evacuation must be consciously considered. Some patients, if the tactical situation allows, may be better served by additional stabilization in place prior to movement. However, nonavailability of specialty treatment or tactical circumstances may dictate evacuation as soon as possible. AE aircraft do not have any intrinsic medical capability or supply, so resource austerity during transport likely exceeds that of your facility ("P/L/X": pharmacy/laboratory/X-ray limitations) with absolutely no capability for operative intervention. During strategic AE from Landstuhl Regional Medical Center, Germany, to Brooke Army Medical Center, San Antonio, Texas, AE patients were in-transit outside a medical facility for as long as 24 h including all ground and air travel time.

AE requires coordination of global resources so the process for requesting AE movement ("regulation") is more deliberate than MEDEVAC. The AE process begins with submission of a *patient movement request* (PMR) [AF Form 3899] (Fig. 38.6) to the US Transportation Command (TRANSCOM) Patient Movement Requirements Center (PMRC) supporting the originating location (Fig. 38.7). Administrative support staff usually performs this task, but surgical input is important to ensure that the PMR accurately reflects patient precedence and need for any special equipment (or medical personnel such as CCATT). Precedence for AE movement is urgent (as soon as possible), priority (within 24 h), and routine (within 72 h). Precedence influences mission planning, so be careful not to overstate the

**PATIENT MOVEMENT RECORD**

*DATA PROTECTED BY PRIVACY ACT OF 1974* PERMANENT MEDICAL RECORD

(S) - Information needed to submit patient movement record

**SECTION I** **PATIENT IDENTIFICATION**

(s) NAME (Last, First, Middle Initial) | (s) SSN | DATE OF BIRTH

(s) AGE | (s) SEX M F | (s) STATUS | (s) SERVICE | (s) GRADE | (s) UNIT OF RECORD AND PHONE NUMBER | CITE NUMBER

**SECTION II** **VALIDATION INFORMATION**

(s) Medical Treatment Facility Origination and Phone Number | (s) Ready Date (Julian Date) | APPOINTMENT DATE | NUMBER OF ATTENDANTS (s) MEDICAL (s) NON-MED

(s) Medical Treatment Facility Destination and Phone Number | (s) CLASSIFICATION 1A-5F | AMBULATORY | LITTER | (s) PRECEDENCE

(s) Reason Regulated | Max # Stops | Max # RONS | Altitude Restriction | (s) CCATT Required yes no | Name, sex, weight, rank of attendants: | U | P | R

**SECTION III** **OTHER INFORMATION**

(s) Attending Physician name, Phone Number and e-mail | (s) Accepting Physician name, Phone Number and e-mail

(s) Origination Transportation 24 Hour Phone Number | (s) Destination Transportation 24 Hour Phone Number

(s) Insurance Company | Address | Phone # | Policy # | Relationship to policy holder

**(s) Waivers (med equip, etc)**

**SECTION IV** **CLINICAL INFORMATION**

**(s) Diagnosis** | **(s) Allergies** | **LABS (Date and time drawn in Zulu)** WBC | HGB | HCT | Other Labs

(s) WEIGHT: | (S) Blood type: | **Vital Signs (Date and time taken in Zulu)**

battle casualty | disease | Date | Time (Zulu) | B/P | Pulse | Resp | Pain Level: /10 | Last Pain Med: | $O_2$/LPM: | Route:

non-battle injury

**CLINICAL ISSUES** | Baseline 02 Sat If Applicable ____________ Temp ____________

**Infection Control Precautions:** | **LMP:**

**Date of last bowel movement:**

**High Risk for Skin Breakdown** yes no

**Initial appropriate boxes:**

| Yes | No | | Yes | No | |
|---|---|---|---|---|---|
| | | Hearing Impaired | | | Hypertension |
| | | Communication Barriers | | | Dizziness |
| | | Vision Impaired | | | Voiding difficulty |
| | | Cardiac Hx | | | ***Takes long-term meds** |
| | | Diabetes | | | ***Will sef-medicate** |
| | | Motion Sickness | | | Has adequate supply of meds |
| | | Ears/Sinus Problems | | | Knows how to take meds (verbalized understanding) |
| | | Respiratory difficulty | | | |
| | | ***Medication listed on physician's orders** | | | |

**SPECIAL EQUIPMENT (Check all that apply)**

| | | | |
|---|---|---|---|
| Suction | Traction | Orthopedic devices | OTHER: |
| NG Tube | Monitor | Restraints | |
| Foley | Trach | Chest Tubes | |
| Incubator | IV Pumps | IV Location: | |

Cast Location: ____________ Bivalved: yes no

Ventilator Ventilator Settings:

**DIET INFORMATION (Check all that apply)**

NPO Soft Full Lig Cl Liq Reg

Renal ______Gm Protein ______Gm Na ______Meq K ______Mag Sulfate

Tube Feeding ______Type ______cc/hr ______Discontinue for Flight

Cardiac Diabetic ______ cal Infant formula: Pediatric Age:

TPN:

Other(specify):

**SECTION V** **PERTINENT CLINICAL HISTORY (Transfer Summary)**

Physician's Signature | Date/Time

Signature of Clearing Flight Surgeon | Date/Time

**AF IMT 3899, 20060819, V1**

**Fig. 38.6** Patient movement request

urgency. Since there are not standby aircraft, aircraft selected will have been diverted from other real-world airlift missions to transport the patient.

PMRs are reviewed by a PMRC validating flight surgeon (VFS) to ensure that the casualty is appropriate for AE. If inadequate information is provided on the initial PMR, validation may be delayed until additional data is received. Direct discussion

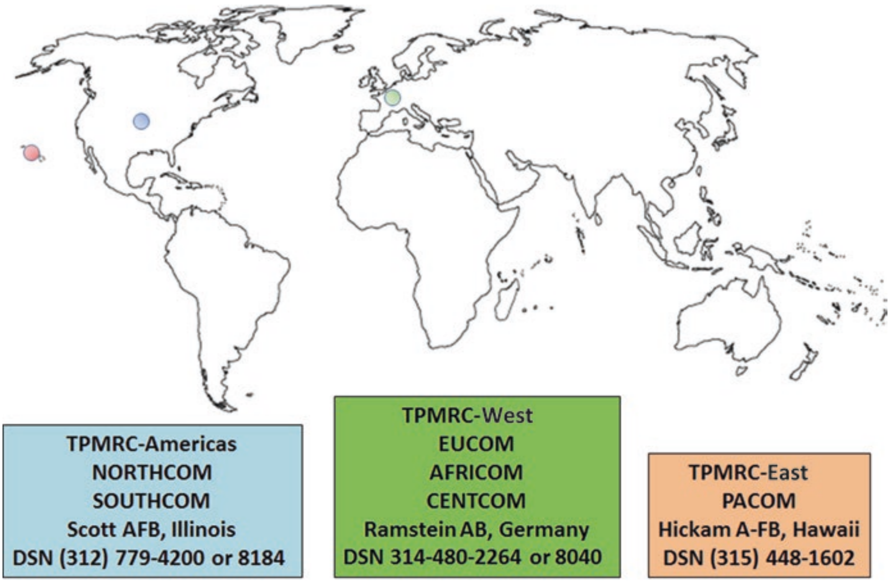


**Fig. 38.7** TRANSCOM Patient Movement Requirement Centers (TPMRC)

between the surgeon and the VFS can facilitate this process especially for complex patient scenarios; this line of communication should be confirmed in advance of the first need to use it. Minimal requirements for validation are (1) secure airway, (2) control of accessible hemorrhage, and (3) immobilized extremity fractures. PMR validation then generates the formal AE tasking. The PMRC coordinates AE crew and equipment assignment, selection of an appropriate aircraft, and confirmation of a destination capable of receiving the patient and providing care.

A standard AE flight crew is comprised of flight nurses (AFSC: 46 FX) and enlisted flight medical technicians (AFSC: 4N0X1F). Crew size is adjusted for the number of patients manifested and the anticipated mission duration. AF registered nurses and medical technicians are eligible to apply for AE training after 2–3 years of inpatient clinical care experience. Training focuses on aviation safety and impact of the flight environment on patient physiology and care. Once assigned to an AE squadron, these personnel work outside the hospital/clinic setting which may impact their clinical currency. AE crews can provide care only as directed by physician's orders received with the patient from the sending facility or by established protocols for specific clinical situations. It is beyond their scope of care to initiate or modify treatments without a physician's order. While in-flight, verbal physician's orders are requested by radio from the PMRC when there is not a physician on the aircraft. Physician presence on an AE mission should be requested on the PMR, but this may delay AE if a specific specialty is required or may necessitate a physician attendant from your facility.

For transport of critically ill and injured casualties, a Critical Care Air Transport Team (CCATT) can be requested. The three-person CCATT consists of a physician with critical care skills (most frequently anesthesia or emergency medicine), a

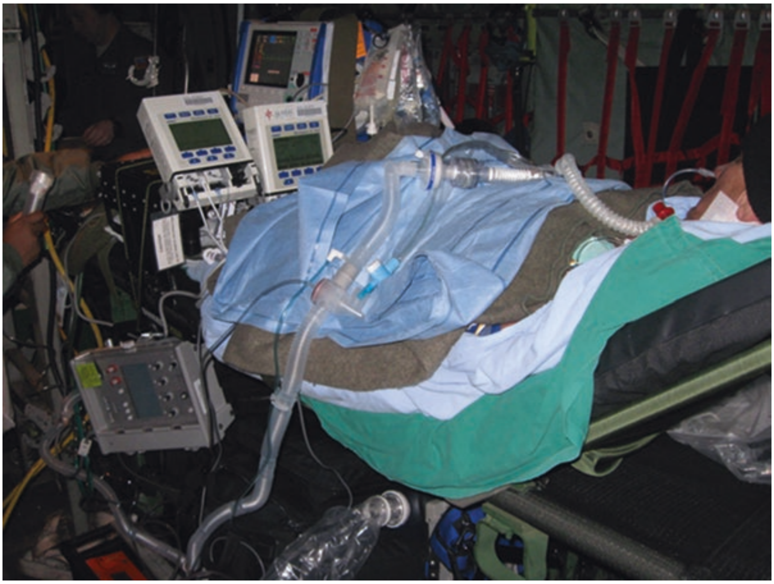

**Fig. 38.8** Critical Care Air Transport Team (CCATT) patient during tactical AE on a C-130 Hercules

critical care nurse, and a cardiopulmonary technician (respiratory therapist) (Fig. 38.8). CCATTs increase the AE level of care and assist in the care of other AE patient as well. CCATTs carry transport ventilators, physiologic monitors, and point-of-care blood testing capability as well as an expanded medical supply and medication allowance. CCATTs provide basic critical care support (airway management, ventilator management, and hemodynamic support) and can perform some invasive, nonsurgical procedures (percutaneous vascular access and chest decompression). Knowledge of the standard CCATT equipment and medication allowances enables you to inform the PMRC of nonstandard items that they should bring to support your patient's care during AE.

Hypobaria, hypoxia, low humidity, noise and vibration, and ambient temperature instability are environmental stressors of flight. Hypobaria and hypoxia increase supplemental oxygen requirements, low humidity increases insensible fluid losses, and noise and vibration increase pain and agitation. Patients are often confined to their litters, so deep venous thrombosis prophylaxis must be considered unless contraindicated. By Boyle's Law, trapped gas expansion will occur within both air-filled body cavities (sinuses, stomach, pneumocephalus, pneumothorax, etc.) and medical equipment (endotracheal tube balloon, colostomy bag, ventilator tidal volumes delivery). If feasible, a recent chest radiograph may be required for validation because prophylactic chest tube placement may be requested prior to flight even for small asymptomatic pneumothoraxes especially if CCATT is not involved. To allow for tissue swelling, prophylactic fasciotomies should be considered for at-risk extremity injuries, and orthopedic casts must be bivalved. A collaborative relationship with the PMRC and VFS is the key to successful AE planning. AE mission

| | | |
|---|---|---|
| **RT** | Switch to 754 | Calibrate |
| | | HME |
| | | Bacterial Filter |
| | Confirm tube placement | |
| | Check Cuff Pressure (<20) | |
| | Secure Airway | |
| | Validate Tidal Volumes | |
| | Lung assessment | On 100% O2 |
| | SMEED Setup | |
| | Calibrate ISTAT | |
| | Obtain ISTAT Cartriges | |
| | Perform oral care/Suctioning | |
| | Repeat ABG | |
| | O2 Calculation | |
| | Obtain Backrest | |
| | O2 Source Set up | |
| | Ambu Bag Setup | |
| | Suction setup | |
| | Check CXR and labs | |
| | Team Food and Drinks | |

| | | |
|---|---|---|
| **RN** | Drop off Pharmacy/Blood list | |
| | Sign-out/handover | |
| | | Confirm Meds |
| | | Confirm Orders |
| | | Obtain Flowsheet |
| | Full assessment | |
| | | Vitals and Urine output |
| | | I's and O's |
| | | Neuro exam |
| | | Pulses |
| | Equipment Setup | |
| | | Triple Channel setup |
| | | EndTidal CO2 |
| | | Monitor setup |
| | | A-Line set up |
| | | CVP Set up |
| | Confirm Values | BP |
| | | CVP |
| | | ICP |
| | | Abdominal pressure |
| | Transfer to litter | Use Backrest |
| | | Use Litter pad |
| | | Use Occipital pad |
| | Obtain records | |
| | Restraints | |
| | Pt Warming Devices | |
| | C-Collar | |
| | change NG to OG? | |
| | Pickup Pharmacy drugs/Blood | |

| | | |
|---|---|---|
| **Physician** | Sign-out/Handover | |
| | | Meds |
| | | Orders |
| | | Confirm spine clearance |
| | Set vent settings | |
| | | PIP and Plateau Pressures |
| | | Oxygenation concern for flight? |
| | | Calculate ideal Body Weight |
| | | Lung Protective Strategy ? |
| | Full Assessment | |
| | | Neuro exam |
| | | Lung exam |
| | | R/O Ext compartment syndrome |
| | | R/O Abd Compartment |
| | Place Lines/Transduce | |
| | | A-Line |
| | | CVP |
| | | D/C femoral lines? |
| | Confirm tube placements | |
| | Review Studies | |
| | | CXR |
| | | EKG |
| | | Head CT |
| | | ECHO/FAST results |
| | | Labs |
| | End points of resuscitation | Lactate and Base Deficit |
| | Hemoglobin shown stability? | |
| | Need Blood? | |
| | Obtain/review records | |
| | | Burn Flowsheet |
| | Equipment | |
| | | Suction |
| | | LTV with BOTH cords |
| | | Codman interface |
| | | PCA |
| | | Pain Catheters/Epidural |
| | | Wound VAC |
| | | SCDs for flight? |
| | DVT Prophylaxis | |
| | VAP prevention strategy | |
| | Ulcer Prophylaxis | |
| | Special Cases | Diabetes Insipidus |
| | | Elevated ICP |
| | | Renal Failure |
| | Need to call ahead? | |
| | MCD/Flight issues | |
| | | Flight altitude restriction? |
| | | Patient Load position in Aircraft |
| | | Head forward (all) |
| | | O2 Requirments |
| | | Electrical Requirments (Amps) |

**Fig. 38.9** Critical Care Air Transport Team (CCATT) preflight checklist

outcomes are primarily determined by preflight preparation on the ground to anticipate and prevent potential problems and to mitigate risk (Fig. 38.9).

Two specialty AE teams, the Army Burn Flight Team and the Acute Lung Rescue Team, have been utilized to support casualties evacuated from Iraq and Afghanistan, and a third, new team is being developed to support AE operations in austere, remote locations.

Since 1951, the Army Burn Flight Team (BFT), formally the Specialized Medical Response Capability, launches from the US Army Institute of Surgical Research (USAISR) Burn Center, Fort Sam Houston, Texas, to treat and to transport severely burned military beneficiaries worldwide. The BFT and its prepackaged equipment will travel to the casualty's location by commercial air carriers if more opportune than coordinating military airlift. If the casualty is located in a hostile combat zone, the BFT and the patient typically rendezvous at a common location (i.e., Landstuhl Regional Medical Center) with the casualty's initial transport accomplished by deployed CCATT. Each five-member BFT is comprised of personnel whom work daily in the USAISR Burn Center Intensive Care Unit. A fellowship-trained burn surgeon leads the team supported clinically with two nurses and a respiratory therapist. A medical noncommissioned officer serves as the Operations NCO enabling the clinical team members to focus on patient care. Upon arrival to the bedside, the BFT assists with managing the patient's burn care needs and coordinates evacuation to the USAISR Burn Center for subsequent care. USAISR burn consultation is available at e-mail usarmy.jbsa.medcom-aisr.list.armyburncenter@mail.mil or DSN: 429-BURN (2876).

In 2005, medical personnel at Landstuhl Regional Medical Center created the ad hoc Acute Lung Rescue Team (AleRT) to enable AE from the US Central Command of casualties with respiratory support requirements beyond the capability of standard CCATTs. The ALeRT was manned by fellowship-trained medical and surgical critical care physicians as well as critical care nurses and respiratory therapists with ongoing experience in advanced critical care to include rescue therapies for severe respiratory failure. ALeRT utilized pumpless extracorporeal lung assist (a form of arteriovenous extracorporeal membrane oxygenation [ECMO]) to transport a casualty from Afghanistan in 2009 and first utilized full veno-venous ECMO to transport another casualty in 2010. The Landstuhl ALeRT was deactivated in 2013, but this capability has been replicated by the 59th Medical Wing, Lackland Air Force Base, Texas, in collaboration with the USAISR to support AE of DoD beneficiaries globally. The Air Force is actively working toward formalization of ALeRT as a required AE capability. Early ALeRT/ECMO consultation is recommended for any potential requests at the same USAISR DSN: 429-BURN (2876).

In future operational environments, widespread deployment of surgical capability to provide resuscitative treatment within 1 h of injury ("the Golden Hour") may not be feasible due to the combined challenges of vast distances with extremely rare utilization. For these scenarios, the Air Force is developing AE teams with intrinsic damage control surgical capability that can be initiated when the casualty is received at the aircraft on the ground (preferred if the tactical situation allows) or in-flight once flight conditions have stabilized. Control of noncompressible torso hemorrhage may be achieved once the AE platform arrives to the casualty and not delayed until arrival at the destination treatment facility. This concept may benefit from taking the best elements from the "scoop and run" and the "stay and play" approaches into a new "scoop and play on the way" paradigm!

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Hypothermia prevention.
2. Intratheater transfer and transport.
3. Prehospital care.

## Suggested Reading


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# 39 The Homefront: Role 4 and 5 Care

Warren C. Dorlac and Carlos J. Rodriguez

**Deployment and Role 4/5 Experience**

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|---|---|
| *Warren C. Dorlac* | Chief of Trauma, Landstuhl Regional Medical Center, Germany 2004–2007 |
| | Critical Care Air Transport Team, USAFE, 2004–2007 |
| | Medical Director, SICU, AF Theater Hospital, Balad, Iraq Jan–Mar 2007 |
| | USAF SG Trauma Consultant: 2008 Afghanistan theater survey |
| | Joint Theater Trauma System Director, CENTCOM, Baghdad, Iraq and Bagram, Afghanistan Apr–Nov 2009 |
| | USAF SG Trauma Consultant: 2010 Afghanistan theater survey |
| *Carlos J. Rodriguez* | Chief of Trauma, Walter Reed National Military Medical Center, 2011–2017 |
| | Camp Leatherneck, Role 2, Helmand, Afghanistan Jun–Nov 2014 |
| | Camp Bastion, UK Role 3 Helmand, Afghanistan, Apr–Oct 2010 |
| | Al Taqaddum, Role 2, Iraq, Mar–Jun 2009 |
| | Persian Gulf, USS Harry S. Truman, Ship's Surgeon, Nov 04–Apr 05 |

W.C. Dorlac (✉)
Medical Center of the Rockies, University of Colorado Health, Department of Surgery, Loveland, CO, USA
e-mail: Warren.Dorlac@uchealth.org

C.J. Rodriguez
Walter Reed National Military Medical Center, Department of Surgery, Bethesda, MD, USA




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*We shall defend our island, whatever the cost may be, we shall fight on the beaches, we shall fight on the landing grounds, we shall fight in the fields and in the streets, we shall fight in the hills; we shall never surrender.*

Winston Churchill

**BLUF Box (Bottom Line Up Front)**

1. Three tenants of Role 4 and 5 trauma care are communication, communication, communication!
2. The system and its components are not perfect: take nothing for granted and be hypervigilant about every detail. Extremity compartment syndromes are an example of this.
3. Understand the physiology of flight and the stressors of the air transport environment: air evacuation is not a magic box.
4. Anticipate that the casualties may be at the end of their physiologic reserve on arrival and need immediate life-saving interventions.
5. Wounded warriors typically arrive on predictable schedules at Role 5. Narratives precede arrival. Take time to review who is coming and injury patterns, and make contact with other services who will be involved with longitudinal care.
6. Infectious issues typically present post-injury days 3–5. Be ever vigilant when surveying wounds, and take aggressive multimodal approach to treatment should invasive fungal infection be suspected.
7. Disposition planning begins upon arrival. In the combat setting, disposition may mean a 3000 mile or longer flight, so preparation for transport and anticipation of potential major problems are key to safe transfer to the next echelon of care.
8. Performance improvement at every level is critical and will save future lives. Have a system in place.

A 25-year-old infantry soldier is severely injured by an IED blast while on foot patrol. The patient has the typical dismounted complex blast injury with multiple amputations, open pelvic fracture, and bowel injuries. He undergoes damage control surgery at a Role 2 facility and reoperation at a Role 3, and within 72 h of injury, he arrives at the Role 4 facility in Germany. He undergoes a complete and protocolized reevaluation that discovers several additional injuries that were not identified at the Role 2 and 3 levels. He undergoes several rounds of additional operations and is then evacuated to the Role 5 facility in the United States. Over the next 6 months, he undergoes over 100 operative procedures, multidisciplinary evaluations and management from head to toe, prosthetic fitting and physical therapy, psychiatric and neuropsychiatric therapy, treatment for bacterial and invasive fungal infections, and then finally discharged to a rehabilitation facility. Although the focus in combat care is often on that initial 72-h period, the vast majority of this patient's care and management of his multiple medical issues occur at the Role 4 and Role 5 levels. This aspect of combat casualty care is as important, or arguably even more important, to the recovery and long-term outcome for our wounded warriors.

## Role 4 Care of Combat Casualties

### Introduction

The nature of wartime military trauma care leads to distinct clinical and logistical challenges. Transferring a casualty through staged, geographically disparate sites of care can impair communication and impact clinical decision-making. It is impossible to know with certainty what has fully transpired before you receive a patient. Although a segmental and dynamic trauma system is in place, the potential for fragmented care requires thorough review of the patient and extreme vigilance on the part of the clinician. When the patient reaches the Role 4 facility, any missed or neglected details must be captured and corrected. For the decade-plus of combat operations in Iraq, Afghanistan, and other areas, the primary Role 4 receiving facility was Landstuhl Regional Medical Center (LRMC) in Germany. This chapter highlights some of those key lessons that we learned as we went to war and ramped up a relatively small military medical center into a high volume and highly effective facility for providing care to thousands of wounded US and coalition service members and civilians.

### Downrange Documentation

Documentation may be sparse or easily misplaced by transferring teams. In a mature theater, lab data, radiologic reports, and clinical notes are all documented in the electronic medical record (EMR). Non-mature sites and some forward operating bases that are controlled by coalition allies may not have information reliably input into the EMR, demanding greater dependence on paper charting and manual transfer of data. The development of a central e-mail box is an additional means by which downrange providers can transfer data electronically. The Patient Movement Record (PMR) that is generated by the system notifies receiving facilities of incoming patients but should not be considered a transfer summary: critical information may be lacking. The PMR is only a first step in the investigation into the prior care received.

### History

Details of initial presentation may be inaccurate or incomplete, and complete details of intervening treatment may be difficult to obtain. If a patient presented during a multiple casualty event (a fact which may be unavailable), there may have not been time for the expected attention to detail. Make no assumptions: reassess for cervical spine and thoracolumbar injury and look for retained sponges or Combat Gauze. The mechanism of injury data, which is important for guiding injury evaluation, is often unknown when the patient reaches the Role 4. Many patients may have multiple mechanisms of injury and thus more than one injury pattern, for example:

- IED blast injury, which may include primary blast injury, thermal injury, blunt trauma from being thrown, and penetrating fragment wounds
- Shot while on rooftop, resulting in a 20-foot fall
- Driver shot while traveling 60 mph in a vehicle, resulting in additional injury from rollover
- IED blast with subsequent rollover into a canal, resulting in a near drowning

## Staffing

The regularly scheduled turnover of downrange provider teams results in a frequent need to relearn best treatment practices. Clinical practice guidelines (CPG) provided by the Joint Trauma System (freely available online for download) minimize this relearning curve but may be unknown to the deploying surgeons. It is ideal to know these downrange team members and their capabilities and to monitor how well CPGs are being followed. Staff at the Role 4 facility are well positioned to note when standards are not being met.

Role 4 facilities are most likely staffed by a combination of permanent party and temporarily deployed staff. Permanent party staff is responsible for onboard training and education as well as monitoring practice-deployed staff. Varying standards of quality and experience exist among providers, and rapid turnover of Role 4 nursing staff and physicians may be the norm. Therefore, standard operating procedures (SOPs) should exist for many issues.

## Compassion Fatigue

Permanent staff at the Role 4 are in a distinct and potentially stressful situation: they are stationed OCONUS for 3 or more years, with the comforts of family and home, yet they are caring for casualties on a daily basis. Some refer to it as "being deployed with your family." Depending on the pace of casualty flow, they may experience compassion fatigue. Leaders would be well advised to implement programs to educate, monitor, and intervene in those situations.

## Capability Limitations

While a Role 4 facility is able to provide services and specialty care not available downrange, there are still potential limitations. These may include:

- Less than robust ancillary support.
- Lack of some point-of-care testing.

- Subspecialty limitations, such as:
  - Interventional radiology: some diagnostic studies and limited interventional procedures, such as IVC filters, may be done by providers in radiology, cardiology, or surgery. More advanced potentially life-saving interventions such as aortic stenting and solid-organ embolization may need to be performed at outside local national facilities.
  - Neurosurgery may not be routinely or immediately available. Role 4 may need to obtain services from local national facilities. These relationships need to be developed in advance and not expected on demand.
- Renal replacement therapy.
- Blood supply.
  - May not be leukocyte reduced.
  - Plasma supply is not gender controlled.
  - Platelets may or may not be available; consider whole blood as an alternative.
- Many potentially useful lab tests may be "send out" only; delays in results can be long

## Organizational Expectations

American College of Surgeons Level II trauma center optimal standards should be practiced at all Role 4 facilities. There should be a designated Trauma Director, Trauma Program Nurse Director, Registrar, etc. Trauma protocols and policies should be developed. Mass casualty and disaster plans are especially critical for military facilities. The Role 4 surgeons should assist the Joint Trauma System (JTS) in monitoring care from the different downrange facilities and may be required at times to intervene if the stressors of flight are not being properly addressed before transport.

The Role 4 ICU should be a Trauma Surgeon led, multidisciplinary team available to care for critically ill patients. ICU admission criteria should be standardized, admitting all intubated patients and those non-intubated patients whose injuries or diseases qualify them for intensivist coverage, at the discretion of the surgical and medical intensivists on the team. Care should involve a combined ICU team with pulmonary/critical care, general surgery, and surgical critical care, with employment of Role 4-specific SOPs.

Twice daily ICU rounds are expected. Pre-rounding should be carried out by the assigned resident and staff so that daily team rounds are meaningful. Morning rounds should be multidisciplinary, led by a surgical critical care provider including representatives from nutrition, pharmacy, infectious disease, and the trauma performance improvement program, in addition to the members of the primary ICU team. The nurses assigned to the patients, the ICU charge nurse, and the critical care clinical nurse specialist should attend rounds as their clinical duties allow. For discharge planning, the regional validating USAF flight surgeon should round on the days preceding CONUS flights to assist with mission planning. At the end of rounds, daily tasks should be assigned by the service chief. Afternoon team sign-out rounds should be conducted daily, and performance improvement (PI) rounds should occur daily to capture PI events.

In-house coverage should be provided 24/7 for critical care patients. The on-call physician (or another designated team member) “must” be present for the arrival and departure of all Critical Care Air Transport (CCAT) teams to provide patient care and to interact as needed with the transport teams, answering questions and assisting with review of x-rays, labs, etc. Providers should limit (as much as possible) elective clinic appointments and operative cases during their ICU weeks. These “should not” be performed during AM rounds or on a team members’ designated “on-call” day without previous discussion with the service chief.

## Clinical Guidelines: Initial Assessment and Admission Care

Table 39.1 outlines a checklist for receiving injured patients from the forward medical treatment facilities. Typically, Role 4 providers have forewarning of incoming patients. Patients arrive near simultaneously, so any tasks that can be completed in advance can greatly streamline patient care. Providers should review downrange documents from the EMR in advance and any paper documentation upon arrival and transfer this information into the accepted electronic medical record. Providers should have access to an online radiology system so they can confirm the presence of downrange radiologic films, coordinating with the Role 4 radiology department to load the films into the hospital’s radiology system. The development of this system is complex and time-consuming but is worthy of the initial investment. Note that missing films or

**Table 39.1** Checklist for Role 4 when receiving ICU level patients

| |
|---|
| Prepare for arrivals, review any available records or imaging prior to arrival |
| Get sign-out from CCATT on status and any critical in-flight events |
| Complete tertiary survey – assume injuries have been missed! |
| Order additional imaging (i.e., spines, face, etc.) |
| Assess physiology and volume status |
| Evaluate pulmonary status and vent settings |
| Take down all dressings and splints – either at bedside or in the OR |
| Calculate %TBSA for burns, and ensure resuscitation appropriate |
| Evaluate wound for fungal infections and follow JTS CPG for fungal infections |
| Notify ORs, and warm all OR suites ahead of time |
| Measure bladder pressures on all who are s/p laparotomy or have major abdominal injuries |
| Assess all extremities for compartment syndrome |
| Chlorhexidine bath on arrival, contact precautions |
| Change all central and peripheral catheters |
| Change NT tubes to OG tubes if intubated |
| Begin enteral nutrition within 12 h of arrival if possible |
| Place distal feeding tube whenever possible |
| Initiate VTE prophylaxis immediately – double coverage with LMWH and SCDs if able |
| Contact family after arrival and assessment – do “not” overlook this! |
| Implement standardized ICU admission orders and protocols |
| Begin planning for next evacuation to Role 5 facility |

**Fig. 39.1** Critical Care Air Transport Team (CCATT) arrives at the Role 4 facility (Landstuhl) in Germany with a critically ill soldier who is 48 h from the time of injury in Afghanistan (Photo courtesy of US Air Force)

images of certain studies may not have been included in the downrange evaluation and will require either reformatting at the Role 4, or new imaging will need to be completed (i.e., coronal and sagittal reconstructions of the spine in high-energy blunt trauma). Upon patient arrival (Fig. 39.1), the admitting surgeon should review the entire downrange medical record, including any radiographic data available (e.g., CDs). Providers may need to have downrange films reread by the on-call Role 4 radiologist if an official report is not available from the downrange radiologist.

While the PMR and downrange records are useful for preparation, casualties often arrive at the Role 4 with significant interval changes. Upon arrival of new patients, the provider should receive sign-out from the CCAT team and perform a thorough tertiary exam to evaluate for missed injuries (e.g., spine fracture) or newly developed complications (e.g., compartment syndrome). The provider should perform or review appropriate studies to rule out common injuries. For blunt trauma, falls or blast injury, possible cervical/thoracic/lumbosacral spine injuries must be evaluated with CT scans. Plain films alone are inadequate, and physical exam may be unreliable in predicting thoracolumbar injuries. Patients with blunt trauma, falls, blast injury, or close proximity penetrating injury (e.g., high-velocity injury to the neck or face) should be evaluated for intracranial injury with CT of the head without contrast. High-velocity injuries to the head and face have resulted in pseudoaneurysms and have resulted in delayed hemorrhage and death prompting a call by many to perform delayed CT angiograms. Patients with blunt trauma or blast injury should be evaluated for thoracic, abdominal, and pelvic injury with CT scan if not already accomplished downrange. Casualties with trauma suspicious for vascular injury should be assessed with CT angiogram or conventional angiography when multiple fragments exist. The latter can be accomplished either in the OR using a C-arm or preoperatively in the angiography suite. Penetrating extremity injuries that are suspicious by proximity alone do not warrant further vascular evaluation beyond physical exam unless the ankle-brachial or brachial-brachial indices are less than 0.9. (Note: suspicious exam findings such as thrill and bruit will also warrant further evaluation.)

Patients often arrive to the Role 4 at the end of their physiologic reserve. Casualties with severe injuries who would not be considered “stable enough” for a CT scan at a stateside civilian trauma center may be transported by the military system via air for 5–10 h. Critical care transport teams may have been doing everything that they could just to keep the casualty alive. Immediate care and assessment is often required to salvage these critically injured. The following exam and laboratory values are encouraged to facilitate assessment of resuscitation status:

- Pulse pressure variation and central venous pressure
- Base deficit, lactate, and urine output
- Abdominal compartment pressure (if intra-abdominal hypertension develops)

Casualties supported by transport mechanical ventilators often suffer some degree of pulmonary decompensation en route. Note the ventilator settings used en route. Evaluation with chest radiograph and blood gas should be done, with consideration for recruitment maneuvers and adjustments in mechanical ventilation strategies based on those results. For casualties with blast injuries, blunt chest trauma, or history of cardiac compressions, consider obtaining a bedside echocardiogram to evaluate cardiac function and the possibility of blunt myocardial injury. In those requiring vasopressor support, consider the measurement of $S_{cv}O_2$ by drawing a venous blood gas from the distal central venous port. Also, consider placing continuous $S_{cv}O_2$ catheter or a continuous cardiac output/mixed venous $O_2$ saturation ($CCO/SVO_2$) pulmonary artery catheter if a patient continues to require significant vasoactive agent support. For critically ill ICU patients receiving PRBC transfusions, consider requesting from the blood bank the youngest units available for transfusion along with leukocyte reduction.

All downrange dressings/splints should be taken down and wounds assessed as soon as possible, though timing of exam may be adjusted at the provider’s discretion based on the situation and plan to return to the OR. All wounds must be evaluated on the day of arrival to the Role 4. Aeromedical evacuation may predispose wounds to increased bacterial growth secondary to hypoxia of flight. Circumferential dressings may have become tourniquet-like with extremity swelling secondary to edema and ongoing resuscitation. All extremities should be assessed for compartment syndrome and for adequacy of previously performed fasciotomies. All burn wounds should be reassessed for the calculation of %TBSA and need for escharotomy and/or fasciotomy. Burn casualties should have all fluids and resuscitation recalculated and recorded on the Burn Flowsheet (see JTS CPG). Blast wounds tend to contain foreign bodies despite multiple operative washouts and debridements.

Do not be surprised to hear back from the "up-range" surgeons of their need to reexplore and debride and remove additional foreign debris. Casualties with wounds suspicious for fungal infection should follow the JTS CPG for diagnosis, wound management, and antifungal treatment. The Role 4 is a critical link in the early detection of these highly lethal infections.

Notify the OR several hours in advance of the need to warm ORs for all ICU patients, especially burn patients. Remind them to acquire "French fry" lights and additional Bair Hugger and to adjust the OR thermostat to warm the room prior to beginning the case. The operating surgeon should personally confirm that the room is warm "before" the patient arrives to the room.

Measure bladder pressures on casualties who have undergone damage control laparotomy, who have received a massive fluid resuscitation (with or without primary abdominal injury), or any patient with concern for abdominal compartment syndrome (ACS): elevated peak airway pressures, decreased urine output, and/or hypotension. If bladder pressure is >12 mmHg but ACS not definitively diagnosed, monitor bladder pressure every 4 h and follow abdominal perfusion pressures (APP should be greater than 60 mm Hg).

Measure extremity compartment pressures for any suggestion of an elevated compartment pressures. This is mandatory for any decrease in pulse, sensory loss, or other signs of neurovascular compromise. This is especially important in burn patients and intubated patients. Prior compartment release downrange does not eliminate the possibility of developing compartment syndrome, due to the potential for incomplete fasciotomy.

Casualties often arrive to the Role 4 facility with multidrug-resistant organisms colonizing their skin and wounds. Contact precautions were implemented to stop the spread to the other casualties on arrival to the Role 4. However, it must be realized that it is not feasible to maintain such precautions in the aeromedical environment. All casualties admitted to the ICU undergo a chlorhexidine bath on arrival and daily. This may be accomplished with prepackaged chlorhexidine-impregnated wipes if available. This practice has been shown to decrease multidrug-resistant infections.

Casualties frequently arrive with central venous catheters in place. It is difficult to know under what conditions these catheters were placed at the prior facility. Furthermore, the aeromedical transport environment poses some contamination risk. Role 4 practice has been to change all previously placed central venous and peripheral catheters on arrival. If existing catheters *are* used for infusion, best practice is to first assess proper venous placement by aspirating and injecting through all ports and also reviewing admission radiograph. These catheters have been seen to migrate out of the vein.

Nasogastric (NG) tubes in intubated patients should be changed to oral gastric tubes (unless contraindicated, as by facial trauma) to help prevent sinusitis and avoid nasal bleeds. Virtually all patients with NG tubes in place will have evidence of sinus fluid regardless of the time the tube has been in place. One anticoagulated patient had an eight-unit bleed from NG tube trauma.

Nutrition is essential to recovery, and most critically injured casualties arrive to the Role 4 already NPO since the time of injury. The goal is to begin enteral nutrition within 12 h of arrival unless contraindicated. Feeding tube should be placed and enteral nutrition started as soon as clinically feasible. Although distally placed feeding tubes (distal to the ligament of Treitz) have not been shown to be beneficial for most patients in traditional ICU practice, they are recommended for Role 4 because of their ability to deliver more consistent caloric input in these patients. Gastric feeds are too frequently held, resulting in significantly diminished nutrition. Frequent operative interventions and studies require cessation of gastric feedings 6–8 h prior to planned procedures. Aeromedical policies require cessation of gastric feedings 6–8 h prior to and throughout planned transport. Delays in aeromedical evacuation (AE) flights or cancellations result in many lost hours or days of nutrition. In contrast, jejunal feeds can be continued through CT scans, operative cases, and air evacuation system (to include during flight). This may require education of the CCAT team that tube feedings distal to the ligament of Treitz "do not" need to be discontinued the night before or during a planned flight. An abdominal radiograph is required within 24 h of evacuation to document tube placement distal to the ligament of Treitz.

Trauma comprises the largest high-risk group in medicine for developing deep venous thrombosis (DVT). Risk factors include spinal cord injury, pelvic fractures, lower extremity fractures, severe head injury, and prolonged ventilation/immobilization. Transport immobility may further increase the risk for the military casualty. The hypercoagulable state often begins at the moment of the traumatic insult. It is important to begin prevention once hemorrhage has been controlled and to continue until ambulating with definitive treatment. Unfractionated heparin (5000 U every 8h) is not as effective for trauma patients. A dual approach with both sequential compression devices and twice daily (potentially weight based) low molecular weight heparin (LMWH) for all nonambulatory inpatients should be used unless contraindicated. LMWH in recent head or spinal injury must be cleared with the treating neuro/spinal surgeon but generally should begin 48 h postoperatively if repeat head CT is stable, or following stable repeat head CT 24 h after injury if treated nonoperatively. If the patient was not on LMWH on arrival due to a concern of one of these, discuss this with the neurosurgeon prior to the initiation of therapy. The question of when to start LMWH in these patients should be addressed *daily*. Current Role 4 guideline is to begin LMWH 48 h post craniectomy/craniotomy if no documented rebleed is seen on CT scan. Follow current dosing guidelines for efficacy (e.g., standard dosing vs. weight based, therapeutic anti-Xa levels). All patients that are admitted with a history of femoral venous cannulation and any casualty who has not received appropriate DVT prophylaxis should receive a screening venous duplex exam to rule out an already existing DVT.

The admitting physician should attempt to contact the casualty's family after arrival and initial assessment at the Role 4 and for any major changes in patient status. This can only occur after the authorization from Casualty Affairs. If unable to contact the family, please "sign-out" this task to the on-call physician. Casualty Affairs/Unit Liaisons will post family contact numbers after initial administrative notification has been completed. The soldier's unit usually must be the first to inform the family of the hospitalization. Be aware that the family may have been misinformed regarding the patient's condition. This is typically the "first" call the family will receive from a clinician, and they may have been sitting by the phone for the past 24 h waiting for the call.

Standardized protocols in critical care have been shown to provide more consistent care in most settings. Given the high turnover of staff at the Role 4, this institutional standardization is probably even more important. Consider the implementation of standardized admission orders and typical ICU clinical protocols (electrolyte replacement, fever evaluation and treatment, sedation and agitation assessment and management, insulin infusion, ventilator liberation, etc.). As with all ICU protocols used, it is important to review all aspects of the protocol before automatically ordering them all on every patient and to ensure that each is appropriate and meets the needs of each individual patient.

- Electrolyte replacement protocol is "not" appropriate for patients with significant renal insufficiency.
- Ibuprofen and acetaminophen administered in fever protocol may not be appropriate for all patients.
- Definition of fever: 101.0 °F most patients, 102.5 °F burn patients, and 100.0 ° F for head-injured patients.
- Insulin drips can be dangerous for the patient, especially when a protocol is not followed.
- Review protocol goal blood glucose level to be sure it is appropriate for your patient.
- Stop insulin drip when holding tube feedings or TPN!

## Documentation

### Downrange Documentation Note

An EMR note template should be used to transfer clinical provider notes and radiologic reports, permanently recording the downrange care in the Role 4 inpatient record. Primarily, this is for physician notes (H&P, daily progress, and discharge summary), specialty consultations, and operative notes. Include all CT reports as well as any other pertinent radiographic studies.

### History and Physical

Document date and time of injury, initial vital signs (at presentation to first provider downrange), all previous diagnoses and procedures, previous blood products received (to include recombinant Factor VIIa, prothrombin complex concentrate, or tranexamic acid), mode of transport to the Role 4 (i.e., AE vs. CCAT), and Role 4 admit date and time. Document all casualties who arrive with open abdomens, intubations, and amputations. Document all downrange diagnoses and surgical procedures to include escharotomies and fasciotomies.

Document a complete "tertiary" exam to include vital signs, Glasgow Coma Score off sedation, complete neurologic exam, tympanic membrane exam if exposed to blast injury, location and type of all tubes and lines on arrival, presence or absence of any compartment syndromes, and full spine and back exam. Include the presence or absence of bulbocavernosus reflex if a spinal cord injury is present. Grade all injuries to the best of your abilities using the American Association for the Surgery of Trauma (AAST) scaling system. Orthopedic injuries should be graded as well: for open fractures use Gustilo grading (originally designed for tibia fractures).

### Radiology Reports

It is the responsibility of the primary or ordering physician to review the formal reports of all radiology studies. This should be accomplished "before" the transfer of any patients. Do not take the verbal report as the final report; look for a final written report.

### Daily Progress Note

All patients should have a daily note to document their care. Early documentation on the day of CONUS transfer is of particular importance to ensure labs and radiographs have been reviewed and are satisfactory for flight.

### Multidisciplinary Discharge Summary

Any ICU admission that stays overnight before going to the floor should have an interim narrative summary started by the admitting physician. Spine clearance should be documented in both the history and physical and the multidisciplinary discharge summary. Record how and where the patient was cleared (i.e., "cleared at Role 3 using clinical exam and CT"). Document malaria prophylaxis and administration of post-splenectomy vaccinations when pertinent on the narrative summary. The narrative summary should include a section that lists all pending cultures and sensitivities. E-mail and telephone contact numbers should be included for the "up-range" surgeons to easily reach back for questions or clarification.

### Procedure Notes (OR and ICU)

Document all procedures. Writing "see dictation" is not acceptable unless the dictation can marry up to the EMR in short order as these procedure notes are important to stateside receiving facilities. Certain operative procedures such as extremity compartment syndrome release, escharotomies, or tracheostomies may be performed in the ICU, especially if there will be a delay in moving to the OR. Operative cases performed in the ICU should be accompanied by an OR technician/nurse/anesthesia provider, and these cases "must" be documented in the same manner as if they had been performed in the OR (i.e., formal dictated operative report). Procedure notes must document the following:

- Consent form completed (signed by two physicians if unable to contact family).
- There must be a separate consent form for each specialty provider's operative procedure (i.e., for an abdominal washout by general surgery and open fracture incision and debridement by orthopedics, there must be a separate form for each procedure).

- Separate specialty providers working together on the same procedure (i.e., spine exposure for spinal fixation) require one form with both providers names on it.
- Procedure and site verification note signed on the date of operation.
- Update the medication reconciliation form.

### AE Form 3899 Patient Movement Record

Paperwork to manifest all AE/CCATT transfers should be initiated ASAP, especially for casualties arriving the day before a mission is scheduled. Know the CONUS mission departure schedule. A missed deadline for submitting paperwork can stall the casualty for several days at the Role 4. Include the patient's unit on the top of the form. Update this as needed, especially just before the patient is transferred out to ensure that discharge medications are current and accurate. Follow up with system to verify that paperwork is properly submitted and that the patient will be manifest for evacuation in a timely fashion.

### Seriously Ill/Very Seriously Ill (SI/VSI) Forms

All ICU admissions must have this form completed, and all ICU admissions must be designated as either seriously ill (SI) or very seriously ill (VSI). If you transfer a patient from the ICU to the ward, you must remove them from the SI/VSI list by re-accomplishing the same forms.

### Invitational Travel Orders

ITO should be requested for very seriously ill patients. This allows family members to travel at government expense to the Role 4. If you think that the casualty will remain at the Role 4 beyond 3 days or is not likely to survive, consider having the family brought over.

## Disposition Planning

### Floor Transfer

Patients should not be transferred to the ward service until evaluation is complete. Patients should not have a new injury or diagnosis discovered on the ward. The ICU provider should contact the receiving provider and give a brief account of the patient. The receiving team (ward service) will write complete transfer orders. Casualties must be re-manifest for air evacuation immediately. The patient will "fall out" of the system if this is not done. Remove patient from SI/VSI list and notify TPMRC of the planned move so as to prevent the patient from being pushed out of the AE system. The ICU team should have begun the multidisciplinary discharge summary and included all interim events so the ward team does not have to go back and fill in what happened in the ICU. Ensure that all AE paperwork is complete and updated (AF3899).

## CONUS Evacuation

While the Role 4 has the ability and resources to hold any individual patient for as long as is clinically required, there is an ongoing necessity to ensure patient throughput. There may be a strong pressure to return the casualty to CONUS as soon as possible, and in addition the holding capacity at the Role 4 is not unlimited. Providers must keep the clinical needs of the patient foremost in deciding when and to where the casualty should be transferred. Knowledge of stateside receiving facilities' team members and their capabilities is essential. A receiving facility may be selected in certain circumstances based on specific injury patterns. As an example, burn patients meeting burn center criteria are transferred to the USAISR in San Antonio, all penetrating brain injuries are transferred to Walter Reed at Bethesda, and all significant TBIs are transferred to Role 5 referral centers. Be cognizant of the pressure to transfer as many patients as possible to their respective home base and that this is often not the best trauma care for them.

Discharge planning begins prior to admission and continues throughout the hospital stay. Vigilance is required to monitor alterations in patients' status; pulling a patient off the flight manifest may be required even at the last minute but usually could have been predicted earlier with better attention to detail. Thorough evaluation by the ICU team is essential to ensure that the patient has not worsened overnight or developed a new problem that makes it unsafe to fly. Outgoing patients should undergo a full presentation on rounds and not be glossed over due to their impending departure. Chest radiograph should be reviewed, and the patient should not fly with a new infiltrate (can result in en route hypoxia). All tubes should be confirmed to be in good position. There *must* be direct Role 4 physician-to-CCAT physician communication/handoff to include diagnosis, treatment plans, potential problems, etc.

Aeromedical evacuation regulations are extensive and designed to facilitate safe transfer. Patients being transported by CCAT teams have different requirements because they are physician attended and monitored by nursing at a much higher ratio. For example, there is no required minimum hemoglobin (Hgb) for patients leaving CCATT; clinical judgment should prevail. Try to communicate with CCAT physician the night before, in case the team wants to take PRBCs. For non-CCATT patients, minimum hemoglobin is typically >8.0. Trauma studies show no benefit for transfusion above a Hgb of 7.0 once the patient has been resuscitated, acidosis corrected, and no longer bleeding (to include critical care patients at altitude), but AE doctrine will prevail.

CCATT can manage many problems in flight, but the Role 4 provider's job is to anticipate any possible in-flight issues. An understanding of the austere environment and physiologic stressors of flight helps in this regard. Avoid surgery on the day of a planned flight transfer. This complicates the transfer and adds an additional stressor to all involved. Chest tubes should not be removed within 24 h of flight.

Patients should not be extubated within 4–6 h of flight unless willing to have that patient's evacuation delayed to the next flight. This is somewhat at the flying CCAT team's discretion. There is no absolute CCCAT/AE rule; however, intubation in flight is difficult and dangerous in itself. Discuss extubations within 24 h of flight with responsible CCAT team. Do not send a patient with a new problem that has not been fully evaluated (this includes unexplained hypotension, hypoxia, new infiltrates, rising intracranial pressure, high fever (>102), or other evidence of sepsis). Do not send patients who are just starting a new treatment with no idea yet of response (i.e., newly diagnosed pneumonia may be very problematic in flight unless patient responds quickly to new therapy). Stop all bleeding before transfer! Hold patients for some period of time (72 h) with observed splenic injuries so as to avoid the risk of a rupture during 18 h of transport (average time door to door). Consider obtaining CT angiography of the spleen to exclude a splenic pseudoaneurysm. There is a significant incidence of delayed extremity vascular graft blowout leading to hemorrhage, especially for grafts placed in a wound bed. Decompensation in flight is potentially devastating. Any concern for wound infection or delayed healing in the area of vascular graft should be thoroughly assessed prior to transfer.

Do not fly casualties with potassium below 3.0 or greater than 5.5, magnesium level < 1.4, phosphorus level < 1.5, or hemoglobin <7. There *must* be a post-op Hgb/Hct on patients who have undergone any operative procedure. Patients being transported with Hgb < 8.5 and lack of documented stability over more than two Hgb levels, 4 h apart, should be sent with two units of blood available for administration in case of hemodynamic instability or symptoms in flight.

Departing patients will need an updated discharge summary, CD with all radiology films (unless destination has access to the EMR), updated AF3899, and an adequate supply of medications per system requirements (3-day supply if going to the national capital area hospitals, 10-day supply of medications for other destinations, and civilian and coalition AE transport services may or may not desire a stock supply of medications). Standard order sets for discharge medications can facilitate accuracy and adequate supply.

Culture data that finalize after patients are transferred should be updated into the multidisciplinary discharge summary, and the CONUS team should be notified by e-mail or phone. If you are waiting on suspicious results, make it clear in the EMR and in the multidisciplinary discharge summary and leave your contact information. Even negative data can be important if it helps the next team stop empiric antibiotics. The same should occur for other new pieces of information not listed in the discharge summary, such as a change in a radiologic interpretation. When important lab values return after the patient has left, results must be forwarded to the patient's current providers as quickly as possible. Enter the information into the EMR and have the Trauma Coordinators pass the information on to the receiving team and document in Theater Management Data Store (TMDS) that this has been accomplished.

The standard of practice in theater is to vaccinate post-splenectomy patients immediately post-op. Please validate that has occurred. If not, then vaccinate all patients post- splenectomy before stateside flight to avoid non-vaccination. Enter the information into the EMR and have the Trauma Coordinators pass the information onto the receiving team.

## Role 5 (Continental United States): Care of Combat Casualties

### Pre-Role 5: Medical Evacuation from Landstuhl

The majority of evacuated patients during OIF and OEF received Role 5 care at Walter Reed National Medical Center (WRNMC), formerly Walter Reed Army Medical Center and Navy National Medical Center Bethesda. Typically, wounded warriors (WW) arrive to the Role 5 fully resuscitated and in a more stable physiologic condition than when arriving to the Role 4. Due to a mature medical evacuation system, WWs arrive to the Role 5 within 3–5 days of injury. Prior to their arrival, the Role 5 receives a copy of the Patient Movement Record (PMR). The PMR has patient demographics, injury mechanism, injury patterns, and a summary of care that has been received since the time of injury. Role 5s receive varying types of WWs, those requiring critical care air transport teams (CCATT), those who are less severely injured, but require surgical reconstruction (aeromedical evacuation or airevac), and those who are transiting back to their home duty station, but need a place to remain overnight (RON). As a matter of policy, patients with epidural catheters arrive via CCATT and are admitted to the ICU until they can be evaluated – regardless of injury pattern or severity. It is not uncommon for these patients to not spend more than one night in the ICU.

#### Prior to Arrival

The day prior to arrival at WRNMC, PMRs are received by Patient Administration Department (PAD). PAD then disseminates these PMRs to the various services throughout the hospital. While it may vary by hospital policy, all WWs should be admitted to the Trauma Service for at least 24 h. After the initial 24 h, following a quaternary survey performed by the Trauma Service, WWs with single-system injuries may be transferred to an appropriate surgical service.

Prior to arrival, the Trauma Service will work with PAD to have the WW admitted. The following checklist is provided as a guide to the house staff to ensure smooth transition of care:

- H&Ps are started (based on PMR data).
- Preadmission orders are written (especially medications for PCAs, epidurals, and sedation).
- Pre-Role 5 imaging should be imported into PACS by radiology.
- Downrange records are accessed via Theater Management Data Store (TMDS)
- All WWs are posted for the operating room (for next morning).
- Trauma Service will also ensure PMRs have been received by all services who may be involved with care of the incoming WW – orthopedics, neurosurgery, facial trauma, ophthalmology, etc.

#### Arrival at Role 5: Logistics of Arrival

As mentioned above, WWs typically arrive stateside between 1800 and 2100. Face-to-face turnover occurs with the flight crew and the Trauma Service. Printed charts from LRMC are handed over and fully reviewed following the timely physical evaluation of all WWs. All wounds and negative pressure dressings are inspected upon arrival. Since a majority of combat trauma wounds involve extremities, orthopedics should be present when WWs arrive. This allows all wounds to be evaluated just once. The volume of arriving patients should dictate the number of house staff and attendees present.

Negative pressure wound vacuum devices have been standardized across the continuum of care. The Role 5 must have an ample supply on hand to swap out suction devices with the aeromedical evacuation team. All intubated WWs should receive chest x-rays upon arrival to ensure proper endotracheal tube positioning has been maintained. Likewise, all WWs with naso-enteric feeding tubes should have abdominal films performed. Many of the feeding tubes placed at the Role 4 are naso-jejunal. If it can be shown the tube is beyond the ligament of Treitz, and planned surgery does not involve the abdomen, feeding may be able to be continued through the operative procedure, regardless if the WW arrives intubated.

Since most combat trauma wounded have extremity injuries, the Trauma Service must work closely with orthopedics. By convention, at WRNMC, if an extremity wound involves a fracture, orthopedics will take over the management of that extremity; if not, Trauma Service maintains the extremity management. After all WWs have been evaluated and appropriate consultations have been placed, next day operative planning and logistics should be discussed. As many WWs have multiple injuries over multiple body compartments, it is preferred to operatively work in parallel, vice in series, in order to minimize operative time. Lastly, should a WW arrive with signs of wound sepsis or bleeding, they should be taken emergently to the operating room for full exploration and debridement or source control.

### Day 1: Wound Evaluation

The first trip to the operating room is most important. All services should be present, and all wounds should be inspected and debrided, rarely are wounds closed on this initial Role 5 evaluation. This is typically post-injury days 4–6 and typically the time when the onset of wound infections are seen – particularly invasive fungal infections (IFI). Clinically, IFI has several hallmarks – high spiking temperatures (> 102.5 F), profound leukocytosis (> 25 K), and evidence of recurrent necrosis upon wound inspection. Should IFI be suspected, tissue must be sent to the lab for evaluation as these wounds are typically coinfected with multiple organisms:

1. Culture for fungus and bacteria (aerobe/anaerobe)
2. Histopathology – Hematoxylin and Eosin stain (H&E), Grocott-Gomori methenamine silver (GMS) stain

Tissue sent for histopathology should be at the boarder of viable and nonviable tissue to allow for pathological determination if fungal elements have invaded tissue vasculature. Surgically, debridement should be taken back to grossly bleeding, viable tissue, although even this is not a guarantee of adequacy. As fungal elements (such as mucormycosis) will invade along the vessels and perivascular space, even

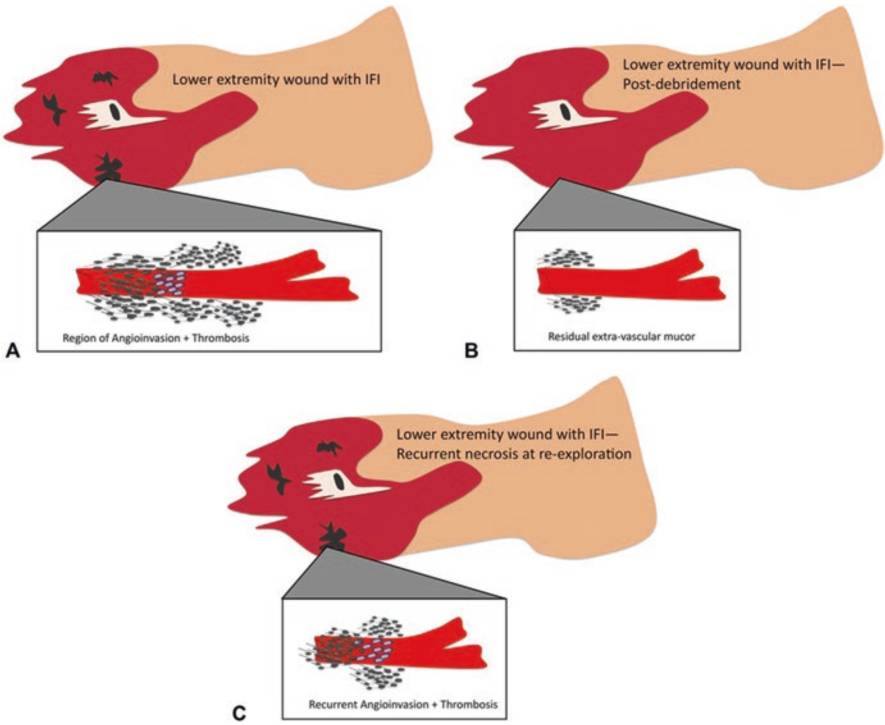


**Fig. 39.2** Cycle of recurrent necrosis in the setting of an invasive fungal infection (IFI). (**a**) Infection with fungal elements results in angioinvasion and local thrombosis. (**b**) Debridement back to visibly healthy tissue can still leave microscopic fungal elements in the interstitium. (**c**) These residual fungal elements then proliferate and invade local vessels, resulting in thrombosis and recurrent necrosis of the previously viable soft tissue (Reproduced from Journal of the American College of Surgeons, Dismounted Complex Blast Injuries: A Comprehensive Review of the Modern Combat Experience, 223(4), Jeremy W. Cannon, Luke J. Hofmann, Sean C. Glasgow, Benjamin K. Potter, Carlos J. Rodriguez, Leopoldo C. Cancio, et al., 652–664, Copyright 2016, with permission from Elsevier)

debriding to just bleeding tissue will often leave pockets of perivascular fungi that then leads to recurrent angioinvasion (Fig. 39.2). To minimize morbidity and mortality associated with IFI, multimodal therapy consisting of aggressive surgical debridement, systemic antimicrobial medications, and application of topical agents is recommended. As most IFI wounds are coinfected with bacteria and multiple fungi, each with their own sensitivities, it is suggested to empirically start liposomal ambisome, voriconazole, meropenem, and vancomycin in these WWs – even before culture results have returned. The antimicrobial spectra should be narrowed as culture/histopathology results return. Histopathology results may be available in 24 h, but communication with pathology is imperative to ensure this occurs.

Ambisome is aimed at mucormycosis and voriconazole is aimed at aspergillus terreus. Mucor (e.g., bread mold) is easy to grow in culture. Results should appear within a week. Aspergillus is not as easy to grow. Cultures should be checked daily for 1 week and then weekly, thereafter, for a total of 4 weeks. Topical therapy is with 0.025% Dakin's solution in an installation negative pressure wound vacuum device. The solution is instilled and allowed to soak on the wounds for 5 min, followed by 55 min of negative pressure therapy. WW with suspected or confirmed IFI should be taken to the OR for daily debridements – until evidence of recurrent necrosis is gone. Please see the Joint Trauma System's Clinical Practice Guideline on "Invasive Fungal Infection" for more details.

### Day 2 and Onward: Wound Stabilization

Typically, WWs are in the OR every other day for debridement and wound stabilization. Depending on wound characteristics, it may take 2–3 weeks (or more) for wounds to reach the closure/reconstruction phase. This high operative tempo requires coordination among all involved services. To ensure all efforts are coordinated, routine multidisciplinary rounds are recommended. These rounds should be led by the Trauma Service and should include all consultative services – surgical, rehabilitation, social work, TBI, PT, OT, military service liaisons (i.e., Army, Air Force, Navy, and Marines), PAD, ICU nursing, ward nursing, VA Liaison, etc. – attend this meeting. Discussion for each patient should include operative planning, disposition, and social issues.

Here is a list of pearls that should be heeded throughout the hospitalization:

1. Pay attention to the default timing of medications by your institution's EMR. For example, liposomal ambisome is a once daily medication. What time of day does QD mean at your institution? If QD means 0900, this could be problematic as WWs are oftentimes in the OR at 0900. A system must be in place to ensure medications are not missed but administered in a timely fashion.
2. Venous thromboembolism (VTE) is very prevalent in blast patients – incidence upwards of 25%. Proper chemical prophylaxis must be given. To minimize the risk of developing VTE, 30 mg low molecular weight heparin should be scheduled for 0600 and 1800 (or 40 mg at 0600 for those patients with epidural catheters). Should chemical prophylaxis not be possible, consider placing an IVC filter.
3. An IVC registry should be maintained by the Trauma Service to include date placed, indication for placement, and IVC filter serial and lot numbers. All IVC filters should be removed when no longer necessary. Should the WW be transferred to another institution prior to removal, documented communication of its presence should be made. Should conversion to permanent filter be decided, this, too, should be documented.
4. When patients develop VTE and therapeutic anticoagulation begins, the stop date should be annotated in the narrative summary as WWs oftentimes are transferred to other institutions or services for rehabilitation.
5. Many WWs were either injured by blast or had been exposed to concussive blast forces prior to being injured. As such, the following "blast consults" are recommended for "all" WWs regardless of injury mechanism that required their

evacuation from theater. For the single-system injured WWs, these consultations should be placed prior to transferring of surgical service. All consultations should be completed prior to transferring out of the Role 5.
   (a) Traumatic brain injury (TBI)
   (b) Audiology
   (c) Dental
   (d) Ophthalmology
   (e) Physical therapy
   (f) Occupational therapy
   (g) Physical medicine and rehabilitation
   (h) Social work
6. For the more severely injured WWs, hospital stays can approach 2 months. It is imperative that narrative summaries be updated on a regular basis.
7. For those WWs who underwent splenectomy, ensure downrange documentation details post-splenectomy vaccinations have been given.
8. Ensure patients receive terminal malaria prophylaxis.
9. There are weekly Joint Theater Trauma System (JTTS) teleconferences (Thursdays, 0800 EST) where patient care is discussed and reviewed, beginning at point of injury and extending throughout the continuum. This is a good opportunity to learn additional information about the WW, to provide feedback on care rendered, and to update the system on patient status/outcome.
10. There are monthly JTTS process improvement meetings for the Trauma Medical Directors.

## Wound Closure

When any signs of SIRS and wound infection have abated, wound closure is conducted. Delayed primary closure is preferred; however, skin grafting, rotational muscle flaps, and myocutaneous free flaps are suitable alternatives. An overriding principle in dealing with traumatic amputations is that length preservation does promote better functional outcomes. Role 5 orthopedic and plastic surgeons have rotated muscle flaps and even brought free flaps to preserve length to below-knee amputations.

## Discharge to Rehabilitation

Discharge planning should begin at admission and is based upon the overriding injury.

1. Traumatic brain injury – Those WWs with TBI requiring inpatient rehabilitation will need to utilize the VA Polytrauma System. Currently, those centers are in Richmond, VA; Tampa Bay, FL; Minneapolis, MN; San Antonio, TX; and Palo Alto, CA. The VA Polytrauma System also provides emerging consciousness services.
2. Amputation rehab – Those WW requiring amputation rehab may utilize the VA Polytrauma System but may also utilize the Role 5s at the Walter Reed National

Military Medical Center in Bethesda, MD; San Antonio Military Medical Center in San Antonio, TX; or the Navy Medical Center San Diego in San Diego, CA.

3. Other injuries – Many other WWs have injuries that do not require inpatient rehabilitation. Those WWs may be able to return to their home bases for rehabilitation. The Army, Air Force, Navy, and Marines all have different requirements and different resources at their respective installations nationwide.

If transferring WW to another institution, physician-to-physician contact should be made to discuss details of care and any outstanding issues (e.g., presence of IVC filter, VTE therapy, etc.). In addition to being an invaluable resource for coordinating the logistics of daily care, routine multidisciplinary meetings are where a large portion of disposition planning occurs. The discussion of disposition throughout a WWs hospital stay (though the phases of care) will allow the Role 5 to ensure a seamless transition from acute surgical care to rehabilitation when the patient is ready without undue delay.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at[1]: www.usaisr.amedd.army.mil/cpgs.html

1. Intra-theater transfer and transport.

[1] Most of the existing JTS CPGs are relevant to specific aspects of Role 4 and 5 care.

# Active Shooter and Intentional Mass Casualty Events

# 40

Alexander L. Eastman and Matthew L. Davis†

**Operational Experience**

| | |
|---|---|
| *Alexander L. Eastman* | Lieutenant and Chief Medical Officer, Dallas (TX) Police Department |
| | Special Deputy United States Marshal, US Marshals Service |
| | Senior Medical Advisor, US Department of Homeland Security |
| *Matthew L. Davis* | Trauma Director for responses to Fort Hood, Texas active shooter events in 2009 and 2014 |

**BLUF Box (Bottom Line Up Front)**

1. Our nation sits at a time of unprecedented threat from active shooter or other intentional mass casualty events.
2. The frequency of active shooter/intentional mass casualty events is rising and is being seen in every region and setting, including hospitals.
3. Military bases and setting have not been immune, and multiple incidents such as the Fort Hood mass shooting events have specifically targeted military bases and personnel and likely will continue to target them.

(continued)

A.L. Eastman (✉)
The Rees-Jones Trauma Center at Parkland/Department of Surgery, UT Southwestern Medical Center and The Dallas Police Department, Dallas, TX, USA
e-mail: alexander.eastman@utsouthwestern.edu

Matthew L. Davis (deceased)




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(continued)

4. The Hartford Consensus, a series of four documents, has helped take TCCC concepts and apply them to the civilian response to the active shooter.
5. Hemorrhage control is a core law enforcement skill that all LEOs must master and be equipped for.
6. In order for a seamless response, hemorrhage control must be taught to the public on a wide scale. It is the CPR of the twenty-first century.
7. Fire-rescue integration must occur in a standardized way but allow for local variations in practice and operating procedures.
8. Public access hemorrhage control training must be free and available and allows bystanders to be transformed into immediate responders.
9. Hemorrhage control equipment should be prepositioned in large occupancy public spaces across communities, similar to the placement of automated external defibrillators.
10. You must be prepared to respond in an active shooter event. Preparation and practice will prevent you from "freezing up." Know the THREAT acronym for response to an active shooter (Fig. 40.1).


**Fig. 40.1** THREAT acronym outlines the recommended actions/response for an individual in an active shooter event

## In Memory of Matthew L. Davis, MD, FACS (1974–2015)

This chapter is dedicated to the memory of its coauthor, Dr. Matthew L. Davis, who was tragically killed in a climbing accident in September, 2015. The editors of this book and many of the authors had the good fortune to know Matt, and we all certainly knew of his incredible dedication to the care of the injured patient throughout his


**Fig. 40.2** Seven of the contributing authors of this book, including Matt Davis (center)

career. As the trauma director at Scott and White Medical Center in Temple, Texas, Matt led that facility's response to two mass casualty active shooter events that occurred at nearby Fort Hood and that involved primarily military service members. Matt's calm and professional leadership through both events was recognized locally and nationally and credited with saving a number of lives on those 2 dark days.

Matt was all about learning from these horrible events, getting better at what we do and how we care for trauma victims, and also working to prevent future similar events. He was generous and open with his knowledge, expertise, and experience and unfailingly humble about his leadership role during these events. Matt was also a great family man, father, husband, and close friend to myself and many other authors of this book. We wish that he could be here to see the final product of his contribution to this project, and he is sorely missed by everyone whose life he touched (Fig. 40.2).

*Courage is being scared to death and saddling up anyway.*

John Wayne

## Introduction

What at first were seemingly rare events that shocked our national consciousness, a list of recent active shooter incidents or intentional mass casualty events (AS/IMCEs) reads more like a recap of recent second-page stories than a list of extraordinary incidents. It is an unfortunate fact of modern American life that communities, responders, trauma surgeons, and other must not only go about their daily jobs but also must continuously prepare themselves for the active shooter/intentional mass casualty event (AS/IMCE). I have a relatively unique perspective on these types events, as I currently serve as an officer with the Dallas Police Department in addition to being a practicing trauma surgeon. On a personal note, having recently been a responder to an active shooter event in Dallas that resulted in multiple police officer deaths, these lessons are real, poignant, and truly have the potential to improve survival with wide implementation.

## The Hartford Consensus

Originally convened in an attempt harness, the power of the Tactical Combat Casualty Care (TCCC) program and formally known as The Joint Committee to Create a National Policy to Enhance Survivability from Intentional Mass Casualty and Active Shooter Events, the Hartford Consensus was originally formed by a partnership between the American College of Surgeons, the Federal Bureau of Investigation, the Major Cities Chiefs Association (Police), and the Committee on Tactical Combat Casualty Care. The HC originally met twice in 2013 and has continued to work on this topic, most recently meeting in Dallas, Texas on January 7–8, 2016. The current membership of the Hartford Consensus is listed in Table 40.1.

## The Hartford Consensus I

No matter the event type and scope, law enforcement officers (LEOs) represent the first responders to each and every active shooter/intentional mass casualty event (AS/IMCE) when they occur. Even with the most aggressively integrated operations plan, the response to these events must begin with LEO response and hence places the LEO in the position of being the first professional responders that have an impact on survival. Because of this unique role, hemorrhage control has got to be as much a core law enforcement skill as de-escalation, driving, and firearm use. Couple this unique opportunity with the fact that despite major strides in equipment, body armor, vehicle design, tactics, and the delivery of modern trauma and critical care, we've only barely improved our ability to minimize law enforcement officer injuries and deaths. To address both problems, it is imperative we equip our officers with the knowledge and tools to mitigate and minimize the consequences of injuries when they occur. We must prepare, and to prepare, we must teach lifesaving skills to all our officers. What has been limited historically to the tactical team medic or delegated to a civilian fire/rescue or EMS agency, now must be delivered to the hands of each officer who has the potential for hostile contact. This idea is exactly why our nation's largest law enforcement agencies unanimously support the findings of the Hartford Consensus.

Recognizing this, the Hartford Consensus I called for the recognition of hemorrhage control as a core law enforcement skill and outlined the THREAT acronym (see Fig. 40.1) as the core response steps in improving survival from the AS/ICME.

**Table 40.1** Hartford consensus founding members

| |
|---|
| Lenworth M. Jacobs, MD, MPH, FACS |
| Chair |
| David B. Hoyt, MD, FACS |
| Executive director, ACS |
| Richard Carmona, MD, MPH, FACS |
| 17th US surgeon general |
| Norman McSwain, MD, FACS |
| Medical director, PHTLS |
| Frank Butler, MD, FAAO, FUHM |
| Chairman, Committee on Tactical Combat Casualty Care |
| Andrew L. Warshaw, MD, FACS, FRCSEd(Hon) |
| Past president, American College of Surgeons |
| Jonathan Woodson, MD, FACS |
| Assistant secretary of Defense for Health Affairs |
| Richard C. Hunt, MD, FACEP |
| Director, Medical Preparedness Policy, The White House |
| Ernest Mitchell |
| Administrator, US Fire Administration |
| Alexander L. Eastman, MD, MPH, FACS, DABEMS |
| Medical advisor, Major Cities Chiefs Association |
| Kathryn Brinsfield, MD, MPH, FACEP |
| Chief medical officer, US Department of Homeland Security |
| William Fabbri, MD, FACEP |
| Director, Emergency Medical Services, FBI |
| Matthew Levy, DO, MSc, FACEP |
| Johns Hopkins University |
| John Holcomb, MD, FACS |
| Division of Acute Care Surgery, UTHSC-Houston |
| Ronald M. Stewart, MD, FACS |
| Chair, ACS Committee on Trauma |
| Doug Elliott |
| President, the Hartford Insurance |

## Hemorrhage Control and the Law Enforcement Officer

While it would be optimal to have a trauma surgeon at the side of every officer at the time of wounding that is clearly not feasible. LE physicians have been instrumental in pushing medical techniques previously thought only to be reliably and safely used by certified medical providers out to those with mere basic training. The translation of these skills from medical textbooks to wide applicability and implementation by nontraditional responders has and will continue to save lives. Based on principles established in the Tactical Combat Casualty Care (TCCC) program, these hemorrhage control techniques are battlefield tested, supported by data from

**Table 40.2** Dallas Police Department Downed Officer Kit (DOK) contents

| |
|---|
| SOFT-W Tourniquet |
| QuikClot Combat Gauze LE |
| 4″ Olaes Modular Bandage |
| Latex/EMS gloves |

both military and civilian sources, and have eliminated preventable death in some battlefield spaces by their widespread adoption. Officers are trained in hemorrhage control, and other medical techniques can treat injured persons until they can receive more advanced medical attention. LEO hemorrhage control programs must contain simple, easily replicable, easily taught and learned skills, and must be focused on those interventions that can be applied by police officers to the injured at the point of wounding.

Because the predominant cause of preventative battlefield death is exsanguinating extremity hemorrhage, the use of tourniquets and other hemorrhage control techniques plays a large role in the management of these types of casualties. Table 40.2 lists the contents of a basic Downed Officer Kit (DOK) issued to every LEO in the Dallas (TX) Police Department. As you can see, the contents mirror those of the TCCC program, and each officer issued these kits receives training to become expert in the use of these pieces of equipment in austere environments.

## The Dallas Experience

While some detractors initially thought that the introduction of these skills into the armamentarium of the LEO would distract from other, more traditional LE responsibilities, in fact they have proven to be very complimentary, particularly in response to the active shooter. On June 12, 2015, an assailant in an armored vehicle attacked the Dallas, Texas Police Department (DPD) headquarters building with automatic weapons and improvised explosive devices (IEDs). While officers returned fire, negotiated the IED-containing suspicious packages, and evacuated endangered civilians, other DPD officers ensured that no one was injured, provided care to those banged and bruised, and ultimately ensured that the only loss of life that day was that of the suspect. Even in times of utmost crisis, LEOs are capable of not only performing traditional duties but also of providing care to those around them that need it.

On the evening of July 7, 2016, a peaceful protest was winding its way through the downtown Dallas, Texas central business district. Organized by the Next Generation Action Network, an offshoot of the Black Lives Matter organization, several hundred protestors worked their way through the streets of downtown protesting recent law enforcement (LE) shootings and other enforcement actions. The protestors were protected by several hundred Dallas police officers in a combination of traffic, fixed, and other assignments designed to ensure the protestors' safety and to ensure that their first amendment rights to free speech and free assembly remained intact. While there were shouting and signs, none of the protestors were violent in any way.

Shortly before 9 p.m., a young adult male parked an SUV on the Lamar Street side of the Dallas County Community College building. He exited the vehicle wearing body armor and armed with an AKS-74 rifle. After walking a half block south toward where police officers were blocking the street to accommodate protestor foot traffic, the suspect open fire on a crowd of Dallas police officers. Six officers, three fatally, and two civilians were wounded in this initial volley of gunfire. The gunman retreated north, killing a Dallas Area Rapid Transit police officer on Lamar Street and then moved around the El Centro building, ultimately gaining access inside. During an interior gunfight, two Dallas County Community College District police officers were wounded but continued to push/advance on the suspect. After gaining access to the second floor of El Centro, the gunman fired down into the street from an elevated position. Additional officers and an additional civilian were wounded with the last officer killed during this incident sustaining his injuries from this position. A massive law enforcement response ensued.

From the trauma care standpoint, all LE casualties were given TCCC-based self-aid/buddy-aid (SABA) care under fire by fellow officers and all with the exception of one were transported by police vehicle. All casualties were treated and evacuated to two local trauma centers within 7 min of their wounding. While optimal from the standpoint of the field treatment of penetrating injuries, e.g., the rapid transport of the injured to the trauma center by the most expeditious means possible, this caused some challenges in terms of notification to trauma center staff.

Because of the dynamic nature of an incident like these, with multiple distinct scenes, continuing gunfights, multiple IEDs, and multiple business and residential occupancies at risk, these scenes are simply inaccessible to non-law enforcement responders like fire/rescue/EMS. Had there been more injuries, care would have had been the responsibility of the DPD officers there. What remains clear is that the care described in the Hartford Consensus represents the most acutely delivered response in the unique nexus of the roles of law enforcement, trauma surgery, and public health, and this has to continue to be based on the lessons learned in the TCCC program.

## The Hartford Consensus and the Major Cities Chiefs Association

From its inception, the agencies represented by the Major Cities Chiefs Association and many other law enforcement agencies around the United States and the world have been supporters and contributors to the Hartford Consensus. In addition to the adoption of the response concepts represented by the THREAT acronym, the provision of hemorrhage control has been recognized by many as a core law enforcement skill. While data with regard to specific utilization during active shooter situations is scarce, agencies across the country are reporting multiple lives saved with these techniques. In Tucson, AZ, the police and sheriff's departments have a long history of a LE agency-based hemorrhage control program. Responsible for saving more than 75 lives over the years, it is hailed as a real example of the improvement in community safety when law enforcement officers can provide effective hemorrhage control at the point of wounding, not just summons help from other public safety agencies. Law enforcement agencies around the state of Texas have saved more than 100 lives in a relatively short period of time alone.

At the October 2013 meeting of the Major Cities Chiefs Association (MCCA), the Hartford Consensus was presented to the membership and the concepts therein unanimously endorsed. Since that meeting, more than 50 of the 70 agencies represented by the MCCA have or are in the process of training and equipping their LEOs with hemorrhage control training and equipment. This translates into more than 180,000 LEOs in our nation's largest cities (or around 1:5 of US LEOs) are now capable of saving an injured civilian or one of their fellow officers injured in an active shooter or other situation. These officers presently provide this protection to nearly 80 million Americans.

## The Hartford Consensus II: A Call to Action

After an overwhelming response to the original report from the HC, the group was convened again and produced a second document that served as a call to action. In the interval between meetings, subsequent AS/ICME events made it clear that further work on the topic was necessary. The HCII was one of the first calls to recognize a previously untapped resource: uninjured bystanders at the scene of an AS/ICME. Including these "immediate responders," the HCII called for the public, law enforcement, EMS/fire/rescue, and trauma systems to work together to craft novel educational material and programs that would continue to develop a seamless response along the lines of those developed to combat out-of-hospital cardiac arrest in the 1970s. Equally as important as the response and education calls that came from the HCII, perhaps more importantly, was a call for methods of response evaluation. To quote the HCII, "Scientific evaluation of the implementation of Hartford Consensus concepts must ensure that future efforts are focused on ideas that are effective." A specific call was made for measurement of the following:

- Accessibility of hemorrhage control equipment across the response spectrum
- Documentation of the use of hemorrhage control equipment
- Creation of a national registry
- Use of THREAT by relevant providers

At the conclusion of the second Hartford Consensus meeting, while it was clear that some progress had been made with regard to an increased penetrance of law enforcement-based hemorrhage control programs and LE/Fire-Rescue integration, it was also apparent that there was more work to be done.

## The Hartford Consensus III: A Seamless Spectrum

One of the facts that became clear through the HC process was that even in the best hands, in communities with the most integrated active shooter response programs, time spent waiting for professional first responders was still time wasted, while active hemorrhage was still potentially occurring. By virtue of this, the HCIII sought to continue work thus far but also recognize a previously underutilized resource: those people caught in an AS/IMCE who are willing and able to provide assistance to injured victims. Termed “immediate responders” by the HC (or first care providers by the Committee on Tactical Emergency Casualty Care. Ultimately, the HCIII heralded the call for better equipment capabilities for these providers, better educational materials, and increased resources for communities to build bleeding control programs. To further these ideas, the White House National Security Council held a series of roundtable discussions with a wide variety of stakeholder organizations that culminated in an interagency initiative across the federal government and many other communities: the Stop The Bleed (STB) initiative. STB represents a concerted effort to deliver a true public access hemorrhage control capability designed to enhance community resilience from multiple hazards across the United States.

## The Hartford Consensus IV: Bleeding Control Basic

The fourth and most recent meeting of the HC occurred in Dallas, Texas in early 2016. By this point, it had become clear that hemorrhage control training, a basic, simple to adapt, teach, and understand version, had to become the CPR equivalent of the twenty-first century. As AS/IMCE events continued to mount and terror tactics continued to evolve, the clamor for this training and hemorrhage control equipment grew louder and louder. The HC, the ACS, and several other organizations heeded the call for an organized training program to become the core piece of a Stop The Bleed program. Named Bleeding Control Basic, this program is designed to teach hemorrhage control to a new class of responders. Evidence clearly shows that a not insignificant number of people will stay in place during an AS/IMCE event to assist their fellow citizens that are injured in the attack. Formerly known as “bystanders,” Bleeding Control Basic is designed to turn these individuals into true “immediate responders.”

## Beyond the Individual Response: Comprehensive Active Shooter Incident Management

As trauma surgeons and those involved with training first responders and the lay public, we often focus on medical interventions and initiating treatment for life-threatening injuries in ASI. However, it is critical to understand that this is only one aspect of a large and multidimensional system that is required to optimally manage

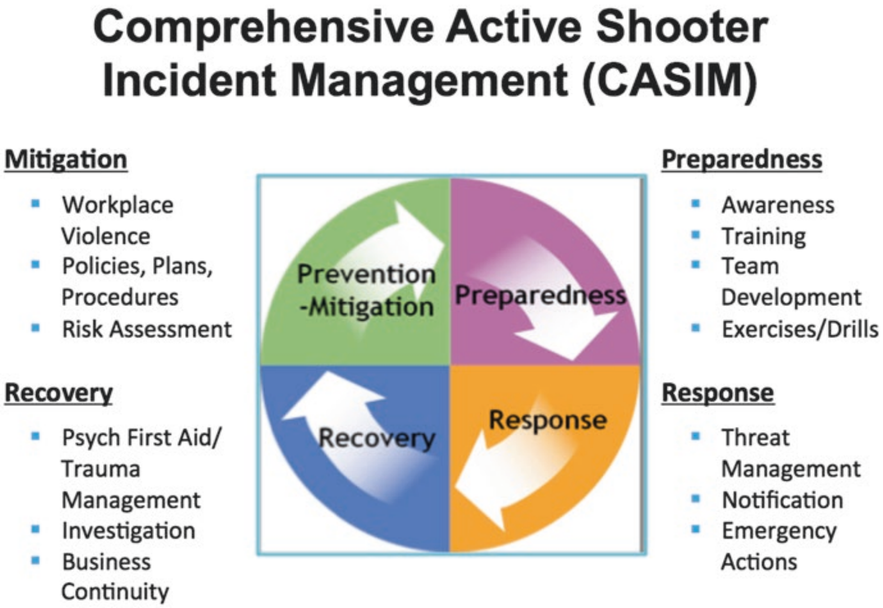


**Fig. 40.3** The four components of the Comprehensive Active Shooter Incident Management (CASIM) system. Note that activities both before and after the event are also critical to prevention/mitigation and to maximizing survival and recovery (Image courtesy of Captain Mike Sebastionelli)

(and even hopefully prevent) these events. Figure 40.3 outlines the key aspects of the Comprehensive Active Shooter Incident Management (CASIM) system. This includes actions prior to the event focused on preparedness/training as well as prevention and mitigation strategies, actions during the event, and then actions after the event in the "recovery/consolidation" phase. All of these are critical to maximizing our readiness for these events and to minimizing resultant casualties. As physicians, and particularly as trauma surgeons and emergency medicine providers, we can have an impact or make a significant contribution to every aspect of CASIM by partnering with all local leaders and stakeholders such as police and fire departments, EMS, violence prevention programs, and the local Incident Command System (ICS) planning and execution process.

## Conclusions

Our nation faces unprecedented threats—both from outside and from within. It is an unfortunate fact that AS/IMCEs will continue to occur and that individuals and communities need to stay prepared, vigilant, and ready to respond. The Hartford Consensus has done a remarkable job in translating TCCC concepts to audiences that were previously unfamiliar, at best, or unwilling, at worst, to learn the lessons that have been taught to us through recent conflicts. The continued goal of the HC is to study and build a seamless system of hemorrhage control across our nation and, by doing so, serve to improve our resilience and readiness as a whole.

## Suggested Reading

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# 41 Tactical Emergency Casualty Care (TECC): Principles and Practice

Geoff Shapiro, Babak Sarani, and E. Reed Smith

*Your brand will be called on upon when it's needed. When it's not needed at the moment, keep it safely till its call comes. Some brands shine occasionally!*

Israelmore Ayivor

**BLUF Box (Bottom Line Up Front)**

1. Decreasing the time from injury to initial stabilizing care is *the most critical step* in mitigating preventable trauma fatalities. Therefore, rapid extraction of a patient to an area where treatment can be rendered is paramount for survival.
2. Medical interventions and tactical goals of care during high-threat incidents must be weighed against the probability of additional injuries to casualties and/or providers. Hemorrhage control remains the single greatest objective.
3. Tactical Combat Casualty Care (TCCC) and Tactical Emergency Casualty Care (TECC) are medical practice guidelines to be utilized during high-threat incidents in the military and civilian settings, respectively.

(continued)

G. Shapiro
Emergency Medical Services and Operational Medicine Training Programs, George Washington University, Emergency Medical Services, Washington, DC, USA

B. Sarani (✉)
Associate Professor of Surgery and Director of the Center for Trauma and Critical Care, Department of Surgery, George Washington University, Washington, DC, USA
e-mail: bsarani@mfa.gwu.edu

E. Reed Smith
Assistant Professor of Emergency Medicine, Department of Emergency Medicine, George Washington University, Washington, DC, USA


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(continued)

4. The TECC phases of care are divided into: Direct Threat (Hot Zone, risk of harm to the patient or provider is greater than risk of death due to injury itself) goal is mitigating threat, controlling extremity hemorrhage expeditiously, and extricating patient if possible; Indirect Threat (Warm Zone, potential for harm is less than risk of death due to injury) goal is rapid patient assessment and treatment of life-threatening disorders. Evacuation Care (Cold Zone, potential for harm is considerably less) goal is stabilization of all injuries and transport to definitive medical care.
5. MARCHE mnemonic can be used to establish treatment priority during the Indirect Threat phase of care: Major Hemorrhage Control, Airway Management, Respiratory Management, Circulation Control/Shock Management, Head/ Hypothermia Prevention, Everything Else.
6. The First Care Provider, usually an active bystander or law enforcement official, should be trained in hemorrhage control, basic airway management techniques, basic shock management, and rapid evacuation of patients in order to address the most common causes of preventable death following trauma.

## From ATLS to TCCC

In the mid-1990s, a Special Operations medical research project funded by the United States Special Operations Command and led by Capt Frank Butler resulted in the drafting of a series of combat medical guidelines, referred to as Tactical Combat Casualty Care (TCCC), for the Special Operations Community. The goal of this project was twofold: to define the prioritization and application of medical care under military combat conditions and to account for the competing priorities between tactical/mission objectives and care for the wounded. Prior to development and implementation of TCCC, the military based its resuscitative strategy and initial care for the combat wounded on the civilian standard Advanced Trauma Life Support (ATLS) guidelines. These general guidelines recommend an "Airway, Breathing, Circulation" approach to the evaluation and initial resuscitation of the wounded regardless of the mechanism or setting. ATLS is based on the assumption that the medical provider is in a safe, stable, resource-rich environment and that the most common cause of immediate death is related to respiratory failure. As such, this civilian approach to trauma in no way is able to account for any of the multiple tactical considerations in combat, the on-going dangers inherent in the military environment, the specific pattern of combat wounding with a prevalence of penetrating and blast injury, the austere conditions, or the advanced physiology and medical complications created by commonplace delays to evacuation (Table 41.1).

The implementation of Tactical Combat Casualty Care has been one of the major factors in reducing preventable death on the modern battlefield from approximately 14% in Vietnam to 8% during Operation Iraqi Freedom (OIF) and Operation

**Table 41.1** Differences between TCCC and ATLS

| TCCC | ATLS |
|---|---|
| "CAB" – hemorrhage control before airway assessment | "ABC" – airway, breathing, circulation assessment |
| Incorporates situation into medical decision making (see Table 41.2) | Does not take into account scene safety/tactical situation |
| Encourages the use of hemostatic dressings and tranexamic acid | Does not mention hemostatic dressings or tranexamic acid |
| Encourages the use of tourniquets for severe hemorrhage | Discourages tourniquets and espouses direct pressure |
| Allows for "hypotensive" or "damage control" resuscitation | Calls for 1–2 l of crystalloid to treat hypotension |
| Encourages the use of nasopharyngeal airway | Encourages the use of endotracheal intubation |
| Allows to enteral pain medication administration and the use of nonnarcotic parenteral pain medications | Only encourages parenteral opioid medication |
| Does not encourage spine immobilization for most mechanisms of injury and considers tactical situation in decision to utilize spine immobilization | Encourages the use of a cervical collar and spine board for many blunt mechanisms of injury |
| Addresses importance of early antibiotic administration for severe extremity and abdominal wounding | Does not address role of antibiotics in initial trauma care |

*TCCC* Tactical Combat Casualty Care, *ATLS* Advanced Trauma Life Support

Enduring Freedom (OEF). In a memorandum dated 6 August 2009 and as supported in 2 studies, the Military Defense Health Board (DHB) noted that several Special Operations units in which all members were trained in TCCC reported no incidents of preventable battlefield fatalities during the entirety of their combat deployments. Given the simplicity of training and this high rate of efficacy, TCCC training is now recommended for all deploying combatants and medical department personnel.

Given the proven success of TCCC on the battlefield, the civilian medical community began to examine closely the tenants of the TCCC doctrine and, driven by prehospital training programs, to integrate portions into civilian trauma care. In fact, many civilian emergency medical system agencies began to simply incorporate TCCC into their operations. Others, however, have resisted implementation of TCCC, citing concerns about military language and operational concerns regarding difference in patient populations, resource limitations, and legal constraints. Given these differences, the issue of the direct applicability of TCCC for civilian operations has been discussed and challenged in many operational medical circles.

Examination of the civilian high-threat medical operations, especially with the "all-hazards" approach necessitated by the wide variety of civilian operations, quickly finds that there are a multitude of scenarios and considerations which are not addressed in the objectives or scope of TCCC. Characteristics that distinguish civilian from military high-threat prehospital environments include, but are not limited to, the following:

- Scope of practice, liability, and differences/breadth of medical care protocols
- Patient population to include geriatrics, pediatrics, pregnancy, and special needs
- Differences in barriers to evacuation and care

- Differences in baseline health of the population
- Differences in wounding patterns and use of protective gear
- Chronic medication use in the injured
- Equipment acquisition and budgetary restraints

## From TCCC to TECC

Given the gap in civilian high-threat medical response, a group of voluntary subject matter experts in emergency medicine, trauma surgery, critical care medicine, anesthesiology, pain management, EMS, law enforcement, tactical medicine, and medical education founded an independent nonprofit (501c3) organization called the Committee for Tactical Emergency Casualty Care (C-TECC) in 2011. Using the foundation of the military TCCC guidelines, C-TECC created the Tactical Emergency Casualty Care (TECC) guidelines as a best practice, evidence-based operational medical care framework that balances the threat, varying scope of practice of responders, differences in patient population, limits on medical equipment, and variable availability of resources that may be present in all high-threat atypical emergencies and mass casualties in the civilian setting. Additional goals of TECC include establishing a framework that balances risk-benefit ratios for all civilian operational medical response elements, providing guidance on medical management to mitigate preventable deaths at or near the point of wounding, and minimizing provider risks while maximizing patient benefits. Overall the concepts and medical approach of TECC are similar to TCCC, but the developmental considerations, language, and scope of application have been adapted to the various needs of the civilian sector (Table 41.2). Additionally, the ongoing evidenced-based analysis of the TECC guidelines and the annual updates to the guidelines are firmly founded in civilian medical evidence. Since inception in 2011, TECC has been endorsed by a number of professional and governmental entities and has been included in a wide number of federal operational guidance documents.

**Table 41.2** Differences between TCCC and TECC

| TCCC | TECC |
|---|---|
| 3 phases of care:<br>1. Care under fire<br>2. Tactical field care<br>3. Tactical evacuation | 3 phases of care<br>1. Direct Threat (Hot Zone)<br>2. Indirect Threat (Warm Zone)<br>3. Evacuation Care (Cold Zone) |
| Separates skill/knowledge for:<br>1. Soldier/sailor<br>2. Medic<br>3. Physician | Separates skill/knowledge for<br>1. First Care Provider<br>2. First responder with a duty to act<br>3. EMR/EMT<br>4. Paramedic<br>5. Physician |
| Does not address extremes of age | Addresses all ages, pediatrics to geriatrics |
| Restricted to a uniform methodology | Allows for variability in practice based on jurisdiction and state scope limitations |

*TCCC* Tactical Combat Casualty Care, *TECC* Tactical Emergency Casualty Care

## Tenets of TECC

Decreasing the time from injury to initial stabilizing care has been defined as the most critical step in mitigating preventable trauma fatalities. Dr. Nicholas Senns, the founder of the Association of Military Surgeons, wrote in 1891 that, "the fate of the wounded rests in the hands of one who applies the first dressing." A century later, this concept was translated to the Platinum 10 min and the Golden Hour as a way to define the importance of the rapid initial care and stabilization of the traumatically injured patient; thus simple, stabilizing care at or near the point of wounding is at the foundation of TECC.

At most basic level, TECC balances the operational threat against the need for medical care for the wounded in a risk-benefit matrix. As compared to a standard prehospital trauma scenario (e.g., a few patients with plentiful resources), there are significant differences that must be accounted for when addressing medical care in a hostile scene where patients outnumber resources, and/or scene security cannot be guaranteed. As such, TECC recommends organizing these tactical situations into phases of care defined by the threat itself: Direct Threat (Hot Zone), Indirect Threat (Warm Zone), and Evacuation (Cold Zone). Within each phase, the feasibility and utility of medical interventions change based upon the risk of further injury to the patient or provider.

Throughout all phases of care, TECC stresses the importance of immediate hemorrhage control followed by simple airway and breathing management, hypothermia prevention, and damage control resuscitation. Therefore, TECC strongly espouses the use of direct pressure, tourniquets, wound packing, and pressure dressings and hemostatic dressings and the use intravenous medications such as tranexamic acid based on the skill level and scope of practice of the responder. TECC also encourages the use of all possible care providers, including first care providers (formerly known as civilian bystanders), while taking into account the tactical situation and scene safety.

## Direct Threat (Hot Zone)

A Direct Threat or Hot Zone is any dynamic area where the risk of harm to the patient or provider is imminent and may be greater than the risk of death posed by the injury itself. This may be a static geographically defined area with perimeters such as seen in traditional hazardous materials or police tactical response, but the Hot Zone may also be dynamic and shifting with fluid boundaries. Direct Threat (Hot Zone) phase applies for, but is not limited to, active shooter situations, immediately dangerous to life and health (IDLH) environments (e.g., hazardous materials spills, fire scene, unstable structural collapse, etc.), close proximity to unexploded improvised devices, and other technical rescue and mass casualty situations. The majority of effort during this phase is directed at mitigating the threat and extricating those in danger from the threat area. As such, very limited medical care is provided during this phase of care due to the likelihood of incurring additional casualties as a consequence of both redirecting resources away from threat mitigation to providing patient care as well as of spending more time within close proximity of the threat.

It is important to note, and is emphasized during this phase, that accessing and extricating the patient from an area of threat should be considered a medical intervention and prepared for by trained first responders. “It is no longer acceptable to stand and wait for casualties to be brought to the perimeter” because “external hemorrhage control is a core law enforcement skill.” As such, joint training and integration of resources between police and fire/EMS prior to an actual event is pivotal to allow for the rapid deployment of escorted and protected medical assets, often referred to “Rescue Task Force” units, into areas of high threat.

During Direct Threat (Hot Zone), external hemorrhage control is the only medical intervention that is recommended, through the rapid application of tourniquets only if the hemorrhage is considered so severe that it is likely the patient will exsanguinate prior to immediate evacuation to a safer area. Given the need to limit time spent in proximity to a threat, direct pressure should be applied immediately and followed quickly by tourniquet application as high up on the extremity as possible. These tourniquets should be placed over any clothing present to minimize time to application and control of bleeding. If tourniquets are not available and the injured person is capable, he or she should be instructed to apply direct pressure to his or her own wound during evacuation. The use of wound packing, pressure dressings, and hemostatic agents for hemorrhage control is deferred to later phases of care due to the amount of time and need for specialized equipment and training required to properly apply these interventions. All other medical interventions are deferred to later phases of care.

## Indirect Threat (Warm Zone)

Indirect Threat (Warm Zone) care begins once the patient and provider are in an area where there is still the potential for harm, or there is a chance that the dynamic situation may deteriorate back to a Direct Threat situation. Because of the dynamic and changing nature of high-threat environments, the care provider must maintain constant situational awareness and adjust the treatment strategy as appropriate. Examples of Indirect Threat (Warm Zone) include an active shooter event where a particular room/corridor has been cleared by law enforcement, but the assailant him/herself has not yet been neutralized; the immediate aftermath of an exploded improvised explosive device involving multiple wounded patients in need of care and rescue, but the risk of a secondary or delayed explosive device remains; or industrial accident where the possibility of further structural collapse or recurrent event is not likely but has not been definitively ruled out.

Operational mitigation of the threat and safety considerations for responders remains paramount; however, in this phase, patient assessments and treatments are more comprehensive and methodical. As with all considerations in TECC, Indirect Threat (Warm Zone) medical interventions remain primarily focused on rapidly correcting any of the potentially preventable causes of death, preventing further medical complications, and evacuating the patient to a safe area and definitive care. Several common acronyms are used to aid providers in recalling the correct order to address potentially preventable causes of death, but the most common for prehospital medical personnel is MARCHE: Major Hemorrhage Control, Airway Management, Respiratory Management, Circulation Control/Shock Management, Head/Hypothermia Prevention, Everything Else (Table 41.3). Another common one for providers with a more limited scope of practice is SCAB-E: Situational awareness, Circulation/bleeding control, Airway management, maintenance of Breathing, and Evacuation/Everything Else.

**Table 41.3** MARCHE skills

| Objective | Skill set/tasks |
|---|---|
| Major hemorrhage control | Tourniquet |
| | Direct pressure |
| | Wound packing |
| | Hemostatic dressing |
| Airway management | Sit up or place in "recovery position" |
| | Jaw thrust/chin lift |
| | Nasopharyngeal airway |
| | Supraglottic airway |
| | Endotracheal intubation |
| | Surgical airway |
| Respiration/breathing | Seal open chest wounds |
| | Needle thoracostomy or burp chest seal |
| | Provide oxygen (Evacuation Care only) |
| | Assist ventilation with BVM |
| Circulation | Assess peripheral pulse and mental status as indices of shock |
| | Establish IV/IO access |
| | Administer fluid/blood as needed allowing for |
| | hypotensive resuscitation |
| | Administer TXA if indicated |
| Head injury | Use IV fluids to keep systolic blood pressure > 90 mmHg |
| | Avoid hypercapnia |
| | Provide analgesia |
| | Elevate head 30–45° |
| Hypothermia prevention | Remove wet clothing, remove from or protect from cold surfaces, and cover patient to prevent conductive and convective heat loss |
| Multimodal pain control | Initiate pain control using combination of non-opioid and opioid medications to maximize effects while minimizing side effects |
| Smoke inhalation and burns | Aggressive airway management for potential airway burns |
| | Oxygen for carbon monoxide exposure |
| | Consider cyanide antidotes for smoke exposure and any altered mental status |
| CPR | CPR not indicated with rare exceptions |
| | Consider bilateral needle decompression prior to cessation of care |
| Communication and record keeping | Maintain clear and encouraging communication with the wounded |
| | Maintain clear and frequent communication with rescue and medical teams |
| | Document all care provided and maintain with patient throughout the phases of care |

## Major Hemorrhage

Major exsanguinating external hemorrhage remains the initial focus of care in this phase as well. This includes reassessing the efficacy of any tourniquets applied in a Direct Threat (Hot Zone) phase and immediately addressing any unrecognized or uncontrolled bleeding and/or any bleeding not amenable to tourniquet use, such as junctional bleeding in the axilla, groin, or neck. In this phase, the benefit of other hemorrhage control techniques instead of tourniquets begins to outweigh the operational risk. Although tourniquets remain the only option following traumatic amputations and a feasible option for other exsanguinating extremity wounds, wound packing with mechanical pressure dressings and/or the use of topical hemostatic agents are recommended as well. New devices designed to control junctional bleeding may also be placed during this phase of care. These devices allow for significant pressure to be maintained over a packed wound without the need for personnel to maintain manual control. However, these devices may be costly, not readily available, and require additional training.

## Airway

Once all significant bleeding is controlled, the next medical priority is airway maintenance. Clearing the oropharynx of obstruction, the use of simple airway adjuncts such as nasopharyngeal airways, and proper body positioning are emphasized over definitive airway techniques such as orotracheal intubation. These interventions can easily be incorporated into the skill set of the nonmedical civilian first care responder and law enforcement personnel with appropriate training and oversight.

Emphasis is placed on allowing conscious patients to maintain whatever position they need in order to manage their own airway and improve breathing instead of forcing them to lay supine. This includes an emphasis on the effectiveness of the "sit up-lean forward" position for patients with facial trauma. Forcing patients to remain supine, especially to maintain cervical spine control, is ineffective, may be agitating, and may actually cause airway obstruction, aspiration, or worsen respiratory mechanics.

Intubation in this phase is allowed and may be necessary depending on the operational situation and evacuation plan; however, traditional orotracheal intubation is time consuming; requires additional training, equipment, and supplies; and creates a patient with much higher requirements for medical maintenance such as the need for ongoing sedation. Instead, if there is need for a more advanced airway, supraglottic airways are emphasized, and, for properly trained and authorized providers under an approved medical protocol, surgical techniques to obtain an airway are allowable.

## Respiration

The primary focus of maintaining adequate respirations is through addressing and maintaining the integrity of the chest wall and pleural space. This includes covering open pneumothoraces ("sucking chest wounds") with an occlusive dressing and early recognition and treatment of tension pneumothoraces. Simple recognition of developing tension pneumothorax in this resource-limited operational phase is accomplished through monitoring any penetrating torso trauma patient for increasing respiratory distress, hypoxia/air hunger, and hypotension. Tension pneumothorax should be aggressively treated, either through burping of an occlusive chest seal for lower scope providers or through needle thoracentesis by trained advanced providers. Needle chest decompressions should be performed with a minimum 14-gauge 3.25 inch device and only by properly trained, appropriate scope providers under an approved medical protocol. The decision to artificially ventilate any patient must be made with the consideration of the resources it will require as well as the feasibility of evacuating such a patient.

## Circulation

Early recognition of shock and implementation of damage control resuscitation is the tenet of circulation and shock management during the Indirect Threat Care (Warm Zone) phase. Judicious administration of fluids is recommended only when it is determined that the patient is in profound shock. Normal measurement of vital signs will be difficult at best during Indirect Threat care, so altered mental status in the absence of a head injury, skin condition, and appearance, and the absence of distal pulses may be the only clinical indicators used to determine shock. In general, if a patient is mentating appropriately, they are not in an immediately life-threatening state of shock irrespective of the vital signs. Similarly, the presence of a radial or pedal pulse connotes a sufficient blood pressure to maintain perfusion to the vital organs in the immediate future.

Damage control principles of resuscitation are followed in this and the subsequent phase of care in TECC. In addition to permissive hypotension, the use of tranexamic acid for patients in hemorrhagic shock from noncompressible hemorrhage is emphasized. The preferred intravenous fluid for hemorrhagic resuscitation is whole blood or blood products (packed red blood cells, plasma, and platelets) at a 1:1:1 ratio; however, the logistical requirements and advanced protocol and scope of practice required make this unlikely in the prehospital setting with few exceptions. As such, TECC recommends, if blood or blood products are not available, crystalloid should be administered in 500 mL boluses until a radial/pedal pulse is obtained or the patient's mental status improves.

## Head Injury

In the case of suspected traumatic brain injury, it is imperative to maintain an adequate cerebral perfusion pressure (CPP). Generally, a systolic blood pressure of at least 90 mmHg is required to maintain a CPP of 60 or more. Fluid resuscitation to achieve or support this blood pressure should supersede permissive hypotension that would otherwise be permitted under the tenets of damage control resuscitation. Body positioning by placing the patient in a semi-Fowler's position at 15–30°, keeping the head midline, and avoiding tight cervical collars may also allow for better venous drainage thereby lowering intracranial pressure and increasing CPP. Moreover, pain relief can also lower intracranial pressure and help maintain CPP.

## Hypothermia

Prevention of hypothermia is a key component of reducing the effects of the lethal trauma triad (cold, coagulopathy, acidosis). In the prehospital and high-threat setting, it is easier to prevent hypothermia from occurring than it is to reverse it. TECC places emphasis on both the awareness of the effects of and the prevention of hypothermia through simple techniques such as removing wet clothing to prevent evaporative loss; positioning the patient off of the ground/cold surfaces and placing materials between the patient and whatever surface they are on to prevent conductive loss; covering the patient – under and over – with blankets, clothing, or anything to prevent convective loss; and utilizing reflective materials to prevent radiation heat loss.

## Everything Else

As with any model of trauma care, proper sequencing is essential to assure no essential interventions are overlooked and that all are completed in an order that will address life-threatening conditions ahead of other important injuries. As such, TECC defers decontamination, treatment of burns, pain control, musculoskeletal injuries, and splinting until the final segment of Indirect Threat phase of care. This does not imply less significance to the management of these wounds but provides proper emphasis on the timing in resource-limited operational conditions.

Several of these conditions deserve additional discussion. TECC recommends the use of multimodal pain control through combinations of non-opioid and opioid analgesics in a strategy to maximize patient benefit without creating an additional medical burden as a result of oversedation. For situations involving smoke and fire, TECC emphasizes the importance of airway management and fluid resuscitation with facial and torso burns, as well as the potential for carbon monoxide and cyanide toxicity along with recommendations for the use of specific antidotes. As a whole, CPR is not recommended for any patient; however, consideration should be given to perform bilateral chest decompression (if appropriately trained and authorized) in any patient with penetrating torso trauma prior to cessation of care to treat possible unrecognized tension pneumothorax. Finally, communication with the patient is emphasized, and the importance of clear documentation of care forwarded with the patient is specifically listed.

## Evacuation Care (Cold Zone)

The Evacuation Care phase describes actions taken to continue providing appropriate trauma care once the patient has been moved from an Indirect Threat (Warm Zone) area to any area where there is minimal if any further risk. Evacuation Care

(Cold Zone) principles also apply during transport to definitive medical care and the initial phases of trauma bay resuscitation, especially in medical receiving facilities that are not designated trauma facilities. Examples of Evacuation Care (Cold Zone) are the care provided in the triage/treatment area or a secure casualty collection point during a mass casualty event as well as the care provided when transporting patients in an atypical platform such as a police cruiser.

During Evacuation Care (Cold Zone), higher level of resources and additional personnel should be available and are reflected in the TECC guidelines. In addition to reassessing all previous interventions applied, it is in this phase that a traditional triage system should be applied to define both patient evacuation priority and to allow for proper destination distribution to avoid overwhelming any one receiving facility. A common casualty collection point should be identified in instances involving multiple casualties. This will allow concentration of skilled medical resources and transport resources and will also facilitate triage of injured to appropriate definitive care facilities.

Care provided in the Evacuation Care (Cold Zone) more closely resembles that recommended by various trauma and emergency medicine manuals, such as Prehospital Advanced Trauma Life Support or International Trauma Life Support. The difference in the TECC in this phase of care as opposed to a routine trauma scenario is related to the need for resource and personnel allocation, the number victims and nature of injuries present, and the ongoing operational scenario that creates competing priorities for resources.

## Implementation of TECC

Tactical Emergency Casualty Care is most effective when applied as an entire system of care for medical response to unexpected disasters. This TECC "Chain of Survival" links the continuity of care across all potential medical providers, from the bystander to the nonmedical law enforcement/first responder, to the EMS first responder, and to the trauma center first receiver (Fig. 41.1). Each link in the chain has an appropriate scope-limited set of TECC knowledge and procedures that are built upon and carried forward as the injured moves up the chain (Table 41.4).

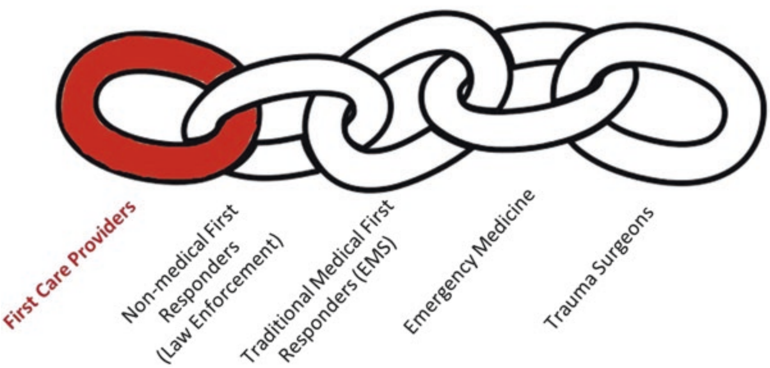


**Fig. 41.1** The TECC chain of survival

**Table 41.4** TECC recommended skills by provider level of training

| Provider level | Direct pressure | Tourniquet | Wound pack / pressure drsg | Hemostatic agents | Body and airway positioning | Nasal airway | Invasive airway | Surgical airway | Needle thoracostomy | Pain management |
|---|---|---|---|---|---|---|---|---|---|---|
| FCP | X | X | X | X | X | | | | | |
| FR | X | X | X | X | X | X | | | | |
| EMR/EMT | X | X | X | X | X | X | X[a] | | | |
| EMT-P | X | X | X | X | X | X | X | X | X | X |

*FCP* first care provider, *FCR* nonmedical first care responder with a duty to act, *EMT* emergency medical technician (basic/intermediate/advanced), *EMT-P* paramedic

[a]Supraglottic tube only

TECC can and should be initiated at or near the point of wounding by those bystanders that are capable and geographically involved by circumstance. Recognizing the gap created by the inherent delay in care provided by professional public safety responders, TECC stresses the importance of the “First Care Provider,” a position also endorsed by the Hartford Consensus Statement. Similar to the strategy utilized in teaching “bystander CPR,” to improve community resiliency and to improve immediate survival of the wounded in mass casualty and high-threat events, these individuals should be trained in the basic tenets of TECC point of wounding care as noted in Table 41.4. The US Army 75th Rangers Regiment’s experience with TCCC and the American Heart Association’s experience with bystander CPR form the basis for the recommendation to use the first care provider following trauma. The Committee on TECC believes that with sufficient funding and time, similar programs should be taught nationally for civilian initiation of TECC trauma care in the immediate aftermath of a disaster. Current courses, such as the PHTLS Bleeding Control for the Injured (B-Con), and public awareness campaigns, such as the White House Stop the Bleed campaign, represent early efforts to promulgate this strategy. Next steps for successful implantation begin with the C-TECC recommendation to go beyond the current singular focus on bystander hemorrhage control and expand the knowledge set to include appropriate simple TECC procedures to “Stop the Clock” on all causes of potentially preventable death.

There is only one study on the cause of civilian mortality following public mass shooting events. In contrast to that found in combat studies, this study found that only 7% of patients had potentially survivable wounds. Moreover, these wounds consisted only of non-airway facial injuries and pneumo-/hemothoraces, not peripheral exsanguinating hemorrhage. It is possible that a simple intervention involving putting the patient in a “recovery position” – on their side to mitigate blood and vomit aspiration – may have allowed at least one victim to survive long enough for public safety first responders to arrive. Furthermore, it is also possible that a responding nonmedical public safety first responder (e.g., law enforcement officer) may have been able to temporize some of these patients by simply inserting a nasopharyngeal airway and/or placing an occlusive chest seal to restore the integrity of the chest wall – similar to the strategies used by the soldiers of the 75th Ranger Regiment – until extrication of the wounded could be arranged.

On a similar motif, there are multiple reports of civilian law enforcement officers applying tourniquets to arrest hemorrhage with potential result of a life saved. These reports clearly demonstrate that nonmedical first care providers can be trained in basic medical interventions and that they will apply these skills effectively when needed. Implementing TECC training for all law enforcement responders as a part of basic law enforcement training will solidify that link in the TECC chain of survival, allowing the first-arriving law enforcement responders to address the immediate tactical threat and then quickly begin or continue the TECC care for the wounded.

Special populations and the effect on age and trauma resuscitation is a current focus of C-TECC. Because civilian events often include pediatric patients, as best exemplified most recently in the Sandy Hook Elementary School public mass shooting event, TECC has a separate set of guidelines directed to care of these young

**Table 41.5** Sample of TECC pediatric guidelines

| |
|---|
| *Communicating with the child during the event* |
| Approach from eye level |
| Use non-threatening/soft language |
| Use common analogies (e.g., describe a tourniquet as a rubber band) |
| Do not provide excessive detail or be too explicit |
| Have child repeat back what you said |
| Allow child to make some choices and participate in his or her care |
| Hold a younger child's hand |
| Give a sense of autonomy over their body |
| *Post-event care* |
| Assign a single person to care for kids to establish trust |
| Do not separate siblings or repatriate as soon as possible |
| Reunify whole families as soon as possible |
| Given anticipatory guidance |

patients (Table 41.5). Physiologically, the approach to the injured child is the same as the adult: hemorrhage control first followed by airway management. However, psychologically, a different approach is needed. Kids cannot process complex events quickly thereby impairing their ability to comprehend events and may have difficulty with communication. Together, this inability to understand and communicate exposes them to significant emotional distress with possible long-lasting effects and also predisposes them to being uncooperative with first responders. Simple strategies such as approaching them at eye level, softening one's tone and using non-threatening language, allowing the child to participate in their care as much as possible, keeping siblings (and ideally families) together, and assigning a single caretaker for a number of children may significantly improve a child's well-being, both in the immediate as well as distant future.

## Conclusion

In summary, TECC represents adaptation of proven concepts from the military environment to the civilian setting. TECC should be implemented as a system with specific training and messaging for each specific level of provider. Programs for training citizen first care providers, law enforcement responders, fire/EMS tactical and non-tactical assets, and medical first receivers are being developed and implemented across the United States and internationally. Ongoing research into the effectiveness of the TECC procedures as well as complete medical evaluation of the wounding patterns and medical lessons learned from civilian mass casualty events must continue. Given the data available to date, the biggest opportunity to mitigate preventable death remains founded in the rapid evacuation of wounded to appropriate definitive care facilities.

## Suggested Reading


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# Humanitarian and Local National Care

# 42

Matthew J. Eckert, James Sebesta, and Sherry M. Wren

**Deployment Experience**

| | |
|---|---|
| *Matthew J. Eckert* | Trauma Surgeon, Camp Bastion Role 3 Hospital, Helmand, Afghanistan, 2012-2013 |
| | USSOCOM Surgical Support, Iraq, 2014-2015 |
| | USSOCOM Surgical Support, Horn of Africa, 2015 |
| | USSOCOM Surgical Support, Iraq, 2016 |
| *James Sebesta* | General Surgeon, 31st Combat Support Hospital, Baghdad, Iraq, 2004 |
| | Deputy Commander Clinical Services, 14th Combat Support Hospital, FOB Salerno, Afghanistan, 2006–2007 |
| | General Surgeon, 8th Forward Surgical Team, FOB Shank, Afghanistan, 2009 |

*Never underestimate the power of a small but committed group of people to change the world. Indeed, it is the only thing that ever has.*

Margaret Mead

M.J. Eckert (✉)
Uniformed Services University, Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA
e-mail: matthew.j.eckert.mil@mail.mil

J. Sebesta
Bariatric Surgery, MultiCare Health System, Tacoma, WA, USA

S.M. Wren
Palo Alto VA Medical Center, Stanford University, Department of Surgery, Palo Alto, CA, USA




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**Fig. 42.1** Iraqi government and civilian officials presenting gifts of thanks for the care delivered to injured local policemen at the 47th Combat Support Hospital in Tikrit, Iraq. *Inset*: Afghani citizen presents a token of appreciation to forward surgical team member COL Craig Shriver

Deployments can provide a surgeon with a wide range of experiences. Depending on your location, patient flow may make you feel like you are drinking from a fire hose or it can be totally absent and your time is spent surfing the internet and working out. Some areas may experience occasional surges in patient numbers separated by long periods of inactivity due to the operational tempo of the units around you. Local national patient care is one way to improve your operative experience while keeping your team busy and their skills polished. Humanitarian surgical care (HSC) for local nationals has the added benefit of helping to "win the hearts and minds" of the local population. There is no better tool for instantly winning the friendship and admiration of the local community than by taking care of their sick or injured loved ones. This can be an effective tool for improving intelligence and creating an environment that is increasingly friendly to US and coalition forces (Fig. 42.1).

Humanitarian aid or local national care can come in many forms including medical rules of engagement (MROE) positive patients, medical civic assistance programs, local national treatment clinics, and educational opportunities for local national physicians and nurses. The amount of planning and prior coordination will depend on the type of care that you are providing. Your ability to provide the various levels of care will also depend on the type of medical unit you are located with and the amount of equipment and supplies available to you. The mission to care for US and coalition forces personnel always takes precedent, and you must ensure that any humanitarian efforts that you undertake do not interfere with this. The best way to get buy-in and support from your superiors for engaging in humanitarian medical

**BLUF Box (Bottom Line Up Front)**

1. There is no faster or more effective way to "win the hearts and minds" of the local citizens than by providing quality and compassionate medical care to them and their loved ones.
2. Humanitarian and local national care must always be done within the framework of the medical rules of engagement (MROE), but you can often adapt this framework significantly to your particular situation.
3. Local populations with little access to modern medical care will seek out US medical units, so it often takes little to no outreach to establish these programs.
4. Every US medical unit should have a person who is responsible for coordinating transfers of local nationals into the local hospital or outpatient care system. This should usually be a local national with medical experience, ability to translate, and contacts.
5. Operating a local national clinic can benefit both the patients and your unit by keeping their medical and surgical skills sharp.
6. Provide as much care and resources as possible, but never compromise your primary mission of caring for US and coalition combat casualties.
7. You may need to supplement your unit supply list to provide more elective type surgical care, particularly for pediatric patients.
8. Participating in education and training programs with local medical providers is one of the greatest gifts you can make toward the future of the local populace.
9. Be conscious of the local national medical capabilities, particularly with the capacity to provide follow-up care for your patients both in expertise and supplies.
10. Remember, you are going to go home in a few months but your patients and the local national medical system will remain. Try to make your impacts sustainable, timely, and provide as much

and surgical care is by open communication. Demonstrate how it can actually improve your unit's ability to accomplish the mission and increase morale, and you will usually see resistance vanish and more personnel wanting to participate.

## Medical Rules of Engagement

Medical rules of engagement are criteria established by the task force or combatant commander that is responsible for the regional medical care or local regulations for interacting with the civilian population. In developed theaters of operations, thorough guidelines are often established for the various types of injuries that can be treated addition to the amount and type of care that can be provided by US medical personnel. As a baseline, the MROE usually allow for care of injuries that threaten life, limb, or eyesight. However, the MROE change with time, operational conditions, and by location: so always know your local MROE before you commit yourself or US resources! Patients that are injured by coalition activities are usually MROE approved but this can vary depending on the circumstances. In some instances, MROE dictates the type of treatment that can be performed. One example of this is the guideline that local nationals with greater than 50% total body surface area burns are only entitled to comfort care at US facilities. This guideline is based on the resource-intensive nature of burns of this size and the absence of burn care or rehabilitation facilities in the host country that make these injuries nearly uniformly fatal. Another key consideration for whether a local national patient can be accepted and cared for is the hospital capacity and census. These rules usually dictate the refusal or diversion of local national patients when the census reaches 80 or 90% of capacity, leaving the remaining capacity for US or coalition personnel in need of urgent care.

Qualifying for treatment at one facility based on MROE does not guarantee that additional care will be provided at higher echelons of care. This also doesn't guarantee follow-up care for that patient. This situation can create a disposition nightmare for smaller medical units. In some cases, your team will provide medical treatment to a patient for life-threatening injuries for which the patient will need continued hospital care but the next higher echelon refuses to accept the patient due to limited bed space. This requires creativity and prior coordination with medical treatment facilities of all types. Small local facilities will sometimes take these patients if the family demonstrates the ability to pay or assist with their care. Military or police hospitals in the host nation can be utilized if the family has any connection with these organizations. Other humanitarian aid organizations or nongovernmental organizations (NGOs) can potentially provide care for some patients. In addition, the unit that injured or authorized transportation of the patient to your facility is responsible for arranging transportation back to the patient's home and assisting with disposition. In some cases, these patients may need to be held at your location until they are ready for discharge to home.

It is *CRITICAL* that you establish good lines of communication and policies with local hospitals or other medical facilities to facilitate the transfer or medical follow-up of local nationals that you have cared for. Before you do an operation or procedure that depends on close follow-up or postoperative therapies, you must ensure that either your unit can provide this or it is available in the local community. Do not assume that even basic things such as physical or occupational therapy, enterostomal therapy and supplies, limb prosthetics, or local wound care will be available to your patient once they are released from your care. In addition, because there is no medical evacuation chain for injured or ill local nationals, it is critical that you have a mechanism in place to disposition them. If you do not, then your facility will quickly become mission incapable or compromised because of the bed space and resources utilized by these patients. This was a very rapidly learned lesson in the early war experience that led to the hiring of local national medical liaison personnel at most facilities. Your medical liaison will be one of your most valuable assets in helping you navigate the often chaotic and byzantine local healthcare system for patient transfers or follow-up care.

## Medical Civic Assistance Programs

Periodically, units will approach your team for assistance in a medical civic assistance program (MEDCAP) mission. These missions are designed to provide medical assistance to small towns or remote areas that lack any treatment providers. This is another method used by various units to "win the hearts and minds" of local people to improve the environment for US and coalition forces. MEDCAP missions require medics, nurses, and physicians to perform quick symptom-guided examinations of patients and then provide medications or focused definitive treatments to help improve their symptoms (Fig. 42.2). In this setting, time constraints and the lack of testing equipment require that presumptive diagnoses be made based on the history and physical examinations. Often patients are treated to relieve the symptoms despite the lack of a known diagnosis. A significant number of patients will present with common medical problems making their treatment fairly straightforward (Table 42.1). Patients with more complex disease processes such as cirrhosis, renal insufficiency, heart failure, or diabetes should not be given more advanced treatments because of the inability to monitor their response to the treatment and for possible side effects. If a patient has a bad outcome from a treatment or dies, this can be


**Fig. 42.2** The 102nd Forward Surgical Team performing a MEDCAP mission in Kandahar, Afghanistan. *Insets*: Team members perform patient interviews via an interpreter (*upper left*) and focused physical exams (*upper right*) on local civilians

**Table 42.1** Common medical problems encountered during MEDCAP missions

| | |
|---|---|
| Headaches | Arthritis |
| Gastroesophageal reflux | Peptic ulcer disease |
| Parasitic infections | Urinary tract infections |
| Colds/flu/otitis media | Osteomyelitis and soft tissue wounds |
| Malignancies (breast, skin, oral) | Dental infections |
| Diarrheal diseases | Gynecologic |

**Table 42.2** MEDCAP medications

| | |
|---|---|
| Tylenol | Motrin |
| H2 blockers/PPI | Hydrocortisone cream |
| Multivitamins/prenatal vitamins | Mebendazole |
| Antibiotics | Peridex oral rinse |
| Antifungal cream | Antimalarials |

twisted into the idea that the medical team is providing poor-quality care or intentionally harming local nationals.

MEDCAP medications are typically provided by the unit requesting the assistance with the mission. These units have funds that can be used to purchase medications from local vendors or requested through regional military medical supply. Most of the medications are what we consider "over the counter" but are unavailable to the people in these regions. These units will need your assistance deciding on which medications and in what form. When ordering medications, remember that there will be men, women, and children of all ages, so having pill and liquid forms of the medications is important (Table 42.2). Additional items can include tooth brushes, toothpaste, soaps, clothing, and recreational or sports equipment. You will be amazed at how far some soccer balls and equipment can go toward fostering goodwill in almost any part of the world.

To ensure that the unit setting this mission up gets the greatest return for its efforts, make sure to provide all of the services possible during that time. Coordinating with veterinarian services to deworm and immunize local livestock can improve herd qualities and reduce disease related losses. Utilizing the services of the dentist to remove decayed and infected teeth will help to prevent long-term complications and dramatically improve the patient's quality of life. Familiarizing yourself with the common diseases and infections of the indigenous population will save time and allow you to better tailor your medication and supply list. Physicians with training in infectious disease or tropical medicine are invaluable assets for these types of missions. To be effective, you must be able to communicate clearly and quickly with your patients. Ensure you have an adequate number of translators available, and if possible have translators with a medical background (local nurses or physicians).

There are a few things that are important to ensure a safe and successful MEDCAP mission. The first thing is to allow the line unit to provide transportation, security, and supplies to complete the mission. This is what they do and we need to use their expertise in these areas. Secondly, allow them to determine the location of the MEDCAP site. They are much more in tune with the communities that would benefit the most from the mission and the threat level associated with each area. When setting up at the site, try to be located inside a building or a perimeter wall to reduce your vulnerability to sniper or indirect fire. Patients should pass through security screenings more than once. Utilizing an outer perimeter with local national police or army forces that perform an initial screen followed by a secondary screening prior to entering the building will help prevent weapons or explosives from reaching the treatment area. Let the US or coalition combatant commander decide whether or how to announce the mission for risk mitigation and always be vigilant.

As physicians, we are often uninformed or unaware of the major security issues that even a simple convoy movement can entail. Despite your goodwill, medical units and personnel are very attractive targets for enemy attacks, often by indirect fire or suicide bombings. Efforts to improve relations with the local population will be looked upon as a direct threat to enemy and/or terrorist elements, and they will go to great lengths to destroy or discredit these missions. Do not advertise the date, time, or location of the mission. Doing so will significantly increase your chances of IEDs or organized attacks. You should plan on one interpreter at each of the screening points and for each of the providers. The interpreters assist you with all parts of your interaction and provide verbal and written instructions on medication use. Also, be prepared to honor local customs regarding the interaction with and examination of female patients.

## Local National Clinics

Some of the most rewarding experiences from deployments can come from developing a clinic that provides care to the local national population. These clinics provide an opportunity to provide care that is either not available or is not safe in the local community. It also exposes surgeons to disease processes that may not be seen in their normal practices. These include rabies, cutaneous tuberculosis, giant inguinal hernias with loss of domain, enormous goiters, echinococcal disease, and very advanced forms of tumors or malignancies (Fig. 42.3). It also has the added benefit of providing you a steady stream of surgical cases. In many cases you may be exposed to pathology or to levels of advanced disease that you just don't see in the typical civilian practice (Figs. 42.4 and 42.5).

The most effective local national clinics are operated in cooperation with a local physician. This allows the local physician to refer patients for care that they are unable to provide, but more importantly, it gives the deployed surgeon the opportunity to educate and expand the capabilities of that local physician. This also helps to prevent your efforts from undermining the role of the local physician. In some areas, medical students and surgical residents can volunteer to be interpreters in exchange for the chance to work with deployed surgeons. This group also can provide an additional source of patients as they bring patients from their communities.

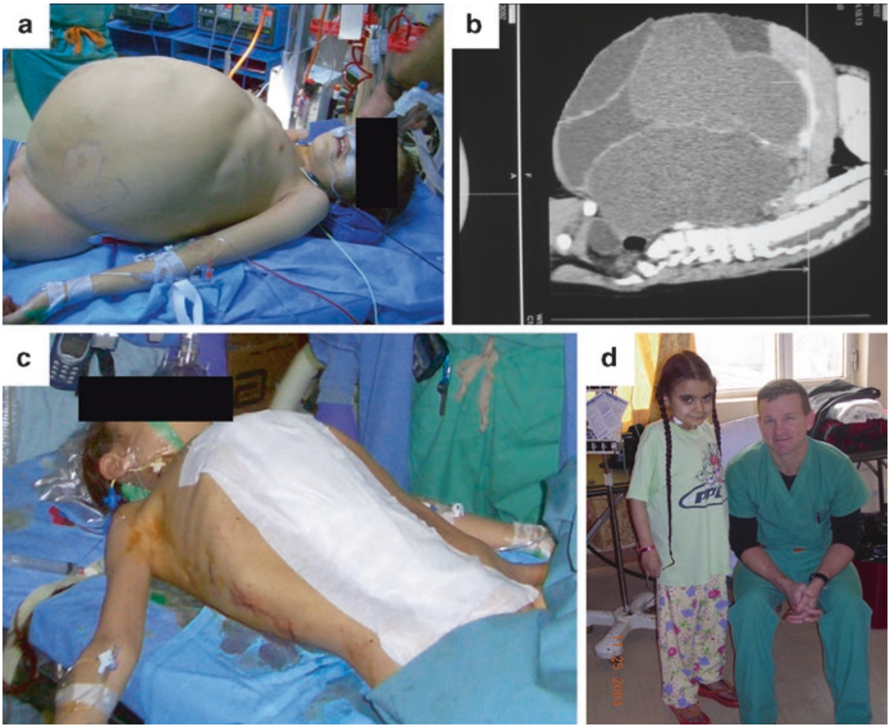

**Fig. 42.3** (**a**) Young Iraqi female with massively distended abdomen; (**b**) giant cystic abdominal mass on CT scan; (**c**) same patient following laparotomy and mass resection; (**d**) posing with her surgeon, LTC Tommy Brown, on the inpatient ward after surgery

Local national clinics can be as large or as small as you would like. A balance needs to be achieved between the workload of the local national clinic, treatment of trauma patients, and maintaining adequate time for your team to rest and perform their normal duties. In general, once you open your doors, word will spread like wildfire and the patients will begin to line up. It is important to firmly establish the numbers and the types of problems you will treat. Families will travel hundreds of miles to see a coalition physician because they are told of the “miracle” treatments that can be provided. Patients with devastating strokes, spinal cord injuries, coronary artery disease, and transplant desires will come to your clinic expecting treatment and even cure. Establishing guidelines will help to decrease these kinds of problems. A good rule of thumb when establishing the kinds of treatments you will provide is that your patient should not need any further hospital care, rehabilitation, or medications. Combat support hospitals can tend to be more aggressive in their patient selection, but smaller units need to be very careful. Even if you can provide the necessary medication or treatment, there is no guarantee that the unit following will be willing or able to provide it. Most patients do not have the access to or the ability to pay for medications or additional treatments.

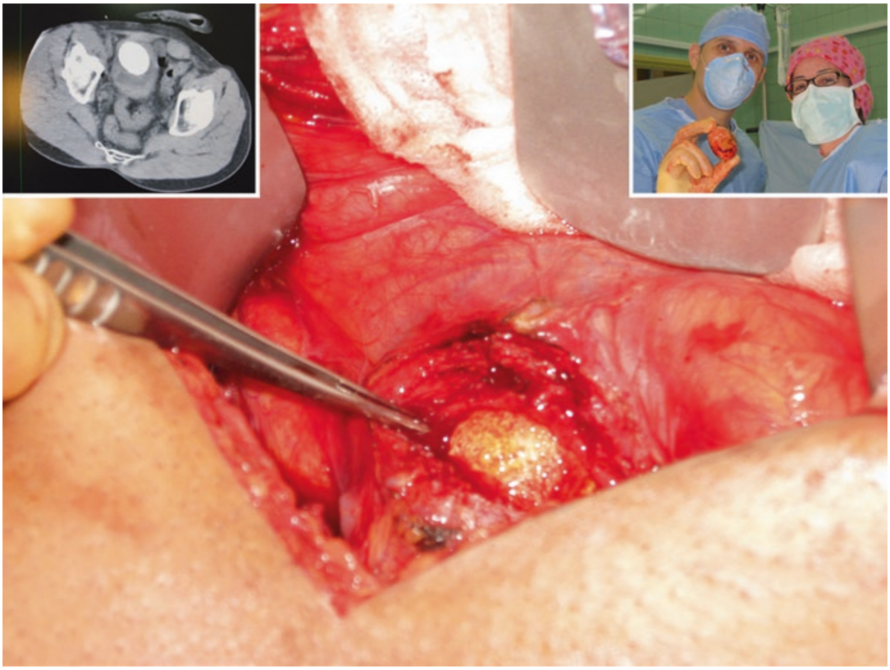

**Fig. 42.4** Giant bladder stone being removed via cystotomy in an Iraqi civilian patient seen in the 28th Combat Support Hospital clinic. *Insets*: CT scan shows the large bladder stone (*left*) and the stone displayed by the operating surgeons (*right*)

One of the keys to a successful local national clinic is determining the disposition of the patient prior to the procedure. For minor procedures, this is not much of an issue, but for major cases, having a preset plan that the family and the patient are aware of will help to prevent disposition nightmares. This is greatly simplified if a local physician is involved in the care. After surgery, the local physician can take the patient back to his facility for recovery and return the patient for any follow-up treatments. Families can arrange with the local hospital to provide hospital care or the family can take the patient home. With good cooperation between the local hospital, families, and coalition treatment facilities, even 30–40% TBSA burns can be treated as outpatients with good outcomes (Fig. 42.6).

Another consideration of local national care is the amount of resources required to treat each patient. This includes blood, dressing supplies, and staff/facility time. In small units such as forward surgical teams (FST), preplanning to ensure that the required supplies are on hand can facilitate the ability to perform surgeries. Prosthetic mesh, anoscopes/proctoscopes, and cement to make antibiotic beads are some examples of equipment or supplies that may not be standard for FSTs. Small units that lack adequate personnel to have rotating work shifts need to be very careful about doing surgeries that require a prolonged hospitalization. The patient that requires "around-the-clock" care can exhaust personnel and make your team less

**Fig. 42.5** Four-year-old Iraqi female with giant lymphangioma of the tongue (*inset*) and immediately after (*main figure*) subtotal glossectomy done by general surgeons at a combat support hospital

**Fig. 42.6** Iraqi child with fractures and severe right leg burn underwent split thickness skin grafting at a combat support hospital (*left*) and made an excellent recovery after inpatient and outpatient rehabilitation (*right*)

**Table 42.3** Types of procedures

| Forward surgical team | Combat support hospital |
|---|---|
| Hernias | Intra-abdominal malignancies |
| Skin and soft tissue tumors | Cholecystectomy |
| Anorectal diseases | Oromaxillofacial procedures |
| Osteomyelitis | Thyroid goiter |
| Contractures secondary to burns | Appendectomy |
| Fracture splinting and fixation | Splenectomy |
| Incision and drainage of abscesses and minor wound care | Cesarean section |

effective when battle-injured patients arrive. Combat support hospitals will have a more robust supply system and staffing allowing for more complicated procedures to be performed (Table 42.3). Having adequate staffing and supplies is a particularly challenging issue in caring for local national children. The specialized equipment and supplies for pediatric patients are often inadequate or absent, and the majority of deployed providers are less familiar with pediatric specialty care. Virtually every deployed unit will be involved with caring for sick or injured children, and you must anticipate this in order to succeed. Despite these limitations, deployed medical units have consistently gone above and beyond to provide an incredible array of care and services to these patients, from caring for premature babies or performing emergent caesarian sections to caring for adolescents wounded in combat (Fig. 42.7).

Performing surgery on the local national population requires a very thorough evaluation by the surgeon. Patients often will not know their age and may have never seen a physician prior to your visit. Simple things that rarely are problems in your practices can play a significant role when deployed. Nutritional factors ranging from malnutrition to vitamin and mineral deficiencies can be seen. Patients may not be able to keep their dressings or wounds clean and dry. Patients may not have access to dressing materials or medications, or more importantly, they may not understand instructions about medications or wound care. Communicating without an interpreter may make getting an accurate review of systems nearly impossible. This can inhibit your ability to accurately assess the patient. Cultural differences may have the patient acting in ways that can result in complications. Examples include remaining NPO for days after surgery or remaining in bed for over a week after a minor procedure. Thorough counseling in addition to written instructions can help to reduce some of these challenges.

## What Can I Expect?

Every deployment medical experience is unique. No two deployments will have the same level of patient acuity, disease/injury variety, MROE, volume, or resource availability. Do yourself and your patients a big favor, and contact the person you will be replacing to gain insight into the current medical activities, resources,


**Fig. 42.7** (**a**) Army ICU nurse caring for a burned infant; (**b**) premature baby delivered via emergent caesarian section; (**c**) pediatric ICU care at a forward hospital; (**d**) CDR Carlos Brown and LCDR David Junker with Iraqi children sheltered at a navy medical facility after a bombing incident

and patterns of injury. Firsthand intelligence of this sort is invaluable and can help you hit the ground running with local national care since you will have an idea of how things work where you are going. You also might identify some key supplies to bring along. But remember, the type and level of care provided to local nationals can change by the day and especially with the rotation of different combat units.

There are numerous published accounts of individual and unit military humanitarian medical experiences across previous conflicts. Not all accounts paint humanitarian medical care positively, primarily due to frustration providing limited treatment for chronic conditions, security risks, resource consumption, and perceived lack of effect upon the overall military mission. However, humanitarian surgical care in the recent conflicts in Iraq and Afghanistan has become a routine practice and part of the overall counterinsurgency strategy of coalition forces. A 2014 survey of all surgeons deployed in both theaters found that the majority provided at least some humanitarian surgical care to a diverse population of local national patients, across the spectrum of age, acuity, and disease type (Porta et al., *Am J Surg* 2014). Although the vast majority of surgical care provided was emergent/urgent for acute injury or illness, the breadth of surgical disease was encountered by deployed surgeons (Fig. 42.8). The majority of the surgeons felt these experiences improved unit readiness, provided personal satisfaction, positively benefited local national medical care, and contributed to the overall counterinsurgency strategy.

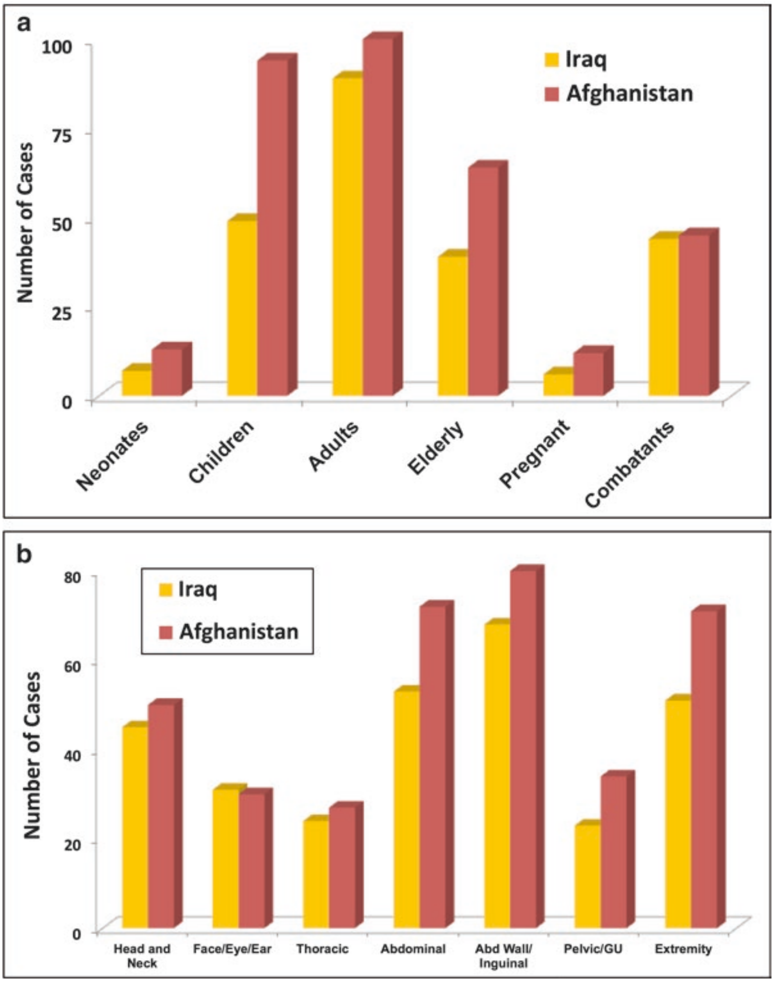


**Fig. 42.8** (**a**) Demographic distribution of humanitarian surgical cases performed by deployed surgeons in Iraq and Afghanistan, 2002–2011; (**b**) anatomic distribution of HSC cases (Reprinted from *The American Journal of Surgery*, 207(5), Christopher R. Porta, Richard Robins, Brian Eastridge, John Holcomb, Martin Schreiber, Matthew Martin, The hidden war: humanitarian surgery in a combat zone, 769, Copyright 2014, with permission from Elsevier)

Providing humanitarian surgical care can run the spectrum of human experience, from exciting and inspiring to frustrating and depressing. This is true in any third-world medical experience, but for the deployed military surgeon, the burden and severity of injuries and disease encountered can often seem overwhelming. If you are experiencing these feelings, rest assured that the other members of your team are too. Many of your team members and perhaps yourself have not encountered these conditions before; thus, it is important to involve all team members inasmuch of the care as possible as well as the decision making. Conducting after-action reviews or informal discussions about why certain medical decisions were made can help ameliorate these emotions and help strengthen the unit members' resolve to continue providing humanitarian care. This is particularly important with difficult cases, expectant triage, and when challenges arise in finding local care or further treatment options for your patients upon discharge.

As the study by Porta and colleagues found, most deployed surgeons feel as though their general surgery or surgical residency training adequately prepared them to provide humanitarian surgical care. However, the vast majority encountered new injuries or diseases not previously experienced and required consultation with outside experts or medical literature. Take heart in knowing that you are not the first surgeon to deploy to an austere, underdeveloped nation with chronic and acute diseases rarely or never encountered in your home country. Basic surgical principles (and this book) will provide a solid foundation for almost any surgical condition you encounter. Internet access is virtually ubiquitous in every deployed setting today, so you will have ready access to all the medical information you will need for the rare condition encountered. (See suggested readings from some additional resources.)

## Educational Opportunities

The final area of opportunity is in providing educational opportunities for local care providers. This can take many different forms ranging from lectures to hands-on patient care. Depending on the team's location, host nation care providers may include nurses, midwives, medical students, residents, and practicing physicians. Utilizing the nursing and physician expertise from your unit can provide the material to perform a wide range of educational activities in regions where continuing medical education is unavailable. These educational opportunities are best performed within the safety of your compound, but in some cases, these will be done at the local hospitals or other facilities. These classes may be given in the lecture form with an interpreter or hands-on class such as basic trauma life-support classes. Depending on the incidence of a particular disease, hands-on patient care can be the format to teach providers various stages of treatment. The treatment of burns and basic wound care are good examples of this form of teaching.

In any combat zone or country affected by war and other internal conflicts, the local medical system is often decimated and needs to be rebuilt from the ground up. Iraq serves as an excellent example of this, where much of the infrastructure was destroyed or looted, and medical professionals often fled the conflict area. Helping to support and rebuild these crippled systems then becomes one of the primary missions of deployed medical forces, and this starts with education of a new generation of medical providers. The initial education efforts should focus on training local nurses and physicians to care for the common and more emergent conditions that they will be facing, such as traumatic injury. A good example of this type of program was the Iraqi trauma training program which was established by US forces at the Ibn Sina Hospital in Baghdad, Iraq. With a relatively small investment, a training center was established that provided local physicians and nurses with a multi-week course modeled after basic medic and EMT training, as well as the ATLS course. The course was continuously staffed by a series of rotating nurses and physicians assigned to the medical unit operating the hospital. Graduates of this program are then able to put their newly acquired knowledge and skills to work in their local hospitals and clinics and to conduct training of other healthcare providers.

These educational opportunities provide updated information to local providers who have limited contact with current methods, research, or evidence. It also provides a platform that allows you to develop friendships and working relationships with the local treatment facilities. Physicians are generally very highly respected in their communities, and these friendships can be an important step in building alliances between coalition forces and community leaders. It can also expose deployed providers to experiences that are personally and professionally rewarding and rarely available to them in their current practice.

## Final Points

Deployment to a combat zone will be one of the most memorable periods of your professional career, for both positive and negative reasons. One of the best ways to help ensure that something positive comes out of the incredible destruction and misery of war is by actively participating in the humanitarian opportunities available to you. If none are available, then you have a great opportunity to establish such a program and truly make a difference for your patients, your colleagues and unit, and yourself. You may want to dull your memories of wartime medical care, but these are the experiences and the patients that you will never forget (Fig. 42.9).

## Civilian Translation of Military Experience and Lessons Learned

Sherry M. Wren

**Key Similarities**

- Broad range of conditions and procedures
- Large numbers of patients needing attention
- Mission parameters dictated by NGO (all cases or urgent/emergent cases only)
- Team security
- Resource limitations
- Education of local nationals


**Fig. 42.9** Military physicians and nurses with their memorable local national patients

**Key Differences**

- Humanitarian NGO's relationship with military: perception/belief that military humanitarian medicine endangers humanitarian aid providers.
- Your facility is the "definitive" center, no transfer capabilities.
- Education by local nationals.

## Discussion

There are broad similarities between humanitarian surgery practiced while on a military deployment and the experience one would have working with a nongovernmental humanitarian organization (NGO) such as Médecins Sans Frontières (MSF) or the International Committee of the Red Cross (ICRC). Humanitarian surgical deployments are often in active conflict zones, sites of natural disasters, and post-conflict countries with continued instability. The humanitarian NGO teams are based within the local communities, employ national staff, and must keep open communications with all local actors including militias and thus rely upon "goodwill" for the personal security of the team. Major incidents against aid workers have risen significantly in the twenty-first century. Killings, shootings, kidnappings, and assaults reached a peak of 475 total victims in 2013 and continue to be a significant

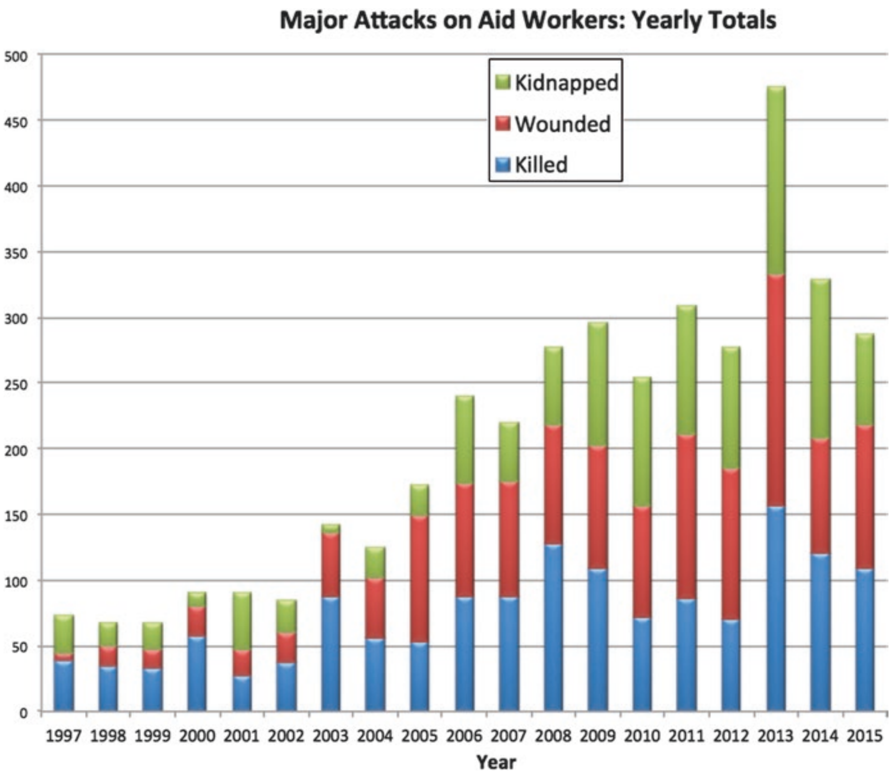


**Fig. 42.10** Data from the Aid Workers Security Database, a project of Humanitarian Outcomes https://aidworkersecurity.org/incidents

problem with over 300 incidents yearly (Fig. 42.10). The civilian worker must understand that they serve in potentially volatile and dangerous settings without the benefit of armed escorts or guards (Fig. 42.11).

An additional area of similarity with that seen in the military setting is the never-ending influx of patients, many whom require help for conditions which are either rarely seen in Western practice or presenting at a much more advanced state. The mission parameters are set by the NGO and cover the analogous "rules of engagement" and what types of patients you will be treating. In some missions care may be limited to only urgent or emergent surgical cases, while other missions may also perform elective procedures. Understanding your role and the mission profile is critical because many first-time humanitarian surgeons mistakenly assume they will have the leeway to make all treatment decisions. Patients will present from significant distances because the care is provided free of charge, and they often have no other options making it very emotionally difficult to turn them away.

A humanitarian deployment frequently goes far beyond a US surgeon's comfort zone, even when they are highly experienced. In general, the military deploys with equipment and resources that are more similar than different to what the surgeon is

**Fig. 42.11** Photo taken of OR nursing staff and surgeon (Kale, Jackson, Sherry, Jean Pierre) 2 days before Jackson's murder, MSF Mission, DRC 2009 (Photo courtesy of Dr. Sherry Wren)

used to back in their home setting. Working in the civilian humanitarian setting can be quite challenging because a typical US "high" resource surgeon now needs to adapt to the "low" resource environment. Supplies are limited; modern operating conveniences such as staplers and energy devices are not available; power, water, and electricity can be lacking; and limited drug formularies and supplies are the norm. Simple studies such as X-rays may or may not be available let alone more sophisticated imaging or diagnostic tools. Blood tests often are not possible beyond hemoglobin determination, and access to blood for transfusion may not always be available. It is critical that the surgeon understands the resources they will have access to when making operative decisions. Patients often present severely anemic from parasites and malnutrition, suffer from untreated HIV or TB, and have had no medical care for any preexisting conditions. Perioperative care is limited and it is critical to know what antibiotics, analgesics, fluids, OR supplies are available to you prior to starting cases. Anesthesia machines and bottled oxygen are lacking, so it is common to operate under ketamine and opiates or a spinal anesthetic. Postoperative ventilation most often is not an option, and strategies to provide this service can even include family members hand ventilating the patient with the Ambu bag. Postoperative care is limited with family members performing toileting and feeding duties. ICU care is often impossible; there may be no IV pumps, monitors, or other high resource tools. Dressing supplies are not limitless, so improvisations such as

**Table 42.4** List of essential skills for civilian humanitarian surgical care

| Essential surgical skills for humanitarian surgery | | |
|---|---|---|
| OB/GYN | Trauma/injury | Abdomen/GU |
| Postpartum hemorrhage | Trauma laparotomy | Appendectomy, cholecystectomy |
| Uterine evacuation, D/C | Chest drain | Bowel obstruction, resection, colostomy |
| Ectopic pregnancy | Fracture reduction, irrigation, pin | Hernia (+/− incarcerated, +/− mesh), hydrocele |
| Uterine rupture | Burns: escharotomy, STSG, fasciotomy | GI perforation (ulcer, typhoid) |
| Cesarean (obstructed labor, malpresentations) | Amputations | Suprapubic catheter (bladder obstruction) |
| Hysterectomy | Blind burr hole | Open gallbladder, appendix |

"air dressings" for burns, sugar, and restricting dressing changes to every few days if no foul odor or pus is present all become common practice. Flexibility and openness to suggestions from the local staff, all of whom are used to working with these limitations, are important.

The scope of surgical practice in both the military and civilian humanitarian setting is much broader than it is in the USA. The civilian humanitarian surgeon often needs to be the "everything" surgeon since there are no other consultants or specialists for you to refer to. Practice can include everything from dental emergencies, plastics, neurosurgery, orthopedics, burns, pediatric surgery, GU, ENT, and tropical and neglected diseases. Disease manifestations of tetanus, typhoid, TB, malaria, and parasites are quite common and not something typically encountered in the USA. The surgeon also plays a critical role as the obstetrical emergency doctor for obstructed labor, uterine rupture, septic abortions, and postpartum hemorrhage. Table 42.4 outlines many of the key surgical skills necessary for the humanitarian surgeon. Current training in the USA does not encompass all of these specialties, and it is not easy to get education outside of your designated specialty due to hospital privileging and malpractice constraints. This presents a great opportunity for you to learn from the local staff who typically have much better knowledge of their local diseases than you. These staff have also worked in environments where task shifting has been commonly practiced and your nurse may have performed 100s of cesareans, whereas you have only had the chance to observe them prior to your deployment because malpractice insurance would not have covered you actually scrubbing on a case. In numerous low-income countries in Sub-Saharan Africa, trained health workers (health officers and/or nurses) often perform the bulk of surgical procedures, including complex laparotomies. Recognize that these staff are preferentially hired by the NGOs and take advantage of their skills and learn from them. In turn they greatly appreciate and are thrilled to advance their own practice through your education efforts, and this will continue to benefit patients after the NGO leaves. Bidirectional learning is a great perk of a humanitarian mission.

Referral to another facility is not typically available when you are working for a NGO humanitarian mission. The NGO started a surgical program in the area because of a severe lack of access to care, making your hospital the definitive one in the area. Typically there is a lack of specialists or consultants within the hospital, so surgical care is provided as a single service within the hospital. In some contexts there may be special government- or faith-based programs for specific diseases such as Buruli's ulcer or obstetric fistulas that will accept unique specialty care transfers. This is much more the exception than the rule though so lack of transfer capability should be your expectation. Another challenge in humanitarian settings is that patients can't be discharged to "home" because they are internally displaced, refugees, or have no place to go to. Flow of patients into the hospital is complicated: double bunking, tents, and floor mats all occur on a frequent basis. It is important to communicate with your on-site head of mission since they are the person speaking with all of the involved actors in the region and will be the most knowledgeable about the local situation. In this sense the civilian and military humanitarian missions are similar in that focusing on disposition and throughput is critical to maintaining your capability to continue to provide medical and surgical care.

Mass casualty events are difficult in any setting, but in the resource-limited context, they present additional challenges that you may have not encountered in the standard US "high" resource setting. The typical scenarios for this type of event are either a road traffic crash involving a truck piled high with supplies and passengers on top which is then followed by fuel ignition at the site or an explosion of a bomb in a crowded market. All of the sudden there are upward of 40–50 adults and children injured, in a setting where there are no prehospital systems of care or transport beyond what family and bystanders provide and your hospital is the only place in the region providing care. This is often the only setting in which "high" resource surgeons practice triage in its truest form. A typical scenario could be 1–2 surgeons in a 1-2 OR hospital that now has to respond to this sudden large influx of wounded. It is prudent to think about these situations as soon you arrive on site so you have a plan or enquire if a plan already exists. There is no universal definition of who should be triaged first, but it's important to save as many casualties with the resources at hand. In some settings that may mean that severe head injuries are triaged to a non-active treatment area since there are no resources to diagnose or treat, or severe burns get palliation with analgesics only. The inability to care for all can be emotionally difficult and cause psychological pain (see Chap. 43 for additional information).

The area of greatest controversy in the humanitarian context between military and international humanitarian NGOs is the role the military should play in providing humanitarian care outside what is stipulated within the Geneva Conventions. The concept for using healthcare as a means of winning "hearts and minds" is controversial. The perception that humanitarian aid is used as an incentive for cooperation, and is thereby a form of coercion, is a significant concern. Humanitarian healthcare programs run by the military are viewed as intrusions by the military into humanitarian spaces, confounding delivery of humanitarian aid and neutrality. A 2001 address by then US Secretary of State Colin Powell to the National Foreign Policy Conference for Leaders of Nongovernmental Organizations stating: "I want you to know that I have made it clear to my staff here and to all of our ambassadors around the world that I am serious about making sure we have the best relationship with the NGOs who are such a force multiplier for us, such an important part of our combat team" is referred to by the humanitarian community as an unacceptable blurring of the line between neutral agencies and military actors. The concern is that this results in increased distrust and attacks on humanitarian workers. Recent tragic destructions of NGO hospitals, with resultant deaths of both patients and humanitarian aid workers in Afghanistan and Yemen by the USA or its local allies, have only served to further influence and reinforce the NGO community's negative beliefs. Although on casual examination it would seem logical that the US military medical forces and NGOs should work together and cooperate in providing humanitarian assistance, this denies the highly complex and interconnected web of politics, perception, and unforeseen tragic consequences that can result from NGOs becoming associated with foreign military assets.

Clearly both civilian and military surgeons have a key role to play in provision of surgical care to patients in difficult settings. Preparation before deployment would be advantageous to arrive prepared and ready for the expanded scope of practice and resource limitations.

## Suggested Reading

1. Martin M, Beekley A, editors. Front line surgery: a practical approach. New York: Springer; 2011.
2. Porta C, Robins R, Eastridge B, Holcomb J, Schriber M, Martin M. The hidden war: humanitarian surgery in a combat zone. Am J Surg. 2014;207(5):766–72.
3. Primary surgery, vol. 1–3. http://global-help.org/publications/books/help_primarysurgery.pdf. Accessed 12 Dec 2016.

# Expectant and End-of-Life Care in a Combat Zone

**43**

Robert M. Rush, Matthew J. Martin, and Christine S. Cocanour

**Deployment Experience**

| | |
|---|---|
| *Robert M. Rush, Jr.* | Chief, General Surgery and Trauma, 10th Combat Support Hospital, Tuzla, Bosnia-Herzegovina, 1999 |
| | General Surgeon, 250th Forward Surgical Team, Kandahar Airfield, Kandahar, Afghanistan, 2001–2002 |
| | Deputy Commander, 250th Forward Surgical Team, Kirkuk, Iraq, 2003 |
| | Deputy Commander Clin Services, Craig Joint Theater Hospital, Bagram Airfield, Afghanistan, 2009 |
| | Chief of Surgery, 256th Combat Support Hospital, Mosul, Iraq, 2011 |
| | General surgeon, 555th FST, Kandahar, Afghanistan, 2014-2015 |
| *Matthew J. Martin* | Chief of Surgery, 47th Combat Support Hospital, Tikrit, Iraq, 2005–2006 |
| | Chief, General Surgery and Trauma, 28th Combat Support Hospital, Baghdad, Iraq, 2007–2008 |
| | Commander, 655th Forward Surgical Team, FOB Ghazni, Afghanistan, 2010 |
| | Chief of Surgery, 758th Forward Surgical Team, FOB Farah, Afghanistan, 2013 |

R.M. Rush • M.J. Martin (✉)
Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA
e-mail: traumadoc22@gmail.com

C.S. Cocanour
University of California-Davis Medical Center, Department of Surgery,
Sacramento, CA, USA


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*"Above all, let us remember that our duty to our patients ends only with their death, and that in the preceding hours there is much that we can do for their comfort. At the very least, we can stand by them."*

Alfred Worcester

*Every surgeon carries within himself a small cemetery, where from time to time he goes to pray.*

Rene Leriche

A severely wounded soldier arrives by helicopter at your Combat Support Hospital or Forward Surgical Team. Half of his abdominal wall is missing with exposed viscera and active bleeding. He arrests on arrival and you get him back with an emergency department thoracotomy and aortic cross-clamp. In the operating room, you start on his abdomen while anesthesia continues to resuscitate with blood products. He has so many injuries you don't know where to begin, but you get to work and are finally gaining ground when the pagers go off again. Seven "urgent surgical" patients are inbound, and your anesthesiologist tells you he just hung the tenth unit of blood, which is half of your total blood supply. All eyes are on you – what are you going to do? Do you continue and exhaust your unit's blood supply on this patient with a low probability of survival? Do you stop and make this patient "expectant," allowing him to die so that you can tend to the other injured patients?

These are the types of decisions regarding the provision, withholding, and withdrawal of aggressive care that you are rarely faced with in civilian practice but will frequently encounter in the combat environment (Fig. 43.1). You are used to giving your all and doing everything possible for your patients until you have either won the battle or reached the point of futility. In the combat setting, you must also give equal weight to your situation, capabilities, and available resources. Are you dealing with a single casualty or are you in the middle of a mass casualty scenario? Is there another facility willing and able to provide the needed care? Do you have the medical evacuation (MEDEVAC) assets available to get that patient to a higher level of care? Do you have the required expertise, equipment, and training available at your facility to care for this patient? Is your facility at 10% occupancy or is it near capacity with already exhausted personnel? Will this patient require resources that you do not have available or resources that are scarce and needed for other patients? And finally, is this patient a US or allied service member who will be evacuated to a state-of-the-art medical facility, or is it a local national civilian who will have to rely on the scarce local health-care facilities and resources for any subsequent care? Not infrequently, the answer will be that you cannot provide aggressive care or need to cease aggressive care and manage the patient as an "expectant" casualty. The goal of this chapter is to familiarize you with the common situations and decisions you may face about the level of care to provide and some key concepts in providing compassionate and competent expectant care.

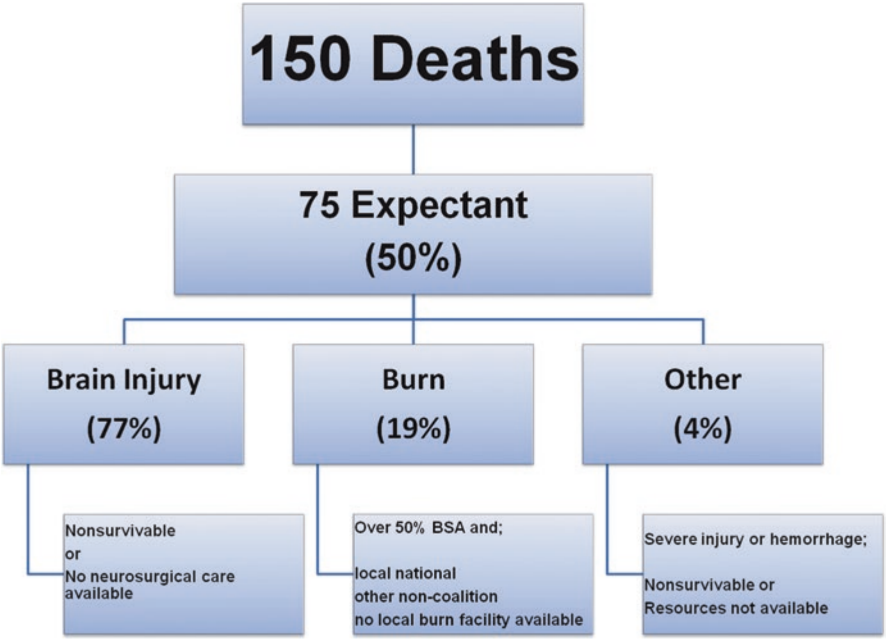


**Fig. 43.1** Analysis of 150 in-hospital deaths at a Combat Support Hospital over 1 year. Note that 50% of these were managed as "expectant" and consisted of primarily head injury and burn patients

**BLUF Box (Bottom Line Up Front)**

1. There is no faster cure for the "God complex" than serving in an austere medical environment.
2. You will not have unlimited resources or transfer options available and will have to make some hard life and death decisions.
3. Severe head injuries and major burns (>50% body surface area) will be your two most common reasons for providing expectant care.
4. "Expectant" care does not mean "no" care. Don't ignore or forget them.
5. Set aside a separate area for expectant care, with privacy but adequate access to health-care providers.
6. Comfort, compassion, and dignity should be the cornerstones of expectant care.
7. Remember to take care of your personnel also. Expectant care exacts a heavy emotional toll – *particularly on the nursing staff*.
8. Having a "group huddle" and discussion after a particularly difficult case can work wonders for individuals and the team.
9. If you have a scarce resource that could save multiple lives, do not waste it on a heroic but low probability attempt to save one life.
10. Expectant management or withdrawal of care for a pediatric patient will be the most difficult decision you can make and will be the hardest on your staff.

## Combat Care and the "God Complex"

In the movie "Malice," an arrogant surgeon is being sued for malpractice. When questioned about whether or not he has a God complex, he replies "If you're looking for God, he was in operating room number two, on November 17, and he doesn't like being second guessed. You want to know if I have a God complex? Let me tell you something – I AM GOD!" Although this is quite an advanced case, many of us have fallen into this type of thinking at one point or another. There is no faster cure for the God complex than to deploy to an austere environment. You will quickly realize how little your individual skills, talent, and dedication mean when you don't have the level of support and infrastructure to which you are accustomed. It is a sobering moment, but it truly makes you appreciate how much everyone around you contributes and how dependent you are on the entire system to be able to deliver high-quality care.

Along these same lines, you may have no significant trauma experience or you may have spent your entire career at a level 1 trauma center. You may be right out of training or be a senior surgeon with decades of experience. Either way, you will have a lot to learn about combat trauma care in general and the specifics of your local facility – all in a very short time. There will likely be some established policies for all aspects of care, including expectant care, that have been developed by your predecessors based on experience and previous mistakes. Learn from those that came before you. There is often a temptation to ignore these "lessons learned" and think that you can somehow do it better than everyone who came before you. With personnel turning over every 3–12 months, this kind of thinking results in cycles of repeating the same mistakes rather than making continual progress and improvement. As a wise sergeant once said to me, "we're not 6 years into our combat experience; we're on our sixth 1-year experience."

## Determining Expectant Status

In general, those patients who have injuries that make them unlikely to survive given the available realities of care and resources are declared expectant. This definition depends on many factors in any environment but especially where far-forward combat surgical support is delivered. In Afghanistan and Iraq, those local national casualties who sustained burns of >50% body surface area, head injuries with an initial Glasgow Coma Score of <5, and those who sustain blunt traumatic arrest in the field or in the evacuation chain without an easily identifiable and correctable cause are classified as expectant. In fact, the NATO guidelines specifically classify any host nation casualty sustaining either of the former two injuries as expectant and not meeting the "medical rules of eligibility" or engagement. It is very important to review the theater medical rules of engagement (MROE) prior to initiating care of anyone on the battlefield. The MROE are designed to ensure that the maximal numbers of injured patients who can survive are treated based on the medical and logistical resources deployed in support of military operations in any given country. The MROE must also account for the status of the evacuation and medical capabilities of the host nation – whether it is during a response to support earthquake victims in Haiti or far-forward combat operations in Afghanistan. However, the MROE can never anticipate every particular situation that might arise and should never replace your judgment and ethical decision-making when faced with an injured patient in front of you or en route to your facility.

There are other potential situations where the expectant category can be used. Patients initially selected for treatment may need to be re-triaged as expectant based on changes in the situation (e.g., more casualties arriving, patient not doing well, resources dwindling, etc.), as in the example that opened this chapter. This can be a difficult decision, particularly for providers in the midst of herculean efforts to save a patient. The triage officer, chief of surgery, or hospital command may need to help the involved surgeons reach the decision to cease further resuscitative efforts in these cases. Another situation arises when host nation or enemy combatants require dialysis or other specialty treatment either emergently or long-term, and the host nation has no such capability. These patients are considered expectant and are provided comfort care with no escalation. In these instances, the expectant category is similar to making patients DNR/DNI (do not resuscitate/do not intubate) in the less acute setting.

If a service or therapy is available at a local host nation medical facility, then early transfer to that facility is warranted. There are situations where a specific therapy (e.g., peritoneal dialysis) has been used in the USA or coalition facilities to stabilize host nation casualties with certain conditions (e.g., acute renal failure) prior to transfer to a host nation medical facility. Such therapies should be employed sparingly and only after consideration of the ultimate goal of the therapy, the expected short- and long-term requirements of the patient, and the capabilities of the host nation. The medical rules of engagement are made with regard to host nation capabilities and the likelihood of survival of the patient if that patient were to sustain the injury and be cared for at a hospital in the region where the casualty was injured. On occasion, the highest standards at the best host nation medical facility can be used to guide therapy on a host nation patient at your facility, but only if there is a reasonable expectation that the patient can be transferred to the host nation facility after they are stabilized. Transfer should occur within 48 h of presentation but can occur anytime provided the patient has a reasonable chance of survival. Upon your arrival to any forward deployed facility, one of your earliest efforts should be to gather information about the status and capabilities of the local host nation facilities in your area of operations and the process for arranging a transfer and ensuring safe transport and transition of care. If no process is currently in place, then you would be well served to work toward establishing such a relationship and process. Enlisting the help of a local national physician or surgeon to assist in this process is critical to success.

Some of the biggest challenges you will have are in educating the combat maneuver or line units regarding the expectant patient. One difficulty will be in explaining why you may not be devoting every possible resource to save one of their soldiers who comes in as described at the outset of this chapter – one who requires ED thoracotomy, massive transfusion, etc., and is unlikely to survive no matter what you do. Additionally, nonmedical/combat units may not understand what the medical rules of engagement mean and how to execute them to meet the mission without giving the appearance to the local community that you are doing nothing for their injured citizen that they drop off at the front gate of the base. Such a casualty may meet the criteria of having a life, limb, or eyesight injury but cannot be transferred to your higher CSH or Theater Clearing Hospital because the higher in-country medical control says that there is no room at the higher level care facility for the patient. To meet these challenges, medical facility commanders should establish liaisons with maneuver commands (ideally via battalion or brigade surgeons) to open dialogue and foster understanding.

## Location of Expectant Care

The intensive care unit setting provides the best location for care of the expectant patient because it provides near one-on-one nursing care. This is usually appropriate for a large and well-staffed facility like a CSH, but less appropriate for a standard Role 2 facility. If you only have one ICU/recovery bed and you are busy, this is simply not feasible. A quiet area away from any busy trauma bays where family (in the case of local nationals) or other unit members can stay with the casualty is a good place, possibly with at least a curtain for privacy. Other locations could be a separate tent, tent section, or room if available. In the case of multiple or mass casualties, the location of care should be spelled out in your unit's mass casualty plan and should be tiered – meaning that the number of casualties presenting requires that the expectant category patients may need to be moved away from the ICU or ER in order to make room for those who can be saved. However, moving them to an isolated, quiet area does not equate to neglecting them, and thus someone from the nursing staff must be assigned to care for them.

The issue of whether to provide care at the current facility or attempt to transfer the casualty to another facility commonly arises. You may find that many units, particularly far-forward facilities, are not fully aware of the limited capabilities or expectant policies of the larger hospitals. If the patient is clearly in an expectant category, that should be communicated clearly to the referring facility. Mandating MEDEVAC missions for expectant patients should be avoided, as transporting expectant patients in high-risk environments has the potential to produce unnecessary casualties among MEDEVAC crews and medical personnel. Furthermore, casualties killed in action should not be transported with live casualties, as this can be both detrimental to morale and take up extra space needed to care for the living injured.

**Sample Expectant Care Order Set**

Patient Name: ID Number:
Admit to: Expectant Care Area
Diagnosis:
Status: DNR/DNI
Physician: Pager number:

**Medications:**

1. Morphine sulfate 5mg/10ml (100 mg in 200 ml)
   step 1: 5 mg iv push q5 minutes until comfort or respiratory rate < 20
   step 2: Start drip, hourly rate at the dose required to achieve comfort in step 1
   step 3: If pain or distress, return to step 1 and treat anxiety as in #

2. Midazolam (Versed)
   step 1: 2-4 mg iv push q30 minutes for anxiety/agitation
   step 2: if continued agitation or frequent dosing, start drip at 4mg/hr and titrate

3. Haldol 5-10 mg q10 minutes for continued agitation

4. Albuterol nebulizer q2 hours for wheezing
5. Scopolamine patch 1.5 mg topically BID as needed for secretions
6. Glycopyrrolate 0.1 mg iv q1 hrs as needed for secretions

**Treatments:**

1. Titrate oxygen for sats > 92% with maximal support of non-rebreathing mask
2. If intubated, extubate when pain and agitation control achieved as above
3. Stopany previously ordered labs or blood draws
4. Stop any previously ordered radiologic studies
5. Change IV fluids to Normal Saline at 10-20 cc/hr as a driver
6. Remove any unnecessary tubes or lines – nasogastric tube, central lines, etc.
7. Turn off all monitor alarms in the patient's room or area
8. Discontinue visiting hours, family/friends to be present as requested
9. Maintain comfortable environment – quiet, temperature, lighting, positioning
10. Call MD for resp rate > 30, discomfort, agitation, or anxiety not controlled by medications
11. Notify chaplain or other religious support as requested by patient or attendants
12. Notify physician and Patient Administration of patient death

**Fig. 43.2** Sample order set for expectant and end-of-life care

## Delivery of Expectant Care

A protocol for treating those patients who are classified as expectant should be established and disseminated (Fig. 43.2). Not only should some guidelines be set as to what types of injuries might be called expectant, but the treatment algorithm should be clearly communicated to the care team. The last thing anybody wants is for a patient to die a slow, painful death; neither do you want to give the appearance of performing arbitrary euthanasia. These scenarios are never spelled out in the official policies or rules of engagement, so it is often up to you to create them. At every level where far-forward surgical care is delivered, provisions for an ad hoc or formalized ethics team should be in place and exercised when necessary. This can be done very simply in the trauma bay with the attending surgeon or team commander quickly reviewing all the known information about the patient, out loud, for all team members to hear. Either the attending surgeon or another team member can bring up the option of the expectant category and all can quickly give input. Alternatively, the team leader can state why they are going to place the patient in the expectant category and set a quick treatment plan and short-order reassessment time to insure that any miraculous changes in patient status or information have not occurred. The expectant patient should be placed out of the way of the busy areas of the intensive care unit or emergency room whenever possible, preferably where family or unit members may spend time with the casualty for the remaining moments of life.

Ideally, a registered nurse is assigned to the patient to monitor for pain and provide comfort. Sometimes this can be difficult, as the patient's family or other caregivers/unit members will not understand some of the movements and vital sign changes that dying patients display. If there are family or friends with the patient, we have found it very useful (and emotionally calming) to enlist their help and participation in the dying process. They are encouraged to comfort the patient, to touch and talk to them, and to notify the nurse immediately if they feel that the patient is showing any signs of pain or anxiety. You will typically have at least one, and typically several, local national civilian translators dedicated to assisting your unit in treating civilian casualties. The translators are invaluable assets in communicating with the expectant patient (if alert and awake) and any family and explaining the plan of care and intent of treatment.

Usually, pain and antianxiety medications are the mainstays of expectant care. A well-monitored morphine drip with continuous or intermittent intravenous benzodiazepine (midazolam, lorazepam) as needed will usually suffice. Other common options for pain relief are fentanyl or hydromorphone. Anxiolytics/sedatives should be used liberally and include benzodiazepines, dexmedetomidine, haloperidol, or even ketamine. High doses of these medications should not be given expressly to end life (euthanasia), but the principle of "double effect" should guide your care. Give whatever dose is necessary to alleviate pain and suffering (primary effect), even if a secondary effect will be the hastening of death. The goals are allowing the patient to die with dignity and be as comfortable as possible in doing so. However, as the situation develops and changes, expectant patients can become treatable, and thus the care team should continually reevaluate the patients in this category and make adjustments as necessary.

Spiritual care can be provided anywhere on the battlefield – the US Army Chaplain's Corps are assigned to battalion-level units and higher. While religion-specific care is preferable, military chaplains are trained to give spiritual care to patients, unit members and families of those injured and killed. In most host nations, local religious leaders are available to aid with the interpretation of local customs and can provide valuable input on any ethics discussions involving local national casualties who are expectant or being evaluated for DNR status. Sometimes these individuals are employed at the base or airfield you are working on. Others are readily available in the local community but must undergo adequate security screening before being brought on base.

## Aftermath of Expectant Care

Patients who are brought into the hospital alive and subsequently die take a heavy toll on providers of all types and experience levels. It is important to know how your people are doing – especially your nursing staff – because they are constantly at the patient's bedside executing the minute-by-minute care plan. In most of these cases, friends or family members are not available, and thus it falls on the nurse to both care for and comfort the patient. Another population to pay particular attention to is your younger hospital staff members – the medics, nursing assistants, operating room techs, etc. It is easy to forget that what seems routine to an experienced trauma surgeon or nurse can be emotionally devastating to an 18-year-old medic who is suddenly thrust into the chaos of combat medicine.

It is vital to perform a debriefing for events that include mass casualties as well as anytime a patient dies at your facility. While you may have in your mind that the patient's injuries were obviously non-survivable, the rest of the team may have feelings that it was their fault that the patient died or that not enough was done to save them. They may have no idea what you are thinking, and thus it is up to the physicians to lead the team in discussing what happened, what could be done better the next time, and most importantly why it was not their fault that the patient died. It is critically important that your people have an outlet to express some of the emotions they are feeling after these events. This will go a long way toward improving morale and mental health and lessening compassion fatigue.

In-hospital deaths, and particularly those of young and previously healthy soldiers, will and should have a significant impact. You will be surrounded by incredibly dedicated people who have devoted their lives to caring for sick and injured patients. This is not a group that admits and accepts defeat easily or lightly. It is not uncommon to have the entire hospital assemble to honor the evacuation of a patient who died in their facility (Fig. 43.3). It is an honor to work with these people and take care of these patients across all spectrums of injury. This includes recognition of the end of life and providing the best possible care when it is most needed.

## Civilian Translation of Military Experience and Lessons Learned

Christine S. Cocanour

End-of-life care decisions are difficult for civilian trauma surgeons, just as they are for military combat surgeons, but for different reasons. In the civilian world, the population is graying. By 2040, 20% of Americans will be over 65 and they are

**Fig. 43.3** Members of a Combat Support Hospital salute a departing helicopter (“angel flight”) carrying the body of a fallen soldier

staying more active. As a consequence, we are seeing more elderly in our trauma rooms. The young, healthy, fit soldier is instead an overweight, older patient with multiple medical comorbidities and varying degrees of frailty. Age, frailty, and loss of physiologic reserve not only increase mortality, they prolong the recovery process. Patients – especially those that are old and frail – never recover to their pre-injury baseline level of functioning.

Goals of care and expectations of care are becoming increasingly important conversations. Patients and their families should never be given the option of “do you want everything done?”. Of course a family member is going to say yes. Instead, the conversation should be about the patient’s pre-injury life, what are the patient and their family’s hopes and expectations for recovery, and what is the expected course and outcome given the patient’s injuries, comorbidities, and pre-injury functional status. The dilemma for the care team is not “could we offer this treatment” but “should we offer this treatment.” Treatments should be based on what is appropriate, not just because we can do a procedure or treatment. These conversations are rarely accomplished in a single meeting or even in a single day. In the civilian trauma center, we usually have the luxury of time and resources in which to support the patient while this shared decision-making conversation is ongoing.

One afternoon when on trauma call, a patient who had just celebrated her 85th birthday the day before was brought in from a motor vehicle crash. Hypotensive from a severe pelvic fracture, multiple bilateral rib fractures, and a tear of the thoracic aorta, she was resuscitated in the standard fashion. Vascular surgery was called and determined that her vessels were too tortuous to allow a TEVAR, and the aortic repair would require a thoracotomy. By this time, her daughter and son-in-law arrived. The magnitude of her injuries that would necessitate extensive pelvic reconstruction, thoracotomy, and a prolonged recovery process that left in doubt whether she would ever be able to work in her beloved garden allowed her family to decide not to pursue aggressive treatment, and her goals of care were changed to that of comfort. This patient illustrates the value of patients talking with their families as to what they would want if medically incapacitated.

Ideally, patients and their families have talked about what they want in the event of a medical catastrophe. There has been a significant increase in the rate of older Americans with advance directives, from 47% to 72% between 2000 and 2010. In transitioning to expectant care or comfort care, it is important to remember that we may withdraw support such as withholding blood products, or not offering dialysis, but we never withdraw care. Making a patient comfortable at the end of their life is just as important as taking out their injured spleen. This is simply a shift in the goals, priorities, and expectations of care and NEVER an abandoning of the patient and their family/friends.

In the military setting, resource availability may require decisions to be made that in a level 1 trauma center would never be an issue. However, in the civilian world, not all hospitals are level 1 trauma centers or have unlimited resources. Civilian hospitals may be limited by surgeon availability, blood bank resources, transport limitations, or other resource issues. For example, a 40-year-old woman with a vertical shear injury of her pelvis, hemodynamically unstable, is brought to a non-trauma center. The hospital has no interventional radiology capability and no available surgeon. On the first attempt to transfer her, she arrests as she is loaded into the helicopter. She is taken back into the ED where she is further resuscitated with blood products and vasopressors. Another attempt is made to transport her and she arrests as the helicopter is lifting off. The flight crew decide to go on to the level 1 trauma center where after 30 min of CPR, and a heart in asystole, she is pronounced dead. On autopsy she was found to have completely transected her right iliac artery. It can be argued that because she was never able to be stabilized for transfer that further expenditure of resources – whether blood products or transport – was futile.

Physicians in civilian hospitals must also be aware of their available resources before providing ED procedures that cannot be supported. When an ED physician trains or works in a level 1 or 2 trauma center, they may take for granted the patient that comes in with a GSW to the abdomen and arrests; they proceed to ED thoracotomy and then realize that in the small country hospital, there is no surgeon or anesthesiologist. Even if stabilized and transferred with an aortic clamp in place, the transfer will take time, reducing the patient's survival to nil. The civilian physician may know that they can temporarize a patient's condition and that in a different setting, the patient may survive, but in their current surroundings and resources, the patient cannot be salvaged.

End-of-life decisions are tough whether in a military or a civilian setting. Deciding whether someone can survive devastating injuries is difficult. We don't have crystal balls. But taking into account the patient's injuries, their pre-injury level of functioning, the resources available to the care team and military and civilian trauma teams alike care for their patients to the best of their abilities even when they know the outcome is death.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. Catastrophic care.
2. Management of pain, anxiety, and delerium.
3. Neurosurgery and severe head injury.

## Suggested Reading

4. Silveira MJ, Wiitala W, Piette JJ. Advance directive completion by elderly Americans: a decade of change. Am Geriatr Soc. 2014;62(4):706.

# Trauma System Development and the Joint Trauma System

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Kirby R. Gross, Brian Eastridge, Jeffrey A. Bailey, and M. Margaret Knudson

**Deployment Experience**

| | |
|---|---|
| *Kirby R. Gross* | Deputy Commander Clinical Services 86th Combat Support Hospital 2003, Commander 772d Forward Surgical Team 2005–2006 |
| | Surgical Support to United States Special Operations Command 2006 and 2007 |
| | Trauma Surgeon 541st Forward Surgical Team 2010–2011 |
| | Director Joint Theater Trauma System (US Central Command) 2011–2012 |
| | Director Joint Theater Trauma System (US Central Command) 2013–2014 |
| *Brian Eastridge* | Trauma Surgeon, 947th Forward Surgical Team, Afghanistan, 2002 |

K.R. Gross
Army Trauma Training Department, Jackson Memorial Hospital, Department of Trauma, Miami, FL, USA

B. Eastridge (✉)
University of Texas Health Science Center at San Antonio, Department of Surgery, San Antonio, TX, USA
e-mail: eastridge@uthscsa.edu

J.A. Bailey
Uniformed Services University, Walter Reed National Military Medical Center, Bethesda, MD, USA

M.M. Knudson
American College of Surgeons, University of California San Francisco, Department of Surgery, San Francisco, CA, USA



M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_44

| | |
|---|---|
| | Trauma Surgeon, 67th Combat Support Hospital, Mosul, Iraq, 2004 |
| | Director Joint Theater Trauma System (US Central Command), 2004, 2007, and 2010 |
| | Trauma Surgeon, 911th Forward Surgical Team, Afghanistan, 2014 |
| *Jeffrey A. Bailey* | Chief of Trauma ("Trauma Czar"), 332nd Expeditionary Medical Group, Air Force Theater Hospital, Balad Air Base, Iraq, 2006–2008 |
| | Chief of Trauma ("Trauma Czar"), 332nd Expeditionary Medical Group, Air Force Theater Hospital, Balad Air Base, Iraq, 2006–2008 |

**BLUF Box (Bottom Line Up Front)**

1. The military surgeon must have an understanding of the trauma system in which they are working and how it impacts management decisions.
2. If you have seen one trauma system, you have seen one trauma system. The trauma system in which one is working in garrison is different from the trauma system during deployment.
3. As a surgeon, you may be the only individual in your team who understands trauma systems. Take the opportunity to inform your colleagues on the importance of systems.
4. The military surgeon should not only be the subject matter expert within their military treatment facility on trauma, but should be the subject matter expert for the area from which the military treatment facility is receiving casualties. Seek to understand the resources and capabilities of your referral base. If training is necessary for your referring providers, ensure the opportunities for training are made available. If materiel resources are lacking in your catchment area, inform theater medical leadership of deficiencies. A surgeon advocating on behalf of your regional providers may be more effective and will gain loyalty from your colleagues.
5. The surgeon must emphasize the importance of accurate documentation of care. Not all members of the medical treatment facilities may understand the critical importance of documentation of care. The surgeon understands timely accurate documentation is critically important for the providers who will be receiving the casualty. Documentation is also critically important for abstraction for the trauma registry.
6. There is no improvement in care, particularly for system-level issues, without a robust quality improvement process. Identify all problems and complications, and ensure they are discussed and actions taken to improve or change the root cause.
7. The US military should never again go to war without a robust Joint Trauma System or similar trauma care system and infrastructure. This is arguably the most important of the many lessons learned over the past decade-plus of combat operations; do not let it be forgotten!

## Who Needs a Trauma System?

Shortly after the attacks on the United States on September 11, 2001, the military responded with significant combat operations in Afghanistan and then Iraq. As general and trauma surgeons, we were among the most heavily deployed of the military medical specialties and maintained a sustained high operational tempo for over a decade and one that continues to this day. The authors of this chapter have all had the relatively unique experience of serial deployments from the earliest phases of combat operations, through the "surges" in both Iraq and Afghanistan, and continuing now during the relatively quieter and lower volume phases of these operations. What became readily apparent to all of us during our initial deployments was that we had put in place all of the individual elements of a standard military combat casualty care system, but we lacked a true robust and overarching "trauma system" like we have seen in civilian trauma care in the United States. There was no routine patient-level data collection and no trauma registry, no identification and analysis of adverse events (complications, deaths, errors in management), no real-time data analysis or system-wide efforts at process and/or quality improvement, and no one person or organization with responsibility for this key aspect of trauma care. The system was effective, care was provided, and patients were processed through the continuum efficiently, but it was readily apparent that there were problems that needed to be addressed. We saw things like incomplete (or omitted) fasciotomies, failures to apply damage control surgery principles, primary closure of contaminated combat wounds, adverse events occurring during patient transfer between facilities, and poor communication/coordination of care along the continuum from the point of injury to the Role 4 (Landstuhl) and 5 (United States) facilities. Fortunately, this missing element was identified and led to the establishment, introduction, and growth of a robust in-theater trauma system that included routine data collection and entry into a custom trauma registry, vigorous QI/PI processes and oversight, the development of evidence-based clinical practice guidelines for combat trauma care, and the coordination of communication and information exchange across all echelons of battlefield care. This chapter describes that process, the key elements of this incredibly important endeavor, and the current status and future plans for this system.

One of the benefits of providing medical care in a combat zone is the freedom from many of the administrative hassles, burdensome regulations/policies, and endless paperwork that has come to characterize modern medicine and surgery. Asking a trauma surgeon at a busy forward deployed Role 2 or Role 3 facility to stop and fill out a data sheet for abstraction into a trauma registry can be (and was) a tough sell, particularly if the downstream benefits of that administrative task are not readily apparent. However, the immediate impact of this trauma system and the improvements in care that were seen became quickly obvious to even the most cynical providers and have even now been used by civilian experts as a model of a "learning health system." As a deployed provider, you are now a key and important part of that system. We implore you to support it, champion it, and most importantly ensure that it continues to be utilized, enhanced, and improved. We should never again go to war without a true robust trauma system in place and on the ground from day 1 of combat operations.

## Definition of a Trauma System

Trauma care requires a myriad of disciplines, sites of care (both within health-care facilities and outside health-care facilities), and planning for trauma care. A *system* is necessary to ensure the multiple individuals are trained, material resources are available, and the various resources are arrayed to ensure optimal care. In general terms a system is "a regularly interacting or interdependent group of items forming a unified whole." The concept of a trauma *system* can more readily be understood by an analogy to another commonly referenced system.

A regional transportation system offers a reasonable example of a system. Transportation systems coordinate logistics of the numerous component elements required to move people and goods utilizing multiple modes of transport in order to optimize efficiency and value. It is intuitive that an area with a planned transportation system with oversight would provide better service than an area with an ad hoc arrangement of travel in a region. Key to oversight is leadership with an understanding of transportation and the region.

## Origins of Trauma Systems

The origins of trauma systems in the US civilian experience can be dated back to a report in 1966 from the National Academy of Sciences. The title "Accidental Death and Disability: The Neglected Disease of Modern Society" clearly described the problems with trauma care as it existed in more than 50 years ago [3]. Although not specifically identified as a system in this report, this recommendation for the development of organizations of community councils on emergency medical services to link to a national trauma association sought to remedy the lack of coordination of trauma care. The current stateside model of regional advisory councils for trauma (endorsed by the individual states) with the regional advisory council leaders interacting with their State Committees on Trauma and the American College of Surgeons Committee on Trauma through their regional leadership can be clearly seen in the recommendations in the 1966 report.

Trauma systems became incorporated into stateside trauma care in earnest in the 1980s and 1990s. The impact of a functioning trauma system on outcomes became clear in the late 1990s. Mature trauma systems were felt to decrease morbidity and mortality between 15% and 20% [4]. Of note, the use of the National Trauma Data Bank as championed by the American College of Surgeons Committee on Trauma served as a way to obtain data. Also, the need for a trauma registry had been identified in the 1966 report.

The military experience of rudimentary trauma systems dates back centuries. Larrey and Letterman are examples of military medical leaders who recognized the capabilities needed for casualties were not available at the point of injury. The evacuation of casualties off the battlefield to a higher level of care, even though only a short distance away, demonstrated the recognition of interactions in an organized fashion.

The distinction between the earliest battlefield casualty evacuation programs and trauma systems which were employed in the early years of operations in Iraq and Afghanistan is related primarily to the agility to change based upon outcomes. Information describing outcomes in near real-time fashion only became available as effective data capture, analysis, and application occurred. For all practical purposes, the data capture in near real-time fashion only occurred since 2000. No doubt improvements in practice, materiel, and array of trauma assets have occurred for as long as there has been war. A hallmark of a trauma system is the organization and incorporation of this learning concept.

## Introduction of a Trauma System in a Theater of Operations

A report by Mullins and colleagues [4] identified the benefits of trauma systems in the late 1990s. When war developed in response to the September 11 attack on the World Trade Center and Pentagon, the concepts of trauma systems had yet to be incorporated into the US military medical planning. COL (accepted Army abbreviation) John Holcomb, Commander of the US Army Institute of Surgical Research, traveled to Iraq for a survey of trauma care. The survey was conducted in May 2003, 2 months after onset of hostilities. He identified no trauma system existed in Iraq. Medical planning had indeed been conducted, but in many circumstances, the planning was service specific. COL Holcomb, LtCol (corrected rank with accepted US Air Force abbreviation at time cited) Don Jenkins (US Air Force), and LTC (accepted US Army abbreviation) Brian Eastridge (US Army Reserve) proposed the establishment of a theater trauma system for the entire battlespace. The proposal to establish a Joint Theater Trauma System for the US Central Command (CENTCOM) area of responsibility was approved by Col Doug Robb, CENTCOM Command Surgeon.

Critical to the success of the Joint Theater Trauma System (JTTS) was assigning the Director of the JTTS directly responsible to the CENTCOM Surgeon. By doing so, the JTTS Director served as the CENTCOM Surgeon's advisor on combat casualty care. For issues in the CENTCOM area of responsibility that could not be resolved locally by the JTTS Director, the CENTCOM Surgeon would provide direction. This command oversight was imperative in the complex environment of a theater of operations. Over the subsequent decade-plus of sustained combat operations in Iraq and Afghanistan, the JTTS achieved unparalleled success in data collection, real-time data analysis, and robust evidence and data-based quality/process improvement initiatives. The implementation of the JTTS, now known as the Joint Trauma System (JTS) as it encompasses care along the entire continuum and not just "in theater," is widely credited for achieving improved battlefield survival despite an increase in the average injury severity.

The benefits of the JTTS were recognized by leaders of the military health system. To ensure the US military does not go to war in the future without a trauma system, the Department of Defense Instruction (dated 28 September 2016) established a Combatant Command Trauma System (CTS) modeled after the JTTS [5].

## Personnel and Roles of the Combatant Command Trauma System (CTS)

The Combatant Command Trauma System (CTS) is to be modeled after the Joint Theater Trauma System (JTTS). No doubt the CTS will adapt to fit the relevant battle space and contingency. However, the JTTS as deployed in Iraq and Afghanistan will serve as a frame of reference as each Combatant Command develops its own trauma system. The CTS of Pacific Command will look much different than the JTTS of Central Asia Command of 2001–2015. And the CTS of Central Asia Command in 2025 will look much different than the JTTS of Central Asia Command of 2001–2015. The CTS is to be scalable to contingency requirements. The CTS may also maintain operations between contingencies to sustain capability for rapid expansion and adaptation based upon the Combatant Command's requirements. In the face of the variations in region and contingencies, to follow will be general guidelines for personnel and roles to be considered during contingencies. CTS members may be of active or reserve component of all three services.

The CTS should consist of a headquarters element of a CTS Director, CTS Program Manager, and CTS NCOIC. The Director should be a senior trauma surgeon who is clinically active, typically of O-6 rank (Army and Air Force Colonel, Navy Captain), but occasionally a senior O-5 (Army and Air Force Lieutenant Colonel, Navy Commander). The Director must have previous deployment experience in a leadership role. Ideally, the Director would have experience as Trauma Director in a stateside facility.

The Director is responsible to ensure optimal trauma care throughout the area of operations. The Director must be viewed as a trauma subject matter expert. This view is enhanced by remaining clinically active. The Director would ideally have full staff privileges in the military treatment facilities in theater and have scheduled clinical time. Communication skills are an absolute must for the Director. The Director must be available and receptive to information offered. As issues are identified, the Director's immediate leadership, the Combatant Command Surgeon, is to be informed. Not all issues warrant elevation to the level of Combatant Command Surgeon, but in cases in which lower-level communications do not resolve issues, then the chain of command should be invoked. The Director should also remain in close communication with Joint Trauma System (JTS) leadership in San Antonio.

The Program Manager is a Registered Nurse, with a rank of O-5. Officers of O-4 (Army and Air Force Major or Navy Lieutenant Commander) or O-6 are also acceptable. More important than rank is previous nursing experience. Nursing leaders with performance improvement experience is particularly desirable. The Program Manager coordinates activities within and among the CTS members. The Program Manager's expertise in performance improvement can be applied as projects are conducted within individual military treatment facilities or system-wide. The Senior NCO is a medic or corpsman with previous deployment experience. The Senior NCO manages the day-to-day issues of the deployed team.

One of the most difficult areas of combat care in terms of routine data collection and capture in the DOD trauma registry has been the prehospital arena. Therefore, a PreHospital Director and PreHospital NCO are key to the success of the CTS. The PreHospital section facilitates data capture from point of injury and serves as liaisons with the individual war fighter unit medical leadership. The PreHospital Director is a physician with deployment leadership experience and operational clinical experience. Intimate knowledge of Tactical Combat Casualty Care guidelines is imperative for members of the PreHospital section. The PreHospital NCO served in a particularly key role. Line medics and corpsmen will be much more responsive to CTS colleagues who have experience in point of injury care.

The headquarters element of the CTS should be located at a site that provides optimal information technology support, communication resources, and access to travel. In an immature theater of operations, no site may provide such capability. One good reference in considering the site for the headquarters element should be an air hub. An air hub will have as many technologic resources, communication assets, and access to travel as any site in theater.

The Director and Program Manager should travel about theater to gain an understanding of the trauma system first person. Travel may be dictated by concerns from the Combatant Command Surgeon or clinical colleagues who may have concerns about standards in a location. However, travel should not be undertaken only to troubleshoot. The PreHospital Director and PreHospital NCO should be aggressively traveling in theater provided the security situation permits. The number of medics and corpsmen in the line units dwarfs the number of health-care providers in military treatment facilities manyfold. The point of injury providers and their leadership will be widely dispersed throughout the battlefield. Only by interacting with the medics, corpsmen, and their leadership will issues be identified.

CTS personnel would ideally be located at Role 3 military treatment facilities in theater. CTS personnel should be Trauma Nurse Coordinators (TNCs) and a medical NCO. The CTS TNCs' primary missions are to ensure appropriate data capture and local facility performance improvement. TNCs must be closely linked to both the nursing and surgical staff of their assigned military treatment facility. By integrating into the facility, the TNCs can more readily identify opportunities for improvement. As the JTTS was initially introduced into theater in 2004, the TNCs conducted data abstraction from the deployed military treatment facility into the trauma registry. An improved practice for the CTS will be identifying patients whose records require abstraction and ensuring the records are electronically transmitted to the Joint Trauma System in San Antonio. Abstraction can then be performed by full time trauma abstractors who are well away from the combat zone.

TNCs should also work shifts in their military treatment facility as long as the shifts do not prevent the TNC from completing CTS obligations. In surge situations such as MASCAL events, the CTS TNCs can readily augment the military treatment facility staff.

## CTS and Joint Trauma System Interactions

The Joint Trauma System was developed as a Directorate of the US Army Institute of Surgical Research to train deploying JTTS members and to serve as the enduring institutional knowledge of deployed trauma care. Trauma surgeon architects of the JTTS initially served as Directors of the Joint Trauma System (JTS). Mary Ann Spott, PhD, Deputy Director of the Joint Trauma System, envisioned and brought to development the military trauma registry. Dr Spott oversaw the training of the military registry to deploying JTTS members. Other subject matter experts on performance improvement, data analysis, relevant information technology, and data abstraction were added to the Joint Trauma System membership. The duration of training for deploying JTTS members by JTS would typically last 2 weeks. However, ongoing dialogue occurred between JTTS and JTS. No formal command and control existed between the JTTS and JTS. JTTS command and control flowed to the US Central Asia Command Surgeon. For JTS, command and control flowed through US Army Institute of Surgical Research. However, like many relationships for JTTS, those informal relationships are important for training and continued effectiveness. The relationship between JTTS members and military treatment facilities in which they are located is another example of a key informal relationship. Effective TNCs are able to work with their host facility by bringing opportunities for improvement to nursing, surgical, and military treatment facility leadership. This information may not be well received if the TNC is viewed as an outsider, rather than a good faith partner.

## Department of Defense Trauma Registry

The military trauma registry was modeled after the National Trauma Data Bank of the American College of Surgeons Committee on Trauma. The trauma registry was identified as the Joint Theater Trauma Registry (JTTR) at the time of its original development in 2004. In 2012, the trauma registry was relabeled the Department of Defense Trauma Registry (DoDTR). As of December 2016, the DoDTR has 130,000 records on 65,000 casualties.

## Operational Cycle

The key principle of the Joint Theater Trauma System is a learning system. The learning revolves around data, with the source of the data being the DoDTR – the operational cycle (Fig. 44.1). Key points of care recorded in the medical record are

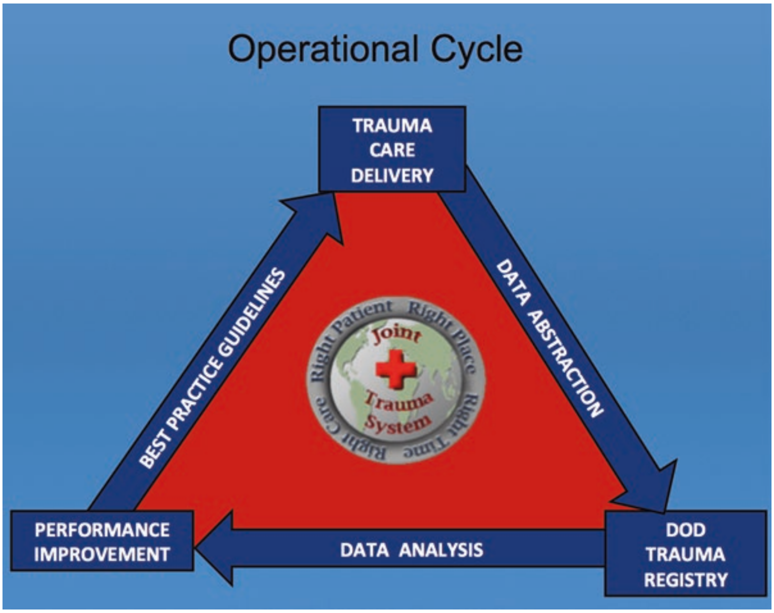


**Fig. 44.1** Graphic of the operational cycle of the Joint Trauma System

**Table 44.1** Impact of evidence-based clinical practice guidelines

| | Pre-CPG | Post-CPG | *P* | CPG compliance |
|---|---|---|---|---|
| Burn resuscitation-associated abdominal compartment syndrome mortality (burn CPG) | 36% | 18% | <.05 | 94% |
| Hypothermia on presentation (hypothermia CPG) | 7% | 1% | <.05 | 84% |
| Massive transfusion mortality (≥ 10 U RBCs/24 h) (damage control resuscitation CPG) | 32% | 20% | <.05 | 85% |

Table from an analysis demonstrating the improvements in morbidity and mortality in several select areas before and after the introduction of JTS clinical practice guidelines (Reprinted from Eastridge et al. [6], Copyright 2009, with permission from Elsevier)

abstracted into the DoDTR; the data is then analyzed in ongoing performance improvement, with the outcome being generation of best practices in the form of clinical practice guidelines. The cycle is then repeated by abstraction of the record, analysis of outcomes, and generation of best practice. The ongoing analysis involves assessment of compliance with the clinical practice guidelines as well as outcomes of care as recommended in the guidelines. This process has been shown to positively impact the outcomes in several areas of combat casualty care, including demonstrated reductions in morbidity and mortality (Table 44.1).

The operational cycle is not a new concept. It takes its origins from Sir Francis Bacon in 1621 who labeled this as the "scientific process." More recently, Deming and others have used this cycle as the central theme for ongoing quality assurance.

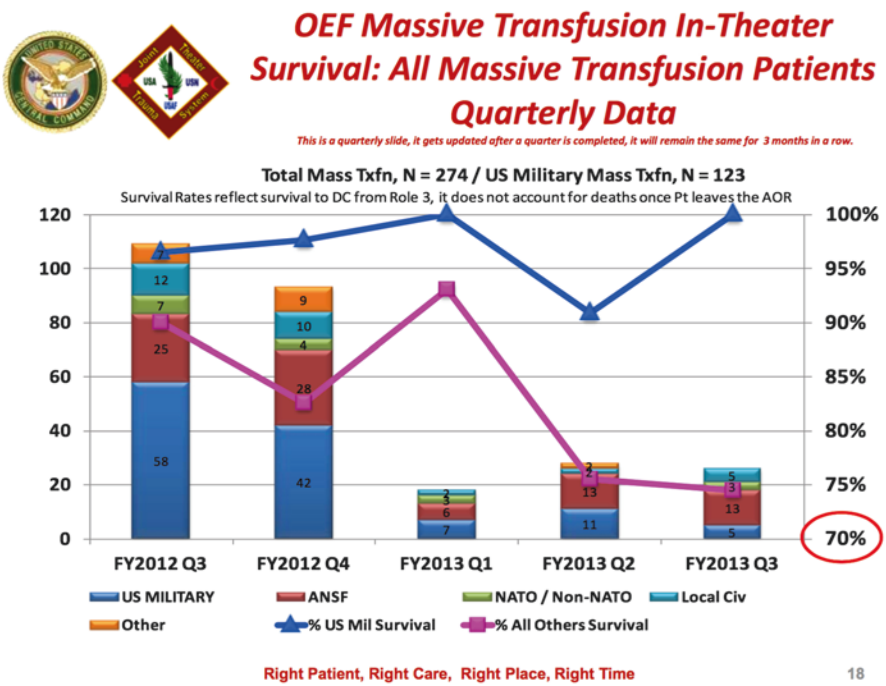


**Fig. 44.2** Graph from a monthly JTTS report showing statistics on the numbers of massive transfusions, the associated mortality, and the trends in mortality rates over time

Critical is the capture of data, with ongoing analysis. It has been said that "not using trauma data is as bad as not collecting it in the first place." One of the hallmarks of the JTTS was the continuous and concurrent collection and analysis of patient- and facility-level data in order to identify trends, problems, strengths, weaknesses, and most importantly areas for closer inspection and improvement. Monthly comprehensive JTTS reports with select data from the DOD trauma registry were compiled and were made available to not only the JTTS personnel, but to all military providers at any deployed or stateside facility. Figure 44.2 shows an example from one of these reports that highlights the incidence of massive transfusions administered in 2012–2013, the associated survival rates, and the trends in survival over that time period. These comprehensive reports and dissemination of this type of data played a crucial role in monitoring and intervening in key areas of combat casualty care at all levels.

## Functional Means by Which the Trauma System Seeks to Improve Outcomes

One metric that has been used to assess combat casualty outcomes is case fatality rate [7]. The case fatality rate is imperfect, but it does serve as a way to compare current outcomes with historical outcomes. Holcomb reported in 2006 the case

**Table 44.2** Comparison of proportional statistics for battle casualties, US military ground troops, World War II, Vietnam, Afghanistan/Iraq

| | WWII | Vietnam | Total Iraq/Afghanistan | Afghanistan | Iraq |
|---|---|---|---|---|---|
| %KIA | 20.2[a] | 20.0[b] | 13.8[c] | 18.7 | 13.5* |
| %DOW | 3.5[a] | 3.2[b] | 4.8[c] | 6.7 | 4.7* |
| CFR | 19.1[a] | 15.8[b] | 9.4[c] | 16.4 | 9.1* |

Comparisons between WWII, Vietnam, and total Iraq/Afghanistan, a, b, c ˂0.05
Comparison between Iraq and Afghanistan *$p < 0.05$
% KIA = 100 × KIA/(WIA-RTD) + KIA; % DOW = 100 × DOW/(WIA-RTD); CFR = 100 × (KIA + DOW)/ (WIA + KIA)
Table reporting historical KIA, DOW, and case fatality rate from WWII, Vietnam, and conflicts since 2001 (Reproduced from Holcomb et al. [7]; with permission from Wolters Kluwer Health, Inc.)

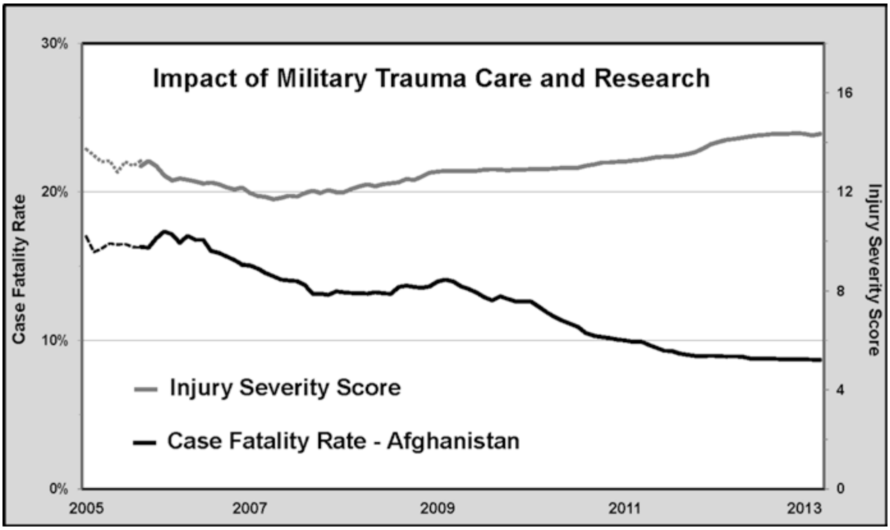


**Fig. 44.3** Graph demonstrating decrease in case fatality rate despite an increasing average Injury Severity Score (*ISS*) over time from Afghanistan

fatality rate was 19.1% in World War II, 15.8% in Vietnam, and 9.4% for the combined Iraq and Afghanistan theaters (Table 44.2) [7]. The case fatality rate continued to drop over the course of Operation Enduring Freedom (Fig. 44.3). The specific reasons for the improvement in case fatality rate are difficult to quantify. However, the increased use of tourniquets, better resuscitation protocols, wise array of resources on the battlefield, and effective evacuation practices have all positively impacted outcomes.

The decreasing case fatality rate observed in Afghanistan should further inspire military providers to improve outcomes. Military providers should embrace their roles as leaders in the trauma system. Four specific ways to participate in the trauma system that will further improve outcomes are:

1. Participation in facility and system-wide performance improvement.
2. Ensuring compliance with clinical practice guidelines.
3. Taking advantage of theater communication channels such as the weekly combat casualty care curriculum as hosted by the joint trauma system.
4. Informing medical theater leadership of issues which warrant leadership attention. Issues which would negatively impact outcomes are to be elevated to leadership. Lack of necessary medical equipment and the need for additional training are examples of such issues.

## Conclusions

Military providers must not only be clinical experts for the individual patients to whom they provide care, but they must understand trauma systems. With the introduction of a trauma system into the US Central Command area of operations, case fatality rate dropped significantly. A trauma system permits optimal patient care and facilitates ongoing improvement in outcomes. Military surgeons must ensure all members of their local team are informed of the need to work within the system and all members of the team are educated that individual members of the team all have a responsibility to actively seek to improve outcomes. Key to improvement of outcomes is timely and accurate documentation of patient care. Documentation is the source of date which is then translated to information which is then translated to quantifiable outcome measures.

## Civilian Translation of Military Experience and Lessons Learned

M. Margaret Knudson

As a way of a full disclosure, I must confess that I am not (nor have I ever been) a member of the US military. My exposure to military surgery began in 2003 when I traveled with other members of the American College of Surgeons (ACS) National Ultrasound Faculty to a small military treatment facility on the US Army base at Landstuhl, Germany. During the visit, while we were teaching deploying surgeons how to perform FAST exams for trauma patients that they would be evaluating in Iraq, I was exposed for the first time to the severity of the injuries being encountered in that theater of war. I subsequently returned to Landstuhl several times as part of the Senior Visiting Surgeons program, a program that allowed civilian surgeons to work alongside their military colleagues in the ICU and operating room while caring for those evacuated from theater. This collaboration, jointly sponsored by the Department of Defense, the American College of Surgeons, and the American

Association for the Surgery of Trauma, assisted in the transition of Landstuhl Regional Medical Center (LRMC) from a relatively small hospital to a level 1 trauma center verified by the ACS Committee on Trauma. While working in Germany, I expressed my desire to see the military trauma system in its entirety and was honored to be allowed to travel into the theater of war for a 10-day tour. My orders allowed me to obtain operating privileges through the Air Force, and I took call with the deployed surgeons, caring for troops evacuated directly from the battlefield. I twice flew with the Air Force's Critical Care Air Transport Teams (CCATT), observing with fascination how critical care could be provided with professionalism and compassion during prolonged flights across three continents. I traveled to Walter Reed Army Medical Center with patients and visited the Bethesda Navy Medical Center as well as the Army's ISR burn center in San Antonio during the periods of highest ops tempo. Additionally, I had an opportunity to participate in the weekly military video teleconference (VTC) from various locations including in theater, in Germany, and in San Antonio. A tour of the Palo Alto VA Polytrauma Center as well as the Center for the Intrepid in San Antonio was part of the final stages of my military education as I observed firsthand the advances in rehabilitation accelerated by the large number of returning troops with TBI and amputations. As a result of these personal experiences, I have developed a deep appreciation for the challenges encountered by military medical personnel who are called upon to care for war injuries but also a passionate drive to preserve the Joint Trauma System and to facilitate the translation of the lessons learned on the battlefield over the past 15 years into the civilian trauma system [8].

It should be noted that the US military did not go off to the wars in Iraq and Afghanistan with a trauma system in place. This remarkable system, the Joint Theater Trauma System (JTTS) that has saved the lives and limbs of so many service men and women, was developed during combat operations by trauma surgeons with experience in the civilian trauma system. And while there is no doubt that mature trauma systems save lives, even within the United States, an estimated 45 million people lack access to major trauma centers within 1 h of their injury [9]. A marriage of the US military and civilian trauma systems, as advocated by the recently released report by the National Academies of Sciences, Engineering, and Medicine, would insure a well-maintained and ready military trauma system while increasing access and augmenting disaster response throughout the United States [10]. In order to accomplish this, however, it is necessary to understand the current similarities and differences between these two systems as outlined in Table 44.3.

The biggest difference, however, is what happens to the systems over time. The civilian trauma system, although imperfect, will continue to function, whereas, if history repeats itself, the military trauma system that currently exists is in jeopardy of being put into senescence until it is needed for the next conflict. Fortunately, at this time, there is considerable movement to assure that does not happen, and there is recognition that maintaining a ready military trauma system within military treatment facilities and selected civilian trauma centers would be beneficial to both systems. The public should expect ready access to high-level trauma care throughout the

**Table 44.3** Comparison of civilian and military trauma systems

| Civilian trauma system | Military trauma system |
|---|---|
| Stable leadership under Trauma Director | Leadership changes with deployments |
| EMS prehospital care/equipment variable | Standardized protocols based on TCCCC |
| No nationwide standard CPGs | System-wide CPGs |
| Performance improvement – local | Performance improvement – global |
| Loop closure delayed | Loop closure weekly via VTC |
| Tiered system: level 1 highest | Tiered system: level 3 highest in theater |
| Primarily ground transportation | Primarily air transportation |
| Includes pediatric/geriatric patients | Focused on young healthy adults |

United States, while those who volunteer to place themselves in harm's way deserve the same high-quality care no matter where in the world they are injured. Now is perhaps the best opportunity to get this right.

## Relevant Joint Trauma System Clinical Practice Guidelines Available at: www.usaisr.amedd.army.mil/cpgs.html

1. CENTCOM JTTS CPG process.
2. Use of electronic documentation.

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# The Next Generation of Hemorrhage Therapy

# 45

Vahagn C. Nikolian and Hasan B. Alam

> *Every surgeon carries within himself a small cemetery, where from time to time he goes to pray.*
>
> —René Leriche

**BLUF Box (Bottom Line Up Front)**

1. Hemorrhage is still the leading cause of preventable deaths in both military and civilian traumas. The final "holy grail" we need to solve is noncompressible truncal hemorrhage (NCTH).
2. Early and effective hemorrhage control is likely to save more lives than any other intervention in battlefield trauma.
3. Tourniquets, junctional tourniquets, and advanced hemostatic dressings are the current solutions for extremity and junctional hemorrhage. That still leaves NCTH!
4. Timing matters. Every minute of ongoing bleeding worsens the outcome. In a well-equipped hospital, a patient hardly ever dies because we run out of fluids/blood/drugs to administer. They die due to delays in hemorrhage control.
5. Resuscitation is an adjunct to hemorrhage control, not a substitute. You can't fill an empty tank with a big hole in the bottom. It is reasonable to

(continued)

V.C. Nikolian
University of Michigan Health System, Department of General Surgery, Ann Arbor, MI, USA

H.B. Alam (✉)
University of Michigan, Department of Surgery, 1500 E. Medical Center Drive, 2920 Taubman Center/5331, Ann Arbor, MI 48109, USA
e-mail: alamh@med.umich.edu



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start careful resuscitation (using blood products in appropriate ratio when available) while making efforts to control the hemorrhage. However, early, aggressive fluid resuscitation (especially with crystalloids) in the absence of hemorrhage control is a bad idea.

6. REBOA is a promising new adjunct for early control of NCTH. But remember—you will pay a price for the resulting ischemia and reperfusion.
7. Self-expanding injectable foam may be one of the next big advances for controlling truncal hemorrhage outside of the OR. Further study is needed to identify the optimal indications and the optimal techniques for ensuring intraperitoneal injection.
8. New developments (pro-survival drugs, hypothermia, etc.) may be available in the near future that could serve as a bridge to definitive care by expanding the time that the body can survive shock.
9. Valproic acid is one of the more promising of these pharmacologic adjuncts, has markedly improved survival from massive hemorrhage in large animal models, and is currently in preliminary study in human trauma patients.

## Editor's Prologue

Each of us has unfortunately had the same scenario played out multiple times over the past 12 years of combat deployments. A patient arrives in profound shock from hemorrhage and quickly dies either in the resuscitation bay or on the OR table despite our best efforts. Our prehospital personnel have gotten extremely good at controlling any visible hemorrhage (extremity or junctional), but the "holy grail" that continues to elude us is the invisible and noncompressible bleeding, typically from the chest or abdomen/pelvis. Other than rapid transport and rapid surgical exploration, we currently have little to offer these patients in terms of effective early interventions or treatments that will enhance their survivability. However, there are a number of very exciting areas of active research and development that are focused on this topic that is of prime interest to both the military and civilian trauma communities. One of the most well-respected and visionary researchers and thought leaders in this area is Dr. Hasan Alam, and his current research team at the University of Michigan. Dr. Alam has worked tirelessly to find novel solutions to the problem of massive hemorrhage, including novel hemostatic dressings, emergency preservation and resuscitation techniques, and most recently on novel pharmacologic strategies to induce a "pro-survival" state characterized by improved tolerance to hemorrhage. For these reasons, we invited Dr. Alam and his colleague Dr. Nikolian to author this chapter reviewing novel and cutting-edge devices, interventions, and pharmacotherapeutics for the treatment and salvage of patients with massive or exsanguinating hemorrhage.

## Introduction

The classical trimodal distribution of trauma deaths was described by Trunkey and colleagues in 1983. In that report, nearly half of the deaths occurred within minutes after injury due to disruption of major blood vessels, devastating central nervous (CNS) injuries, or a combination. This was followed by a smaller second peak where ongoing hemorrhage and CNS injuries played an almost equal role. This group has been the impetus for the development of better trauma delivery systems. The third peak occurs days to weeks after injury due to infections, multiple organ failure, and various other late complications. In more contemporary studies, the trimodal distribution has evolved into essentially a bimodal distribution, where 61% of the deaths are immediate, 29% are early, and only 10% are late. The late peak has markedly diminished, most likely due to significant improvements in surgical intensive care, which has "flattened" the third peak and improved our ability to "rescue" patients even if they develop complications. Today, in massively bleeding patients (without head injuries), mortality beyond the first 24 h is only ~10%. Unfortunately, the area where we have failed to alter the mortality remains the period immediately following the injury, including the prehospital phase—with a significant proportion of these deaths resulting from hemorrhage.

Despite obvious differences in the mechanisms of injuries, hemorrhage is a leading cause of death not only in civilian centers but also in the combat trauma population. Effective treatment strategies in this area have the potential to save many lives from injury on the battlefield. It should be emphasized that survival in these patients requires definitive control of bleeding. These challenges are compounded in austere circumstances such as a battlefield, where 87% of deaths occur before patients reach a medical facility, with nearly a quarter of these injuries being considered potentially survivable. As such, novel therapies that may improve hemorrhage control, and keep the injured alive long enough to get to higher echelons of care, have the potential for the greatest impact. Similarly, novel therapies or adjuncts that could preserve cellular viability in the prehospital environment, and thereby extend the length of the window of survivability with ongoing major hemorrhage, are likely to have a major influence on outcomes in this population. In this chapter, we will highlight recent exciting advances and promising future prospects in the management of the exsanguinating patient.

## Current Technologies Deployed in the Field

### Extremity Tourniquets

Extremity tourniquets are one of the oldest, yet controversial, elements of hemorrhage first aid. Direct pressure over the site of bleeding can provide effective hemorrhage control when isolated injuries are identified. When used properly and applied early, tourniquet application has been shown to significantly increase survival. When applying an extremity tourniquet, arterial occlusion is paramount.


**Fig. 45.1** Junctional tourniquets approved for field use. (**a**) Combat Ready Clamp (CRoC), (**b**) Junctional Emergency Treatment Tool (JETT), (**c**) Sam Junctional Tourniquet

Remember, venous occlusion alone (with intact arterial inflow) may actually worsen hemorrhage and increase complications. Current tourniquet devices and usage are covered elsewhere in this text. Some ongoing work on next-generation tourniquet devices includes the development of "smart tourniquets" that can detect arterial flow (via ultrasound) and self-adjust their compression to ensure initial arterial occlusion, as well as continued occlusion with changes in the systolic blood pressure. Future uniform designs may also include built-in tourniquets on each sleeve and leg that can be readily deployed in the case of extremity hemorrhage and that would obviate the need to carry separate tourniquets.

## Junctional Tourniquets

Given the success of extremity tourniquets in controlling hemorrhage and improving survival, focus has shifted to hemorrhage control from other sites of bleeding. Nearly one fifth of lethal hemorrhage occurs from junctional regions—defined as regions in which extremities join the torso (i.e., the axillary and groin regions). These sites are challenging to manage as they are too proximal to be controlled via an extremity tourniquet and in areas too difficult to compress manually. In an optimal setting, junctional tourniquets should be able to safely control hemorrhage, be amenable to deployment into the field, be simple to apply quickly, and maintain mechanical stability once applied.

Multiple junctional tourniquets have been approved for use and include the Sam Junctional Tourniquet (SAM Medical Products, Portland, OR), Combat Ready Clamp (CRoC; Combat Medical Systems, Fayetteville, NC), and the Junctional Emergency Treatment Tool (JETT; North American Rescue; Greer, SC) (Fig. 45.1). Primarily, these devices are indicated in the setting of inguinal hemorrhage. The CRoC can be applied for unilateral bleeding, but the Sam Junctional Tourniquet and the JETT may be used when bilateral sources of bleeding are identified. These junctional tourniquets are relatively quick to assemble (less than 2 min to apply) and easy to apply (<10 steps for proper application). The JETT and Sam Junctional Tourniquet incorporate a pelvic binder in their design to help control pelvic hemorrhage. In cadaveric and swine models of hemorrhage, these devices have been able to control arterial hemorrhage just distal to the inguinal ligament within 1 min. There have now been over 20 documented uses of these devices in the combat setting, with excellent reported efficacy.

Unfortunately, these devices are of limited use in the setting of hemorrhage originating from the iliac vessels, aorta, or inferior vena cava. Abdominal aortic tourniquets have now been developed which can apply the necessary force to occlude the aorta and inferior vena cava, without injuring bowel. When placed properly over the iliac crests, these tourniquets have been shown to stop flow through the femoral artery in healthy human volunteers. Given these promising findings, the TCCC guidelines have been updated to allow for abdominal aortic tourniquets to be used in the battlefield. Case reports have documented the successful use of abdominal aortic tourniquets to treat casualties suffering from bilateral lower extremity amputations. However, these devices should be used with caution in the patient with multiple injuries and particularly with any penetrating abdominal or thoracic wounds or suspicion for abdominal or thoracic hemorrhage. By occluding the distal aorta, they could raise the systolic pressure above the level of aortic occlusion and markedly increase any associated hemorrhage.

## Hemostatic Dressings

Adjuncts to uncontrolled bleeding have been fielded for years. Research and development has expanded the options available for hemostatic agents that can allow for earlier control of hemorrhage and improve survival in the prehospital setting. Researchers focus on developing dressings which meet the following characteristics:

- Rapidly (within 2 min) stop arterial and venous bleeding
- Elicit no additional pain nor injury upon application
- Present no risk to the individual applying the agent
- Be lightweight, rugged, and easy to pack and remove from wounds
- Be biodegradable and bioabsorbable
- Be functional in a variety of environmental conditions
- Provide effective control of wounds not amenable to tourniquet placement
- Have a prolonged shelf life and be cost-effective

Based on preclinical data, many experts believe that QuikClot Combat Gauze (Z-Medica, Wallingford, CT) stands as the current standard of care for hemostatic dressings (Fig. 45.2). This flexible gauze made of rayon and polyester is impregnated with kaolin, an activator of the intrinsic clotting pathway. Hemostasis takes time to occur following the application of the dressing. As a result, wounds dressed with Combat Gauze should be manually compressed until active bleeding stops or at least 3 min.

New-generation dressings (e.g., Celox Gauze, MedTrade Products, Crewe, UK; Celox Trauma Gauze, MedTrade Products, Crewe UK; and ChitoGauze, HemCon,


**Fig. 45.2** Hemostatic dressings currently supported for field use. (**a**) QuikClot Combat Gauze, (**b**) Celox Gauze, (**c**) ChitoGauze

Portland, OR) have been developed and evaluated relative to Combat Gauze. Based on these studies, experts have concluded that these chitosan-based hemostatic agents are at least as effective as Combat Gauze in controlling severe bleeding. New TCCC recommendations support the use of Celox Gauze or ChitoGauze as acceptable substitutes for Combat Gauze in the management of external hemorrhage (see Fig. 45.2).

## Compressed Hemostatic Sponges

When dealing with penetrating injuries, visualization and identification of bleeding vessels may be challenging. Large cavities may be present but difficult to appreciate secondary to small entrance wounds—making packing of gauze into these wounds unpredictable. Given these obstacles, compressed hemostatic sponges have been developed. XStat (RevMedx, Wilsonville, OR; Fig. 45.3) is now recommended by the TCCC guidelines to control external hemorrhage from junctional bleeding sites that are poorly controlled with tourniquet application. XStat is devised to be used in gunshot or fragment injuries in which the entrance tract may be narrow, making it challenging to appropriately visualize bleeding vessels. Compressed, nonabsorbable mini-sponges coated with chitosan are housed within a lightweight syringe. Upon injection into the wound cavity, the mini-sponges contact blood and expand to greater than 15 times their original size, effectively increasing intracavitary pressure and eliminating the need to provide manual pressure on the site.

Preclinical data regarding the use of XStat versus traditional gauze has shown that the product is lighter to carry, is faster to apply, and provides a better ratio of pressure around wound cavities. Researchers have looked at the use of XStat-coated sponges in models of subclavian arterial and venous bleeding. These injuries are especially challenging to control as the clavicle overlies the vessels. In these models, all animals treated with the device survived, whereas survival for groups treated with standard gauze dressings only had survival rates of 38%.

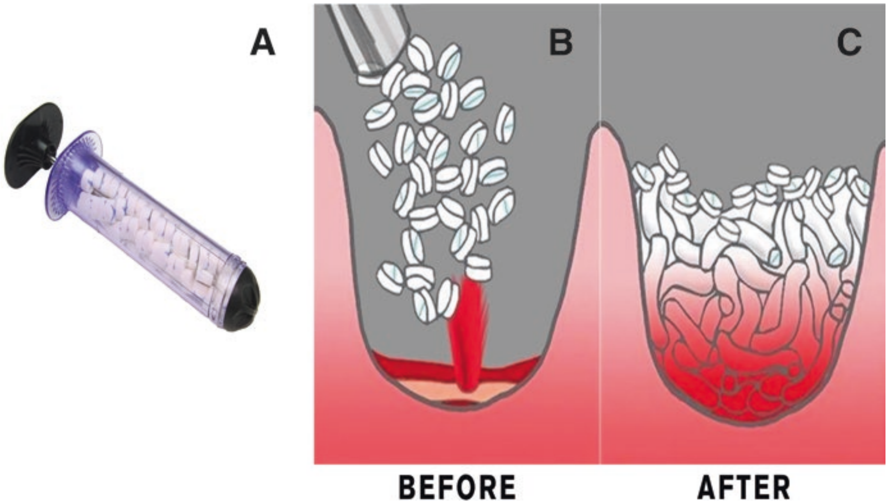


**Fig. 45.3** XStat application. (**a**) Applicator syringe with mini-sponges. (**b**) The mini-sponges are injected into the wound cavity. (**c**) Upon contacting blood, the sponges expand to exert pressure on wound

## Resuscitative Endovascular Balloon Occlusion of the Aorta

While junctional and abdominal aortic tourniquets may provide control of iliac and femoral sources of bleeding, other options should be considered when bleeding sources are suspected to arise from higher in the torso. Resuscitative endovascular balloon occlusion of the aorta (REBOA) for the management of central aortic and pelvic hemorrhage was first described in the mid-twentieth century. However, its clinical implementation has recently increased as endovascular techniques have improved. Balloon occlusion suppresses distal flow and hemorrhage and simultaneously increases cardiac afterload and aortic pressure, thereby increasing perfusion to the heart and brain. Moreover, when compared to traditional approaches such as resuscitative thoracotomy, REBOA has demonstrated a higher probability of survival and is obviously a less morbid and physiologically stressful intervention than an ED thoracotomy.

Arterial access is typically gained via femoral arterial cannulation (via either femoral cutdown, ultrasound guidance, or percutaneously without imaging). Following placement and balloon deployment, a variety of imaging studies (i.e., fluoroscopy, ultrasonography, and plain radiography) may be used to confirm appropriate placement of the balloon. If imaging is unavailable, then blind placement using measurements based on external landmarks has been shown to reliably place the balloon in the desired zone of the aorta in the majority of cases. When imaging studies are unavailable, deployment of the balloon should result in an immediate increase in systolic blood pressure that can serve as confirmation of proper placement. In a recent multicenter study, significantly more patients achieved hemodynamic stability when compared to open aortic occlusion techniques. Given these findings, REBOA stands as a viable option in the setting of noncompressible torso hemorrhage. That said, further studies will be necessary to determine the optimal indications for its use, the complication and adverse event profile, and improved device design to make placement easier and to potentially allow for controlled balloon deflation to allow partial restoration of flow prior to full balloon deflation.

## Emerging Technologies in the Management of Hemorrhage

### Plasma Protein Dressing

As we described earlier, many hemostatic agents and dressings have been developed and shown to be effective in controlling arterial bleeding. The best performing agents in use primarily rely on gauze that has been impregnated with clot-inducing chemicals that react with a patient's blood and activate coagulation or platelet plug formation. Unfortunately in the austere setting, massive hemorrhage is often complicated by hemodilution secondary to resuscitation with large volumes of crystalloid, prolonged evacuation times, and prolonged durations of hypovolemic shock, contributing to the development of trauma-induced coagulopathy. Given the dependence of traditional dressings on patients' compromised coagulation systems, one is not surprised to find that these agents do not always perform as well in field use.

New dressings are being formulated to better counteract the coagulopathy that develops following massive hemorrhage. Specifically, research is now evaluating the use of biologic dressings that contain precursors of hemostatic clots (e.g., thrombin, fibrinogen, and factor XIII). When compared to traditional hemostatic dressing products, plasma protein dressings have been shown to be more effective at treating arterial bleeding in the setting of hemodilution and hypothermic coagulopathy.

### Self-Expanding Foam

Using principles similar to the abdominal aortic junctional tourniquet, alternatives that may provide a mechanical tamponade effect to torso hemorrhage are being explored. Researchers are using minimally invasive approaches to provide more definitive bleeding control from major vessels in the abdomen. One such intervention that is being studied for the management of noncompressible abdominal hemorrhage is the use of expanding polyurethane foam that can be percutaneously administered into the abdominal cavity. Once instilled, the foam expands to nearly 30 times the original volume and provides a tamponade effect to slow or stop bleeding. In addition, the foam can cross-link with fluids in the peritoneal space to form a solid that provides more effective pressure on bleeding vessels and simplifies the removal of the foam at a later time.

The use of foam has been shown to be effective when compared to resuscitation alone in models of portal venous and iliac hemorrhage. These findings, however, are tempered by the potential safety risks associated with the use of foam. Concerns related to abdominal access, compartment syndrome, bowel injuries, thermal injuries, and the long-term impact of retained foam have justified further investigations. Recent studies have demonstrated that long-term survival and recovery are possible following treatment with expanding foam. Future work related to the use of foam will likely focus on the longer-term safety of foam products as well as the establishment of safe dosages in humans. If these unknowns are addressed, expanding foam products have the potential for application in the prehospital and hospital setting.

## Innovative Approaches in Management of Hemorrhage

### Hypothermic Arrest and Suspended Animation

In the clinical setting, the use of therapeutic hypothermia has been evaluated and identified to be of use in elective transplant, cardiac, and neurosurgical cases. However, its use in the trauma setting is challenging because of the diversity of patients and injury patterns. Cardiac arrest following trauma has very poor prognosis—even in the era of advanced trauma life support algorithms and invasive bedside procedures. When patients present with major vascular injuries and exsanguinating hemorrhage, brain and cardiac injuries can develop within 5 min. In the 1980s, Tisherman, Safar, and colleagues developed modified cardiopulmonary bypass systems to allow for instillation of cold saline to rapidly cool the heart and brain in canine models of hemorrhage. Using these techniques, prolonged periods of hypothermia were attainable, potentially affording surgeons time to perform damage control operations that could allow the injured the opportunity to live and fight another day.

Large animal studies have been conducted to evaluate the role of therapeutic hypothermia in hemorrhagic shock with and without a component of polytrauma. These resource- and labor-intensive experiments highlight many of the challenges associated with effective evaluation of the therapeutic potential for hypothermia. The time point at which hypothermia is induced, the velocity by which hypothermia is achieved, the duration of time it is maintained, and the rewarming process have all been explored with conflicting conclusions identified by different researchers.

When hypothermia is induced, survival has been shown to significantly improve with mild, moderate, and profound hypothermia. In addition, no adverse outcomes have been identified related to increased coagulopathy or postoperative bleeding. The benefits of hypothermic arrest are often attributed to a decrease in overall metabolism and inflammation. The decreased metabolic demands in the setting of hypothermia allow for increased oxygen delivery to vital organs, increased energy-rich molecule availability, and fewer perturbations in electrolyte levels. In addition, inflammatory processes are blunted following hypothermia, leading to improved function and decreased destruction of organs.

Overall, many questions remain before therapeutic hypothermia can become a reality for the management of traumatic hemorrhage. Currently, the Emergency

Preservation and Resuscitation for Cardiac Arrest from Trauma (EPR-CAT) study (ClinicalTrials.gov identifier NCT010402015) stands as the first feasibility and safety study to evaluate the role of therapeutic hypothermia for traumatic cardiac arrest. The primary outcome measures that will be evaluated in the study will include survival to discharge without major disability compared to controls undergoing current standard of care resuscitation. This study, once completed, will further expand our understanding of how we may extend the duration of time we have to save patients from exsanguinating hemorrhage.

## Valproic Acid and Pharmacologic Resuscitation

Many of the devices, interventions, and strategies described in this chapter rely on the principles of damage control resuscitation, specifically the avoidance of aggressive and excessive crystalloid resuscitation in favor of rapid hemorrhage control and early administration of blood products. Blood component administration provides the body with the oxygen-carrying capacity and coagulation factors needed to survive lethal hemorrhage. Unfortunately, blood products are not practical in many prehospital settings, especially in the battlefield. Even when available in the prehospital or MEDEVAC phase, they are typically not available in sufficient quantities to successfully treat ongoing massive hemorrhage. One of the most exciting and promising areas of research in this area involves novel pharmacologic agents that can induce metabolic, physiologic, and genetic/epigenetic changes that enhance the body's ability to tolerate hemorrhage or other major injuries. We believe that short of some revolutionary advances in prehospital interventions to control truncal hemorrhage, this represents the most promising area of next-generation research with the potential to significantly enhance survival among this patient population.

Our group has focused on the subcellular changes that occur following hemorrhage, to determine if pharmacologic measures may improve outcomes. Following hemorrhage, nearly 7% of the genes change their expression based on the type of resuscitation that is administered. Given these findings, new agents are being explored to exploit the changes that occur at the subcellular level to develop a *pro-survival phenotype*. Specific drugs, known as histone deacetylase inhibitors (HDACIs), are being studied for their ability to induce posttranslational modifications to a wide variety of proteins. In small and large animal models of hemorrhage, the changes induced by these drugs have been shown to mitigate some of the adverse physiologic consequences of hemorrhage. Specifically, drugs such as valproic acid (VPA) have been shown to decrease the severity of acidosis, coagulopathy, and fluid resuscitation needs and the use of vasopressors following hemorrhagic shock. One of our early large animal studies of VPA for hemorrhagic shock in 2009 demonstrated that the administration of VPA to animals in hemorrhagic shock markedly improved their survival compared to controls that did not receive resuscitation. Even more exciting was the fact that administration of VPA alone (without blood product administration) resulted in a survival rate that approached that of animals who received aggressive resuscitation with whole

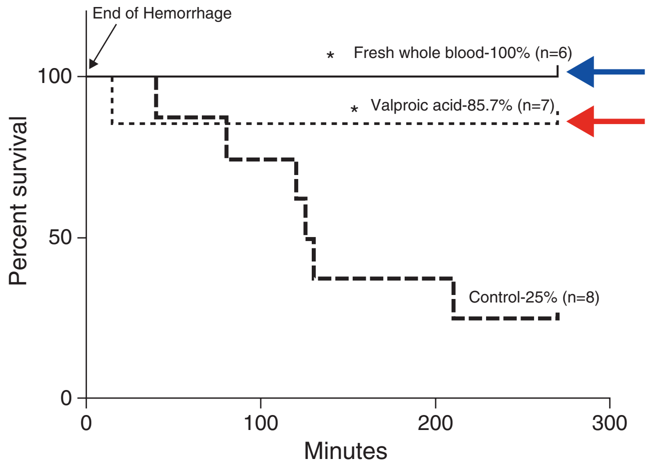


**Fig. 45.4** Survival in a porcine model of hemorrhagic shock. Note the 25% survival of control animals was markedly improved to 86% with valproic acid administration only (*red arrow*), which approached the survival seen with full whole blood resuscitation (*blue arrow*) (Reprinted from *Surgery*, 146, Hasan B. Alam, Fahad Shuja, Muhammad U. Butt, Michael Duggan, Yongqing Li, Nikolaos Zacharias,et al., Surviving blood loss without blood transfusion in a swine poly-trauma model, 325–-333, Copyright 2009, with permission from Elsevier)

blood (Fig. 45.4). Since that time, we have demonstrated a beneficial effect of VPA not only in hemorrhage but also in models of severe traumatic brain injury, multisystem trauma, and in nontraumatic sepsis. In 2012, following years of this preclinical data supporting the use of VPA, the Food and Drug Administration approved a phase 1, single-ascending-dose, double-blind, placebo-controlled study to evaluate the safety and tolerability of in healthy volunteers and trauma patients (ClinicalTrials.gov identifier NCT01951560). Since that time, nearly 60 healthy human volunteers have participated in the study, which has identified the maximum tolerated dose of VPA. The two highest tolerated dosages of valproic acid will now be used in the second part of the trial, evaluating its tolerability, pharmacokinetics, and pharmacodynamics in trauma patients presenting with hemorrhagic shock. Through this work, the mechanism by which valproic acid exerts its effect will potentially be identified, thus opening the door for more specific pharmacologic agents that may be used in different clinical scenarios.

## Conclusions

Severe hemorrhage remains a challenging problem for the modern-day trauma team. The management of these problems will require the collaboration of groups including medical providers, engineers, basic scientists, and the military. Researchers will need to devise strategies to assist first responders in effectively identifying patients who may benefit from new-age interventions. In order to maximize the yield for future studies, efforts are currently being directed toward continuous analysis of battlefield injuries. This data-driven approach allows for evidence-based improvements to be made to current recommendations that exist for the management of traumatic hemorrhage—ultimately resulting in lower death rates for the injured.

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# Resident Readiness and Training the Surgeon for Battlefield Care

# 46

Jennifer M. Gurney, Daniel W. Nelson,
and C. William Schwab

**Deployment Experience**

| | |
|---|---|
| *Jennifer M. Gurney* | 758th Forward Surgical Team, Tarin Kowt and Asadabad, Afghanistan, 2005–2006 |
| | 102nd Forward Surgical Team, Mosul, Iraq, 2008 |
| | 86th Combat Support Hospital, Baghdad, Iraq, 2008 |
| | 115th Combat Support Hospital, Helmand Province, Afghanistan, 2011 |
| | KFOR Combat Support Hospital, Camp Bondsteel, Kosovo, 2012 |
| | 745th Forward Surgical Team, Jalalabad, Afghanistan, 2015 |
| | 8th Forward Surgical Team, Kabul, Afghanistan 2015 |

J.M. Gurney
United States Army Institute of Surgical Research, San Antonio Military Medical Center, Department of Surgery, San Antonio, TX, USA

D.W. Nelson (✉)
Brian Allgood Army Community Hospital, Department of General Surgery, Seoul, South Korea
e-mail: daniel.w.nelson.mil@mail.mil

C.W. Schwab
University of Pennsylvania Perelman School of Medicine, Penn Presbyterian Medical Center, Department of Surgery, Philadelphia, PA, USA




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*War is the only proper school for surgeons.*

Hippocrates

*But when it's all over and the new surgeon is turned loose to practice his art, somehow he's ready. He has to be.*

William A. Nelson, MD

## Daniel W. Nelson, DO: The Chief Resident's Perspective

**BLUF Box (Bottom Line Up Front)**

1. There are many "unknowns" when preparing for your first combat deployment.
2. Resident training has provided the necessary foundational elements to safely and effectively treat even the most devastating injuries. Trust your training.
3. Several validated trauma programs are available and being implemented to supplement the surgical training core curriculum.
4. Experience with MASCAL situations, although rare in civilian trauma, is the norm during deployment.
5. Re-acclimating to civilian practice following deployment remains an issue.

### Introduction

Springtime. Chief year. After enduring 5 (or more) arduous years of training, most general surgery residents are preparing to embark on a career in surgery in their first professional staff position or continue their training in fellowship. A much smaller proportion of us, having sensed a calling to service, will instead be receiving our first official orders and instructions to prepare for our first combat deployment. Although military surgical residency training programs largely follow the same processes and paradigms as any civilian program, the military staff and trainees must always be aware of the one key and stark contrast between the two: when the civilian resident graduates, he or she will either be moving on to fellowship (more years of direct supervision) or to a civilian clinical practice in a well-resourced facility and with senior colleagues/mentors readily available to assist them with any problems of difficult clinical scenarios. In contrast, the military residency graduate has to be prepared to go from trainee status on June 30 to potentially getting on a plane on July 1 to deploy with a forward surgical team to an active combat zone. In this environment, he or she may have no senior colleague or more experienced surgeon located with them and will be called upon to take care of the most severely injured trauma patients that exist.

## Am I Ready?

As I'm sure many can attest, preparing for that first combat deployment can provoke unparalleled anxiety. *How close to the "action" will I be and how busy has the area where I'm going been? Will I be the only surgeon or will I have backup? If I have backup, what is their level of experience? How experienced is my support staff? What diagnostic capabilities will I have available? How will I deal with injuries that I've never encountered before?* Certainly, these questions only strike the surface of the many concerns that will dominate my thoughts, not to mention the endless litany of clinical scenarios I will begin to mentally examine and determine how I'll handle them when they occur.

Assessing the competency and readiness of surgical trainees to move on from residency as licensed practicing providers is a hot topic in the surgical literature, so how could anyone fresh out of residency possibly be ready to be placed in a situation as a solo provider in an austere environment dealing with devastating injuries, using minimal equipment and a head lamp? On the one hand, I am certainly confident that my surgical training has provided the foundational elements necessary to deal with everything from the most basic to the most complex surgical dilemmas. Knowing normal anatomy, understanding physiology of injury, and trusting the technical skills acquired during the training years will all allow the recent graduate to approach a significantly injured patient in an organized and systematic fashion.

Relying on the experiences and lessons learned from our mentors over the last 15 years of active military engagements, a greater emphasis has been placed on preparing surgical trainees for deployment. In addition to the required trauma rotations mandated by the ACGME core curriculum, the trauma experience of trainees is being increasingly supplemented by emphasizing Advanced Trauma Life Support algorithms, providing courses such as the Combat Casualty Care Course (C4), and instituting simulation-based training such as Tactical Combat Casualty Care (TCCC) and, more recently, the implementation of the American College of Surgeons-affiliated courses Advanced Trauma Operative Management (ATOM) and Advanced Surgical Skills in the Exposure of Trauma (ASSET). These programs provide the opportunity to become familiar with the diagnosis and management of traumatic injuries as well as procedures that generally fall outside the realm of traditional civilian general surgical training.

## Did Residency Prepare Me for This?

While experiences gained on trauma rotations and the addition of supplemental training programs provided me with some semblance of confidence that I will be able to address an individual patient's injuries, there are a few issues for which I'm not sure my training has adequately prepared me.

As a resident, I had the opportunity to spend 6 months at major level 1 trauma centers in the Pacific Northwest. While I was exposed to a variety of injuries and injury patterns, I had experienced this in a considerably controlled environment surrounded by the luxuries that accompany high-volume civilian trauma centers, such as specialized trauma teams consisting of multiple experienced providers,

**Table 46.1** Recommendations for the senior surgical resident (R4/R5) to help prepare for future deployments

| Clinical | Educational |
|---|---|
| • Operate! Scrub as many cases as possible your chief year | • Stay current in ATLS<br>• Become an ATLS instructor |
| • Do as many teaching assistant cases as possible. Taking a junior through a case if the BEST way to advance your skills | • Take the ATOM course<br>• Take the ASSET course<br>• Take advantage of animal labs |
| • Seek out the most challenging cases and patients<br>• Don't adopt the "shift work" mentality; take ownership of every patient | • Read *Top Knife* cover to cover<br>• Read available journal articles on combat topics and experiences<br>• Prepare for your board exams |
| • Bone up on your ICU care – you may be the intensivist for your unit<br>• Use your staff mentors – talk to them about their deployment experiences and cases | • Take advantage of online educational resources through the major trauma organizations like AAST and EAST<br>• Attend regional and national trauma meetings like AAST, EAST, and WTA |
| • Learn how to do a rapid temporary abdominal closure if you are not already comfortable and familiar | • Read up on basic orthopedic fracture management and basic genital and urologic trauma management |
| • Perform as much bedside ultrasound (FAST, eFAST, limited echo, procedural guidance) as you can – you will need it! | • Take an ultrasound course if you are able. If not, there are many self-study courses available online |

well-trained and experienced support staff, rapidly available advanced diagnostic imaging, readily accessible consulting specialists, and ample consumable resources. In addition, it was rare to have to deal with more than one to three acutely injured patients at any given time. Conversely, in the combat casualty environment, it seems that multiple severely injured patients and mass casualty management are common. This is probably my single greatest anxiety related to deployment – *with no prior experience and lack of the amenities and resources associated with a civilian trauma center, how will I be able to prepare and effectively deal with my first MASCAL scenario?* The cornerstone of effective mass casualty management requires experience with triage and patient prioritization. Trauma rotations did not prepare me for making life or death decisions regarding who I have the best chance of saving, let alone how to deal with the guilt of not being able to save them all.

I have also often thought about the difficulties associated with the transition back to civilian practice following deployment. Much of the operative experience in today's surgical residencies consists of minimally invasive surgery. In the vast majority of cases in this day and age, residents will perform their first appendectomy or cholecystectomy via laparoscopy. Many advanced procedures such as gastric bypass or fundoplication may only be performed using the laparoscopic approach during a resident's training. Conversely, surgery in the deployed setting is performed through a large laparotomy incision. After being deployed for 9 months, what will happen to these perishable skills that I only recently acquired? I have had colleagues who on the one hand were fortunate enough to have not had to operate on many soldiers. The flip side of this is that following training, instead of entering a busy practice where they could fine-tune their skills and grow as individual surgeons, they immediately spent close to a year with minimal operative experience. Their greatest anxiety ended up being a lack of confidence to operate once they returned from deployment. Table 46.1 lists a number of recommendations for clinical and educational efforts that you can take as a senior resident to better prepare yourself for potential deployment shortly after you graduate.

## Jennifer M. Gurney, MD: The Junior Surgeon's Perspective

**BLUF Box (Bottom Line Up Front)**

1. There are many "unknowns" when preparing for any deployment.
2. Trust your training, but continue to train.
3. On deployments, prepare your team, stay prepared; train your team, stay trained; have a MASCAL plan; have a whole blood plan; know and utilize the resources on your base; be a leader.

*While failing to prepare, you are preparing to fail.*

*Benjamin Franklin*

### Introduction

It has been touted a million times "War is the only proper school for surgeons." Hippocrates was correct circa 400 BC. But this raises the question: how is a surgeon properly schooled for war? There is no doubt that military surgeons have improved their capabilities during wars in Afghanistan and Iraq over the last 14 years. Parallel with our skill improvement were advances in patient transport, battlefield vehicles, body armor, prehospital care, the development of the Joint Trauma System Clinical Practice Guidelines, and resuscitation strategies. This begs the question: how do we really know if military surgeons became better surgeons after multiple busy combat deployments, or was it just an improved system of care? The answer: ask one. If one were to ask any military surgeon who had one or more busy combat deployments if that experience made them a better surgeon, the answer would uniformly be yes. The old adage *practice makes perfect* does not sound so virtuous when discussing the craft of surgery, but can instead be translated into *experience saves lives*. The statement is adjudicated every day around the world when the *experienced surgeon* gets called into the operating room to help with a complex case or for an opinion regarding an unexpected finding. This brings us back to the question: how is a surgeon properly schooled for war?

Surgeons *may* be the most ready for deployment in the months to a year following residency training. In residency we are broadly exposed to surgical disease, including trauma. The ACGME has recently increased the trauma requirements, and most military training programs are staffed with surgeons who have been deployed to at least one combat zone and incorporate combat trauma-relevant pearls into daily residency training and teaching. While many would argue that it is not ideal to deploy a junior surgeon who has just completed training, I would argue that it is less ideal to deploy a surgeon who has spent the last 2 or more years doing mostly laparoscopy and had zero exposure to trauma; at least the new grad would presumably have had exposure to major trauma cases within a year. But we have to realize that we are continually walking a fine line between being a junior surgeon who has recently done significant training in trauma care but who lacks experience and the older surgeon who may be in the exact opposite situation. Where that line is drawn, and how far to one side or the other we steer, is an area of continuing ongoing discussion and debate.

## After Residency

After graduating residency, a proportion of military surgeons get stationed at Military Treatment Facilities (MTFs) with slow clinical practices and minimal to no trauma exposure; in my opinion, this is an unfortunate and potentially perilous reality. The immediate years following residency training are crucial for continued growth and skill development as one embarks on operating with complete autonomy and surgeons with latent practices during the early post-residency years are at risk for struggling on their first deployment. A survey that was done in 2015 as part of a performance improvement (PI) project with the military Office of the Surgeon General Consultants demonstrated that Army surgeons just out of residency were more comfortable with their deployment readiness trauma skills than those who were farther from training. These results either support the earlier statement that military residency training (and presumed recent exposure to complex trauma patients) prepares a surgeon for deployment or it incites the Dunning-Kruger effect where the inexperienced lack awareness of potential incompetence. As a surgeon who deployed 4 months after graduating residency, I hope it is the former; however, the survey results were interesting in demonstrating that surgeons who never deployed (including those remote from residency training) had more confidence in their deployment-relevant trauma skills than those who had deployed previously. The survey is still undergoing analysis and results will be published in the future. What is very clear from the survey is that most respondents deployed within 1 year of completing residency training, and many had not even completed their board certification process at the time of the first deployment (Fig. 46.1).

For the practicing surgeon at an MTF, it is important to participate in structured surgery (and ideally trauma related), PI, and trauma-relevant education on a regular basis. Surgeons at big medical centers or at civilian centers can easily attend these forums as they are usually established and reoccurring meetings; however, this is not always the case for smaller MTFs. As residents, we fear the morbidity and mortality conferences because we are usually the ones presenting the complications and may feel like we are facing a firing squad – at least that was my experience as a resident. As attending surgeons we realize the true value of these conferences and projects. A structured performance improvement system and attendance at conferences enables system-based learning and keeps us engaged in managing complex patients and complications.

While active involvement in continuous educational efforts and PI improves surgical awareness and helps maintain currency, these opportunities are unfortunately not always readily available at some of the smaller MTFs. In these situations,

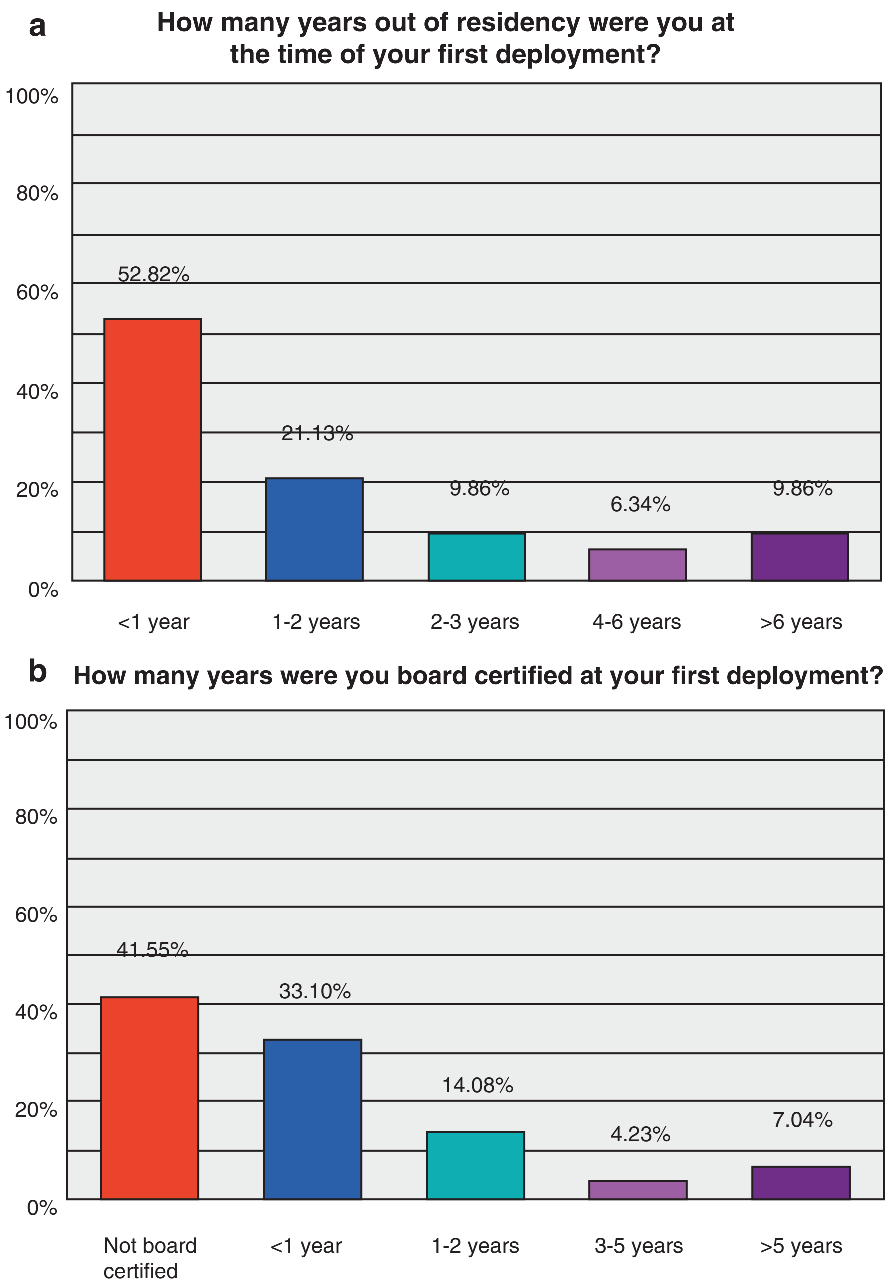


**Fig. 46.1** Results from a survey of military surgeons demonstrated that (**a**) the majority deployed within a year of completing their residency training, and (**b**) many (44%) had not yet completed their board certification at the time of their first deployment

military surgeons should seek out or initiate PI and educational endeavors at their MTF. Military surgeons who are stationed at small MTFs can participate in PI and CME outside their institutions through the American College of Surgeons and the military's Joint Trauma System or by attending meetings and seeking out conferences that address individual and system challenges in caring for complex trauma patient, such as the AAST and EAST meetings. The Joint Trauma System has a weekly performance improvement and educational conference every Thursday. During this conference, which is over 10 years in the running, combat casualties are presented from point of injury through the continuum of care. Patient management and the system of care are discussed, problems are troubleshot, advances in battlefield medicine are highlighted, and system- and provider-relevant issues are addressed with the intent to afford the providers along the care continuum follow-up as well as to continuously analyze and improve patient care. When casualty volumes are low, a continuing education lecture occurs that addresses relevant issues pertaining to combat casualty care.

At this point in time, you absolutely cannot rely on the military to get you trauma-ready for deployment; that is your responsibility and your patients' lives will depend on your initiative to do so. Hopefully in the future, Tri-Service opportunities for trauma surgery skill sustainment will be readily available. The ASSET (Advanced Surgical Skills for Exposure in Trauma) and EWS (Emergency War Surgery) courses are being offered more frequently by the military, but deploying surgeons have to frequently take the initiative to enroll in them. In the previous section, Dr. Nelson mentioned the value of these courses; there is no doubt that they are incredibly valuable. Dr. Nelson also mentioned that these "programs provide the opportunity to become *familiar* with the diagnosis and management of traumatic injuries as well as procedures that generally fall outside the realm of traditional civilian general surgery training." That is a true statement; but I wonder if *familiar* is enough? While the courses indisputably have extraordinary value, I am of the opinion that familiarization training is not sufficient to provide exceptional trauma care to potentially fatally wounded combat casualties. Consider this analogy: in the Army, physicians do *familiarization* weapons training prior to deployment; so I am familiar and can reproducibly hit a target when I fire a pistol; however, this familiarization training has not made me an expert at shooting a pistol. Actually, if I believed there was a likelihood that my life or others' lives depended on me using my weapon, I would take the initiative to become an expert. I am of the opinion that the same paradigm should apply to combat casualty care. Hopefully in the future, ample opportunities will arise to provide military surgeons both sustainment and pre-deployment training opportunities facilitating nothing less than expertise in battlefield trauma care. Table 46.2 lists a number of recommendations for clinical and educational efforts that you can take as a junior staff surgeon to better prepare yourself for potential upcoming deployments. Table 46.3 presents some nonclinical advice for an upcoming deployment.

**Table 46.2** Recommendations for the junior surgeon to help prepare for deployments shortly after completing residency training

| Clinical | Educational |
|---|---|
| • Operate! Be aggressive at finding cases at your current duty assignment | • Become an ATLS instructor if you are not already one |
| • Scrub in with your partners to assist, particularly on any open cases or more complex cases | • Take the ATOM course<br>• Take the ASSET course<br>• Become an ATOM/ASSET instructor if possible |
| • Scrubbing in on basic orthopedic cases will be of huge benefit. Scrub for a few craniotomies as well | • FCCS course is a great refresher on ICU care<br>• Read through the JTS CPGs |
| • Participate in trauma and/or emergency general surgery call at your local trauma center, either through formal cooperative agreements or as moonlighting | • Carry an electronic copy of the CPGs<br>• Read *Top Knife* cover to cover again<br>• Read this book cover to cover |
| • Use your colleagues; many of them will have multiple deployments under their belts and are happy to share their experiences and advice | • Read available journal articles on combat topics and experiences<br>• Take advantage of online educational resources through the major trauma organizations like AAST and EAST |
| • If you did not become proficient at ultrasound in your residency, take a formal course or training program, or set one up with your local radiologist | • Watch and/or listen to online episodes of the "Case Records of the JTS" series. Should be available as both video recordings and audio podcasts |
| • *Operational*: Learn as much military organization and structure in terms of the "lingo" and unit operations. If you are on a small FOB and you understand basic military operations, you will be able to communicate well with base leadership and impact the regional trauma care system | • Try to get your specialty board exams completed and done before the deployment |

## Readiness to Deploy Versus "Readiness" for Deployment

The manner in which the military defines "readiness to deploy" is not congruous to how surgeons define "readiness for deployment." Deployment readiness from a military standpoint has nothing to do with clinical skills and patient care and instead is having a hearing test, passing a physical training test, being up to date on vaccinations, weapon familiarization training, and many hours of computer-based training. However, this does not make us ready to perform our jobs as surgeons! Currently there is no test of proficiency to demonstrate if a surgeon in the military is competent to provide battlefield combat care; fortunately, surgeons are usually self-motivated and incredibly invested in our abilities to provide excellent battlefield trauma care. As stated previously, surgeons cannot rely on military pre-deployment training platforms to generate the skills we need to care for combat casualties since surgeons and the military have inherent differences in the definition of "readiness."

**Table 46.3** List of top ten pieces of nonclinical advice for an upcoming deployment

| | |
|---|---|
| 1. | Find out what unit you are deploying with, where they are going, and who the key leadership personnel are. Contact the unit commander as soon as you can |
| 2. | Do as many of the training requirements as you can BEFORE you leave to either join you deploying unit or go to CRC (if you are deploying as a replacement). This will free up countless hours of your time |
| 3. | Find out the name and contact info for one of the surgeons you are replacing or who is currently at the location you are being sent to. They will usually be very happy to give you detailed information about the location, advice for packing and traveling, what you need to bring, what is available there already, etc. |
| 4. | Minimize the baggage that you bring during the travel process to the combat zone. It is usually a multiday or longer travel process, and you will lug all of your bags around. Pack sparingly and store extra uniforms and duplicate clothing gear with a friend or in a storage locker |
| 5. | Pack a footlocker full of the key stuff that you want to have with you for your deployment, and mail it ahead of you to your contact person at that location. Important items are usually sheets and pillows, extra PT uniforms and athletic shoes, books, study materials, DVDs/hard drive with movies, scrubs, and other personal items |
| 6. | If you are out of shape, hit the gym now to start getting in shape. Deployments are much more physically demanding than duty at your home station |
| 7. | Make sure you get at least 90-day worth of any medications that you take. Enroll with the TRICARE Mail Order Pharmacy for easy online renewal and mail delivery of prescription refills |
| 8. | Summers are hot in the desert – no surprise. Winters can get very cold – which is a surprise to many. Pack appropriate cold-weather gear if you are going to be there during the winter months, and look up the local weather/temperature patterns. The military issues cold-weather gear; bring most of it with you if you are going to be there during the winter |
| 9. | Clear your schedule for the last 3–4 weeks before you leave. You will need this to take care of last minute items and complete your out-processing steps and paperwork but most importantly to spend quality time with your family and friends |
| 10. | Prepare for "Groundhog Day." Deployments have been accurately characterized as long periods of boredom punctuated by minutes of sheer terror. Life on a forward base is usually monotony, so bring entertainment items and overdue work projects that you can finish, enroll in any military professional education that you can (such as ILE), or take up a new hobby. A reliable and rugged laptop computer or tablet is a must |

As surgeons, only we know if our skill set is equipped with the full spectrum of capabilities to manage a severely injured trauma patient. It is prudent to do a candid self-assessment and recognize if there are gaps in our training or current practice. While the military will ensure you have a recent hearing test and an updated Last Will and Testament, there will be no inquiries about the last time you placed a vascular shunt, massively transfused a patient, or performed a resuscitative thoracotomy. Since checks and balances for surgical proficiency and readiness do not exist at this time, it is up to the surgeon to self-assess and take action for personal skill improvement if necessary. This can be achieved by making the effort to ensure trauma care is included in your practice. There are however serious impediments to easily achieve this in our current military system of stateside care, but getting exposure and performing as many complex cases as possible are a crucial part of skill sustainment.

## Deployment to a Role 2

The challenge of being a Role 2 (R2) surgeon is that you may be the only general surgeon on the team if the battle space requires split-base operations. While the personnel requirements of the current Role 2, forward surgical team (FST), is under revision, future operations may still require general surgeons to operate assisted by an orthopedic surgeon, an OR tech, or a medic. The challenges here are obvious: if you are working with an assistant who has never retracted bowel, operated on blood vessels, or helped expose the retroperitoneum, the case will be more challenging and take longer. Orthopedic surgeons can be great assistants in the chest, abdomen, and pelvis, but it is crucial that you train and operate together as much as possible to understand each other's strengths and limitations. Working with the whole team on small cases, doing routine case-based training, going through instrument sets, and explaining how you conduct large operations or obtain hemorrhage control are an investment that will enable success when it is most important. Outcomes rely on the individual skill of the providers comparable more on small teams than at larger battlefield hospitals where there are multiple surgeons. Developing mutual understandings of how you and your teammates operate will improve the conduct and efficiency of the surgeries performed in these challenging, austere, and potentially resource-limited environments.

There has been a trend to break up the R2 into smaller components, sometimes just a surgeon with an anesthesia provider and a nurse, and push the team very far forward where the term "limited resources" is vastly understated, especially when it comes to man power. In these situations, I think it is best to be honest with the leadership about the true capabilities of a two- to three-person team. While you may be able to care for one or two moderately wounded trauma patients, a small team that has not trained together for these far-forward missions will have challenges. If one considers all the procedures that occur within the first 10 min of managing a critically injured patient – getting an airway, removing the uniform, bag ventilation, IV access, transfusing blood, administering medications and anesthesia, FAST, Foley, possible chest tubes, opening instruments, and then operating to control hemorrhage – this is a lot to do quickly with just a few people. We all know that major traumas with life-threatening hemorrhage are very personnel and resource intensive, and it takes more than two to three people to do it quickly and efficiently. This is not to say that two- to three-person teams cannot be greatly beneficial and offset the tyranny of distance that many of these small teams face in ultra-austere areas of operations; however, the importance of team training cannot be overemphasized for these missions, and the clinical limitations are implicit. If you have to support these "ultra-lite missions" on your first deployment, be candid about the surgical capabilities of a two- to three-person team; use as many damage control resuscitation strategies as possible (TXA, whole blood, freeze-dried plasma, tourniquets, limited crystalloid, possibly REBOA) to avoid a major surgery; if you have to operate, attempt to do the minimal amount of surgery possible, especially if you do not have an assistant, get temporary hemorrhage control (packs and clamps), and try to get the patient to an operating room with some support while continuing damage control resuscitation strategies during transport.

In Role 2, forward surgical teams (full or split), it is not just the technical aspects of the surgery that must be mastered but also all the simultaneous activities ongoing in the operating room (fluid and blood resuscitation, patient's physiologic response to anesthesia), the ATLS/resuscitation bay, the continued potential for multiple casualties, and the patient evacuation plan. Since surgeons are natural leaders and many can multitask, most surgeons likely do this as second nature; but during intense and challenging operative cases, our comprehensive focus quickly narrows. While intense focus is necessary for the technically challenging surgical cases, it is an unacceptable disappointment to get hemorrhage control on a patient only to learn that you have been operating for over an hour; the CRNA has given 4 units of blood, no FFP, and 5 L of crystalloid; the patient has been on intermittent vasopressors; their temperature is 33.5 °C; and there are three more urgent surgical patients in the trauma bay. The R2 surgeon must be able to simultaneously operate, communicate well with anesthesia, keep the 10,000-foot view of the trauma bay, and be aware of the inflow and outflow of patients from the facility. This is not easy and may be more of a challenge for the new graduate who has not had much experience as a fully independent surgeon.

## Potential Role 2 Pitfalls

**Pitfall**

*Not recognizing the need for damage control surgery*. Every major trauma in a far-forward, single (general) surgeon R2 environment, with resource constraints, limited holding capacity and robust evacuation capabilities should be a damage control surgery. The cases that are not "damage control" should be the exception, and not the norm, for seriously injured trauma patients. The primary goal of the R2 team is hemorrhage control. At the Role 2, the goal is surgical intervention to prevent or treat the lethal triad with damage control techniques, bridging the gap between the initial injury and definitive care.

**Pitfall**

*Not clearly communicating with the anesthesia provider and understanding their capability*. Lack of good communication with the team on the other side of the blue drape may be lethal for the patient. Some CRNAs have a large amount of experience and know how to resuscitate a trauma patient; on the other hand, you may deploy with a CRNA who has never performed a massive transfusion and has spent the last few years doing conscious sedation in an endoscopy suite. Get to know the anesthesia provider on the team; you will work very closely with them for the entire deployment. Communication throughout the case is imperative – you need to communicate about the status of hemorrhage control, and they need to communicate regarding the intraoperative resuscitation. Facilitating bidirectional communication is another skill that is easier said than done.

**Pitfall**

*Whole blood (WB) – the plan, the practice, not calling for it early enough.* Your team, and the forward operating base (FOB), must have a whole blood plan that is clear and well planned, rehearsed, and redundant. Since forward surgical teams are small and getting smaller, it is best to have reliable elements on the FOB run the WB drives (i.e., Charlie Med, unit physician assistants, senior medics from other units). Usually when WB is needed, the entire FST will be occupied with casualty care. The WB plan should have built-in redundancy (in case one of the trained units is off the FOB) and be well rehearsed. Call for WB early! If the patient meets massive transfusion criteria or you are short on blood product components, call for WB; the sooner you start WB on a massively exsanguinating patient, the sooner their physiology starts to correct.

**Pitfall**

*Not having an excellent MASCAL plan.* Use the many resources on your base available to develop your team's and FOB's MASCAL plan. Plan it, train it, rehearse it, and do an AAR (after action review) – then do that many more times! A good MASCAL plan is imperative for the success of small forward surgical teams. While what you planned will frequently vary during MASCALs, the process of planning, rehearsing, troubleshooting, and refining the MASCAL plan will serve you, the team, the FOB, and, ultimately and most importantly, the casualties well. Do not fall into the trap of thinking that you or your team doesn't need to practice and rehearse for a MASCAL. The "I'll know what to do when it happens" approach is simply foolhardy, and no team can function optimally in a MASCAL if they haven't done realistic and frequent training and rehearsals. Remember the adage that you and your unit "will fight as you've trained."

**Pitfall**

*Not keeping track of your operative time*. Many of us operate a bit slower than we think we do, especially right out of training. You may be surprised how much more challenging and longer cases are without a well-trained assistant. Speed is "a must" for the success of small surgical teams – especially during multiple casualty incidents. Tell your anesthesia provider to give you 15-min time increment reminders from the commencement of surgery. When they say "it has been 45 min," you need to be starting to conclude the damage control operation you are performing. However, there is no rule that you have to rush through every case just because you are at a Role 2. For cases that are *not* a damage control procedure, it is better to spend the extra time to do the surgery right the first time.

In summary, the Role 2 (FST) surgeon must entirely manage all aspects of the battlefield trauma patient – from the resuscitation to the surgery to the post-op/ICU care to the timing of evacuation. Good communication, leadership, and technical proficiencies are all necessary for the success of the R2 surgeon. While these attributes are important for the success of any battlefield, or even stateside, surgeon, they are absolutely crucial for the success of a small, far-forward surgical team.

## Deployment to a Role 3

The nice thing about being at a Role 3 (R3) combat support hospital (CSH) is that there are multiple general surgeons and frequently there is a trauma surgeon, vascular surgeon, and sometimes a neurosurgeon. Just out of residency, a busy R3 deployment is like a trauma fellowship – there is always someone available to help, which is a luxury not always appreciated until you are deployed as the sole surgeon. Just like at the R2, success depends on communication, understanding team and facility limitations, having excellent and frequently trained MASCAL and whole blood plans, and of course being a well-trained, well-practiced surgeon.

During the recent Iraq and Afghanistan wars, strategic placement of surgical capabilities in the battle space was not a priority; instead, a warm body with a “surgeon” designation was sufficient – this may have been secondary to the deployment tempo. A pitfall for a young surgeon recently out of residency is the assumption that an experienced surgeon is experienced in trauma management. For example, you may know more about trauma than a senior cardiothoracic surgeon who hasn’t operated in the abdomen or pelvis in over a decade. Do not assume that seniority equates to experience, although it frequently does. It can be a challenge to have to inform a senior ranking officer that they are taking too long to do a damage control laparotomy, but patients’ lives will necessitate that you speak up, communicate effectively, and do the right thing for the patient. Professional respect and communication are paramount at a CSH. Future R3 hospitals will likely include a Trauma Medical Director as current Air Force CSHs already do.

The “team concept” at a R3 hospital takes on a different dynamic than at a R2. There are multiple other surgical specialties, ER physicians, a variety of nurses, and ancillary staff. Skill level and trauma experience will vary. At the R2 you will more readily know the capabilities and weaknesses of every team member; it becomes quickly apparent following the team’s first major trauma; therefore it is easier to train cohesively and have rapid team progress. Secondary to the size, the heterogeneity of skills, and the multiple specialists at a R3 hospital, it can be more challenging to develop a cohesive team that communicates effectively and is in sync in the resuscitation bay and in the OR. Technical competency, knowledge of, and currency in, trauma management, the ability to communicate well, being a team player, and understanding the theater of operations are elements for a successful deployment to a R3.

## After Deployment

The concerns with returning home from deployment and resuming clinical practice were discussed in Dr. Nelson's section. Skill sustainment, currency, and competency go both ways: from stateside practice to deployed surgery and from deployed combat casualty care to stateside practice. Returning to civilian hospital-based care after spending 6–12 months deployed can be difficult. A relatively straightforward laparoscopic case may be challenging after not performing minimal invasive surgery for many months.

Future surgical leadership should recognize the struggles of surgeons who are in any type of practice transition and encourage opportunities for skill refreshers – whether they are mini workshops, refresher courses, high-fidelity simulation classes, or 2–4-week rotations at high-volume centers. While other elite professions readily adopt this type of paradigm, i.e., the airline industry and professional athletes, in surgery, we mistakenly associate seeking out this type of training opportunity as remedial. Prior to airline pilots switching airframes, refresher training and proof of competency are a requirement. Similarly an elite athlete who spent time away from their sport would not be expected to be a starting player without considerable practice and training. Why we haven't incorporated analogous training platforms in the field of surgery is perplexing, but it may be secondary to long-standing traditions, perceptions, and the belief that general surgeons are experts in all surgical procedures. While this may have been the situation 10–20 years ago, it is no longer true. Surgical leadership will hopefully recognize and adopt professional, collaborative, and valuable training platforms that will meet the currency/competency needs of military surgeons whose careers may require a diverse and dynamic practice environment.

## The Way Forward and Future Directions for the Sustainment of Currency and Competency in the Military Health System

I have heard senior surgical leadership state "trauma is not hard; all you have to do is make a bigger incision." That may be a true statement for 90% of combat casualties, but for 10%, it is more than making a big incision. For some devastating combat injuries, saving the patient's life *is* hard. It encompasses surgical expertise, a well-coordinated approach led by the surgeon and involving the entire operating room team, a well-designed and rehearsed whole blood plan, and an understanding of the resource and evacuation limitations of the environment. Going forward it is imperative that military surgeons sustain their currency and competency in trauma management.

In the first section of this chapter, Dr. Nelson stated: "I am certainly confident that my surgical training has provided the foundational elements necessary to deal with everything from the most basic to the most complex surgical dilemmas. Knowing normal anatomy, understanding physiology of injury, trusting the technical skills acquired during the training years, all will allow the recent graduate to approach a significantly injured patient in an organized and systematic fashion." That is true, to a point. Good surgical residency training does not substitute for continued sustainment training and involvement in ongoing complex trauma care.

As a surgeon who deployed a few months after graduating from residency as the only general surgeon on a busy split-ops FST, I can attest to the angst and concerns regarding preparedness that a young surgeon feels in this situation. The responsibility is incredible and of a much greater magnitude than anything we experience in residency. Following residency, I did feel somewhat prepared for the surgical challenges because as a resident who graduated from Walter Reed in 2005, I had taken care of many hundreds of combat casualties from the Iraq and Afghanistan wars. I remember vividly the night that the first triple amputee of these wars arrived at Walter Reed; so, prior to my first deployment, I had understood the extremely devastating nature of the combat injuries which I would manage during deployment. Also, Walter Reed residents rotated at the Shock Trauma Center in Baltimore where the surgeons were dedicated and greatly invested in our trauma training. I remain grateful for that training and experience; it was integral to my success during my first deployment. Military surgeons in residency must get exposure to complex trauma cases and ideally learn from experts; fortunately, our leadership ensures this occurs.

Military surgeons have challenges going forward in order to maintain currency and competency with surgical combat casualty care. Our leadership must continue to understand the challenges that we face as a surgical community. Currently, most military hospitals do provide the continued volume and experience to provide surgeons with sustainment capability to manage severely wounded battlefield casualties. Systems to help train and sustain combat-relevant trauma skills have to be incorporated into our practices, be maintained, and continue to evolve as emerging techniques and strategies develop to care for complex combat casualties. Training should be individualized as necessary and made readily available. Training and preparedness should ensure individual currency and competency and emphasize the crucial importance of the team training and the system of combat casualty care.

During the last two decades of war, there have been dramatic advances in military medicine that have improved trauma care, not just in combat and deployed mass casualties, but also in civilian trauma and civilian mass casualty events. If combat operations decrease and the focus in military hospitals is no longer war related, surgeon preparedness to care for combat casualties has the potential for significant degradation. National efforts are underway to ensure that the lessons learned from the military experience in Iraq and Afghanistan are sustained; these efforts must be a priority for individual surgeons in order to facilitate their personal success in the deployed environment. It has been said many times that in the last decade, we have seen unprecedented combat casualty survival rates; while they may be the best so far, it does not mean that they can't be better – which is what we should continually strive for. It is also imperative that we avoid the abrupt postwar shifts away from the lessons learned on the battlefield. It is up to military surgeons to make continued readiness a priority. The conundrum remains in that the majority of military surgeons do not care for trauma patients on a regular basis. As a community, we do not want to find ourselves unprepared to manage severely wounded combat casualties. Military surgeons must find a way to invest in training and preparedness to avoid being ill prepared for the demands of battlefield trauma care.

Most military surgeons are faced with the challenge to seek out opportunities to stay surgically relevant, sometimes in our daily practices, but also to continue to evolve and codify our trauma skills. The more you do, the more you do and (likely) the better you are. There is no arguing the statement: *experience saves* lives. Young surgeons who find themselves in "sleepy" surgical practices should take initiatives to care for surgically complex patients – in the operating room and during the perioperative period. If the hospitals we are stationed cannot provide those opportunities, then civilian collaboration is a potential and worthwhile mechanism for skill sustainment. Robust and worthwhile sustainment and pre-deployment training will hopefully be available in the future to enable continued trauma expertise. As a military surgeon, you must be proficient at trauma surgery; it is our obligation.

## Civilian Translation of Military Experience and Lessons Learned

C. William Schwab

*I completed my surgical training in the United States Navy during the Viet Nam era and throughout my career, have remained close to those who served in the medical services of the Department of Defense. In the last 20 years, our trauma programs have been privileged to train more than twenty military surgeons. Eighteen completed their trauma and surgical critical care fellowships at Penn and subsequently, became the inspirations for reframing the paradigm of how to train a modern trauma surgeon. These comments are respectfully offered in honor of all who have served in the Armed Forces and whose labors have forever advanced medicine.*

Perhaps this 2006 email from Iraq might afford a deeper appreciation of the messages contained in this chapter:

> CWS-
> Hope all is well. Bad few days here. In the middle of three days of operating from a MASCAL on Thursday night – 9 patients from same incident – all with 50 cal injuries - have never seen so much devastation in my life – everyone bleeding to death at the same time – couldn't work fast enough. We used a case of Hemcon dressings on those triaged to second OR turn...We are on round two today of washouts, bone stabilizations. Everyone needed colostomies, a few re-vasc – probably lose some limbs today – just unbelievable... exhausted and emotionally drained for the first time. Will try to get some sleep and refuel tonight. Day like this makes me miss Penn and my partners more than anything in the world next to my family.
>
> JP, Thursday March 16, 2006

Although this email from the late John Pryor, who was deployed as an Army Captain at that time, is over 10 years old, it is as powerful today as then. Powerful, because at the time he sent this, he had already been a paramedic, completed a surgery residency with heavy experiences in trauma, and excelled in our 2-year fellowship at Penn. Upon completion in 2001, he remained on the trauma faculty and rose quickly to become the director of our trauma center. John was a superb trauma surgeon, but even a journey as rich as this did not prepare him for the battlefield.

Ours is a busy center with high volumes of gunshot injuries, patients simultaneously arriving from several EMS systems and a large helicopter volume. At the time, I thought these ingredients were the "right stuff" to train trauma surgeons. John Pryor's message was powerful because its stark reality crumbled my delusions. Other similar messages from our surgeons "at the front" and subsequent studies of preventable deaths on the battlefield provided further and compelling insights. Collectively, these demanded a shift in educational philosophy and commanded *that the surgeon going to war first must learn war surgery*.

These personal accounts and sobering lessons made it obvious that to save lives, the trauma surgeon needed an *expanded* skill set and mastering of techniques and procedures *out* of the "general surgery" realm. We, their teachers, needed to find pre-deployment setting and situations to assure each surgeon was brought to a *higher proficiency* level than that accepted in traditional civilian training. We were required to provide operating room experiences that instilled a *confidence* level that was authentic. Last, it was clear that *trauma team training* with the surgeon was a critical part of preparation. Most compellingly, these messages brought an urgent need to find opportunities to train combat surgeons on a continuous basis for rapid deployments.

Drs. Nelson and Gurney, like most military surgeons, will experience or have experienced the first deployment shortly after completing their general surgery residency training. Many surgeons deployed to Role 2 settings were the team's only general surgeon. They routinely confronted mass casualty incidents and the aftermath that John Pryor wrote about. I admired their courage; nevertheless, I was struck by the repetitive theme that most of their learning had occurred "on the job." Subsequently, several papers from surgeons after deployment substantiated this as usual and customary for military surgeons early in their careers. Further evidence showed that "just-in-time" training experiences lacked standardization and were underutilized across the respective services. None provided customized skill training for the individual surgeon. Team training was infrequent and rare to include the surgeon. Our own data supported these messages and revealed that about half of the surgeons felt their trauma and operating room teams were not adequately prepared.

The above issues have not gone unnoticed. In June of 2016, a report published by the National Academy of Sciences, Engineering, and Medicine calls for creating a national trauma system by integrating the military and civilian trauma systems. The report describes a constantly learning trauma system that at the core prepares its providers to the expert level and collaboratively work to achieve zero preventable deaths. This singular national trauma system creates bidirectional flow of experiences, data, and knowledge between the military and civilian sectors at all levels of the system and its stakeholders. The report provides specific recommendations on creating and sustaining an expert military trauma workforce for the future.

Subsequent to the report, federal legislation that will operationalize some of the workforce recommendations in the Department of Defense has been introduced. It places the responsibility at the Defense Health Agency and establishes at that level the Joint Trauma System and Joint Trauma Education and Training Directorate. The JTS will serve as the reference body for all trauma care provided at military treatment facilities by creating standards for trauma care, coordinating the translation of research into these standards, and coordinating the adoption of the lessons learned from civilian training centers into clinical practice. The Joint Trauma Education and Training Directorate will ensure that the trauma providers of the Armed Forces maintain a state of readiness in part by partnerships with civilian academic medical centers and large metropolitan teaching hospitals that have level I civilian trauma centers.

Drs. Gurney and Nelson are to be commended for their open dialogue. It creates a unique chapter filled with important lessons for future surgeons preparing for war. The fact that Dr. Gurney has walked Dr. Nelson's future path and experienced four deployments qualifies her at the expert level as a combat surgeon and forward surgical team leader. She is a "top gun" and her messages should be treated seriously. For Dr. Nelson, who will soon face his first combat deployment, we should realize the moral imperative to him and to his future patients on the battlefield. This includes doing better than the current state of disorganized "just-in-time" pre-deployment training and then relying on "on-the-job" training, where learning opportunities may come at the cost of unnecessary morbidity or even mortality for our service members.

## Suggested Reading


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# The Deployed Advanced Care Provider

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Zaradhe M.S. Yach, Jonathan R. Van Horn,
Matthew J. Eckert, and Matthew J. Martin

**Deployment Experience**

| | |
|---|---|
| *Jonathan R. Van Horn* | 1/162 Infantry Battalion PA, Iraq, 2003–2004 |
| | 1/162 Infantry, Battalion PA, Hurricane Katrina, 2005 |
| | Task Force Phoenix V, 41st Brigade Combat Team Battalion PA, Afghanistan, 2006–2007 |
| | Task Force Gridley 1249th Engineer Battalion, 18th Engineer Brigade Senior PA, Afghanistan, 2011–2012 |
| *Zaradhe M.S. Yach* | Nurse Practitioner, Expeditionary Medical Facility Kuwait/Troop Medical Clinic, Camp Virginia, 2006–2007 |
| | Senior Medical Officer, Provincial Reconstruction Team, Ghazni, Afghanistan, 2009–2010 |

Z.M.S. Yach (✉)
Mercy Medical Group, Department of Family Medicine/Internal Medicine,
Roseville, CA, USA
e-mail: zaradhe@hotmail.com; zaradhe.yach@dignityhealth.org

J.R. Van Horn
Oregon Army National Guard, Legacy Emanuel and Randall Children's Hospital,
Department of Trauma, Portland, OR, USA

M.J. Eckert
Uniformed Services University, Madigan Army Medical Center, Department of Surgery,
Tacoma, WA, USA

M.J. Martin
Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA



M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_47

*Matthew J. Eckert* Trauma Surgeon, Camp Bastion Role 3 Hospital, Helmand, Afghanistan, 2012–2013
USSOCOM Surgical Support, Iraq, 2014–2015
USSOCOM Surgical Support, Horn of Africa, 2015–2016
USSOCOM Surgical Support, Iraq, 2016

*"You filthy surgeons better wash your hands before you touch my patients."*

Margaret Maxiner, NP

**BLUF Box (Bottom Line Up Front)**

1. Advanced care providers (ACPs) compose a large portion of the military medical manpower, including clinical and field medical leadership personnel.
2. The deployed NP/PA is a valuable asset, often with significant advanced trauma, critical care, and operational medical training and experience.
3. Military NP/PAs often have significant field unit experience, including command and staff backgrounds, knowledge of medical logistics, and military medical regulations.
4. Identify any ACPs on your deployed base or area and their resources, as they will often become one of your critical resources.
5. The ACP is a combat medical force multiplier and will bring new depth to your team.
6. Integrate any available ACPs into your unit's MASCAL plan. They will be invaluable to increasing your capabilities when you have a large number of casualties coming in.
7. You will almost never leave your base, but the ACPs will frequently have outreach missions with the local population. They can provide valuable situational awareness and information.
8. Treat them as a provider, not as an "assistant" or "nurse." You will often find them to be more skilled and adept than many of your deployed physicians, particularly for trauma care.
9. Civilian ACPs often are relegated to practice below the level of their degree and training. Deployed ACPs will usually practice at or above that level.

## Scenario 1

At 0300 our Forward Surgical Team (FST) received a warning of ten incoming "urgent surgical" patients from a suicide bomb attack on a US convoy. Our unit sprang into action and set up our six-bed receiving area, including assigning responsibilities. We had only three physicians, and so each took two of the beds, knowing we would have to hop back and forth. If one or more of us had to go immediately to the OR, then the remaining docs would have to cover even more. But then, the nurse practitioner and her team from the base Navy Provincial Reconstruction Team arrived and covered the last two beds and any "walking wounded." The MASCAL ran incredibly smoothly, and when we got out of the OR, the remaining patients were already evaluated and ready for disposition.

## Scenario 2

A 15-patient MASCAL event occurred just outside of the base where our split FST was located. Fortunately, our small unit was colocated with a Role 1 aid station commanded by an incredible physician assistant. All of the incoming patients were evaluated initially by her team, including a search for weapons or explosives, and then triaged to either our FST beds or to the aid station beds. Ten of the 15 less severely injured patients never even came into our FST, and the dreaded "over-triage" that can degrade any MASCAL response was avoided.

## Introduction

The role, numbers, and use of ACPs vary widely across the country from state to state and even more so within various medical systems and practices. Thus, physicians and surgeons may spend their entire training or portions of their career with little to no interaction with nurse practitioners (NP) or physician assistants (PA). Many providers are likely unaware of the military's unique and important part in the development, education, and use of ACPs. Moreover, many young surgeons without significant military experience prior to residency may not have an appreciation for the capabilities, backgrounds, and potential of ACPs in the world of operational medicine.

Physicians in North Carolina and Washington State identified a shortage of doctors following the Vietnam War, particularly in primary care. Former military corpsmen and medics were recruited into the first physician assistant training programs after recognizing the potential role of medical providers with significant experience, practical education, and hands-on training, without the formal background and time commitment required of medical school and residency training. The success of these programs and the ACPs they produced gave rise to training programs across the nation and within all branches of the military. Today, ACPs play a crucial role in the military medical system worldwide, across the spectrum of education and training programs, routine clinical and specialty care, and operational medicine.

ACPs, particularly physician assistants, compose a large part of the military medical manpower. The majority of military advanced practitioners have a background in general or primary care, but subspecialists in surgery, critical care, and emergency medicine exist. Many PAs have former backgrounds and careers in an enlisted field as corpsmen, medics, or other health-care specialty personnel and often with extensive operational and deployment experience. ACPs are routinely assigned to battalion-level units as primary care providers and may command units such as Forward Surgical Teams, Ambulance and Treatment Platoons, and Forward Support Medical Companies. Since these providers often serve a number of rotations in field units, they are well versed in the day-to-day management of military units and command and staff duties.

In the deployed setting, ACPs are heavily utilized in the Role I echelon of care with field units. ACPs can be found staffing sick call, aid stations, and forward medical treatment sites, on the ground with combat arms units, or assisting in Role 2 and Role 3 facilities. The background, experience, and training of these providers can be of substantial help to the deployed surgeon, particularly if you have little operational experience. Most importantly, these providers and their teams can be key assets to augment your Role 2 (or even Role 3) facility's ability to provide care for multiple simultaneous patients, or for any MASCAL incident. You should always identify any of these available assets that are colocated at your base of operations and integrate them into your team's activities and training as much as possible. They should *always* be included in your MASCAL plan and any MASCAL rehearsal drills. Beyond clinical duties, ACPs can be of significant assistance with the development and exercising of medical readiness training, executing mass casualty drills and events, preparing for CBRNE contingencies, understanding the frustrating system of medical logistics, assisting in patient evacuation and movement, and understanding the complexities of combat operations.

For the first-time deployed surgeon, the NP/PA can be a resource for the mundane details of deployed life, as follows: How do I adjust my body armor? What do I need to take with me on a convoy or flight? How can I order more of something? What should I do with this weapon they gave me? When the battalion commander asks me about something, what should I say? This is not to suggest that physicians and surgeons are inept in daily deployed life, but most spend the majority of their early career in the bubble of medical center life. The NP/PA is an important ally and colleague to the deployed physician and surgeon; develop this relationship early as it can make your deployment experiences far more successful and rewarding.

A unique subset of PAs within the military has extensive backgrounds in combat arms fields, serving as prior medics or nonmedical roles in the special operations community or other combat arms branches. These individuals often represent a fountain of knowledge and experience for medical operations planning owing to their mix of tactical and operational experience and medical background. Frequently, these individuals can help "translate" between the clinical providers and the nonmedical military leadership. When faced with difficulty communicating with chains of command or nonmedical leadership, these ACPs can be of great assistance. Regardless of the background of the advanced practitioner, the deployed surgeon is well advised to seek out and partner with these professionals to ensure a successful mission.

## Physician Assistants in the US Military

*The attack started at approximately 2300 h as the infantryman and MPs rotated guard shifts on our small FOB. About 30 soldiers had just finished an outdoor movie and were beginning to head back to their tents for the night when the rounds began to impact. The first few mortars that impacted were white phosphorous and* *fortunately impacted just outside the perimeter. However, because of the dark and sudden flash, several of those on guard duty had to be led to the Battalion Aid Station (BAS) as they were temporarily blinded. The enemy switched to high explosive (HE) at this point. Three of the GP large sleeping tents were impacted, and by sheer providence, these were the tents that housed the platoons that were on patrol that night. The rounds that impacted near those leaving the movie were another story. Multiple patients wandered/walked in the dark to the BAS, and a few were brought in by their buddies. Despite multiple extremity wounds and ongoing hemorrhage, most were ambulatory. We had practiced our mass casualty (MASCAL) plan and implemented pulling all of the casualties into the hardened old bombed out Iraqi building that housed our supply section. Tourniquets were applied, and rapid assessment showed that we had 13 casualties. Four had night blindness but intact visual acuity with ambient light, two had chest and abdominal penetrating wounds but were stable without peritoneal signs or shortness of breath, and the rest had varying degrees of penetrating extremity trauma. One soldier in particular was walking when the mortar impacted right next to a light post he was passing. Every exposed extremity had wounds in it, but his trunk was fortunately spared by the pole. He literally ran out of his shoes getting to the aid station. After the casualties were stabilized and other interventions secured, we converted applied tourniquets to pressure dressings. A 9-line MEDEVAC request was sent, but due to the enemy activity in our area, our request was denied. Because we were 15 km by ground from the nearest Role 3, we discussed the current threat situation with the battalion commander and QRF leader. We decided together to evacuate those that had the truncal injuries and eyesight changes immediately, and the others would be evacuated in the morning when the units on patrol would return and additional assets would be available. Antibiotics and pain management were given to those that remained at the BAS.*

Military physician assistants are licensed providers that function with a high degree of autonomy, often located in remote and austere locations with the units that they are attached to.

## History

The physician assistant (PA) career and training program began with Dr. Eugene Stead at Duke University with four former Navy Corpsman in 1965. The Army, Navy, and Air Force all followed shortly thereafter in 1971 initiating their own programs, and the Coast Guard sent their candidates to the Duke program. The schools were combined in 1996. The program was modeled after the shortened physician training during the World War 2. The role of the military physician assistant was implemented to augment and supplement the physician shortages across the military.

## Training

The majority of physician assistant programs require an undergraduate degree and a substantial number of clinical hours and consist of 24–30 months of training that is divided nearly equally by didactic education and clinical rotations. After training, PAs must pass the Physician Assistant National Certification Exam (PANCE) and are required to pass the Physician Assistant National Recertification Exam (PANRE) every 10 years, along with ongoing continuing medical education.

Physician assistants that matriculate through the Interservice Physician Assistant Program (IPAP) have on average approximately 10 years of prior service. Because of this experience, they are a valuable asset and play a key role in the planning of medical operations and evacuation. Commanders at every level should actively engage their PAs in this planning. Each military branch offers a variety of additional skill sets for PAs including flight medicine, orthopedics, emergency medicine, general surgery, dive medicine, and others. Although most PA programs cover trauma management during the emergency medicine lectures, the IPAP program includes advanced trauma management (ATM), which is an abbreviated ATLS course that includes a live tissue lab; this is only a brief exposure to the skills that will potentially be needed during a deployment. Topics and skills covered include airway management, chest tubes, cutting down, and central line placement.

Each provider and preferably their assigned senior medic/corpsman deployed to Role 1 or 2 facilities should attend the Tactical Combat Medical Course located at Ft. Sam Houston prior to deployment. This exceptional course focuses on hands-on training and the utilization of the supplies that are in the military inventory. Additionally, data that is returned from deployed graduates is implemented into the course so that the information dispersed reflects the current practices in theater. This course also goes into detail on how to develop and conduct a "walking blood bank." The course is 10 days and is prioritized to those that are deployed to Role 1–2 facilities. During this course, review of the current blood component management practice guidelines and the development and initiation of a "walking blood bank" are covered.

Recently the American College of Surgeons Committee on Trauma removed the limitation on the number of "nonphysician" attendees during an ATLS course. This significant change now allows entire courses of PA/NPs to be conducted. Deploying PAs should also attend an ATLS course in order to refresh management of casualties and procedures. Those PAs that are anticipated will be stationed in a remote area, solo, or those that will be assigned to a Role 2 should strongly consider attending a Fundamentals of Critical Care Support (FCCS) course. The information in this course is vital to those that will be initiating and managing ventilators, sedation, and pressors for casualties. Additionally, courses in the use of ultrasound and extended focused assessment with sonography in trauma (E/FAST) exam should be sought out as this can provide a significant clinical tool.

## Roles

Physician assistants are currently utilized in a multitude of roles including Battalion Aid Stations, forward and main support medical companies, Medical Battalions, special operations, aviation, and naval Shock Trauma Platoons to plan and command positions (Fig. 47.1). Battalion Aid Stations are often colocated with Forward

**Fig. 47.1** Physician assistant (author JV) treating a local Iraqi national, 2003, Senior Medic in foreground (Photo courtesy of Jon Van Horn)

**Fig. 47.2** Physician assistant (author JV) and Senior Medic suturing a wounded infantryman (Photo courtesy of Jon Van Horn)

Surgical Teams (USA), EMEDS (USAF), and Naval Forward Resuscitative Surgical System (FRSS) or coalition partners that provide surgical care. The PAs often assist these partners during mass casualty incidents to provide initial evaluation and triage, management of patients that do not require immediate surgical intervention by the local Role 2 element, and to augment the initial care capacity of the local Role 2 or 3 facility during MASCAL events (Fig. 47.2).

Depending on the unit and location, PAs provide the daily primary care of the unit personnel, and depending on staffing, by an assigned MD/DO as well. Care includes all aspects of preventive medicine, immunizations, patient tracking after evacuation, orthopedic evaluation and treatment, and minor procedures. The PA plays a key role in the training of medical and unit personnel in Tactical Combat Casualty Care. Trauma care must be reviewed and rehearsed with team members continuously to ensure expeditious management in preparation of multiple casualties. Efforts should be taken to post resuscitation algorithms in the resuscitation area for quick reference, as well as ready access to all necessary supplies.

## Nurse Practitioners in the US Military

*The Nokia cell phone pealed out its telltale ringtone, and my heart rate immediately quickened. I answered. It was the Forward Surgical Team calling to request support from the PRT medical team for a MASCAL. They were preparing to receive five Afghan National Army (ANA) soldiers who were in a Humvee when it hit an IED, rolled over, and then came under small arms fire. They were expecting a variety of injuries including gunshot wounds, chest and abdominal trauma, and multiple fractures. I quickly grabbed my stethoscope and trauma shears and rushed through the PRT building to notify my corpsmen and Army medic that we were needed in the FST. My mind was going through the ATLS ABCDEs and the roles of my team when I heard the sounds of the ANA ambulance's wheels tearing across the FOB's gravel roads. We rushed to the doors of the FST, nervous but prepared to let our training kick in.*

Nurse practitioners (NPs) have played a vital role in deployed settings around the globe. Our education, training, and skill in practicing both autonomously and collaboratively translates into the ability to support a wide variety of military and humanitarian missions worldwide. With additional training in trauma care and preparation for work in combat environments, NPs are a vital resource in our military force.

### What Is a Nurse Practitioner and What Does the Training Include?

The American Academy of Nurse Practitioners (AANP) succinctly describes the education and training of nurse practitioners (NPs): NPs have completed a master's or doctoral degree program, and have advanced clinical training beyond the initial registered nurse degree. The classroom-based coursework and clinical training during the NP program prepares for practice in primary care, acute care and long-term health-care settings. NPs provide a full range of health-care services, including ordering, performing, and interpreting diagnostic tests such as lab work and x-rays; diagnosing and treating acute and chronic conditions such as diabetes, high blood pressure, infections, and injuries; prescribing medications and other treatments; managing patients' overall care; and counseling and educating patients on disease prevention and positive health and lifestyle choices. When pursuing a master's or doctoral level program, nurse practitioner students select from a variety of specialty areas including acute care, adult health, family health, gerontology health, neonatal health, oncology, pediatric/child health, psychiatric/mental health, and women's health.

Military Nurse Corps officers can complete nurse practitioner programs part time on their own (utilizing tuition assistance or GI Bill funds); or, alternatively, once they have served two years, become worldwide assignable, meet all physical requirements, and are promotable, a Nurse Corps officer can apply for duty under instruction (DUINS) to attend a full-time master's or doctoral program at the Uniformed Services University of the Health Sciences (USUHS) or at a civilian college or university.

### How Does a Nurse Practitioner Prepare for Deployment?

Once a military nurse practitioner has graduated, he or she will be assigned to a job position/billet and will prepare for, then take, a certification exam through the American Academy of Nurse Practitioners Certification Board or the American Nurses Credentialing Center. The first job position, commonly known as the "utilization tour," is essential in gaining experience and confidence. It is also crucial to connect with more experienced NPs, physician assistants, and physicians in the workplace to find clinical and professional mentors.

Military NPs are generally protected from deploying for the first six months. During this first job position, the NP is honing diagnostic and treatment skills in the specific clinic area. Concurrently, it is also important to continue training and preparation for a potential future deployment. This includes maintaining active Basic Life Support (BLS), Advanced Cardiovascular Life Support (ACLS), and Pediatric Advanced Life Support (PALS) certifications. Additionally, it is important to seek out opportunities for trauma training including the Trauma Nursing Core Course (TNCC), Tactical Combat Casualty Care (TCCC), and Advanced Trauma Life Support (ATLS). Also, the Navy Trauma Training Center (NTTC) provides a rare opportunity to work side by side with some of the strongest trauma teams in the nation at Los Angeles County and University of Southern California (LAC + USC) Medical Center.

Finally, the Tactical Combat Medical Care (TCMC) course in San Antonio, TX, is a fantastic just-in-time course for life-saving trauma care skills vital for deployments to combat zones. Some of the most helpful resources to take on deployment to a combat zone are the handbooks and manuals from the courses above, as well as internet access to UpToDate, the Centers for Disease Control and Prevention, and the World Health Organization websites.

### My Experience as a Nurse Practitioner in a Combat Zone

On my second deployment, I was the Senior Medical Officer for a Provincial Reconstruction Team (PRT) in Ghazni, Afghanistan. The responsibilities for this position included taking care of the medical needs for our 88-person PRT, supervising and training a team of three corpsmen and one medic, running a sick call clinic for the Forward Operating Base in a PRT-staffed and supplied Battle Aid Station (BAS), providing medical planning and support for convoy missions off of the Forward Operating Base (FOB), supervising a PRT-run Local National Clinic, augmenting the Forward Surgical Team during mass casualties and Walking Blood Banks, participating in meetings and facility assessments with the Afghan Ministry of Public Health (MoPH) representatives from the provincial and district clinics and hospitals, and providing combat lifesaver and Individual First-Aid Kit (IFAK) training to US Military personnel, civilian contractors, and Afghan National Army (ANA) and Afghan National Police (ANP) members.

Our base had about 2000 people, and the PRT BAS was open for walk-in visits Monday through Saturday, 0800–1100. The patients were typically seen for minor acute illnesses (colds and respiratory infections, gastrointestinal illnesses with mild dehydration, dermatologic issues, musculoskeletal injuries) as well as chronic medical conditions exacerbated in deployed settings (allergies, hypertension, musculoskeletal pains). Additionally, we provided vital, compassionate mental health care. We would frequently treat patients for insomnia, anxiety, acute stress reaction, and symptoms of depression. In addition, we performed traumatic brain injury (TBI) screening for people affected by IED blasts or indirect fire when they did not sustain injuries significant enough to require treatment at the Forward Surgical Team. Our FOB did have access to a combat stress team who came to the base once a month and was available by phone for consultation. Later, the base received a chaplain and chaplain's assistant, and we had a wonderful collaborative relationship with them.

The "big picture" of the work of a PRT is to be a civilian and a military team functioning shoulder-to-shoulder with Afghan government agencies to develop the capacity to sustainably lead. This was done in collaboration with the US Agency for International Development (USAID), the Department of State, the US Army Agribusiness Development Team (ADT), and the US Army Corps of Engineers. This work required frequent ground and air convoys into the villages throughout the province (Fig. 47.3). The PRT medical team provided support for

**Fig. 47.3** Nurse practitioner (author ZY) on an outreach mission to a local village outside of Forward Operating Base Ghazni, Afghanistan (Photo courtesy of Zaradhe Yach)

all PRT missions and some of the ADT and coalition convoys off the FOB. Medical evacuation (MEDEVAC) was a portion of every mission plan and brief, and every military member on a convoy had gone through combat lifesaver training. The PRT medical team provided immediate trauma treatment and MEDEVAC care on multiple missions when our convoys faced improvised explosive devices (IEDs), rocket-propelled grenades (RPGs), mortar fire, small arms fire, a vehicle rollover, and more.

PRT Ghazni also supervised, supplied, and funded a Local National Clinic on our base and employed an Afghan physician, a midwife, and a midwife apprentice on Saturdays and Wednesdays from 0800 to 1200. The Afghan providers would typically see approximately 80–100 patients per day from the local villages for gastrointestinal illnesses, upper respiratory infections, skin diseases and burns, hypertension, prenatal care, musculoskeletal conditions, mental health disorders, dehydration and malnutrition, and much more. This was a very rewarding experience for the PRT medical staff and other members of the PRT, as it gave us insight into the lives of local Afghans who wanted peace and safety for themselves and their families and held out hope for a prosperous future for Afghanistan. It also gave us an opportunity to partner with our Civil Affairs, Public Affairs, friends, families, and charity organizations in the USA and around the world to collect hygiene supplies, shoes, jackets and other cold weather garments, toys, and art and school supplies to distribute to the Local National Clinic and to local Afghans on our convoy missions into the villages.

Another important role of the PRT medical team was to augment the Forward Surgical Team (FST) during mass casualty events (Fig. 47.4). Our FST was a four + bed unit with two operating rooms. They were staffed with a trauma surgeon, a general surgeon, an orthopedic surgeon, anesthesia providers, critical care-trained nurses, and medics. They were simply outstanding and worked hand-in-hand with a top-notch casualty evacuation (CASEVAC) unit. When the FST received more than two to three critical patients, they would call on the PRT medical staff to assist their staff. We would typically run the fourth bed, which would be the lowest acuity trauma patient, but during MASCALs, we were often called upon to manage multiple patients. This was particularly critical when the FST surgeons would have to emergently take a patient to the operating room and rely on our team to assume increased responsibilities in the triage and immediate care areas. Our PRT staff was also instrumental in coordinating and manning the stations for a Walking Blood Bank (WBB), a real-time blood bank assembled quickly in situations where the transfusion needs exceed the blood supply available. In this situation, prescreened donors of the necessary blood type are called upon to donate whole blood for immediate transfusion to the trauma patient in the operating room.

Additionally, as the Senior Medical Officer for the PRT, I worked on health sector development with USAID and the provincial Ministry of Public Health. This included doing site assessments of clinics and hospitals, working with our engineers on building projects, and attending meetings with the district and provincial

**Fig. 47.4** Nurse practitioner (author ZY) and team caring for injured during MASCAL event in Afghanistan (Photo courtesy of Zaradhe Yach)

leaders to discuss health issues in their communities. The Afghan physician, midwife, and the PRT staff also coordinated village medical outreach (VMOs formerly commonly known as MEDCAPs) missions and education programs for the communities utilizing Afghan medical providers to deliver direct patient care and provided vital translation services on missions.

## Conclusion

Military advanced practitioner duties have expanded over the last 50 years, and they continue to be utilized in a multitude of roles, assignments, and units not only clinical but operational in planning and command as well. These professionals are vital to the ongoing training of medics, corpsman, and the continuous training of unit personnel and combat lifesavers in the tenets of Tactical Combat Casualty Care, which directly improves the survivability of the injured. The advanced practitioner is a valuable resource in the deployed setting, combining a rich background in medical knowledge and operational experience that can be leveraged to greatly enhance your team or unit ability to provide optimal trauma and emergency care on the battlefield.

## Civilian Translation of Military Experience and Lessons Learned

Matthew J. Martin

**Key Similarities**
1. Advanced care providers (ACPs) are key components of most trauma and emergency care programs.
2. They are providing an increasing proportion of the day-to-day care due to the decreased availability of resident and staff physicians.
3. The exact role, training, scope of practice, and supervisory requirements for ACPs will vary widely by the setting, applicable local laws and policies, and the needs of the mission.
4. ACPs are licensed providers who can perform evaluations, interventions, prescribe medications, and a variety of other functions.
5. ACPs can greatly enhance any acute care programs.

**Key Differences**
1. In the civilian setting, ACPs are often being utilized as “resident substitutes,” particularly following the work hours regulations. In the deployed setting, they are utilized in more leadership and independent roles.
2. ACPs will usually have easy access to assistance from other medical staff, physicians, technologists, etc. in the civilian setting. In the military setting, they often are the highest-level medical provider in that location.
3. ACPs in the deployed setting often have key nonmedical leadership roles, including serving as the commander of their medical unit.
4. In the civilian setting, ACPs are often utilized within or below the level of their degree and training. In the military deployed setting, they are often used at the upper end of their degrees and training.
5. ACPs in the military setting often also serve as the medical liaison and primary medical advisor to line units and line commanders.

During the initial planning and execution of this second edition of *Front Line Surgery*, we added a number of new chapters on a variety of topics that we felt would be relevant to the deployed provider, and particularly the deployed surgeon. It was not very late in this process that we realized we had made a huge oversight: we did not have a chapter on advanced care providers on the battlefield. Fortunately, the three authors of this chapter were able to put together an outstanding primer on the topic and to help the reader understand and appreciate the incredible asset and “force multiplier” that the ACP can represent in the deployed setting. As a deployed provider, and particularly if you are at the Role 2 level, you will usually have significant interactions with ACPs who are colocated on your base or even colocated with your team to provide a combined Role 1/Role 2 facility. Get to know them, support them, and integrate them with your unit to take advantage of their knowledge, skills, and leadership abilities. A couple quick tips: a PA is a "physician assistant," and not a "physician's assistant," so don't treat them as your personal assistant or resident. An NP is not a "nurse" but is a licensed independent practitioner and should be treated as such. And neither is solely a "physician extender."

I have also had the privilege of working extensively with ACPs in multiple civilian settings, including at two busy Level 1 trauma centers where ACPs have been increasingly relied upon to provide coverage and care for a wide variety of patients including trauma, emergency surgery, and intensive care unit (ICU). I think this is a far cry from the initial gestalt of the physician assistant (PA) or the nurse practitioner (NP) as simply being an "extender" to physicians and to primarily operate in the primary care arena. In today's health-care environment, ACPs can be found in almost every aspect of inpatient and acute care – including the emergency department, wards, operating rooms, and ICUs. One of the most prominent factors in the major increase in ACPs working as trauma providers was the implementation of work hours limitations for residents in US training programs. All Level 1 and many Level 2 or lower trauma centers heavily relied on residents to provide continuous coverage of all aspects of the trauma service, and the work hours limitations drastically changed this paradigm, leaving significant holes in the call and service coverage schedules for these programs.

In response to this, most trauma centers integrated ACPs into their programs and practice models, typically by hiring a number of PAs and/or NPs. I credit the fact that there was little to no degradation in patient care or outcomes following the work hours restrictions to the hard work and dedication of these ACPs who stepped up to fill the void left by decreasing resident coverage and availability. In addition to filling these holes, ACPs have actually enhanced resident training by freeing them up from some other responsibilities, which allow them to participate more on operative cases and bedside clinical care. Figure 47.5 shows responses from a survey of US academic medical centers regarding the primary reason for employing ACPs, with the most common being due to resident work hours restrictions, but also for a variety of other reasons as shown.

From a staff trauma surgeon and Trauma Medical Director standpoint, I also believe that our perception and utilization of ACPs have rapidly evolved as we developed more experience and familiarity with exactly what a PA or NP is and what they are capable of doing. As they were frequently initially brought on to be "resident substitutes," they were often thought of and managed in a similar fashion to residents. This included a significant degree of supervision, limited independence, and hesitation to use them in new roles or responsibilities (such as ICU care). In addition, there also arose areas of conflict where the functions of the resident, the attending, and the ACP overlapped and were not clearly delineated. I would like to say that we have now solved all of these issues, but these are things we continue to struggle with on a daily basis. However, we are slowly evolving and improving our

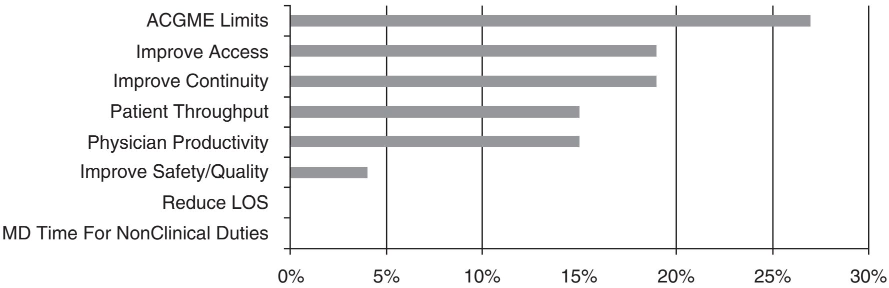


**Fig. 47.5** Graph showing the reported primary reasons for employing ACPs at academic medical centers in the United States (Reproduced with permission from Moote M, Krsek C, Kleinpell R, et al. Physician assistant and nurse practitioner utilization in Academic Medical Centers. American Journal of Medical Quality 201; 26:452–460)

utilization of these incredibly valuable personnel and creating new paradigms where ACPs are extending to provide high-level ICU care, procedural and intraoperative assistance, and even administrative or clinical leadership roles.

In summary, ACPs are critical members of the modern health-care team and have been particularly important and relevant in trauma care in both the military and civilian settings. It is important that you understand exactly what a PA or NP is, what their training and abilities are, and how to best utilize them to provide the best care possible to our civilian patients or to our wounded service members or other combat casualties. The ACP model for trauma care is here to stay, and ACPs are going to continue to play an increasing role in these settings.

## Suggested Reading


1. ATLS Course Availability: http://web2.facs.org/atls/ATLSSearch.cfm?Search=USA.
2. Basic Control of Hemorrhage for the Injured: http://www.naemt.org/education/B-Con/B-Con.aspx.
3. FCCS Course Availability: http://www.sccm.org/Fundamentals/FCCS/Pages/FCCS-Resources.aspx.
4. Interservice Physician Assistant Program: http://www.cs.amedd.army.mil/ipap/.
5. Joint Trauma System Clinical Practice Guidelines: http://www.usaisr.amedd.army.mil/cpgs.html.
6. Tactical Combat Medical Course: https://www.atrrs.army.mil/atrrscc/courseInfo.aspx?fy=2017&sch=081&crs=6H-F35%2f300-F38&crstitle=TACTICAL+COMBAT+MEDICAL+CARE+(TCMC)&phase=.

# Military-Civilian Collaboration for National Preparedness During Peace and War

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Kyle N. Remick, Eric Elster, and Raquel C. Bono

**Deployment/Leadership Experience**

| | |
|---|---|
| *Kyle N. Remick* | Joint Special Operations Aviation Component-North Flight Surgeon, Task Force Dagger, 2001–2002 |
| | Commander, 772nd FST, FOB Fenty, Afghanistan, 2008–2009 |
| | Deputy Deployed Medical Director, UK Role 3 Field Hospital, Operation Herrick 20, Camp Bastion, Afghanistan, 2010 |
| | Military Deputy, Combat Casualty Care Research Program, JPC6, Ft. Detrick, Maryland, 2014 – present |
| *Eric Elster* | Professor and Chair, Department of Surgery at Uniformed Services University of the Health Sciences and Walter Reed National Military Medical Center, 2012 - current |
| | President, Excelsior Surgical Society, American College of Surgeons, 2016–2017 |
| | Chief of Surgery/DSS, Kandahar NATO Role 3 Hospital, Kandahar Air Force Base, Afghanistan, 2010–2011 |
| | USS Kitty Hawk, Ship's Surgeon, Iraq, 2003 |
| *Raquel C. Bono* | Head of Casualty Receiving, Fleet Hospital 5, Operations Desert Shield and Desert Storm, Saudi Arabia, 1990–1991 |
| | Director, Defense Health Agency, Military Health System, Falls Church, Virginia, 2015–present |

K.N. Remick (✉) • E. Elster
Department of Surgery at Uniformed Services University of the Health Sciences and the Walter Reed National Military Medical Center, Bethesda, MD, USA
e-mail: kyle.n.remick.mil@mail.mil

R.C. Bono
Defense Health Agency, Defense Health Headquarters, Falls Church, VA, USA



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*We must, indeed, all hang together or, most assuredly, we shall all hang separately.*

Benjamin Franklin

**BLUF Box (Bottom Line Up Front)**

1. Military-civilian collaboration in trauma education and training will maximize national preparedness for military deployments and for the home front.
2. The Senior Visiting Surgeon Program provided key senior-level civilian trauma surgeon mentorship of military trauma surgeons and critical care staff at Landstuhl Regional Medical Center during the height of OEF and OIF.
3. The Military Health System Strategic Partnership with the American College of Surgeons is a foundational military-civilian trauma collaborative to provide mentorship, combat surgeon curriculum development, quality improvement, and advancement of the Joint Trauma System.
4. The Army, Navy, and Air Force currently all have trauma training platforms at civilian Level I trauma centers, but this model needs to be expanded to provide the optimal degree of military trauma readiness.
5. In 2016, the National Academy of Science, Engineering, and Medicine released a report titled “A national trauma care system: Integrating military and civilian trauma systems to achieve zero preventable deaths after injury” which specifically calls for military and civilian collaboration to ensure national preparedness for trauma care.
6. The creation of the Defense Health Agency and the DoD Joint Trauma System is the foundation upon which a military and civilian trauma system will be built for the future.
7. We must continually focus on the issue of continuous maintenance of competency of our pool of deployable surgeons and other trauma providers; otherwise we will continue to provide suboptimal care in the initial phases of any future conflict or combat operation.

## Introduction

Hippocrates said “war is the only proper school of the surgeon,” and as military surgeons who have deployed, we instinctively know this to be true. When you go to war, you mature your personal surgical skills at an accelerated pace. Oftentimes, experience gained during a single combat deployment is enough to inform the care of civilian trauma patients over an entire career due to the sheer volume and variety of injuries seen in even a short period of war. Similarly during war, the US Military’s medical infrastructure by necessity becomes laser focused on providing an optimal trauma care system throughout the continuum from point of injury and initial lifesaving care in the combat theater all the way back to restoration and rehabilitation of function in the United States (or allied countries).

But where does that leave current trainees and younger surgeons who may not have the opportunity to hone their skills and gain this concentrated experience during war? This is indeed an important question to ask at this juncture, and this point in history is not the first time this question has been raised. However, despite best intentions, history reveals little success at maintaining a combat surgery focus when political and societal will to support this effort wanes in between wars. To this point after World War I, Doctor (Col) Edward D Churchill is noted to have proclaimed, "Surgeons in a current war never begin where the surgeons in the previous war left off; they always go through another long learning period." This chapter, indeed this entire book, is dedicated to the challenge of preventing this from happening yet again.

The purpose of military-civilian collaboration in our current reality of continued conflict, not only abroad but also at home, is to pass along lessons learned to ensure surgeons are prepared for combat in foreign lands and to ensure surgeon readiness in support of national preparedness on the home front. In this chapter, we will discuss several of these recent and ongoing efforts in military-civilian collaboration.

## The Senior Visiting Surgeons Program

There is a notable historic precedent for civilian participation in the care of the injured during war. Particularly memorable is the leadership of the aforementioned Dr. (Col) Edward D. Churchill who volunteered during World War II and served as the chief surgical consultant in the North Africa and Mediterranean theaters. In this capacity, he led a deployed surgical unit from Harvard Medical School, making significant clinical contributions including advocacy for the use of whole blood.

Several generations later at the turn of the millennium, we found ourselves involved in war again but this time in Afghanistan and Iraq. Early on in 2003, three members of the American College of Surgeons National Ultrasound Faculty (Dr. David Wherry, Dr. Jon Perlstein, and Dr. M. Margaret Knudson) were granted permission to conduct the first Ultrasound for Surgeons course outside the United States at Landstuhl Regional Medical Center (LRMC) in Germany. At that time, the facility at LRMC was ramping up personnel and resources to care for an increasingly large number of combat casualties returning from Iraq and Afghanistan. Visualizing the extent and complexity of this effort firsthand, they realized a need for senior civilian mentorship and recommended a program to send senior civilian surgeons to collaborate and mentor the military trauma program at LRMC.

Dr. C. William Schwab, then president of the American Association for the Surgery of Trauma (AAST), and Dr. Wayne Meredith, then chair of the American College of Surgeons Committee on Trauma (ACS-COT), supported the concept of sending senior civilian surgeons to LRMC, in both a teaching and an observer role. The idea also gained positive support through military leadership at the time, namely, Lt. Gen P. K. Carlton, retired Surgeon General of the Air Force and former Air Force Governor of the ACS; Dr. Charles Rice, then President of the Uniformed Services University; and Dr. Ben Eiseman, RADM (retired). Thus, the Senior Visiting Surgeons (SVS) Program was established in 2006 through a combined effort of the AAST and the ACS-COT. The objective of the program was to provide a 2–4-week tour for senior civilian trauma surgeon mentors at LRMC. Dr. C. William Schwab, the first SVS, arrived in Germany in August 2006. The real-time presence of senior-level trauma surgeon expertise provided the surgeons and the whole trauma team at LRMC access to some of the most experienced and respected surgeons in the United States. These senior leaders participated in clinical care of injured service members, contributed to education of junior surgeons and trauma staff, served as side-by-side clinical mentors, and provided expert opinion during performance improvement activities.

An early report on this collaboration by Moore and colleagues offered several examples demonstrating immediate benefit. Grand rounds introduced to military surgeons the novel technique of pre-peritoneal pelvic packing as a damage control technique for exsanguinating pelvic hemorrhage. ICU protocols at LRMC were adapted from the National Institutes of Health Inflammation and the Host Response to Injury research effort. Finally, this early SVS effort in improving the quality of trauma care delivered by the facility assisted LRMC in attaining verification as a Level II trauma center from the ACS-COT in 2007.

Within a short time, surgeons from the Society of Vascular Surgeon, orthopedic societies, and neurosurgical societies were also participating in this program as senior mentors. A review and survey of participants of this program through 2013 revealed 192 participating surgeons. Seventy-eight participated in one tour at LRMC, 13% participated in two tours, and three surgeons participated in more than four tours each. Overall, SVS surgeons participated in two to five operations per week with the most prevalent being debridement of wounds and burn care. Of significant note, Dr. M. Margaret Knudson was able to extend this relationship by volunteering for a tour with the Air Force Theater Clearing Hospital in Balad, Iraq. Several other key civilian leaders in trauma surgery were able to journey beyond Landstuhl and spend time at combat medical facilities in Iraq or Afghanistan (Fig. 48.1). In 2014, a final review of the SVS program also emphasized military-civilian translatable lessons learned and advice for the utilization of the SVS program in times of reduced military operations. Collaboration in the development of clinical practice guidelines (CPGs) included techniques for complex wound management, venous thromboembolism prevention, and principles of damage control resuscitation and surgery. At the top of the list for suggestions for continued use of the SVS program during peacetime included SVS mentor visits to military hospitals and rotations for military surgery residents at civilian trauma centers. The full list of recommendations is shown in Table 48.1.

Lastly, the authors recommended continued collaboration in three important areas. First, military surgeons should maintain their combat readiness in busy civilian trauma centers during peacetime to ensure preparedness to deploy and to be


**Fig. 48.1** (**a**) Dr. M. Margaret Knudson visiting the Air Force Theater Clearing Hospital in Balad, Iraq. (**b**) Several notable civilian trauma surgeons (front row seated, from left to right Dr. Donald Trunkey, Dr. Lynette Scherer, and Dr. Ronald Maier) attended the 2010 Theater-Wide Joint Trauma Conference at Kandahar Air Force Base, Kandahar, Afghanistan

**Table 48.1** Potential contributions of the SVS program during peacetime

| |
|---|
| SVS professor visits to military hospitals |
| Rotations for military residents at civilian trauma centers |
| Participation in local National Guard |
| Assist in maintaining surgeon "combat readiness" |
| Collaboration for disaster planning |
| Assist with rehabilitation |
| Collaborate on research |
| Develop a combat surgeon curriculum |

optimally prepared to care for the very first injured American. Second, military and civilian trauma leaders should collaborate in the development of the optimal clinical care and trauma system response for mass casualty events caused by natural or man-made disasters. Lastly, in between wars, critical military combat casualty care research should proceed without interruption and with funding appropriate to an aggressive urgency to be prepared for the next war and to be ready for a mass casualty event on the home front.

## The Military Health System Strategic Partnership with the American College of Surgeons

In 2014, stakeholders from the US Military and the American College of Surgeons met to discuss and solidify a critical partnership focused on education and training, systems of care, and research and quality improvement. With the successful creation and maturation of the Joint Trauma System (JTS), the experience and lessons learned by military combat surgeons stationed at the Uniformed Services University and at other training programs, and robust wartime research guided in real time by the Department of Defense's Combat Casualty Care Research Program, there arose a need to preserve and protect these medical lessons, advances, and experience that were forged by the blood, sweat, and tears of the US and coalition service members injured in battle. The creation of the Military Health System Strategic Partnership with the American College of Surgeons grew out of a shared ethos of both organizations, centered on education, trauma systems, and quality improvement (Fig. 48.2).

## Creating a "Combat Surgeon" Curriculum

In the realm of combat surgeon education and training, the Uniformed Services University (USU) in Bethesda, Maryland, is taking the lead with the collaboration of the JTS and the ACS Division of Education to create a military "combat surgeon"-specific curriculum for educating and training the next generation of military surgeons. With the exception of San Antonio Military Medical Center, most military


**Fig. 48.2** The Military Health System Strategic Partnership with the American College of Surgeons (MHSSPACS). (**a**) Signing the partnership agreement were Dr. Jonathan Woodson and Dr. David Hoyt. (**b**) The first meeting of the MHSSPACS

surgical residents are not exposed to high volume and acuity trauma care in their military residency programs. With the retirement of experienced surgeons, it is urgent that we retain lessons from combat surgery and permanently ingrain this into our military surgical residency culture. To this end, this partnership is developing an integrated military-specific curriculum with a competency-based evaluation to ensure individual surgeon initial education and training proficiency. This curriculum, coupled with trauma surgical skills sustainment, will likely involve an increased partnership with busy civilian trauma centers and even potentially with rural surgery programs.

## Formalizing the Joint Trauma System Defense Center of Excellence

The ACS-COT Trauma Systems Committee is working directly with the JTS to characterize the structure and form of this body during peace and during wartime and to seek its maturation into a "Defense Center of Excellence" (DCoE). Details of the JTS and this process are described and analyzed in Chap. 44.

## Quality Improvement

Quality improvement is a key element of surgical care. The ACS National Surgical Quality Improvement Program (NSQIP) is working with the US Military to develop military health system surgical quality consortia. This partnership will allow the military to leverage this core ACS program to ensure the highest level of care for service members and their families. Currently, this partnership is developing a toolbox to assist implementation of NSQIP at military treatment facilities, a unique challenge in that the military's medical system has a global presence. This program will address particular military medical quality improvement projects. In addition, the ACS is assisting USU in developing and incorporating a quality curriculum into military residency programs.

## A National Trauma Care System

The ACS is partnering with the DOD CCCRP to develop a national trauma research plan. Despite the fact that injury represents a leading cause of death and a significant burden of lost productivity in America, currently, the DOD-led trauma research program represents the nation's sole enduring investment for injury research. In the short term, the DOD will rely on civilian trauma centers and systems to conduct military-relevant research in trauma care. The trauma research effort in the midterm is propelled by the recent release in June 2016 of the National Academy of Medicine report titled, "A National Trauma Care System: Integrating Military and Civilian Trauma Care Systems to Achieve Zero Preventable Deaths After Injury." This report recommends prioritization and integration of a national trauma care plan, including a research plan, among the highest federal levels. In the long term, this will require a national trauma research institute with enduring and appropriate funding.

## The Excelsior Society

The MHSSPACS resurrected and made permanent the Excelsior Society, a new organization for military members under the umbrella of the ACS. The original Excelsior Society first met in 1945 at the Excelsior Hotel in Rome in the wake of World War II to share knowledge and lessons learned from the battlefield. It met

**Fig. 48.3** The Excelsior Society. (**a**) The first meeting in 1945 at the Excelsior Hotel in Rome. (**b**) Re-initiation of the Excelsior Society in 2014

yearly until the 1980s and was then retired. At the annual Clinical Congress in 2015, the Excelsior Society met again for the first time since then, and all current and former military surgeons were invited to this inaugural meeting of the resurrected Excelsior Surgical Society (Fig. 48.3). The meeting entailed updates from the consultants to the Surgeons General and invited lectures on the current status of trauma care (CAPT Eric Elster and Col (ret) Jay Johannigman), the state of DOD research (LTC Kyle N. Remick), and the future vision for military combat surgery training (Dr. C. William Schwab). There were also research presentations from current military surgery residents. In 2016, the second annual Excelsior meeting was held and included formalization and approval of the organization charter and bylaws and election of the first slate of society officers. This will continue to be a permanent yearly event in conjunction with the annual ACS meeting, with the ultimate goal of the society being the primary "home" for military members of the ACS.

## Military-Civilian Trauma Training Center Partnerships

A report by the Congressional General Accounting Office in 1998 noted that many military medical personnel were not training in the care of trauma patients nor did they have recent trauma care experience, and planning was underway to include trauma training for military personnel in civilian trauma centers. In fact, the prior National Defense Authorization Act for fiscal year 1996 did require a demonstration program, prompting the Assistant Secretary of Defense for Health Affairs to form the Combat Trauma Surgical Committee. This committee subsequently recommended trauma training at civilian centers.

The Joint Trauma Training Center (JTTC) was established by then LTC John B. Holcomb at Ben Taub General Hospital in Houston, TX. Although it faced insurmountable legal conflicts for malpractice coverage causing closure of the program, the JTTC was able to screen other civilian trauma centers for suitability prior to its closure. Ultimately, out of 70 prospective civilian trauma centers, Baltimore, Miami, and Los Angeles were chosen. The Air Force established an agreement with the University of Cincinnati in August 2001, with Baltimore Shock Trauma in September 2001, and with St Louis University in December 2002. The Army established a pilot program at Miami and the Navy in Los Angeles shortly after.

## US Air Force C-STARS Program

The US Air Force Centers for Sustainment of Trauma and Readiness Skills (C-STARS) program integrates training into three sites. The mission of C-STARS Cincinnati is pre-deployment readiness training for the Critical Care Air Transport Teams (CCATTs). C-STARS Baltimore is a mature contingency training platform for surgeons and other physicians and providers for critical care, emergency medicine, operating room, and trauma anesthesia. The 19-day program features didactics, trauma simulations, lifesaving interventions trained on cadavers, and a capstone mass casualty exercise at Ft Detrick, MD. C-STARS St. Louis has operated as a partnership with the Air National Guard to serve as a "Total Force" (active duty and reserve component) platform in support of trauma skill sustainment and training. The curriculum for the 2-week course includes didactics, simulation, and hands-on patient care for physicians, surgeons, and other providers.

### US Army Trauma Training Department

The US Army Trauma Training Department (ATTD), located at the Ryder Trauma Center within the Jackson Health System in Miami, FL, supports pre-deployment training primarily for US Army Forward Surgical Teams (FSTs). This training involves a 2-week-long team-based training rotation at the trauma center. It emphasizes teamwork during stressful combat situations and during mass casualty events to maximize team preparedness for deployment. A large animal physiology laboratory is the setting for the military capstone exercise involving multiple patients (anesthetized swine) needing damage control resuscitation and surgery coupled with real-time combat scenario including battlefield noises, enemy attacks, and resource and personnel constraints. The clinical capstone exercise is conducted within the Ryder Trauma Center during which time the FST takes over care of all trauma patients arriving at the trauma center for a 48-h period.

### US Navy Trauma Training Center

The US Navy Trauma Training Center is housed at the Los Angeles County/University of Southern California Keck School of Medicine. It provides team and individual training to Navy Forward Resuscitative Surgical Systems (FRSS) and fleet surgical teams over a 4-week training period. During this time, trainees are provided didactics, simulations, and hands-on training experiences which start with a surprise mass casualty drill on the trainee housing compound on the day of arrival to add emphasis and urgency to their team building. Trainees are fully integrated into the Los Angeles County system and work side by side with the military trauma cadre and the civilian trauma staff.

## Professional Society Military Committees

Over the course of two wars beginning in 2001, multiple professional organizations have sponsored military committees to address concerns and issues of its military members. Most of these discussions focused around deployment readiness. The ACS MHSSPACS is a prime example of partnering with a professional society. It is discussed in detail in its own section above and so will not be mentioned again here.

### EAST Military Committee

The Eastern Association for the Surgery of Trauma (EAST) created a Military Section to recognize the “mutual benefit of military-civilian collaboration in trauma education, training, and research as well as the outlet that EAST provides for enhancing these relationships.” The EAST Military Section develops “sunrise sessions” involving topics of military trauma relevance for each annual meeting.

The Military Section has also collaborated with the EAST Education Committee to create a pre-deployment website. This site is a one-stop repository for deploying military surgeons to access clinical practice guidelines, national courses of military relevance, recommended books, and a database of combat casualty care relevant articles from the *Journal of Trauma and Acute Care Surgery*.

## AAST Military Liaison Committee

The American Association for the Surgery of Trauma (AAST) was formed in 1938 with a primary purpose to furnish leadership and to foster advances in the surgery of trauma. A battleship and an artillery piece prominently included on the AAST's seal symbolize the long-standing collaboration between civilian and military members toward this pursuit. The mission of the AAST Military Liaison Committee, a permanent AAST committee, is to foster this civilian-military trauma care synergy and advocacy to AAST and military leadership. The AAST supported, with both funding and member volunteerism, the Landstuhl Regional Medical Center (LRMC) Senior Visiting Surgeon Program providing seasoned mentorship and clinical expertise to the assigned military medical staff during the height of casualty flow. These volunteers contributed to LRMC's successful verification as an American College of Surgeons Level I Trauma Center in 2011 and validated that the highest quality care was delivered to our Nations Wounded Warriors. Annually, the most impactful research papers presented at the Military Health System Research Symposium are published as a supplement in the AAST's journal, *The Journal of Trauma and Acute Care Surgery*. The Committee also provides educational activities at the AAST Annual Meeting and webinars throughout the calendar year.

## SAGES Military Working Group

Over the past 7 years, the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) and several military surgeons have created a unique model between the military and civilian surgeons to help overcome challenges facing today's active duty surgeon. SAGES has provided logistical support and a venue where military surgeons could meet, has made their education more affordable, and provided an opportunity for senior military leaders to meet with a large number of their staff surgeons. In 2009 SAGES created the Military Working Group and provided active duty surgeons with a forum to collaborate on academics, surgical education, research, surgical innovation, military-specific education, and career progression. In 2010, the Military Working Group was granted time during the SAGES conference to hold an educational session which featured expert lectures on combat surgery, simulation, and military surgical education. Over the years, their featured speakers have been Assistant Secretary of Defense Health Affairs S. Ward Casscells, MD; VADM (ret) Adam Robinson, MD former Surgeon General of the Navy; and former MEDCOM Commander MG (Ret.) Carla Hawley-Bowland, MD. In 2013, the Military Working Group formed the Society of Military Surgeons and produced the first ever Tri-Service military surgical symposium, again with the help of SAGES. This is a 1–2-day event with 3–4 different plenary sessions that featured the best academic work among the residents of all three services. In 2016, the keynote speaker for the event was the Director of the military's Defense Health Agency, VADM Raquel Bono, MD. Over 75 active duty surgical residents and staff surgeons were able to discuss their concerns openly with the highest-ranking active duty physician for over 90 min, at her request.

### Other Partnerships

There have been a great number of additional partnerships, collaborations, committees, and special projects sponsored by professional civilian medical and surgical organizations with the goal of supporting their military members or partnering their military and civilian members for reasons of mutual support and to enhance battlefield care. These organizations and efforts are too numerous to list here, but they all share the common themes of (1) our civilian surgical colleagues consistently rising to offer an unprecedented level of support to their military members and to military medicine in general and (2) military members taking a leadership role in these civilian societies and establishing a dedicated military presence and forum to foster these types of relationships. These efforts and relationships have sometimes been threatened by a lack of support from military leadership in terms of providing time and funding to attend these meetings or conferences. We believe that these types of efforts are of great benefit to military surgeons and are of even greater importance in times of peace when we will rely much more heavily on our civilian colleagues and organizations to achieve and sustain a high level of competence and readiness for battlefield trauma care.

## The "Winds of War" and the National Academy of Medicine Report

### "Winds of War"

In October 2014, Dr. C. William Schwab presented the Scudder Oration at the ACS Annual Scientific Assembly. It was only appropriate that he, who trained and served in the US Navy and who supported the SVS program as its first volunteer in 2006, presented to the college the culmination of many years of experience and research on "enhancing civilian and military partnerships to assure readiness." As we transition to a relative peacetime setting, he cautions that history proves that the "winds of war" will always return someday, and we must remain vigilant and prepared.

Weaved throughout the fabric of his talk is the need for a "combat surgeon," one specifically and uniquely trained who stands prepared to shoulder the burden of trauma care in the next austere, military environment. Supporting his concept for readiness is advocacy for military-civilian trauma training center platforms to ensure continuous readiness for deployment for trauma teams and surgeons, a need to inspire and maintain a career military surgical cadre who might otherwise leave the military for a more appealing civilian career, and creation of a permanent military combat surgeon culture to ensure lessons are transmitted to the next generation even in times of peace.

In concluding comments of his Scudder Oration, Dr. Schwab makes several very specific recommendations. First, develop and expand a model for military-civilian trauma training platforms throughout the United States. Second, create a new type of trauma surgeon who is “combat designated.” Third, elevate the JTS to a Defense Center of Excellence and empower it to lead combat casualty care readiness. Fourth, establish a military-civilian medical think tank to guide development of the first three recommendations.

### National Academy of Medicine Report

In June 2016, the National Academy of Medicine released a report titled “A national trauma care system: Integrating military and civilian trauma systems to achieve zero preventable deaths after injury.” This report, sponsored in part by the Department of Defense, was the result of a yearlong analysis of the US Military’s healthcare system, specifically with an eye toward preparedness for combat casualty care.

Recommendations from this committee are important to note here in the context of promoting military and civilian collaboration. The report’s vision for a national trauma system specifically calls for military and civilian collaboration as essential to success. In fact, the committee notes, “Military and civilian trauma care will be optimized together, or not at all.” Although these recommendations are broad and bold, implementation of these at a high level will prove essential to successful military and civilian partnerships for national preparedness, preparedness for the next military conflict in foreign lands, and care of the injured on the home front. The report itself contains the recommendations listed in Table 48.2.

## The Future Direction of the Military Health System

As we actualize the vision for US Military preparedness for care of the injured during war, we consider the National Academy of Medicine’s observation that “Military and civilian trauma care will be optimized together, or not at all.” In recent years, the Military Health System (MHS) has reconfigured its structure and governance processes to enhance jointness in our operational and health service delivery efforts. In October 2015, the overarching framework for this reform effort – the establishment of the Defense Health Agency (DHA) – attained Full Operational Capability. Within the DHA, the Department established ten enterprise support activities (ESA) – or shared services – that were designed to support the medical mission requirements for the Military Departments and the Operational Commanders.

**Table 48.2** National Academy of Medicine: "A national trauma care system: Integrating military and civilian trauma systems to achieve zero preventable deaths after injury"

| |
|---|
| The White House should set a national aim of achieving zero preventable deaths after injury and minimizing trauma-related disability |
| The White House should lead the integration of military and civilian trauma care to establish a national trauma care system |
| The Secretary of Defense should ensure combatant commanders, and the Defense Health Agency (DHA) Director is responsible and held accountable for the integrity and quality of the execution of the trauma care system in support of the aim of zero preventable deaths after injury and minimizing disability |
| The Secretary of Health and Human Services (HHS) should designate and fully support a locus of responsibility and authority within HHS for leading a sustained effort to achieve the national aim of zero preventable deaths after injury and minimizing disability |
| The Secretary of Health and Human Services and the Secretary of Defense should work jointly to ensure that military and civilian trauma systems collect and share common data spanning the entire continuum of care |
| To support the development, continuous refinement, and dissemination of best practices, the designated leaders of the recommended national trauma care system should establish processes for real-time access to patient-level data from across the continuum of care and just-in-time access to high-quality knowledge for trauma care teams and those who support them |
| The White House should issue an executive order mandating the establishment of a National Trauma Research Action Plan requiring a resourced, coordinated, joint approach to trauma care research across the US DOD, the US Department of Health and Human Services, the US Department of Transportation, the US Department of Veterans Affairs, and others |
| To accelerate progress toward the aim of zero preventable deaths after injury and minimizing disability, regulatory agencies should revise research regulations and reduce misinterpretation of the regulations through policy statements (i.e., guidance documents) |
| All military and civilian trauma systems should participate in a structured trauma quality improvement process |
| Congress, in consultation with the US Department of Health and Human Services, should identify, evaluate, and implement mechanisms that ensure the inclusion of prehospital care as a seamless component of healthcare delivery rather than merely a transport mechanism |
| The Secretary of Defense should direct the development of career paths for trauma care. Furthermore, the Secretary of Defense should direct the Military Health System to pursue the development of integrated, permanent joint civilian and military trauma system training platforms to create and sustain an expert trauma workforce |

Several of the ESAs are particularly relevant to the combat casualty care readiness: Research, Development, and Acquisition, Medical Education and Training, and Health Information Technology.

However, the establishment of the DHA also serves a broader purpose of providing a representative interface between the Military Health System (MHS) and the private sector, other federal agencies, and academic thought leaders on both policy and operational issues affecting military medicine. As we extract and synthesize the lessons learned in these most recent wars and assimilate them into our preparations for future conflicts, the MHS has a unique opportunity to co-create a collaborative vision for national trauma preparedness with our civilian colleagues. The Military

Health System (MHS) must capitalize on the new knowledge from our recent war experience, leverage the capabilities within the ESAs, and optimize our ability to create robust partnerships with extramural organizations to continue our pursuit of success in trauma care. Using the NAM report as a template, the three main pillars of *training and education*, *trauma system leadership*, *and combat casualty care research* can be developed, honed, and implemented by synchronizing our organic capabilities within the DHA with public-private partnerships.

Within the first pillar of *training and education*, there is a priority to preserve our new combat casualty care knowledge and the "combat surgeon" specialty skills. Key to optimizing trauma care will be ensuring that the MHS identifies organic residency training programs that are best suited in volume and complexity to support foundational resuscitative and surgical skills training. Concurrently, the MHS must optimally allocate its resources to ensure these identified training programs provide comprehensive education and training, which are enhanced by complementary and collaborative partnerships with local, civilian trauma centers to establish joint, regionalized trauma training centers across the country. Locations in which these theoretical constructs between the military and private sector exist can then serve as permanent training duty stations for rapid-response military trauma teams who will be ready to immediately deploy to an austere location in support of initial military combat operations. Concurrently, rotations at busy civilian trauma centers with the appropriate mix of penetrating and operative trauma provide military trauma personnel with individual trauma skill maintenance as military and civilian colleagues work side by side caring for civilian trauma patients.

Underpinning skill maintenance for the existing military combat trauma cadre is initial education and training at USU. As the academic hub of military medicine, the staff of USU are designing and implementing a program of maintenance of currency and competency for military surgeons that begin with residency training eventually melding education, training, and operational experience into a trauma system degree program. The desired end state is a shift away from the current system with little to no emphasis on continuous competency and an overemphasis on "just-in-time" training immediately prior to deployment. Rather, the exact opposite will be emphasized, with the major focus on achieving competency, continuous maintenance of that competency, and additional skill development and then focused on theater- or operation-specific "just-in-time" training.

The JTS DCoE is the focal point for military *trauma system leadership* and is the second pillar for action. The requirement for this capability needs to be codified by military doctrine to ensure sustainability of its operations as an enabler to military operations and is discussed in great detail in Chap. 44.

*Researc*h is the final pillar for action. The DOD Combat Casualty Care Research Program (CCCRP) plans, programs, budgets, and supervises the execution of the DOD's overall investment in combat casualty care research. The CCCRP receives guidance from operationally relevant sources such as the Committee on Tactical Combat Casualty Care, active command surgeons and medical personnel, and the JTS DCoE itself. Leveraging input from these sources while interfacing with the DHA's Research, Development and Acquisition (RDA) ESA allows the CCCRP to most efficiently manage research funds in a targeted, prioritized manner to provide the knowledge and materiel products most needed in the provision of combat casualty care. Focusing and directing research efforts in this way supports the translation and transition of experimental concepts into knowledge and material outputs for rapid deployment and utilization in the battlefield.

An additional ESA that contributes to the MHS' ability to successfully partner with external organizations is the DHA's Health Information Technology directorate, which is facilitating the deployment of a new electronic health record (EHR) across all MTFs. Key to this deployment is the interoperability of the military's EHR with civilian health record systems through Health Information Exchanges (HIE), which will be a key enabler to information sharing and the development of best clinical practices with our civilian trauma center partners. Concurrent with the deployment of the EHR is the development of an operational EHR (JOMIS) for the combat theater that will be configured to the same interoperability standards so that clinical information sharing is preserved and accessible from frontline to MTFs and trauma centers.

The principle mission of military medicine is achieving and sustaining total force readiness (a medically ready force) and combat trauma readiness (a ready medical force). We must develop the infrastructure that will focus on education and training, trauma system leadership, and combat casualty care research. We must develop this in parallel to civilian national trauma leadership to collectively develop a national trauma system, partnering for national trauma preparedness during war and on the home front.

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# Battlefield Resuscitation of the Future

# 49

Matthew J. Martin, Hasan B. Alam, Jeremy G. Perkins, and Todd E. Rasmussen

*"The best way to predict the future is to create it."*

President Abraham Lincoln

**BLUF Box (Bottom Line Up Front)**

1. Hemorrhage is a "supply and demand" problem. Next-generation therapies may start tackling the "demand" side of the equation.
2. If massive transfusion or major surgery at the point of injury or during transport is not possible, then inducing a tolerance to injury and bleeding may be our best bet for further improving battlefield survival from hemorrhage.
3. Hemorrhagic shock is largely an ischemia and reperfusion injury. Preconditioning with short bursts of ischemia and reperfusion appears to induce marked improvement in tolerance to injury and future ischemic insults.

(continued)

Note: portions of this chapter have been excerpted from a chapter by the authors in Out of the Crucible, Borden Press, 2017: in press.

M.J. Martin (✉)
Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA
e-mail: traumadoc22@gmail.com

H.B. Alam
University of Michigan, Department of Surgery, 1500 E. Medical Center Drive, 2920 Taubman Center/5331, Ann Arbor, MI 48109, USA

J.G. Perkins
Walter Reed National Military Medical Center, Department of Medicine, Bethesda, MD, USA

T.E. Rasmussen
DoD Combat Casualty Care Research Program, Fort Detrick, MD, USA



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(continued)

4. Freeze-dried plasma will make damage control resuscitation, and far forward plasma administration, significantly easier and more effective.
5. New blood products or blood substitutes will overcome many of the current limitations and complications of transfusion.
6. Blood pharming, or making new blood products in a "bioreactor", could allow units to manufacture their own blood supply on an as-needed basis.
7. New biopharmaceuticals are in various stages of research that have the promise to alter genetic expression, metabolism, and cellular response to injury to produce a "prosurvival state" that is much more tolerant to injury and ischemia.
8. The next true "game changer" is likely something we haven't even started to consider or understand, which is why robust basic science research is critical for the future.

## Future Battlefield, 2025

An infantry squad prepares for a dismounted patrol through an area of known enemy insurgent activity. Before departing from their forward operating base they enter a tent marked "Battle-Prep" where each soldier has a narrow elastic armband with a digital monitor placed around their right upper arm. In addition to checking their weapons, body armor, and protective clothing, they each drink a small prepackaged vial of liquid issued by their squad leader. This contains a mixture of novel agents that activate or enhance key proteins or enzyme systems, resulting in a greater tolerance to blood loss, increased tissue protection against stress and inflammation, and the ability to tolerate longer periods with decreased oxygen delivery to end organs. During this time period the elastic armband has been intermittently inflating and deflating, much like a blood-pressure cuff. These periods of short ischemia and reperfusion activate additional defense mechanisms that improve the tolerance of tissues and organs to periods of low oxygen delivery.

During the patrol multiple squad members are injured in an improvised explosive devise blast. Medics on the scene place tourniquets and hemostatic dressings to stop external bleeding, and establish intravenous access. A powdered form of plasma (freeze-dried plasma) is reconstituted by adding water and is administered to the injured soldiers. One of the most severely injured soldiers is deteriorating rapidly; he is given an injection containing several agents that modulate his inflammatory response and slow down his metabolism by 90%. Once they arrive at a Forward Surgical Team, synthesized red blood cells and platelets that were "grown" in a bioreactor are administered. These require no "cross-matching" as they are universally compatible with any patient, and also carry no risk of infection. The most severely injured soldier undergoes damage control surgery to stop internal bleeding and repair his injuries, and is then given a reversal agent to slowly bring him out of the temporary "suspended animation" state now that he is stabilized. No soldier injured in this event dies of hemorrhage or hemorrhage-related organ failure.

## The Challenge

Although this scenario may seem like science fiction, many of the resuscitation advances and products that were mentioned are now either available or in various stages of active research and development. The lessons learned over the course of the conflicts in Iraq and Afghanistan are numerous. We would do well to appreciate that the greatest survival benefit can come from improved management of hemorrhage and the dysfunction of the body's inherent clotting system that often occurs with severe traumatic injury. Multiple important advances in hemorrhage control have been fielded with great success and have been described in previous chapters of this book, including tourniquets, topical hemostatics, and antifibrinolytics. Resuscitation has undergone a wholesale change, now favoring the balanced and early administration of blood products (damage control resuscitation) and the avoidance of overzealous crystalloid infusion. In addition, novel strategies to control noncompressible bleeding have been introduced or are in development.

However, the work in this area is far from done. Despite these advances in both the civilian and military arenas, a recent multinational civilian study showed that the majority of trauma deaths occur within the first few hours after injury. In combat trauma, 87% of deaths occur before patients reach a medical facility and nearly a quarter of these are considered potentially preventable. In the injured who live long enough to reach a medical facility, the percentage of potentially preventable deaths increases to 50%, with hemorrhage accounting for 80%. While we have made clear inroads in treating specific types of injuries and hemorrhage, service members continue to die from wounds that may be amenable to some of the innovations discussed in this chapter. Figure 49.1 graphically represents many of the concerns and limitations that we face on the modern battlefield with early combat deaths. Massive bleeding or organ injuries often progress rapidly, result in inadequate oxygen delivery, may not be amenable to treatment in the field, require blood products that currently are not practical for field use, and present only a narrow temporal window for intervention (i.e., "the golden hour"). Even with successful early intervention, the resuscitation and restoration of perfusion itself can have harmful or even fatal effects, known as ischemia-reperfusion injury. Finally, the maintenance of adequate stores of human-donor blood products for transfusion of our wounded warriors is inefficient, expensive, logistically taxing, and carries risks of transfusion mismatches or transmission of blood-borne diseases (hepatitis, HIV, etc.).

This problem can be examined using the economic analogy of supply and demand as it applies to oxygen delivery. Blood carries oxygen to the tissues and organs, and thus the "supply" is a function of how much blood is circulating and how much oxygen it is carrying. The "demand" is a function of how much oxygen that tissue requires to maintain basic function, and how well it can adapt to decreased levels of delivery. As shown in Fig. 49.2, almost all of the past and current strategies to treat hemorrhage have focused on augmenting the supply side of the equation: stopping bleeding, resuscitating with fluids and blood products, and maintaining high oxygen levels in the blood. While this remains an important area for further advances, we believe that cutting-edge or "next-generation" advances that primarily


**Fig. 49.1** Multiple challenges and issues surrounding the central challenge of early combat deaths due to massive injuries and/or major hemorrhage

**Fig. 49.2** The majority of current therapies for major hemorrhage are on the "supply" side of the graph, while future advances may increasingly focus on the "demand" side

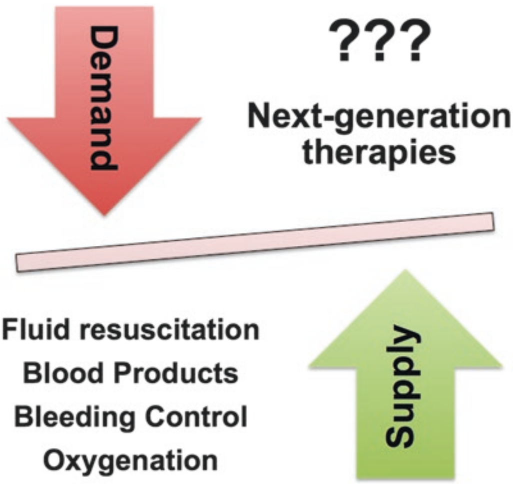

**Fig. 49.3** Freeze-dried plasma can be stored indefinitely in powdered form (*left panel*), and then reconstitutued to liquid form and administered as needed (*right panel*)

target the demand side have the potential to drastically impact battlefield mortality and morbidity and to fundamentally alter our approach to hemorrhagic shock. By reducing, or even temporarily eliminating, the injured patient's dependence on oxygen delivery, these therapies have the potential to expand the window of survivability from severe or even previously fatal injuries.

## The Next-Generation Innovations

### Freeze-Dried Plasma

Plasma is the liquid component of blood that contains thousands of proteins, growth factors, buffers, antibodies, hormones, and enzymes. There is abundant preclinical and clinical data to suggest that plasma can not only replace the lost blood volume, but is also protective for various cells and organs. Although plasma is extremely effective, it requires type and cross match, frozen storage, and thawing before administration, which makes it impractical for austere military settings. Many of these limitations can be overcome by converting the plasma into a freeze-dried, shelf-stable, easy-to-store preserved product, which performs as well as fresh frozen plasma in models of hemorrhage and traumatic brain injury (TBI). Dried plasma can be kept in storage for years without losing efficacy and can be reconstituted easily in sterile water at the time of need (Fig. 49.3). Surprisingly, it is not a new technology. In fact, freeze-dried (or lyophilized) plasma was developed during the Second World War and was widely used. It fell out of favor in the 1970s due to concerns about the spread of hepatitis (and later HIV) as the product was made from plasma pooled from multiple donors. The current manufacturing technologies that use single-donor plasma and robust screening tools for communicable diseases make the freeze-dried product as safe as the commonly used fresh frozen plasma. Freeze-dried plasma products are approved for clinical use in Europe, and are being used by NATO troops in the current conflicts, including administration to US military personnel. However, they are not approved for use in the USA at this time. Prompt approval by the FDA would result in significant logistical benefits to the civilian trauma centers, as well as the US military forces.

## Cryopreserved and Freeze-Dried Platelets

Platelets with their limited shelf-life of up to 7 days storage at 20–24 °C represent a particularly challenging logistical problem for combat casualty care. Cryopreserved platelets (CPP), stored in a special preservative solution, could reduce the logistic challenge as they could be stored for at least 2 years at −20 °C to −80 °C. CPPs have been studied in heart surgery patients and in cancer patients with extremely low platelet counts due to chemotherapy. CPPs are presently used in Europe, although the Food and Drug Administration has not yet licensed them for use in the USA.

In addition to plasma, lyophilized or freeze-dried platelets have also been created and studied. Freeze-dried platelets retain much of their native function and clotting capabilities, though other functions are lost during the current lyophilization process. They have a short duration of action and circulation time, suggesting that they can function more as an active and rapid hemostatic agent by forming primary hemostatic plugs and serving as a “scaffold” to support more long-term clot formation. Additional advances in the freeze-drying process may further improve and enhance the function of these platelets once they are reconstituted from the powder form. Taken together, these two advances in platelet storage have the potential to greatly expand the availability and longevity of platelet products, and to enhance the ability to carry platelets to even the most forward battlefield scenarios.

## Blood Pharming

This exciting advance involves the production of blood cells outside of the human body to provide blood products that are safe, effective, readily available, and do not rely on human blood donors as a supply source. Theoretically, blood pharming could provide an alternative to red blood cell or platelet blood donation by producing large quantities of on-demand, universally compatible blood products free of risk for alloimmunization. This technology would utilize progenitor or “stem” cells that have the potential to differentiate into the desired cell type (red blood cell, platelet, etc.). These blood products would be produced in laboratory machines known as “bioreactors”, and could allow for controlled creation of the desired cell types and potentially even selective enhancement of their oxygen-carrying and

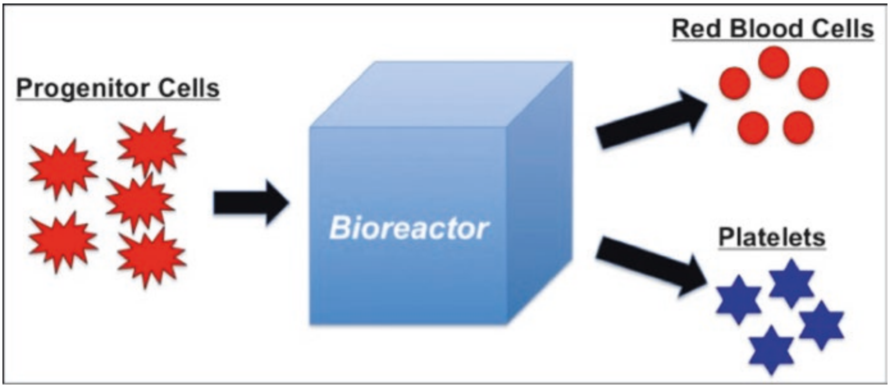


**Fig. 49.4** Schematic of biopharming showing progenitor or stem cells being differentiated and multiplied in a bioreactor to produce large quantities of the desired blood products (red blood cells or platelets)

hemostatic properties (Fig. 49.4). Because the blood products are grown in bioreactors, they could additionally be free of known and unknown infectious organisms. The Defense Advanced Research Projects Agency provided funding starting in 2007 to develop an automated culture and packaging system that would yield a fresh supply of transfusable red blood cells from readily available cell sources. While not yet clinically available, this technology has unlimited potential to revolutionize the creation and supply maintenance for blood products. In addition, these machines could also be scaled down and simplified so that they could become part of the standard equipment of a forward military treatment facility.

## HBOCs

The primary function of red blood cells (RBC) is to carry and deliver oxygen to tissues, and the RBC protein that carries oxygen is hemoglobin. Over the last few decades a number of pharmaceutical companies have tried to synthesize hemoglobin-based oxygen carriers (HBOCs), from chemically modified human or animal hemoglobin molecules. Resuscitation with HBOCs is appealing in that their use could restore intravascular volume and tissue oxygenation, without the limitations in supply and adverse effects that are associated with stored red blood cells. Preliminary animal studies of these compounds were promising, and they were even used in humans with severe bleeding who could not receive blood products (on religious grounds). However, the development of safe and effective agents for human use has been elusive. The first generation of HBOCs showed unacceptable side effects during preliminary clinical trials. This led to further refinement and development of second-generation agents with improved side-effect profiles, and also to research looking at alternative molecules to hemoglobin that can also carry oxygen. This is an area of active ongoing study, and holds obvious immense promise if a safe and effective HBOC product can be achieved.

## Advanced Hemostatic Agents

Soon after September 11, 2001, the US Department of Defense (DOD) funded intensive efforts to develop advanced hemostatic dressings. These collaborative efforts were extremely productive, and very rapidly a number of advanced hemostatic bandages/agents were developed, tested, and deployed. Since then, the original products have been further refined and many effective agents are now widely available. The current challenge is how to control bleeding in sites that are not within the reach of a bandage. These sites are typically within the chest or the abdominal cavity, and are now classified as "noncompressible truncal hemorrhage" (NCTH). This is clearly the next frontier in hemorrhage control research, and many efforts are under way to develop agents that can control or stop NCTH. Some of the most promising include injectable self-expanding foam, vascular occlusive balloons, and special abdominal tourniquets. There is no one technology that would work in all anatomical locations, and most likely multiple complimentary methods will have to be developed and deployed in the future.

## Ischemic Preconditioning

Although stopping blood flow and creating ischemia to an organ or tissue is generally accepted to be harmful, there is a growing body of research demonstrating that brief (several minutes) controlled periods of ischemia and reperfusion can induce a number of changes in the body that make it more resistant to subsequent injuries or ischemia. Even more interesting is that these changes can be induced by brief periods of controlled ischemia in remote tissue beds, and not just in the area that suffers the later injury or trauma. In a recent study of patients with traumatic brain injury, the simple intervention of inflating and deflating a blood pressure cuff on one arm (5 min inflated, 5 min deflated × 4 cycles) significantly reduced markers of brain injury compared to a group that did not undergo this treatment. In the scenario that opened this chapter, the soldiers have ischemic preconditioning performed by intermittent inflation and deflation of a blood pressure cuff on one arm. This simple and harmless intervention could have great promise for improving tolerance to subsequent trauma and ischemic injuries, although further research is needed to clarify the optimal methods, timing, and schedule of ischemic preconditioning.

## From REBOA to Controlled Regional Perfusion

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a relatively new technique gaining wider applications in trauma. It has been described in detail elsewhere (Chap. 45), but the basic description is a balloon-tipped catheter placed into the descending aorta and then inflated to achieve complete aortic occlusion and cessation of perfusion below the zone of occlusion. This is one of the only current options for control of noncompressible truncal hemorrhage in the prehospital or emergency department setting, but it obviously carries the downside of creating a significant ischemia-reperfusion injury commensurate with the location and duration of occlusion. In the category of endovascular hemorrhage control and resuscitation, ongoing "next-generation" efforts are focused on using partial or intermittent REBOA or REBOA-like devices to achieve "targeted regional perfusion optimization". In other words, recognizing that the premise of REBOA works and that technologies will continue to evolve – as they have for all other areas of endotherapy – the aim will be to have such technologies optimize perfusion to different aortic branch points (i.e. reduced or halted to regions that harbor the source of bleeding and increased to vital regions such as the heart and brain). In addition, controlled distal perfusion could mitigate the degree of ischemia-reperfusion injury and markedly prolong the tolerable and survivable period of aortic occlusion, particularly for Zone 1 inflation. Currently there are some pretty compelling large animal models successfully achieving partial REBOA or controlled regional perfusion, and we suspect that new commercially made devices will follow in the next 2–5 years.

One of the chapter authors (TR) was recently asked, "Which do you think will win? REBOA, injectable self-expanding foam, the aortic junctional tourniquet, or the pelvic binders?" To us, this was a disappointing but revealing question. He replied, "They all need to win!" They're not competitors and each has different hemostatic and resuscitative capabilities. In addition, each has different degrees of training likely to be needed for its distribution and ultimate use. We believe that the goal should not be to pit these different devices against one another as if one "will win" versus the others. Combat casualty care will benefit from innovation in all of these areas.

## Toward "Suspended Animation"

As described above in the introduction, the majority of efforts related to traumatic bleeding have focused on "supply side" interventions, including stopping blood loss and administering fluids and blood products. One of the most interesting and promising areas of ongoing research involves novel ways to modulate or interrupt the body's demand for oxygen delivery, or to enhance the ability of the body to tolerate major injury or bleeding. The ultimate extension of this would be to create a state of temporary and reversible "suspended animation", which would buy critical time to intervene and correct what previously would have been fatal injuries. Although we are not close to achieving true suspended animation, there are a number of promising ongoing research efforts in this area. In a 2009 study funded by the DOD, the administration of a drug called valproic acid was shown to greatly improve the survival of pigs with severe hemorrhage, even without administering blood products. This drug has now been validated to induce "prosurvival" changes at the protein and cellular level, and to improve outcomes from a wide variety of traumatic injuries (see Chap. 45). It is currently undergoing study in human trauma victims, and may become a next-generation battlefield therapeutic. A number of other drugs or agents that can alter the genetic or epigenetic response to injury are being studied, including hormonal agents such as estrogens, enzymes that repair injured proteins or DNA, and agents that prevent or reverse oxygen-mediated toxicity (anti-oxidants). Finally, attempts at chemically inducing a suspended animation-like state are currently being investigated. A study in rats showed that administration of a gas called hydrogen-sulfide could reversibly induce significant metabolic depression, and subsequent work validated that this could also be achieved with intravenous administration of these agents. Current attempts at making the leap from small animals to larger animals and humans are under way, and could represent the most promising area for future innovation and inroads into reducing battlefield mortality and morbidity.

## Immunomodulatory Manipulation of Resuscitation

Injuries and blood loss can generate severe inflammation, which can compound the damage to cells and organs. We also know that human beings respond very differently to similar insults based upon how the genes and proteins within our cells respond to shock. The exciting development in the last few years has been our ability to better understand these cellular changes and design strategies that specifically protect against and reverse the adverse consequences of shock . We know that crystalloids can further exaggerate the problem at the cellular level, whereas plasma and fresh whole blood are protective. Currently, we treat everyone essentially the same by replacing the lost blood without delivering any specific prosurvival therapies. In the near future, we would have the capacity to use quick point-of-care tests to determine the cellular status of the injured and deliver specific pharmacological therapies that are likely to reverse the adverse cellular consequences of shock. There are multiple such treatments that are either in the advanced stages of animal testing or undergoing early human trials. For example, administration of valproic acid (as described above) in larger doses can improve outcomes after lethal blood loss, severe sepsis, and combined insults. A phase I clinical trial is just finishing (ClinicalTrials.gov Identifier: NCT01951560), and the phase two trial of valproic acid in trauma patients is scheduled to start in 2016/2017. Ongoing research efforts are likely to add many more such treatments to our armamentarium.

## Injury Mitigation and Prevention

The one common thread in all of the above scenarios and descriptions of interventions is that they are designed to deal with the sequelae of injuries that have already occurred. Arguably the most impactful and effective interventions would be the ones that prevent injury altogether, or that significantly mitigate the extent and

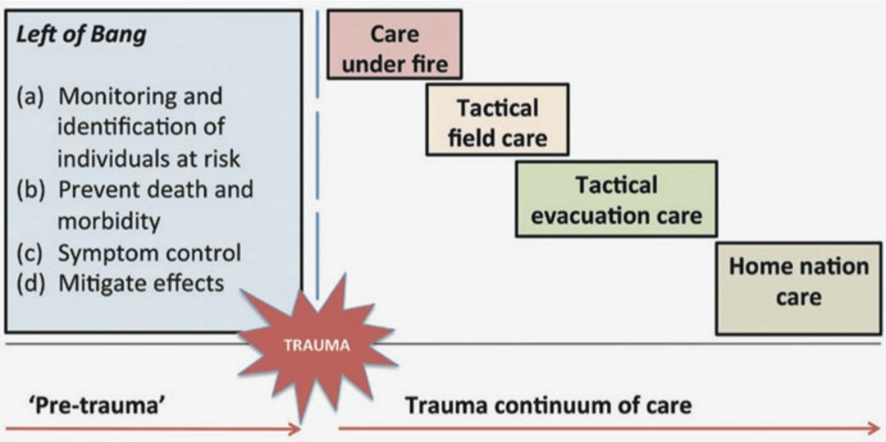


**Fig. 49.5** Schematic of the "Left of Bang" paradigm, where evidence-based preinjury interventions could be performed that could improve the response to injury and mitigate or even prevent many deleterious effects of battlefield injury (Reprinted with permission from Eisenstein et al. [11])

severity of injuries for a given injury mechanism. We have already seen the major impact of prevention and protective strategies such as body armor and improved blast-resistant vehicles in combat. This field is an oft-overlooked but incredibly important area that we, as trauma surgeons, should be paying much more attention to. Continued improvements in protective equipment, body armor, and vehicles are sorely needed. Future advances in this arena will likely include protective clothing and armor that can dynamically react to a given mechanism, such as a blast or missile. Built-in vital sign and other body monitors could provide immediate information on the types and severity of injury, as well as improve triage for urgent interventions and rapid evacuation. Most importantly, we must start to make inroads to preventing or mitigating traumatic brain injury on the battlefield, which remains a common cause of death, but one that is labeled as "not preventable". New protective methods and early protective interventions are sorely needed across the spectrum of TBI, from mild to severe. One recent project included the fielding of helmets with built in blast sensors, which could provide key data for studying the exact mechanics of blast-related TBI. In an excellent article published in the *Journal of Special Operations Medicine*, Eisenstein and coauthors describe the concept of "Left of Bang" interventions that can be done before the traumatic event, and can lessen or even mitigate the resultant degree and severity of injury for a given battlefield mechanism (Fig. 49.5). These include nutritional preconditioning, coagulation preconditioning, antibiotic release preimplanted devices, symptom control, physiologic monitoring, and pharmacologic mitigation of secondary effects and psychological effects of trauma.

## The Potential Impact

In his landmark paper analyzing the patterns and causes of deaths on the battlefield, Colonel (Ret.) Brian Eastridge estimated that one in four of these deaths was potentially preventable, with the majority of these being due to bleeding or bleeding-related complications. One of the most pressing and commonly discussed medical issues of the conflicts in Iraq and Afghanistan has been “hemorrhage control”, and this prioritized focus led to an unprecedented explosion in new life-saving techniques, devices, procedures, and treatment principles. In addition to continuing to augment these existing hemorrhage control capabilities and develop new resuscitation approaches, we believe the next giant leaps forward may come from the ability to induce prolonged “hemorrhage and/or ischemia tolerance”. This ability to have some degree of impact or even control over biologic time and the innate response to injury could help minimize or even eliminate the occurrence of so-called “potentially preventable” battlefield deaths, and even extend the promise of meaningful survival and recovery to injuries that are currently felt to be entirely nonsurvivable.

In closing, we must also recognize the very real and immense implications these cutting-edge advances and exciting lines of research will have for areas outside of the battlefield and other military environments. These technologies and therapeutics could have revolutionary impacts in a wide variety of areas that have continued to produce significant challenges to the delivery of effective urgent or emergent medical care. Rural hospitals are typically in relatively remote locations, and are not well supplied and equipped for major trauma or emergent surgical care. In addition, their blood bank supply is typically severely limited, and the majority could not provide enough products for a single massively bleeding patient. The ability to have stored freeze-dried products, or to have blood pharming technology to essentially grow their own blood products, would be transformative in enhancing their capability to provide initial care and stabilization of a severely injured or bleeding patient. Another potential application is in the field of wilderness medicine, where the availability of effective, rugged, easy-to-administer, light-weight resuscitation strategies could be life-saving. Prosurvival medications in the first aid kit that can be administered by a buddy (or self-injected) after major trauma could keep the injured alive during evacuation to higher levels of care. This “survival shot” would be an extremely useful tool for mountaineers, adventurers, hunters, extreme sports enthusiasts, hikers, long-distance sailors, or other individuals who face a high likelihood of injury in remote settings. Finally, these advances could greatly enhance care in scenarios where there are large volumes of casualties that overwhelm the available resources, the mass casualty event (MASCAL). The triage and management of patients during a MASCAL event often involves tough decisions based on limited resources and available skills. The ability to have much larger volumes of stored blood products, to quickly produce new blood products from a bioreactor, and to deliver easily injectable “prosurvival” therapies could result in the minimization of unnecessary or preventable deaths, and optimize the outcomes among all injured victims.

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# Non-Conventional Forward Surgical Elements

# 50

Matthew J. Eckert, Matthew J. Martin,
and Steven A. Satterly

**Deployment Experience**

| | |
|---|---|
| *Steven A. Satterly* | Surgeon, 772nd FST, Al Asad Forward Air Base, Al Anbar, Iraq, 2015 |
| | Team Leader, Surgeon, Expeditionary Resuscitative Surgical Team, East Africa, Special Operations Command Forward-East Africa, 2016 |
| *Matthew J. Eckert* | Surgeon, Camp Bastion Role 3 Hospital, Helmand, Afghanistan, 2012–2013 |
| | USSOCOM Surgical Support, Iraq, 2014–2015 |
| | USSOCOM Surgical Support, Horn of Africa, 2015 |
| | USSOCOM Surgical Support, Iraq, 2016 |

M.J. Eckert (✉)
Uniformed Services University, Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA
e-mail: matthew.j.eckert.mil@mail.mil

M.J. Martin
Madigan Army Medical Center, Department of Surgery, Tacoma, WA, USA

S.A. Satterly
Madigan Army Medical Center, Department of General Surgery, Tacoma, WA, USA



M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8_50

| | |
|---|---|
| *Matthew J. Martin* | Chief of Surgery, 47th Combat Support Hospital, Tikrit, Iraq, 2005–2006 |
| | Chief, General Surgery and Trauma, Theater Consultant for General Surgery, 28th Combat Support Hospital, Baghdad, Iraq, 2007–2008 |
| | Commander, 655th Forward Surgical Team, FOB Ghazni, Afghanistan, 2010 |
| | Chief of Surgery, 758th Forward Surgical Team, FOB Farah, Afghanistan, 2013 |

*The difference between the good guys and the bad guys is whether they use human shields, or make themselves human shields.*

Unknown author

**BLUF Box (Bottom Line Up Front)**

1. When warfare turns from conventional to an atypical or insurgency type, unconventional medical support will be required, and will come in a wide variety of shapes, sizes, and utilizations. You may be tasked to staff or lead such a unit. Be prepared to be flexible.
2. A smaller, well-equipped, and well-trained surgical unit can save lives. A unit that does not meet all three of the above will lose lives. Make yourself the former.
3. Give realistic feedback to Command and medical planners. A two-person team with a backpack CANNOT do damage control surgery for more than a single patient effectively. You may be the only voice that actually understands the details of combat surgery.
4. Blood is your "bullets." Request blood products a month ahead of an operation, and stay ahead of expiration dates. Carry at least 10 U packed red blood cells (PRBC) and 10 fresh frozen plasma (FFP) with you at all times. Units you support must have current EldonCards, Screening Document for Fresh Whole Blood per Joint Trauma System (JTS) Clinical Practice Guidelines.
5. Rehearsals. Rehearsals. Rehearsals. Specific scenarios from point-of-injury (POI) to OR to Evacuation. Day and night. It is strongly advised that you rehearse with your partner ground forces, using the possible vehicles or airframes.
6. Exercise your walking blood bank and mass casualty scenarios and, based upon your threat analysis, your Chemical, Biological, Radiological, Nuclear, Explosive (CBRNE) contingency plans. Crawl. Walk. Run.
7. Plans change frequently; stay in the loop. Communicate with area medical planners and ground force commanders (GFC) often. Review Operations Order (OPORDs) in advance, look at terrain and evacuation plans, assess risk, ask questions, provide recommendations. The GFC makes the call; enable them to make the best one.

(continued)

8. No "one trick ponies." Everyone pulls their weight. Be more than just the surgeon. Take the initiative, integrate wherever you can (i.e., make dinner, pull security, work out with the team).
9. Don't complain down. Your utility is your expertise, not your rank; bring solutions not problems. You will be greatly appreciated.

with little or no specific preparation. This chapter will briefly describe the composition of several of these currently employed units, as well as some specific considerations for the assigned surgeon.

## U.S. Army Forward Surgical Team (FST)

The concept of the FST has been in the Army's medical playbook since at least World War II, if not earlier. The contemporary FST doctrine and organization as we know it today was established in the 1990s, as a small mobile surgical element designed to support the maneuver brigade in conventional warfare. While the personnel and equipment assigned to FSTs have changed over the years, the general concepts remain. Current FST doctrine includes a 20-person team composed of two general surgeons, one orthopedic surgeon, two surgical technicians, one OR nurse, two critical care nurses, several medics, and the Commander and Detachment Sergeant. Often, the Commander is also a surgeon, permitting two surgeons per OR table. These teams are frequently augmented with additional personnel once deployed, such as a second orthopedic surgeon, primary care provider, or additional surgical support personnel. The FST is designed to be composed of two identical teams, capable of split operations if required. Ideally, an even number of personnel and equipment for each team would be included, but this does not always happen. If split operations are expected, it is strongly advised that the command element and providers discuss the best plan for distribution of personnel and equipment based upon mission requirements and personnel experience.

The deployed FST may or may not have all of its organic assigned equipment, to include vehicles, trailers, tents, and storage containers (Fig. 50.1). More than likely, the unit living and medical equipment will be crammed into a number of shipping containers and you will fall in on it, in theater, or you will inventory and assume the equipment of the unit you are replacing. Equipment inventory is a time-honored tradition of misery and loathing for enlisted personnel; in the FST, everyone works during inventory. If you choose to do something else, and subsequently find your special instrument set is not to be found, you have no one to blame but yourself. Officers, surgeons, enlisted – everyone participates in the daily duties and maintenance requirements for this small unit to function and succeed.

The FST typically occupies a tent or building and its general organization includes a receiving or triage area, operating room, and recovery ward or possibly ICU. If space allows, separate areas for sensitive medical issues or exams, patient


**Fig. 50.1** (**a**) Standard FST OR configuration with two field surgical tables Note the single anesthesia machine while the second table utilizes total intravenous anesthesia. (**b**) FST ORs with two simultaneous cases set up for only one anesthesia provider (tables head to head, *left panel*) or if two anesthesia providers available (side to side, *right panel*) (Photos courtesy of M. Eckert and M. Martin)

waiting, sick call, and administrative section are ideal. When establishing or taking over an FST, think about patient arrival and flow through the facility. What will the area look like in a Mass Casualty event (MASCAL)? Where will you conduct a walking blood drive? Where will you store bodies temporarily? If you are establishing the site, you have a relatively blank slate to work with. If you are taking over for a prior FST, it is ok to reassess and change things up. The FST is not intended or capable of standing alone, for security, logistic, or medical purposes. By doctrine, the FST is meant to be colocated with an Area or Forward Support Medical Company to allow enhanced patient holding, primary care, and additional non-surgical treatment capacity, and modest radiologic, lab, and dental support. In current deployments, the FST may or may not be colocated with these units, but is likely to have some equipment and personnel augmentation.

Some key predeployment and deployment considerations for the surgeon assigned to an FST or any of the surgical units in this chapter are listed in Table 50.1. The role of the FST is to perform damage control surgery (DCS) and damage control

**Table 50.1** Unique considerations for the surgeon assigned to small surgical elements or ad hoc teams

| |
|---|
| Predeployment |
| Team training and equipment familiarization |
| Rehearsal exercises (MASCAL, CBRNE, set-up, patient movement) |
| Surgical train-up: Advanced Trauma Operative Managaement (ATOM), Advanced Surgical Skills for Exposure in Trauma (ASSET), Advanced Trauma LifeSupport (ATLS), Basic Endovascular Skills for Trauma (BEST)[a] |
| Review regional specific medical issues/diseases |
| Tactical equipment and Standard Operating Procedure (SOP) training |
| Close out Officer Evaluation Report (OER) and identify rating chain for deployment |
| Packing list (identify issue items first)…then go shopping |
| Lightweight, packable, breathable, durable clothes (civies) |
| Bug net, water purification, camp stove, hammock |
| Nonelectric entertainment |
| Personal medical items (pill-pack for common problems) |
| Deployment |
| Rehearsals, rehearsals, rehearsals |
| Review medical rules of engagement and regional medical resources |
| Blood product planning, ordering, and preservation (battery, power, solar) |
| Walking blood bank preparations and EldonCards |
| Cross-train with all members of medical team |
| Load out first and be ready before the ground force |

*ATOM* Advanced Trauma Operative Management, *ASSET* Advanced Surgical Skills for Exposure in Trauma, *ATLS* Advanced Trauma Life Support, *BEST* Basic Endovascular Skills for Trauma

resuscitation (DCR). Definitive surgical care is rarely indicated at an FST, and often only with local nationals, if approved by the Commander and in line with the medical rules of engagement. The FST is frequently utilized in a split fashion, allowing a damage control surgical capability to be available across a greater geographic area. As the team breaks down into smaller elements, holding capacity and the ability to care for more than one or two patients at a time becomes limited. A single critical surgical patient will likely consume the resources of a split FST element, and two critical patients may overwhelm a whole FST. Therefore, it is essential to have ongoing communications with the medical planners, and to ensure early resupply and timely coordination with ground force commanders reagarding surgical availability.

Resetting the FST for surgical cases needs to be a rapid process (Table 50.2). Prior planning regarding decontamination and sterilization of surgical instruments is essential. Most FSTs are equipped with two dental-type sterilizers, each able to hold only a limited number of instruments and thus requiring several hours for sterilization and cooling. Various options for liquid sterilization exist and may need to be explored prior to deployment to austere locations. It is strongly encouraged that major instrument sets be broken down into smaller more manageable sizes to include the essential instruments prepackaged into smaller peel packs for use. Many of the cases performed in the FST require only a limited number of instruments, and you are able to get by with far fewer than you may expect. Plan ahead for the common supplies likely to be required: fluids for wound irrigations, gauze bandages and

**Table 50.2** Mission-specific considerations for the small unconventional surgical team

| |
|---|
| Mission-specific preparations |
| Medical rules of engagement |
| Review OPORD |
| Best/worst case scenarios |
| High-risk elements (airborne operations, increased threat, CBRNE) |
| Planned enemy captives or hostage rescue (liaison with intelligence and reintegration team) |
| Premission checks (personal and medical gear) |
| Remember Personal Protective Equipment (PPE) and trash bags |
| Headlamps |
| Personal water, food, clothing, gloves |
| Medical contingency |
| MASCAL |
| Nearest vetted medical facility (host-nation, military, coalition) |
| Nearest subspecialty support (neurosurgery, ophthalmology) |
| Blood product planning (units needed based on risk analysis) |
| Plan for timing of FFP thaw |
| Resupply plan |
| Intermediate supply caches or prepositioned resources for patient evacuation |
| Oxygen (unpressurized aircraft, head/chest trauma) |
| Hyper−/Hypothermia management |

topical hemostatic agents for soft tissue wounds, materials for temporary wound and cavity closure, and supplies for common ATLS-type injuries.

Various types of ad hoc configurations of the split FST have been and are currently utilized in the deployed setting. Common themes to these ad hoc configurations include a single surgeon with a scrub tech, nurse, medic, and other personnel as required. This smaller footprint allows flexibility in the form of decreased personnel to move, and space to occupy. However, the limited personnel and space comes at the expense of available medical supplies and case capacity. If your team is asked to break down into these ad hoc formations, it is essential that you define the scope of your mission and expectations for possible patient numbers, who you are allowed to treat, and expected duration of patient holding. An extensive discussion with your medical operations planner and split team members is highly encouraged prior to the split. While these ad hoc teams have many limitations, they also fulfill an important role in providing a DCS/DCR capability, particularly in the current deployments to areas of irregular and unconventional warfare.

## Special Operations Surgical Teams

The US Army and Air Force each possess several small-scale special operations surgical and resuscitation teams of various configurations. While the intent of this chapter is not to describe in detail every unit configuration possible, contact with these special operations teams is common for the conventional FST-type elements. These special operations teams are often very small, with significantly limited resources and specialization in their mission scope and practice. Their medical mission is strict damage control and resuscitation in the most basic sense and delivery of their patients to Role II or III elements for further stabilization and care. These teams are frequently limited in resources to what they carry, and as such may depend upon resupply and support from the Role II or III element in order to rapidly turn around for subsequent missions. Critical decisions are often dictated by significant tactical and security limitations, making patient stabilization a complex and often step-wise process (ie. POI care from the ground medic, transitioning to the special operations forces (SOF) surgical asset for initial resuscitation/DCS, arriving to the Role II element for additional resuscitation and stabilization before eventual evacuation to a Role III element for imaging, additional surgery and theater evacuation preparation). Not every step in this chain of care is required for all missions, but each fulfills a unique niche. Surgeons will not be randomly assigned to these units for deployment, as significant training, preparation, and qualifications are required to function successfully in these very small teams.

The US Air Force Special Operations Surgical Team (SOST) consists of a general surgeon, anesthetist, emergency medicine physician, OR technician, and orthopedic surgeon. The SOST supports special operations missions of all services as needed. The US Army Special Operations Command maintains several Special Operations Trauma Teams, each including a resuscitation section and surgical section. The surgical team is composed of a general and orthopedic surgeon, anesthetist, OR technician, and critical care nurse. Both of these teams are designed to provide the forward DCR/DCS capability for special operations forces in theaters lacking developed medical care systems.

## Expeditionary Resuscitative Surgical Team (ERST)

The ERST was originally created to address the Area of Operations in Africa. Africa has a relatively unique situation given the size of the continent and the missions supporting the Global War on Terror. Specifically, access to damage control surgery as well as robust evacuation platforms is extremely limited compared to other, well-developed theaters. The ERST was constructed as a composite of two teams: a Damage Control Surgical Team (DCST) and a Critical Care Evacuation Team (CCET). The concept was that a versatile four-person surgical team could be imbedded and placed far-forward to support DCS near point-of-injury (POI) to reduce operational risk to the ground force commander. The CCET, being organic to the ERST, is designed and trained to integrate with any casualty evacuation (CASEVAC) platform, enabling a critical care evacuation for prolonged personnel recovery that is not limited to any one asset or location. Surgical trauma is stabilized in the field by the DCST, and the CCET provides evacuation and resuscitation en route to a higher level of care. The medical goal of the ERST is operational risk reduction without being a tactical liability.

The ERST is still in development; however, the utilization and task organization is optimized for versatility (Fig. 50.2). Typically, the DCST is a four- to five-person team composed of a general/trauma surgeon, an orthopedic surgeon, an emergency physician, and an anesthetist. Early in the concept, a scrub tech was part of the task organization; however, this was found to be redundant given equipment and mission

**Fig. 50.2** (**a**) ERST conducts CASEVAC exercise using open pick-up truck bed for patient movement. (**b**) Urgent field OR set-up during ERST training exercise. (**c**) Temporary OR set-up prior to mission execution (Photos from authors' personal collection and used with permission)

limitations. The CCET is a two- to three-person team including a critical care physician, a critical care nurse, and an emergency care nurse. These task organizations are fluid and often change as needed to optimize care within challenging and unique missions. In one instance, the critical care nurse was placed with the DCST to provide critical care evacuation on non-US CASEVAC as well as prolonged field care if required. In some situations, the entire eight-person element was stationed together to support missions.

Versatility is a tenet of special operations and the ERST embraces this in medical capability. ERST mission planning is primarily based on the mission, its risk, and the number of people, equipment, and blood products required for effective DCS and evacuation. For the DCST, the theme is "lighter, leaner, darker." All surgical equipment is packable and enables approximately two to three major surgical cases without resupply or additional supplies. Surgery is mostly by petzel headlamp for lighting. Surgical sets are hybridized between major abdominal, major vascular, and thoracic sets. Blood products are your primary limitation. The second limitation is volume of space or "cube." Many missions have limited space for equipment and the priority is for mission completion, not your favorite OR equipment. Generally, the GFC will listen to valid assertions on the amount of equipment space and the number of people you need for surgery. However, keep in mind that you and your team are taking up space for ammunition and SOF personnel, and the mission is the priority, not you.

There are many limitations that must be considered by the surgeon in this environment. The first limitation, and most difficult, is whether to operate at all. The GFC will understand medical rules of engagement and effective surgical care will be based off of an honest discussion of your limitations. Obviously, you can use all of your blood and Class VIII in one severe trauma if required. Most missions will incorporate a partner force and expectations for their medical support; however, you will be limited by supply and blood products. Simply put, you cannot save everyone. The GFC should make the call on patients you surgically engage based on mission requirements. Many partner force units will have very limited evacuation or organic medical capabilities, let alone establish military or civilian medical infrastructure. The utility of performing damage control surgery on someone who will never see another surgeon or any medical care should be discussed. Likewise, the stakes of effective triage are raised. Regardless of nationality, using all of your blood and supply on one patient that you cannot save makes your mission ineffective. This notwithstanding, have this balanced discussion with the GFC prior to the mission as this can impact triage as well as GFC decision making.

In summary, the ERST is one of many of the newer small, light, and flexible medical units designed to provide a DCR/DCS capability in austere or unconventional environments. Sharing many of the capabilities and limitations encountered with the other units discussed in this chapter, the ERST will undoubtedly persist given the increased presence of US forces in Africa.

## The "Split FST," "Jump FST," and "Golden Hour Offset Surgical Team" (GHOST)

By conventional US military medical doctrine prior to and during the early experiences in Iraq and Afghanistan, the smallest forward medical treatment with surgical capabilities (Role 2) was the Forward Surgical Team, which is outlined earlier in this chapter. However, due to realities on the ground, appreciation of the effects of transport time and time to intervention on outcomes, and the limitations of available personnel and supplies, we have commonly utilized sub-FST size elements to provide stand-alone Role 2 support to US and coalition military forces. This was particularly required following the mandate from the Secretary of Defense that all injured service members should be transported to a Role 2 or higher facility within an hour of injury, also called the "Golden Hour Policy." The most common of these has been the "split" FST, which essentially splits the standard FST into two equal-sized and equally resourced elements. The latter half of Operational Enduring Freedom in Afghanistan particularly relied on these teams to provide coverage to the entire land mass, which could not be provided by standard Role 3 or even Role 2 elements. Experience has shown that even these smaller elements can provide true damage control surgery and resuscitation capabilities, although admittedly only to a small number of patients simultaneously. Thus, these were well-suited for the lower-intensity conflict, and over time also became incresingly well-supplied and were also commonly augmented with additional personnel, or with colocated Role 1 units that greatly enhanced their capabilities and capacity. However, we should not take this experience, which was achieved during a decade-plus of relatively low-intensity conflict, and extrapolate it to what would be seen in a new high-intensity conflict with much higher numbers of casualties and much less mature supply and resupply lines.

A full discussion of the number and configurations of various unconventional FST variants is beyond the scope of this chapter, but we will briefly comment on several of them. With the success of the split FST, the drawdown in Afghanistan, and the increasing areas that were now outside of the traditional golden hour transport rings, a number of both formal and ad hoc unconventional forward surgical elements were proposed and utilized. One example of this was the "jump FST," which simply took a standard full FST and placed them at a centralized location where they were tasked with being prepared to send smaller elements to any location in theater on demand to provide temporary Role 2 coverage. This had the advantage of offerring a centralized and flexible pool of manpower to provide coverage on an as-needed basis. However, the immediately appreciated downsides of this program were that the teams were generally not trained or equipped for this mission, and transportation and local security options were highly variable, and sometimes frankly inadequate. In addition, there were noted to be long periods of complete clinical inactivity as these units had no standard or ongoing health-care mission. In our opinion, this was a good example of a suboptimal use of combat surgical assets and highlights the principle that high-quality battlefield care is extremely difficult to provide on an ad hoc basis and without consideration of the multiple second- and third-order effects of what initially might sound like a reasonable idea or policy.

A more recent variant of the original jump FST concept has been the Golden Hour Offset Surgical Team (GHOST), which again was primarily designed to fill holes in the 1-h medical evacuation rings that were left when conventional medical assets departed the theater of operations. As opposed to the jump FST, these were a somewhat more formalized and well-planned effort that was used to provide small and highly mobile forward surgical elements in support of both conventional and special forces operations. The GHOST teams would typically consist of five to six personnel who were supplied and staffed to run a maximum of two OR beds simultaneously for somewhere between five and eight cases before needing resupply. The experience with these units has not been robustly analyzed and remains largely anecdotal, so it is difficult to draw any hard and fast conclusions about their role, efficacy, and overall benefit. Proponents of these smaller elements have cited their success in providing far-forward care and even major surgery to wounded service members or civilians, and in providing golden hour coverage to operational forces even during the drawdown phases of the conflicts. Critics, however, have argued that these units may be inadequately supplied, equipped, and staffed to do true damage control surgery and damage control resuscitation, and that the predeployment training in preparation for these missions has been highly variable and in some cases nonexistent. This is in comparison to the more well-equipped and very well-trained USSOCOM medical elements. There has also been significant concern raised about a mandatory golden hour policy itself, as this concept was never meant to be translated to a hard and fast rule of “60 minutes or less,” and the question of whether faster surgery at a less well-equipped facility is superior to a longer transport time but surgery at a more robust facility. These are questions that are being asked and debated currently, and that will surely arise in any future conflicts.

As a combat trauma surgeon, you may be asked to serve on or even to lead one of these unconventional sub-FST teams. Hopefully, you will also have some involvement in the planning and execution phases, and your input into this process can be critical for providing real-world insight to commanders and med planners who may have never seen actual combat surgery at a Role 2 facility. If you have not been explicitly involved, then ask to be involved and become part of the design and implementation. You should also be prepared to provide realistic and honest input and feedback, particularly for ideas or proposals that you know to be unrealistic or unlikely to result in the desired outcome. A real-world example from our experience was a proposal to deploy a “jump FST” to an area because it fell 5 min outside of a golden hour transport ring, and to an area with an extremely low operational tempo and threat level. With some additional evaluation and input, including clarification from medevac assets that they could easily extend their golden hour ring to cover that area, this plan was halted. On the other hand, there are many instances where this type of team and coverage will clearly be needed. In those cases you should focus on ensuring the following critical elements are considered and in place: (1) Your team MUST be trained to do this mission. This cannot be done on an ad hoc or an “I’ll know what to do when I get there” basis; (2) Your team must be realistically but fully supplied and equipped, including enough blood products to resuscitate a patient with massive hemorrhage; (3) You must have a reliable and adequate transportation asset, and know what can and can’t be carried on whatever air asset you are using; (4) Everything should be prepacked and prepositioned for easy mobilization when needed; and (5) Give realistic and honest feedback about your experiences. Doing three successful laparotomies in bleeding patients is a success. Treating minor wounds and placing one chest tube should not be conflated with your presence having been necessary and life-saving.

## General Considerations

For the surgeon who finds him or herself in one of these small-scale surgical teams, perhaps without any real focused predeployment training, the challenge is often mental more than physical. Surgeons are trained and mostly practice in the shiny, well-lit, infinitely resourced halls of medical centers with subspecialists and partners to back them up. Finding yourself as the lone surgeon with limited assitance can be an overwhelming experience. That feeling of uncertainty is in fact a good thing, as it should prompt you to begin to mentally and physically rehearse and "pregame" every contingency your mind can conjure up. Since you are guaranteed to at least be accompanied by an anesthetist, the two of you should pregame these situations together. The "6-Ps" of planning were never more true than in these small surgical teams.

Remember at the outset that you and your anesthetist "know" what to do already. Basic trauma and resuscitation is relatively straightforward. When the chaos and stress rise, fall back to the basics (ATLS, hemorrhage control, and damage control resuscitation). Not every injury requires an immediate operation. If the patient will only be in your tent for a limited amount of time, and the procedure is not absolutely required to be performed to prevent loss of life, limb, or eyesight, it can likely wait until reaching a higher level of care (provided it is not too far away). It is often harder to not operate than to cut. That said, if your instincts tell you to do it, you probably should (unless you have bad instincts, in which case you should find yourself a spot in a hospital that doesn't see trauma).

If you are the lone surgeon, you will likely be performing the tasks of yourself, the absent assistant, and possibly the scrub tech and OR nurse. So plan ahead. Organize your "OR" with things easily reachable or laid out in preparation, so you can point to them for someone else to open. Prepackaged sets for chest tubes, cut-downs, and debridements will prevent wasting large instrument sets on minor tasks. Remember, as a famous surgical text quotes, "sterility is a luxury in trauma, not a requirement." Lay out a few pairs of gloves but do not fret about having to open a package yourself once "scrubbed" or if your hasty skin prep is not perfect. Irrigation and antibiotics are surprisingly effective, and serial irrigations, debridements, and delayed closure will almost guarantee healthy wound healing. Strive for the standards you are used to back home, but do not panic if you fall short in these unique settings. Using the JTS Clinical Guidelines as your basic minimum standards will ensure excellent care, and the system will ensure the limitations of austere care are accounted for.

The blood products in damage control resuscitation are just as essential as suture to the lacerated vessel. Discussion of blood products is presented elsewhere in this text, but remember the time and personnel limitation implications for these teams. You may not have the warm water bath to thaw FFP in an unconventional surgical element. Many bags of FFP have been thawed next to the naked warm skin of team members, but be forewarned, these FFP bags seem to rupture and leak often. A small pelican case with a chemical warming blanket liner and wool blanket wrapped around the products will warm and thaw product remarkably well.

If caring for critically ill patients in these small teams, the adrenaline, volume of work to be performed, and pressure to care for the patients can easily blind you and your teammates to many of the fine details and what is happening around you. If you start a case, try to give an estimate to your medical operations person so mission planning can be adjusted appropriately. Start communications for evacuation planning as soon as possible (you do not have to identify all injuries or be able to decribe the case before an evacuation asset can launch). Think about what might happen en route to the next higher level of care and clearly communicate this to the evacuation team. Secure your tubes, lines, and drains. Provide a concise list of injuries, vitals, medications, fluids and blood products, and procedures performed in written format if possible. Remember the basics and your team will do good things for injured people.

## Final Thoughts

The last 15 years of conflict during the Global War on Terror have covered the entire spectrum of conventional and unconventional warfare, and required the military medical system to adapt in support of these missions. The surgical team has been the primary focus in this medical adaptation given the mission's essential requirement of providing combat trauma care and resuscitation to US and coalition troops. Few deployed surgeons receive specific training for the unconventional surgical unit mission prior to touching down in theater. While basic surgical concepts stand, the unique limitations, flexibility requirements, and mission planning concerns often make these deployments highly demanding. While preparation is always stressed in trauma, it is absolutely essential that these small teams and their surgeons spend considerable time in rehearsals and readiness exercises to ensure success.

# Appendix A
# Improvise, Adapt, Overcome: Field Expedient Methods in a Forward Environment

> In the long history of humankind (and animal kind, too) those who learned to collaborate and improvise most effectively have prevailed.
>
> Charles Darwin

The ability of modern armies to project fully functional medical assets to the most austere environments is truly remarkable. Despite this, you will never have the level of support, supplies, and modern equipment that you are accustomed to in your home practice. One aspect of military medicine that has not changed throughout history is the ability of talented and dedicated people to improvise, adapt, and overcome. The following is a collection of tips, tricks, advice, and improvised techniques from the authors that they have been taught or developed during combat deployments.

## Tubes and Lines

If chest tubes run out or you don't have the correct size for children/infants, an endotracheal tube can be used as a thoracostomy tube.

In a pinch, IV tubing can be used to secure an endotracheal tube or cricothyroidotomy tube.

A Foley catheter can be used as a gastrostomy or jejunostomy tube – tape over the balloon port so it is not inadvertently deflated.

A triple lumen central line kit can be used for thoracentesis or paracentesis.

A large central line (cordis) can be placed into the trachea via Seldinger technique for an emergent temporary airway.

A pediatric central line kit can be used for placing an adult radial or femoral arterial line.

The finger of a sterile glove with a hole on the end attached to a chest tube can be used as a temporary Heimlich valve.

Peritoneal dialysis can be performed through a Foley catheter in the peritoneum and an outflow drain (10 mm JP) in the pelvis, with custom-made dialysate from your pharmacist.



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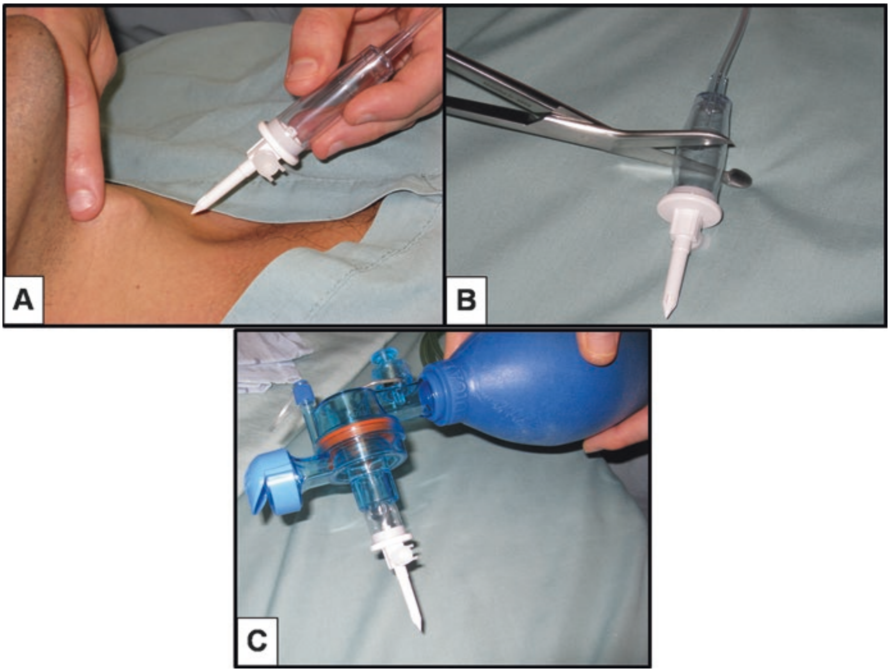



**Fig. A.1** Insert the spiked end through the cricothyroid membrane or between tracheal rings (**a**), cut off the back end of the fluid reservoir (**b**), and this should fit well onto the end of an ambu bag or ventilator circuit (**c**)

Chest tube on a Heimlich valve attached to a Foley catheter bag is more convenient than pleuravacs when transporting.

A rapid emergency airway can be established using a standard IV tubing set (Fig. A.1).

For open ("sucking") chest wounds, a vacuum dressing provides an excellent seal and accelerates closure of the pleuro-atmospheric fistula.

Laparoscopic trocars (3–5 mm) can be placed into the thoracic cavity to rapidly decompress a tension or open PTX. A larger trocar (10–12 mm) can be placed for initial intervention for a large PTX or HTX, and then a standard chest tube can simply be inserted through the trocar and then the trocar removed over the tube.

## In the Operating Room

Sterile gloves can be used as sterile light handle covers.

A sterile gown can be used as a sterile drape for operative procedures.

A Petzl headlamp is great for reading and can be used as a backup OR light.

An NGT tube or IV tubing can be used as a temporary vascular shunt.

A Swan-Ganz catheter can be used as a Fogarty catheter in larger arteries.

If you run out of lap pads, anything sterile will work for packing: gowns, drapes, towels, gloves.

Cardiac pledgets can be made from pericardium or peritoneum.

Skin staples can be used to temporarily close a cardiac laceration, but should be subsequently replaced with suture.

Skin from amputated extremities can be harvested and used for grafting burns.

Veins from the amputated extremity can be harvested and used for vascular patch or repair.

If you are leaving lap sponges in the abdomen, tie them together for easy and COMPLETE removal.

If liver stops bleeding with compression, then take down the ligaments and use sterile ace wrap to wrap the liver instead of packing.

32–40 F chest tubes can be used as an aortic shunt in damage control mode. Secure with double umbilical tape ties at both ends.

An external fixator pin driven trans-tibial makes a nice field expedient traction pin.

If no scalpel blades, a nice pair of curved Mayo scissors can open any cavity and create any incision. To start, simply pinch the skin transversely and cut, then insert the scissors and go.

If you need to leave the chest open after a sternotomy, cut the bottom off a plastic bovie holder in a "U-shape" fashion and wedge between the cut edges of the sternum, then apply vac dressing and ioban.

Use 0-silk to quickly ligate the perforated bowel. Grab the hole with Allis clamp or even sections of bowel and mass ligate. Better than umbilical tapes during meatball surgery as umbilical tapes don't slide and are hard to get vascular control.

Makeshift wound vac: use sponges from the OR prep kit, NG tube and Ioban.

Tensor fascia-lata from the lateral thigh can be used as a dural substitute to cover exposed brain.

If you need to cut bone and don't have a saw, open the chest tray and use the Lebsche knife. It will work for amputations, sternotomies, and cutting ribs.

Make a circumferential wound vac using coban wrapped at both ends on an impervious stockinette.

A bronchoscope or ureteroscope can be used as a choledochoscope.

If operating in a highly contaminated abdomen and vein is not available for an iliac artery repair, always keep 1200 mg of rifampin in the OR (usually comes in 300 mg capsules). The capsules can be crushed and placed in 20 ml of normal saline and a Dacron graft soaked for 15 min prior to insertion.

Exposure of the proximal femoral and distal iliac vessels via the abdomen or thigh can be challenging, especially with a groin vascular injury. The abdominoinguinal

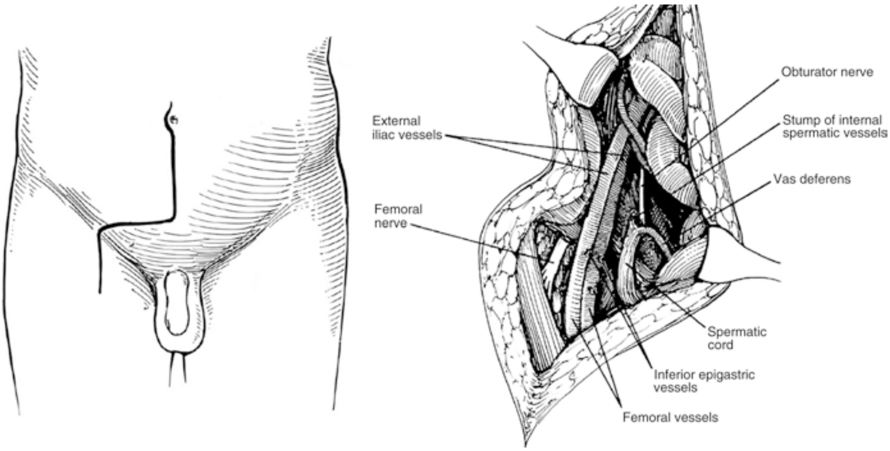



**Fig. A.2** The abdominoinguinal incision provides a rapid and wide exposure of the mid to distal iliac vessels and the femoral vessels and is ideal for groin or proximal thigh vascular injuries. (**a**) Skin incision, (**b**) surgical exposure gained by a division of the inguinal ligament and the inferior epigastric vessels (Reprinted from Operative Techniques in General Surgery, 10, Karakousis CP, The abdominoinguinal incision, 94–106, Copyright 2008, with permission from Elsevier)

incision (Fig. A.2) provides a great wide exposure of the entire area, avoids entering the abdomen, and avoids struggling for proximal control from the groin.

A sterile glove and x-ray cassette cover can make a cover for the Doppler probe and wire for intraoperative vascular evaluations of repairs and distal flow.

Low-dose heparin after an arterial repair (300 units/h) if no major contraindication may prevent thrombosis, particularly in the highly reactive brachial artery.

Use the ventilator tubing from a disposable ventilator circuit set to perform an on-table colonic lavage or rectal washout.

Vascular shunts do not work well in children – repair or ligate. If you repair, use a vein graft if possible and use interrupted sutures to allow for expansion with growth.

A sterilized glass marble can be used as a spacer following the enucleation of an eye if no ophthalmologic spacer is available.

A hemostat can substitute for a scalpel handle (clamp the blade) if one is not available.

A 3.0- or 4.0-silk on a Keith needle is invaluable for quick "whip stitching" of large wounds when no other instruments are available. It is also faster, as no needle driver is needed, and can close several layers with one pass as opposed to a stapler.

Train your nonsurgical colleagues to first-assist on trauma cases. You may not have another surgeon to assist, or it will free up the other surgeon(s) in a MASCAL scenario.

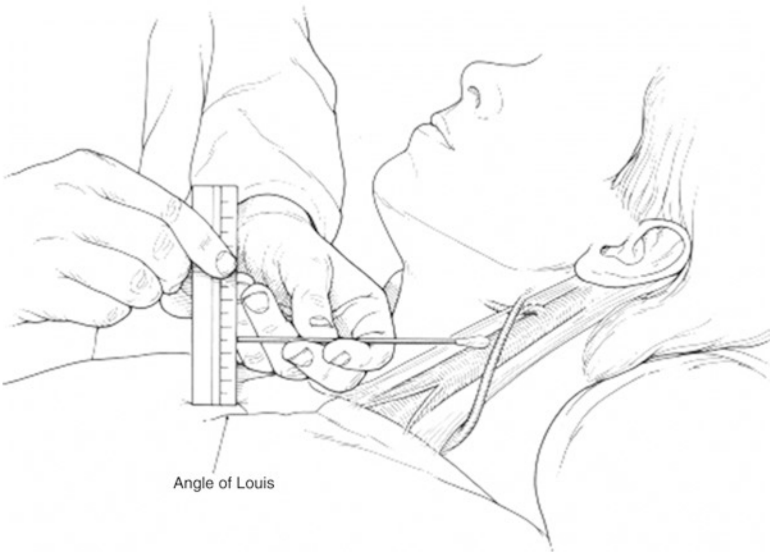



**Fig. A.3** Bedside assessment of central venous pressure by physical examination

## Post-op and ICU Care

Placing irrigation fluid and IV fluid in a box and then running a Baer® hugger hose into the box will warm the fluids.

Keep a stock of the meal heating kits that come with every MRE (meal ready to eat). They can be used for warming IV fluids or irrigation.

For clearing airway secretions (particularly in children), mix equal volumes of normal saline and bicarbonate solution and administer/suction via the ET tube. An alternative solution is hypertonic saline mixed with albuterol nebs.

A mist tent (face or whole body) to deliver nebulized treatments or humidified air to help relieve upper airway obstruction in infants can be made with wire hangers and clear plastic bags.

If patient warming devices are not available, you can use cardboard secured with duct tape to enclose the patient and use a Baer hugger or portable hair dryers to provide warm air.

Lumbar spine support belts or weight-lifting belts can make excellent abdominal binders.

Central venous pressure can be assessed at the bedside using ultrasound (see Chap. 6). Alternatively, measure the vertical height from the sternal notch to the top of the internal jugular vein pulsations in centimeters and add 5 (Fig. A.3).

Also, assessment of intra-abdominal pressure can be done with a ruler and the Foley catheter (Fig. A.4).

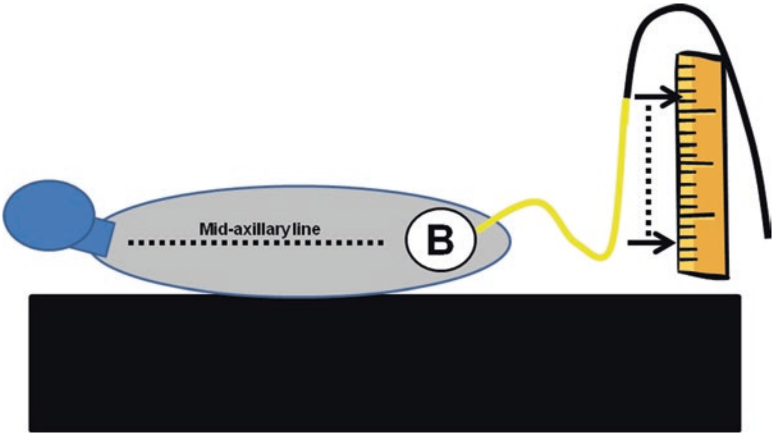



**Fig. A.4** To measure bladder pressure without pressure transducers, establish a column of fluid in the catheter by clamping it for 1 h, unclamp and raise the catheter in the air. With the patient supine, measure the vertical distance from the mid-axillary line to the height of the column. Remember to multiply by 0.75 to convert from $cmH_2O$ to mmHg

Alternative sites for intra-abdominal pressure measurement are the nasogastric tube (instill 50 cc saline) or a needle inserted directly into the peritoneal cavity.

Ketamine is an often overlooked drug that provides excellent procedural sedation with no hypotension. Dose =1–2 mg/kg.

Fogarty catheters make great bronchial blockers in the setting of significant hemoptysis with penetrating lung injury or blast lung. Deflate the ETT cuff and advance the catheter to the side of the ETT under direct bronchoscopic visualization until the bleeding bronchial segment is isolated.

## Miscellaneous

If you are going on a deployment to an austere environment, try to contact the surgeons who are already there. Find out what critical supplies or items (i.e., prosthetic vascular grafts) they don't have and hand-carry them with you.

One of the first things you should do is perform a thorough inspection of your OR supply room. See what you have and don't have – you'll be surprised on both counts.

Canteens can be marked and used as urinals in a mass casualty situation.

Use Excedrin with caffeine far forward to avoid caffeine headaches.

Going days without showers – antifungal cream and baby wipes can come in handy.

Put ambulatory or minimally injured patients to work in MASCAL scenarios. They can apply dressings and hold pressure, help transport patients, and provide comfort.


**Fig. A.5** Sign posted at the Air Force Theater Hospital, Balad, Iraq

Always carry a Sharpie marker for labeling dressings, marking injuries, or writing medical records directly on the patient.

Use Skype for improvised video teleconferencing with stateside colleagues or friends.

Most “disposable” supplies can be cleaned and reused. Pay attention to what gets thrown away; a lot can be reused, especially suture.

Wound irrigation with potable water is equivalent to sterile fluid.

Mail a box or foot locker of critical personal supplies (blankets, exercise clothes, reference books) ahead of you. Every pound less that you have to carry on the long trip is a blessing.

Take pictures, record cases and your thoughts, collect data and participate in the many ongoing deployed research projects.

Always remember who’s the boss in combat trauma (Fig. A.5).

Finally, support your colleagues, do the right thing for the patients, and pass on your experience and lessons learned!

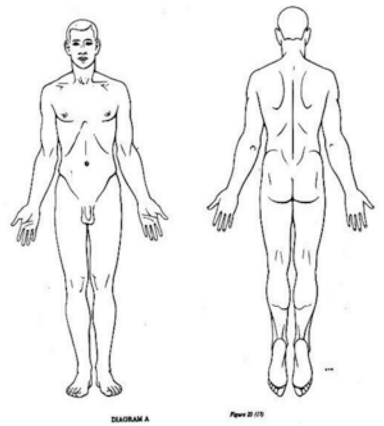
# Appendix B[1]
# Burn Charts and Orders

## APPENDIX B: ADULT LUND BROWDER BURN ESTIMATE & DIAGRAM

| Total Area front/back (circumferential) | | one side--anterior | one side--posterior | Do not include in total TBSA | | | |
|---|---|---|---|---|---|---|---|
| | Adult | adult | adult | 1st ° | 2nd ° | 3rd ° | TBSA |
| Head | 7 | 3.5 | 3.5 | | | | 0 |
| Neck | 2 | 1 | 1 | | | | 0 |
| Anterior trunk* | 13 | 13 | 0 | | | | 0 |
| Posterior trunk* | 13 | 0 | 13 | | | | 0 |
| Right buttock | 2.5 | na | 2.5 | | | | 0 |
| Left buttock | 2.5 | na | 2.5 | | | | 0 |
| Genitalia | 1 | 1 | na | | | | 0 |
| Right upper arm | 4 | 2 | 2 | | | | 0 |
| Left upper arm | 4 | 2 | 2 | | | | 0 |
| Right lower arm | 3 | 1.5 | 1.5 | | | | 0 |
| Left lower arm | 3 | 1.5 | 1.5 | | | | 0 |
| Right hand | 2.5 | 1.25 | 1.25 | | | | 0 |
| Left hand | 2.5 | 1.25 | 1.25 | | | | 0 |
| Right thigh | 9.5 | 4.75 | 4.75 | | | | 0 |
| Left thigh | 9.5 | 4.75 | 4.75 | | | | 0 |
| Right leg | 7 | 3.5 | 3.5 | | | | 0 |
| Left leg | 7 | 3.5 | 3.5 | | | | 0 |
| Right foot | 3.5 | 1.75 | 1.75 | | | | 0 |
| Left foot | 3.5 | 1.75 | 1.75 | | | | 0 |
| | | | | | | | |
| | 100 | 48 | 52 | 0 | 0 | 0 | 0 |

| | |
|---|---|
| Age: | |
| Sex: | |
| Weight: | |

Patient Identification



[1] Reprinted from Joint Trauma System Clinical Practice Guideline, Burn Care http://www.usaisr.amedd.army.mil/cpgs/Burn_Care_11May2016.pdf.

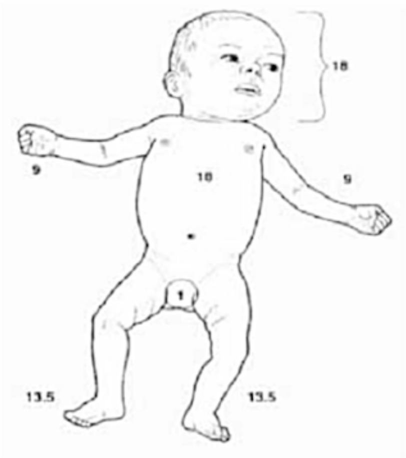


M.J. Martin et al. (eds.), *Front Line Surgery*, DOI 10.1007/978-3-319-56780-8

## APPENDIX C: PEDIATRIC LUND BROWDER BURN ESTIMATE & DIAGRAM

### INFANT BURN ESTIMATE AND DIAGRAM

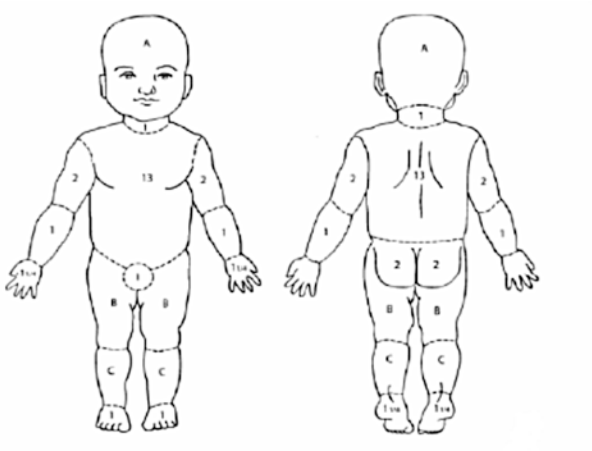
| Total Area front/back (circumferential) | Birth to 1 year | Do not include in total TBSA $1^{st}$ | $2^{nd}$ ° | $3^{rd}$ ° | TBSA |
|---|---|---|---|---|---|
| Head | 19 | | | | 0 |
| Neck | 2 | | | | 0 |
| Anterior trunk* | 13 | | | | 0 |
| Posterior trunk* | 13 | | | | 0 |
| Right buttock | 2.5 | | | | 0 |
| Left buttock | 2.5 | | | | 0 |
| Genitalia | 1 | | | | 0 |
| Right upper arm | 4 | | | | 0 |
| Left upper arm | 4 | | | | 0 |
| Right lower arm | 3 | | | | 0 |
| Left lower arm | 3 | | | | 0 |
| Right hand | 2.5 | | | | 0 |
| Left hand | 2.5 | | | | 0 |
| Right thigh | 5.5 | | | | 0 |
| Left thigh | 5.5 | | | | 0 |
| Right leg | 5 | | | | 0 |
| Left leg | 5 | | | | 0 |
| Right foot | 3.5 | | | | 0 |
| Left foot | 3.5 | | | | 0 |



## CHILD BURN ESTIMATE AND DIAGRAM

| Total Area front/back (circumferential) | 1 to 4 years | 5 to 9 years | 10 to 14 years | 15 years | Do not include in total TBSA $1^{st}$ | $2^{nd}$ ° | $3^{rd}$ ° | TBSA |
|---|---|---|---|---|---|---|---|---|
| Head | 17 | 13 | 11 | 9 | | | | 0 |
| Neck | 2 | 2 | 2 | 2 | | | | 0 |
| Anterior trunk* | 13 | 13 | 13 | 13 | | | | 0 |
| Posterior trunk* | 13 | 13 | 13 | 13 | | | | 0 |
| Right buttock | 2.5 | 2.5 | 2.5 | 2.5 | | | | 0 |
| Left buttock | 2.5 | 2.5 | 2.5 | 2.5 | | | | 0 |
| Genitalia | 1 | 1 | 1 | 1 | | | | 0 |
| Right upper arm | 4 | 4 | 4 | 4 | | | | 0 |
| Left upper arm | 4 | 4 | 4 | 4 | | | | 0 |
| Right lower arm | 3 | 3 | 3 | 3 | | | | 0 |
| Left lower arm | 3 | 3 | 3 | 3 | | | | 0 |
| Right hand | 2.5 | 2.5 | 2.5 | 2.5 | | | | 0 |
| Left hand | 2.5 | 2.5 | 2.5 | 2.5 | | | | 0 |
| Right thigh | 6.5 | 8 | 8.5 | 9 | | | | 0 |
| Left thigh | 6.5 | 8 | 8.5 | 9 | | | | 0 |
| Right leg | 5 | 5.5 | 6 | 6.5 | | | | 0 |
| Left leg | 5 | 5.5 | 6 | 6.5 | | | | 0 |
| Right foot | 3.5 | 3.5 | 3.5 | 3.5 | | | | 0 |
| Left foot | 3.5 | 3.5 | 3.5 | 3.5 | | | | 0 |

| | |
|---|---|
| 1 | |
| 2 | |
| 3 | |



## APPENDIX A: RULE OF NINE'S

1. **Diagnosis**: ____________________________________________
2. **Condition**: VSI SI NSI Category: Nation/Service (e.g., US/USA, HN/IA)
3. **Allergies**: Unknown NKDA Other
4. **Monitoring**
   - 4.1. Vital signs: Q _____ hrs
   - 4.2. Urine output: Q _____ hrs
   - 4.3. Transduce bladder pressure Q _____ hrs
   - 4.4. Neurovascular/Doppler pulse checks Q _____ hrs
   - 4.5. Transduce: _____CVP _____A-line _____Ventriculostomy
   - 4.6. Neuro checks: Q _____ hrs
   - 4.7. Cardiac monitor: Yes / No
5. **Activity**
   - 5.1. _____Bedrest _____Chair Q shift _____ Ad lib _____ Roll Q 2 hrs
   - 5.2. _____Passive ROM to UE and LE Q shift
   - 5.3. Spine precautions: _____C-Collar /C-Spine _____TLS Spine
6. **Wound Care**
   - 6.1. _____NS wet to dry BID to: ______________________
   - 6.2. _____Dakin's wet to dry BID to: ___________________
   - 6.3. _____VAC dressing to _____75 mm Hg _____125 mm Hg
   - 6.4. _____Abdominal closure drains to LWS
   - 6.5. _____Other: ________________________
7. **Tubes/Drains**
   - 7.1. _____NGT to LCWS or _____ OGT to LCWS
   - 7.2. _____Place DHT _____Nasal _____Oral and confirm via KUB
   - 7.3. _____Foley to gravity
   - 7.4. _____Flush feeding tube Q shift with 30 mL water
   - 7.5. _____JP(s) to bulb suction; strip tubing Q 4 hrs and PRN
   - 7.6. _____Chest tube to: _____20 cm $H_2O$ suction (circle: R L Both) or _____Water seal: (circle: R L Both)
8. **Nursing**
   - 8.1. Strict I & O and document on the JTTS Burn Resuscitation Flow Sheet Q 1 hr for burn > 20% TBSA
   - 8.2. _____Clear dressing to Art Line/CVC, change Q 7D and prn
   - 8.3. _____Bair Hugger until temperature > 36° C
   - 8.4. _____Lacrilube OU Q 6 hrs while sedated
   - 8.5. _____Oral care Q 4 hrs; with toothbrush Q 12 hrs
   - 8.6. _____Maintain HOB elevated 45°
   - 8.7. _____Fingerstick glucose Q _____ hrs
   - 8.8. _____Routine ostomy care
   - 8.9. _____Ext fix pin site care
   - 8.10. _____Trach site care Q shift
   - 8.11. _____Incentive spirometry Q 1 hrs while awake; cough & deep breath Q 1 hr while awake
9. **Diet**
   - 9.1. _____NPO
   - 9.2. _____PO diet
   - 9.3. _____TPN per Nutrition orders
   - 9.4. _____Tube Feeding: ______________@ ___________mL/hr OR _____Advance per protocol

**10. Burn Resuscitation (%TBSA > 20%)**

10.1. If available, initiate Burn Navigator™ computer decision support system and follow prompts on screen. System will provide recommendations for burn fluid resuscitation, provider should use clinical judgment and consider entire clinical scenario when interpreting recommendations.

10.2. Start initial infusion of Lactated Ringers (LR) at ______ml/hr IV (10 x % TBSA >40 kg <80 kg) (Add 100 ml/hr for every 10 kg > 80 Kg)

10.3. Titrate resuscitation IVF as follows to maintain target UOP (Adult: 30-50 mL/hr; Children: 1.0 mL/kg/hr)

- Decrease rate of LR by 20% if UOP is greater than 50 mL/hr for 2 consecutive hrs
- Increase rate of LR by 20% if UOP is less than 30 mL/hr (adults) or pediatric target UOP for 2 consecutive hrs

10.4. If CVP > 10 cm $H_2O$ and patient still hypotensive (SBP < 90 mm Hg), begin vasopressin gtt at 0.02 – 0.04 Units/min

10.5. Post burn day #2 (Check all that apply)

_____Continue LR at _____ mL/hr IV

_____Begin _______________@ ____________mL/hr IV for insensible losses

_____Start Albumin 5% at _____ mL/hr IV ((0.3 – 0.5 x %TBSA x wt in kg) / 24) for 24 hrs

**11. IVF (% TBSA ≤ 20%):** ____LR ____NS ____D5NS ____D5LR ____D5 .45NS ____+ KCl 20 meq/L @ ____mL/hr

**12. Laboratory Studies & Radiology**

12.1. _____CBC, Chem-7, Ca/Mg/Phos: _____ ON ADMIT _____DAILY @ 0300

12.2. _____PT/INR _____TEG _____Lactate: _____ ON ADMIT _____DAILY @ 0300

12.3. _____LFTs _____Amylase _____Lipase: _____ ON ADMIT _____DAILY @ 0300

12.4. _____ABG: _____ON ADMIT _____ 30 mins after ventilator change _____Q AM (while on ventilator)

12.5. _____Triglyceride levels after 48 hours on Propofol

12.6. _____Portable AP CXR on admission

12.7. _____Portable AP CXR Q AM

**13. Prophylaxis**

13.1. _____Protonix 40 mg IV Q day

13.2. _____Lovenox 30 mg SQ BID OR _____Heparin 5000 U SQ TID starting_____

13.3. _____Pneumatic compression boots

**14. Ventilator Settings**

14.1. Mode: _____ SIMV _____CMV _____AC _____CPAP

14.2. $FiO_2$: _____%

14.3. Rate: _____

14.4. Tidal Volume: _____ cc

14.5. PEEP: _____

14.6. Pressure Support: _____

14.7. Insp Pressure: _____

14.8. I/E Ratio: _____

14.9. _____ APRV: Phi_____ Plow_____ Thi_____ Tlow_____ $FiO_2$: _____%

14.10. _____Maintain patient in soft restraints while on ventilator

14.11. _____Wean $FiO_2$ to keep $SpO_2$ > 92% or $PaO_2$ > 70 mmHg

14.12. _____nebulizer/MDIs: _____Albuterol _____Atrovent _____Xopenex Unit Dose Q 4 hrs

**15. Analgesia/Sedation/PRN Medications**

15.1. Anagesia/sedation goal is Richmond Agitation Sedation Scale (RASS), scale below, of 0 (alert and calm) to -3 (moderate sedation). Hold continuous infusion for RASS of -4 (deep sedation) or higher.

15.2. _____Propofol gtt at _____ mcg/kg/min, titrate up to 50 mcg/kg/min.

15.3. _____Fentanyl gtt at _____mcg/hr titrate up to 250 mcg/hr; for analgesia may give 25-100 mcg IVP Q 15 minutes for acute pain or burn wound care.

15.4. _____Morphine gtt at _____mg/hr, titrate up to 10 mg/hr, for analgesia may give 2-10 mg IVP Q 15 minutes for pain or burn wound care.

15.5. _____Versed gtt at _____ mg/hr, titrate up to 10 mg/hr ; may give 2-5 mg IVP Q 15 minutes for acute agitation or burn wound care.

15.6. _____Ativan gtt at _____mg/hr, titrate up to 10 mg/hr; may give 1-4 mg IVP Q 2-4 hours for acute agitation.

15.7. Important: Hold continuous IV analgesia/sedation at 0600 hrs for a RASS of -4 or -5. If further analgesia/sedation is indicated, start medications at ½ of previous dose and titrate for target RASS.

15.8. _____Morphine 1-5 mg IV Q 15 minutes prn pain

15.9. _____Fentanyl 25-100 mcg IV Q 15 minutes prn pain

15.10. _____Ativan 1-5 mg IV Q 2-4 hrs prn agitation

15.11. _____Percocet 1-2 tablets po Q 4 hrs prn pain

15.12. _____Tylenol _____ mg / Gm PO / NGT / PR Q _____ hrs PRN for fever or pain

15.13. _____Morphine PCA; Program (circle one): 1 2 3 4

15.14. _____Zofran 4-8 mg IVP Q 4 hrs PRN for nausea/vomiting

15.15. _____Dulcolax 5 mg PO / PR Q day PRN for constipation

**16. Specific Burn Wound Care**

16.1. Cleanse and debride facial burn wounds with Sterile Water or (0.9% NaCl) Normal Saline Q 12 hrs, use a washcloth or 4x4s to remove drainage/eschar

16.2. Cleanse and debride trunk and extremities with chlorhexidine gluconate 4% solution (Hibiclens) and Sterile Water or Normal Saline, before prescribed dressing changes

16.3. Change fasciotomy dressings and outer gauze dressings daily and as needed; moisten with sterile water Q 6 hours and as needed to keep damp, not soaking wet.

Face & Ears

_____Bacitracin ointment BID &PRN

_____Sulfamylon cream to ears BID & PRN

_____5% Sulfamylon solution dressing changes Q AM and moisten every 6 hrs

_____Bacitracin ophth ointment: apply OU Q 6 hrs

BUEs & Hands, BLEs, Chest, Abdomen & Perineum

_____Silvadine cream Q AM & PRN (*deep partial & full thickness*)

_____Sulfamylon cream Q PM & PRN (*deep partial & full thickness*)

_____5% Sulfamylon solution – change Q AM & moisten Q 6 hrs (*superficial burns)*

_____Silver nylon dressing and moisten with sterile water approximately every 6 hrs PRN; dressings may be left in place for 72 hrs)

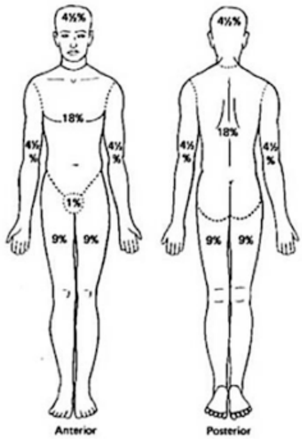
Back

_____Silvadine cream Q AM & PRN (*deep partial & full thickness burns*)

_____Sulfamylon cream Q PM & PRN (*deep partial & full thickness burns*)

_____5% Sulfamylon solution dressings changed Q AM and moisten Q 6 hrs

_____ Silver nylon dressing and moisten with sterile water approximately every 6 hrs PRN; dressings may be left in place for 72 hrs)




Rule of Nines to calculate initial burn size

**17. Other Orders**

17.1. ______________________

17.2. ______________________

**18. Notify Physician if:** SBP < _____, MAP < _____, HR <_____ or > _____, $SaO_2$ < _____%, T > _____, UOP < 30 mL/hour for 2 consecutive hours

## JTS BURN RESUSCITATION WORK SHEET

***Initiate AFTER** completion of trauma assessment and interventions*
***Adults only:** Refer to Burn CPG for pediatric specific recommendations*

**1. Contact USAISR Burn Center (DSN 312-429-2876) or email: burntrauma.consult.army@mail.mil**

Date/Time contact: ______________POC:________________ by:_________________

**2. Estimated Pre-burn Weight (wt):** _________kg (Average Service Members are 82 ± 15 kg)

**3. Estimate Total Burn Surface Area (TBSA) using Rule of Nines** (refine with Lund-Browder after wounds are cleansed)

Partial thickness (2nd)_____% + Full thickness (3rd)_____% = **TBSA_______%**

**IF TBSA >40%:** intubate (use ETT ≥ 7.5 fr to facilitate bronchoscopy)

**IF TBSA <15%:** formal resuscitation may not be required, provide maintenance and/or oral fluids

**4. Standard Burn Resuscitation Fluid:** Lactated Ringers (LR) or Plasmalyte

**5. Calculate INITIAL Fluid Rate using Rule of 10 (adults):**

- IF wt < 40kg: 2ml x %TBSA_____ x wt(kg)_______ ÷ 16 = ______ml/hr
- IF wt ≥ 40kg: %TBSA_____ x 10 = _______ml/hr
  - IF wt > 80kg: add 100ml/hr to initial rate for every 10 kg>80: adjusted initial fluid rate = ________ml/hr
  - (Example: 100kg patient with 50% TBSA burn = 50% x 10 = 500 ml + 200 ml = 700 ml for first hour)

**6. If Inhalation Injury Present:** administer aerosolized heparin in albuterol (5,000 units Q4 hours)

**7. Titrate Resuscitation Fluid:** maintain target **UOP 30-50ml/hr** (Q 1 hour)

- If rhabdomyolysis present: use target UOP 75-100 ml/hr (Contact USAISR Burn Center DSN 312-429-2876)
- Goals: UOP >30 but <50ml/hr; adequate tissue perfusion (normalized lactate/base deficit), MAP >55 mmHg
- Minimum fluid rate 125mL/hr LR
- * Avoid fluid boluses
- ** Too much fluid as dangerous as too little

**High risk for over resuscitation/abdominal compartment syndrome:**

- If hourly rate >1500mL/hr x 2 hrs OR
- If total 24 hr volume exceeds: wt(kg) x 250ml= _______ml (includes all infused fluids)
  - Contact USAISR Burn Center (DSN 312-429-2876)
  - Consider adjuncts (below)
  - Check bladder pressures Q4hrs (>20 mmHg notify physician)
  - Avoid surgical decompression (significant mortality risk in burns)

**Adjuncts:**

1. Colloids: 5% albumin/FFP (hextend only if others unavailable)
   - * Colloids not preferred until hour 8-12; can consider earlier in difficult resuscitation
   - Infuse at ml/hr according to chart below based on adult patient weight and burn size
2. Vasopressors: Contact USAISR Burn Center (DSN 312-429-2876)

| 5% Albumin Infusion (ml/hr) | 30-49%TBSA | 50-69% TBSA | 70-100% TBSA |
|---|---|---|---|
| <70 kg | 30 | 70 | 110 |
| 70-90 kg | 40 | 80 | 140 |
| >90 kg | 50 | 90 | 160 |

**Ensure adequate volume** (CVP trend 6-8 cm $H_2O$); **maintain MAP > 55 mmHg**

- Maintain ionized Ca >1.1 mmol/L

- Start with vasopressin 0.04mg/min. **DO NOT TITRATE**
- Second line pressor: norepinepherine 2-20mcg/min
- Refractory shock: consider epinephrine or phenylephrine infusion
- Refractory shock: consider adrenal insufficiency, give hydrocortisone 100mg IV Q8 hrs
- Manage acidemia (pH<7.2): use ventilator interventions first, then bicarbonate or THAM infusion
- Renal replacement therapy if available (Contact USAISR Burn Center DSN 312-429-2876)

**Assessment/Interventions:**

- Complete full secondary trauma exam
- Ensure thermoregulation; administer warmed fluids; cover with space blanket; elevate burned extremities
- Superficial burn ($1^{st}$ degree): Sunburn, no blister, blanch readily; NOT included in TBSA
- Partial thickness ($2^{nd}$ degree): Blanch, moist, blisters, sensate
- Full thickness ($3^{rd}$ degree): Leathery, white, non-blanching, dry, insensate, thrombosed vessels
- Protect eyes with moisture shields if corneas exposed or blink reflex slow; apply ophthalmic erythromycin ointment at least Q2hrs.
- **Prompt intubation for facial burns, suspected inhalation injury, TBSA >40%**
    - Anticipate induction-associated hypotension
    - Secure ETT with cloth tie, not adhesive tape
    - Reassess ETT position at teeth Q1 hr as edema develops and resolves
    - Intubated patients require oro/naso-gastric tube for decompression
    - Administer IV proton-pump inhibitor
- Monitor bladder pressure at least Q4hrs for large burns or high volume resuscitations
    - Abdominal compartment syndrome: decreased UOP, increased pulmonary pressures, difficulty ventilating, bladder pressure remains > 20 mmHg
    - Avoid decompressive laparotomy; consider percutaneous peritoneal drainage
    - Reduce crystalloid volume using colloid or vasopressors
- Monitor pulses hourly: palmar arch, dorsalis pedis, posterior tibial with Doppler
    - Consider escharotomy if signal diminished; refer to Burn CPG for technique (Call USAISR Burn Center DSN 312-429-2876)
- Monitor extremity compartment pressures as clinically indicated
    - Elevate burned extremities at all times
    - Extremity compartment syndrome: pain, paresthesia, pallor, paralysis, pulselessness (late sign)
    - Fasciotomy may be required
- Wound care
    - Thoroughly cleanse burn wounds, preferably in Operating Room
    - Select topical antimicrobial in consultation with Burn Surgeon (Call USAISR Burn Center DSN 312-429-2876) based on product availability, expected transport time, etc
    - Acceptable to cover burns with dry sheets or clean dressings for first 48 hours
- All definitive burn surgery done at USAISR Burn Center for US Service Members (DSN 312-429-2876)

# Appendix C
# Resources, References, and Readiness

## Combat Trauma References

**Emergency War Surgery Manual** This excellent resource covers all aspects of combat trauma care, and can be ordered free of charge (for military personnel) from the Borden Institute. It can be viewed and downloaded in PDF format at www.bordeninstitute.army.mil/other_pub/ews.html

**War Surgery in Iraq and Afghanistan** Case presentations and numerous photos from combat wounds and management in Iraq and Afghanistan. Available for order through the Borden Institute or other commercial booksellers.

**Combat Casualty Care: Lessons Learned from OEF and OIF** Another more recent resource that covers all clinical aspects of combat trauma care, and can be ordered free of charge (for military personnel) from the Borden Institute. It can be viewed and downloaded in PDF format at http://www.cs.amedd.army.mil/borden/book/ccc/CCCFull.pdf

**Joint Theater Trauma System Clinical Practice Guidelines** As of this writing, there are 42 complete guidelines on a variety of topics related to combat casualty care.

Internet address: http://www.usaisr.amedd.army.mil/cpgs.html

**First to Cut** A series of case studies and lessons learned from OIF (Operation Iraqi Freedom) and OEF (Operation Enduring Freedom) highlighting important concepts and tough lessons learned at the height of combat operations. This is a quick read and ideal for a long flight overseas to help you learn from the challenges faced by those before you: http://www.usaisr.amedd.army.mil/pdfs/First2Cut.pdf

**Out of the Crucible** This is a new publication that is expected to be out in print in 2017. It is a broad review of the key lessons and advances achieved during the wars in Iraq and Afghanistan, but written for a nonmedical audience. Check the Borden Institute website for details on availability and ordering information (www.bordeninstitute.army.mil).



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**War Wounds: Basic Surgical Management** ICRC publication on the management of penetrating and blast injuries sustained in third world conflicts: https://www.icrc.org/en/publication/0570-war-wounds-basic-surgical-management-principles-and-practice-surgical-management

## General Trauma and Medicine References

**Top Knife (Hirshberg and Mattox)** The most practical and useful handbook for trauma surgeons available.

**Current Therapy of Trauma and Surgical Critical Care (Asensio and Trunkey)** A thorough but focused textbook of modern trauma and critical care principles and procedures.

**Clinically Oriented Anatomy (Moore, Dalley, and Agur)** A basic anatomy text is a must, and this one combines normal anatomy with useful clinical information and pathology.

**The ICU Book (Paul L. Marino)** A great ICU reference, and go to the website at www.theicubook.com for access to a variety of ICU clinical practice guidelines.

**The Harriet Lane Handbook of Pediatrics (Custer and Lao)** A definitive resource for pediatric diagnoses, management, and medications.

**Atlas of Vascular Surgery: Basic Techniques and Exposures (Rutherford)** A concise review of vascular surgery techniques and exposure of any vessel in the body.

**Operative Trauma Management: An Atlas (Thal, Weigelt, and Carrico)** Step-by-step diagrams of the common and critical trauma operative procedures.

## Subspecialty References

Ashcraft's Pediatric Surgery (Holcomb and Murphy)
Surgical Approaches to the Facial Skeleton (Ellis and Zide)
Handbook of Neurosurgery (Greenberg)
Surgical Exposures in Orthopedics (Hoppenfeld)
Emergency Ultrasound (Ma and Mateer)
Emergency Vascular Surgery (Wahlberg, Olofsson and Goldstone)

## Internet Resources

Information, pictures, and even videos on almost every topic you might need are now available via the Internet. Many of these are open access sites and your medical library can often provide free access to pay-for-service sites. However, you must take into account that your Internet access will vary widely in the far forward setting. Even if you are fortunate enough to have reliable Internet access, it will typically be much slower than what you are accustomed to. These are some sites that the authors have used while deployed:

MD Consult (www.mdconsult.com): access to multiple online textbooks and full text journal articles.
Vesalius (www.vesalius.com): detailed anatomy and step-by-step surgical photos and instructions for a variety of procedures.
Google Scholar (www.google.com): free online search engine for medical and scientific information with many links to full text articles or references.
Eastern Association for the Surgery of Trauma (www.east.org): features a number of evidence-based clinical practice guidelines for trauma.
Critical Care Medicine Tutorials (www.ccmtutorials.com): reviews and tutorials of basic ICU topics and management algorithms.
Trauma.org (www.trauma.org): trauma-related tutorials, case presentations, and photos.
Primary Surgery Online (www.primary-surgery.org/start.html): online textbook of trauma surgery by the German Society of Tropical Surgery. Covers trauma, general surgery and emergency general surgery and anesthesia in austere settings.
Emedicine (www.emedicine.medscape.com): continuously updated clinical reference covering thousands of medical and surgical topics.
The Amputation Surgery Education Center (www.ampsurg.org): online information and extensive videos of upper and lower extremity amputation techniques.
Joint Trauma System (http://www.usaisr.amedd.army.mil/10_jts.html): homepage for the JTS (Joint Trauma System) with a large collection of up-to-date references, guidelines, forms, links, and points of contact.

# Appendix D
# CBRNE Primer for Surgeons

Chemical, Biological, Radiological, Nuclear, Explosive training probably evokes a familiar apathy and loathing from most physicians. We have all been through the basics of donning a mask and protective garments and learned how to perform self- and buddy decontamination. However, if asked to recall the details of specific agents or treatments, most physicians would fail. Surgeons may ask why this really affects them since casualties will be decontaminated before they ever see them. While CBRNE doctrine clearly outlines how to manage these events, in reality, few US and coalition troops have any experience dealing with this type of warfare. Unfortunately, the CBRNE threat has become a reality in current operations in Iraq and Syria, where improvised munitions and homegrown agents have been found on the battlefield. Crude formulations and low concentrations of mustard agents, chlorine, and others have been used by the enemy against partner forces, civilians, and coalition forces. The brief outline in this appendix is not a satisfactory education in all things CBRNE. It is only a primer for the surgical wound care concerning the relevant chemical agents currently identified in the CENTCOM AOR (CENTCOM Area of Responsibility). If you are deploying soon, you need to review the chapters on CBRNE care in the Emergency War Surgery Manual.

Most CBRNE training and education revolves around protection, antidotes, and symptomatic treatment. However, these agents are typically delivered in munitions, resulting in associated traumatic wounds and injuries that may contain active agents and contaminated debris that the surgeon could encounter. This brief primer addresses the processes and concerns with wound decontamination associated with chemical agents that may be relevant to the surgeon caring for these casualties.

The initial management of the chemical casualty is to remove all potentially contaminated clothing, bandages, tourniquets, and equipment, and perform skin decontamination prior to any vehicle or aircraft transport. A second thorough decontamination is usually required before entering any medical treatment facility. Rushing a casualty through these steps without proper decontamination can result in exposure of medical personnel and equipment that may render you and your facilities unable to care for patients, or worse. The complete exposure of patients and high volumes of irrigation used for skin decontamination is virtually guaranteed to cause hypothermia in the field environment, and warming measures should be considered as soon as possible.



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Wound management of the chemical casualty is relatively straightforward. Any contaminated debris such as embedded clothing, foreign bodies, fragments, etc., must be removed from the wound using a no-touch technique (instrumentation only). All removed foreign materials should be soaked in a bath of 0.5% hypochlorite solution. All tissues removed should be sealed in chemical-proof or rubber bags. Wounds should be copiously irrigated to remove unseen agent and contaminants. Surface decontamination solutions such as simple soap and water, 0.5% hypochlorite bleach solution, or RSDL (reactive skin decontamination lotion, Emergent Biosolutions®, Gaithersburg, MD) may be used to decontaminate wounds and skin surfaces. RSDL is a topical neutralizing agent that can be used on all surfaces but should be irrigated from all wounds after use. Once thorough decontamination is completed, the surgeon should consider changing PPE (Personal Protective Equipment) if circumstances allow, or at a minimum, changing gloves. All OR personnel should use double surgical glove practice, allowing for rapid exchange of clean outer gloves and added protection in the event of minor tears. Tight-fitting butyl rubber gloves are also acceptable.

Once debridement and irrigation are complete, a standard ICAM (improved chemical agent monitor) can be utilized to screen the wound beds for residual mustard and nerve agents, if a high suspicion exists. Instruments that are used in the initial debridement should be segregated and new, clean instruments should be used for definitive procedures. The contaminated instruments should be placed in a 0.5% hypochlorite bath for 10 min prior to standard cleaning and sterilization processing. When all procedures are completed, the OR and all equipment should be washed down with any of the three decontamination solutions mentioned.

Vesicant and nerve agents are the two types of chemical agents of most concern in wound management for the surgeon. If a patient is exposed to a significant amount of nerve agent, it is unlikely they will make it to the OR. However, the potential exists that the active agent could remain on foreign debris or clothing that has become embedded within wounds. Of the numerous types of nerve agents, VX is absorbed more slowly and could persist in the wounds of a casualty. Vesicants such as liquid mustard appear oily in nature and are rapidly absorbed in tissues and bodily fluids, but could remain within wounds, especially if they have been mixed with thickening compounds. These thickened agents persist in wounds longer and are absorbed much more slowly, presenting a potential risk to medical personnel. The local intelligence personnel or CBRNE experts will be able to tell you if thickening agents are a concern. Vapor off gassing from a retained agent in wounds is a theoretical risk but deemed negligible and only a standard surgical mask is required.

While treating patients exposed to chemical agents can seem daunting, the processes for surgical personnel are relatively analogous to routine sterile surgical techniques and surgical infection prevention. Remember to protect yourself and your team, as a contaminated OR will leave you mission incapable for some time.

# Suggested Reading

1. CBRNE Handbook 2009. Edgewood Chemical Biological Center, Rock Island, IL. https://www.ecbc.army.mil/downloads/CBRNE_Handbook.pdf.
2. Emergency War Surgery, 4th Ed. (Chapters 28–30), Borden Institute, Falls Church, VA, 2013. http://www.cs.amedd.army.mil/FileDownloadpublic.aspx?docid=80035d1a-f208-473d-993b-6debfb17db91.
3. Medical Management of Chemical Casualties Handbook, 5th Ed. Borden Institute, Falls Church, VA, 2014. p. 119–22. http://www.cs.amedd.army.mil/FileDownloadpublic.aspx?docid=fb1a74f2-f96f-416f-99bb-01cd28686754.



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