Laura J. Moore
S. Rob Todd
Editors

Common Problems in Acute Care Surgery

Second Edition

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Videos can also be accessed at
http://link.springer.com/book/10.1007/978-3-319-42792-8

ISBN 978-3-319-42790-4 ISBN 978-3-319-42792-8 (eBook)

DOI 10.1007/978-3-319-42792-8

Library of Congress Control Number: 2016956003

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

It is a privilege to provide a foreword for the second edition of *Common Problems in Acute Care Surgery*. One of the editors (LJM) worked with me as a first-year medical student on a research project that won first prize and then later was my surgical critical care fellow. The other editor (SRT) is a former partner when we were both at one of the busiest trauma centers in the country. Both editors are highly committed to acute care surgery.

Acute care surgery is a continuously evolving specialty that encompasses trauma, emergency surgery, and surgical critical care. Trauma developed into an accepted specialty in the 1980s and 1990s. Initially trauma was a busy operative specialty associated with complex critical care, but, as our diagnostic modalities improved, and we realized that not every spleen or liver requires an operation, nonoperative care made the specialty less desirable to surgical trainees. At this same time, hospitals found it increasingly difficult to provide adequate coverage for emergency surgery. In response to fewer numbers of surgeons choosing trauma and surgical critical care as a career, a joint meeting of the American College of Surgeons, the American Association for the Surgery of Trauma (AAST), the Eastern Association for the Surgery of Trauma, and the Western Trauma Association was held in 2003 to address the problems of access to emergency surgical care and the future of trauma surgery. Later this same year, the AAST created an ad hoc committee to reorganize trauma, surgical critical care, and emergency surgery into what we now know as acute care surgery. The first formal AAST-accredited acute care surgery fellowship program began in 2008.

As acute care surgery has matured, it has continued to evolve and expand as the need for urgent or emergent surgical disease care continues to increase, especially as our population ages. The acute care surgeon is uniquely able to provide not only operative expertise but care from admission to discharge including critical care and, even when necessary, end-of-life care. Minimally invasive techniques are an increasing part of their operative lexicon. They must be adept at changing diagnostic modalities and critical care monitoring as these continue to change with technological advances.

Common Problems in Acute Care Surgery, 2nd edition, provides an evidence-based review of common problems that are encountered by the acute care surgeon. The target audience for this book includes trainees, physician extenders, and practicing surgeons who care for patients requiring emergency surgical care. It is organized in the same fashion as the first edition, in three parts: (1) general principles, (2) specific disease states, and (3) ethics, legal, and administrative issues. All of the topics in the first edition have returned and have been updated by experts from the acute care surgery community. In addition, a number of topics have been added. In the section on general principles, perioperative management of the cirrhotic patient, hemodynamic monitoring in the intensive care unit, and principles of vascular access are now included. In the section on specific disease states, management of intra-abdominal infections has been added. In the third section that includes administrative issues, a chapter outlining the development of an acute care surgery program is included.

I would like to acknowledge and thank the distinguished group of authors who participated in writing this book. I would also like to extend special thanks to the editors for taking on the task of updating a book on a constantly evolving field, acute care surgery.

Sacramento, CA, USA — Christine S. Cocanour

Preface

Acute care surgery continues to evolve as a specialty. With the growing patient need for access to emergency surgical services, acute care surgeons are providing much needed care for patients with urgent or emergent surgical disease. The field of acute care surgery has continued to evolve and expand in response to this need for reliable access to emergency surgical care. The care of the emergency surgical patient presents a complex set of challenges for surgeons. An understanding of the technical aspects of an operation combined with the presence of severe physiologic derangements presents a unique set of challenges to the surgeon. In order to deliver optimal care, the acute care surgeon must have expertise in both surgery and critical care. They must be facile with both open and laparoscopic surgical techniques, be familiar with the various diagnostic modalities available, be able to understand optimal resuscitation strategies, and be able to coordinate the care team in order to deliver rapid, evidence-based care for these challenging patients.

Common Problems in Acute Care Surgery, 2nd edition, addresses the common surgical emergencies encountered by acute care surgeons. The purpose of this text is to provide both trainees and practicing surgeons a comprehensive, evidence-based review of the most common clinical problems encountered by acute care surgeons. This second edition of the textbook includes updates to all of the topics from the first edition, as well as several new topics including the management of intra-abdominal infections, the management of the open abdomen, and hemodynamic monitoring of the critically ill surgical patient. The book is organized into three main sections. The first section focuses on general principles of acute care surgery including the initial evaluation and resuscitation, the perioperative management of the hemodynamically unstable patient, and common critical care issues encountered in the management of these patients. The second section focuses on specific disease states that are commonly encountered by acute care surgeons. Each chapter in this section addresses a specific clinical problem by describing the epidemiology, clinical presentation, diagnosis, management (including pertinent operative techniques), potential complications, and follow-up. The third and final section focuses on ethics and legal issues frequently encountered in acute care surgery.

Each of the authors in this text was selected for their expertise in the field of acute care surgery. We are grateful to the many surgeons who devoted countless hours in the preparation of this text. The end result is a resource that we hope will assist acute care surgeons in delivering compassionate, evidence-based care to the emergency surgical patient.

Houston, TX, USA

Laura J. Moore
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Part II Common Diseases in Acute Care Surgery

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Part I

General Principles

Initial Resuscitation and Management of the Hemodynamically Unstable Patient

1

Diane A. Schwartz and John Holcomb

Hemorrhagic and Hypovolemic Shock and Initial Stabilization Maneuvers

In 1946 hemorrhagic shock was induced in animal models and a stratification system emerged: simple hypotension, which was noted to always be reversible if identified and treated; impending shock, which was reversible if treated aggressively; and irreversible shock state, where hypotension, sustained by high-volume blood loss, correlated to notable metabolic derangement [1]. The authors concluded that hemorrhagic shock did not occur at a specific volume loss or blood pressure, but was rather a fluid state that required early recognition by the treating physician and immediate intervention during the reversible period.

Hemorrhagic shock is defined as a mismatch between cellular perfusion and metabolism. Strict adherence to the definition results in difficulty identifying compensated shock states, however, since compensated shock does not always have a straightforward clinical picture. Compensated and severe hemorrhagic shock occur on a spectrum of metabolic acidosis, blood loss, poor tissue perfusion, tissue injury, and ineffective oxygen extraction (Table 1.1 and Fig. 1.1).

Hemorrhage is commonly categorized by volume and percent blood loss with specific findings at defined losses [2]. Interestingly these categories are largely based on opinion rather than objective clinical data. Clinical parameters are not markedly different from baseline in phases one and two of shock, contributing to the difficulty in recognizing shock in its early stages. In providing care to the critically injured patient, it is of utmost importance to have the ability to diagnose impending or early hemorrhagic shock. It is rather easy to diagnose severe hemorrhagic shock; however, the affected patients have already undergone cardiovascular collapse and are near death. The astute clinician will prefer to intervene earlier, when the diagnosis is more obscure and reversal of the shock state is possible. Once recognized, directed treatment of imminent shock or ongoing hemorrhage begins.

During field resuscitation, patients receive treatments necessary to control bleeding. Several centers tout an integrated database or registry to incorporate pre-hospital data to analyze outcomes [3–5]. One pre-hospital intervention to consider in the management of hemorrhage is infusion of blood products. In patients who have the opportunity of survival, meaning that they are in severe hemorrhagic shock, but are able to resuscitate with source controlled prior to cardiopulmonary collapse and death, the first 6 h of resuscitation is an important time frame. This is because outcomes have been shown to improve with early and aggressive resuscitation during the first 6 h.

The Center for Translational Injury Research in Houston has shown improved outcomes and negligible waste associated with the use of blood and FFP in the pre-hospital setting [6]. The outcomes seem to be most notable in patients in severe hemorrhagic shock who survive to hospital arrival. This particular patient population faces imminent death within the first 6 h danger period of hemorrhagic shock. In receiving the products they need earlier, their shock process is mitigated faster and likely accounts for the outcome improvement. The Department of Defense is leading a prospective study for the use of thawed FFP in the pre-hospital setting, results of which are pending [7]. In centers where blood product cannot be transfused in the field or plasma cannot be kept in thawed state, protocols assist to determine hospital transfusion requirements based on field data [8].

Apparent blood loss in the field should be managed with application of direct pressure or a tourniquet. The use of tourniquets has turned some of the most life-threatening

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_1

Table 1.1 Estimated blood loss[a] based on patients' initial presentation

	Class I	Class II	Class III	Class IV
Blood loss (ml)	Up to 750	750–1500	1500–2000	>2000
Blood loss (% blood volume)	Up to 15	15–30	30–40	>40
Pulse rate (per minute)	<100	100–120	120–140	>140
Systolic blood pressure	Normal	Normal	Decreased	Decreased
Pulse pressure (mmHg)	Normal or increased	Decreased	Decreased	Decreased
Respiratory rate	14–20	20–30	30–40	>35
Urine output (ml/h)	>30	20–30	5–15	Negligible
Central nervous system/mental status	Slightly anxious	Mildly anxious	Anxious, confused	Confused, lethargic
Initial fluid replacement	Crystalloid	Crystalloid	Crystalloid and blood	Crystalloid and blood

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[a]For a 70-kg man

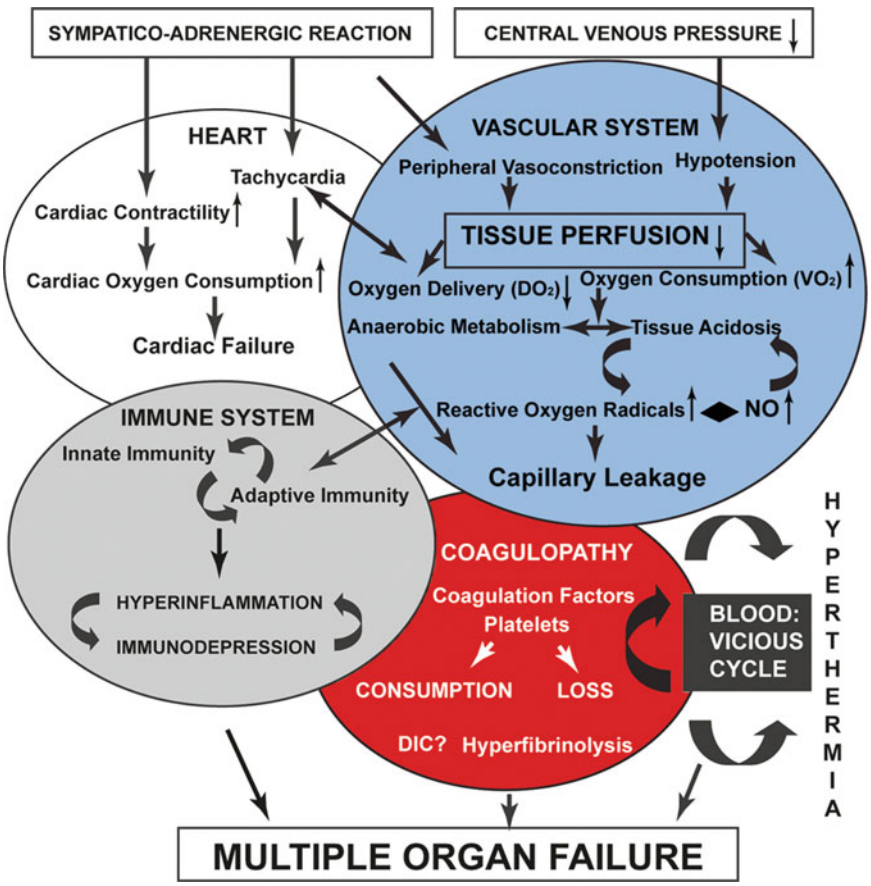

Fig. 1.1 Pathophysiology of hemorrhagic shock. (From Angele MK, Schneider CP, Chaudry IH. Bench to bedside review: latest results in hemorrhagic shock. Crit Care. 2008;12(4):218, with permission.)

injuries into ones where life and limb can be salvaged. The resurgent use of tourniquets has been overwhelmingly supported in the military data from the Iraq and Afghanistan experience, where it is shown that there are virtually no adverse effects of the tourniquet itself if left in place for less than 2 h [9]. Even in inexperienced hands, tourniquets have been shown to prevent life-threatening exsanguination and should be applied in any pre-hospital situation in which extremity hemorrhage exists and prior to the onset of exsanguination [10]. There are several commercial devices available and their purpose is to exert enough circumferential pressure to prevent blood from flowing into the extremity in question [11]. Contrary to older teaching, use of a tourniquet does not cause increased amputation rates [12]. Use of tourniquets is ubiquitous on the battlefield, and in many civilian centers use has become routine.

Massive Transfusion

Since no single injury, other than severe head injury, has ever been identified to correlate with non-survivability, massive transfusion protocols should not be held for an assumption of impending mortality [13]. According to this article, no lab

value, no injury severity score (ISS), no demographic data, and no vital sign, singly or grouped, accurately determine a mortality score. A second manuscript from the same group of authors discusses a potential model for predicting mortality at 30 days; however, still there are cautions against using such a model to withhold much-needed blood products during resuscitation [14]. Factors most predictive of 24-h mortality are pH, base deficit, and amount of blood transfused within the initial 6 h. Factors at 30 days that are of significance include age and ISS on admission.

At The Texas Trauma Institute at Memorial Hermann Hospital in Houston, Texas, the massive transfusion protocol is activated for any patient who is suspected to require substantial transfusion, based on any one of the following: prehospital administration of blood or blood products by Memorial Hermann Life Flight, heart rate on arrival of more than 120 beats per minute, systolic blood pressure on arrival of less than 90, a positive FAST exam, penetrating or blunt trauma mechanism, or having a requirement for uncrossmatched blood in the emergency room on arrival. These recommendations come from retrospective data comparing predictive scores for massive transfusion. Using these parameters a score of two or greater was found to be 75 % sensitive and 86 % specific, correlating relatively well without statistical significance to other published scoring systems [15]. The goal of this guideline is to make a continuous supply of six units of packed red blood cells (PRBC), six units of plasma (FFP), and one dose of a six-pack of platelets readily available. After 6 units of PRBC it is advised to check a fibrinogen level and if less than 150 mg/dl to administer ten units of cryoprecipitate. Serial labs are also drawn during the massive transfusion and include lactate, arterial blood gas, rapid thromboelastogram (TEG), coagulation panel, and complete blood count (CBC) with differential and platelet count. It should be noted that a TEG is available within minutes (5 min for a rapid TEG), whereas the coagulation panel and CBC take more than 45 min to process [16]. Additionally all level 1 trauma activations, which are the highest acuity patients at Memorial Hermann Hospital, are typed and crossed on arrival so that type-specific blood may be given when available.

There seems to be an advantage to maintaining ratio driven resuscitation initially, followed by goal-directed resuscitation once source control is achieved [17]. Data supporting the 1:1:1 FFP:platelet:PRBC ratio initially came from military literature dating from 2007, which shows an improvement in mortality for patients receiving such ratios [18]. This was later extrapolated in several studies to the civilian population and further propagated in several trauma centers as a new standard of care [19]. A review article from 2010 looked at nine additional observational studies that were published after the 2007 article [20]. There are now randomized trials comparing ratios and showing improvement in mortality within the crucial 3 h window for patients receiving 1:1:1 transfusions [21]. The majority of trauma centers now use this approach.

A goal-directed transfusion protocol is a seemingly attractive approach for trauma resuscitation once source control is achieved. Originally, massive transfusion protocols were designed to rapidly and reliably provide products to patients who had clinical evidence of substantial hemorrhage. Products and blood were given without a specific ratio until patients either expired or improved clinically. After introduction of the 1:1:1 ratio, which targets the coagulopathy that accompanies massive transfusion, surgeons began to question if transfusion should be automatic or rather if it should be guided by objective data and lab values. One of several manuscripts on goal-directed resuscitation expresses the idea that resuscitation may be more functional and cost effective if lab values, such as TEG, are used to guide decision making during the resuscitation [22]. This concept relies on laboratory reports being ordered, drawn, sent to, and returned from the laboratory in a clinically relevant time frame. While there have been questions raised regarding TEG's role in reducing mortality or improving transfusion-related outcomes, there is no question that TEG remains the fastest real-time data set available for coagulopathy assessment [1, 23]. Most clinicians have combined these two approaches. Using a ratio based approach is optimal when the patients are rapidly bleeding. As bleeding slows, TEG guided transfusion therapy is appropriate [24].

Acidosis

Acidosis is one component of the trauma triad of death that must be recognized as a propagator of coagulopathy and continued hemorrhage. Animal and human models have shown direct correlation of lactate and mortality risk [25]. Lactate levels are elevated in hemorrhagic shock and will persist in times of suboptimal tissue perfusion. pH correlates with overall resuscitation and tissue perfusion, maintaining statistical relevance even in cases where permissive hypotension is maintained [26]. Lactic acidosis is directly reflective of continued need for resuscitation but takes longer to normalize than other parameters, such as vital signs. In general patients will reach two separate resuscitative goals: source control, which happens first, and physiologic, which lags. Serum acid levels can be extrapolated from pH, lactate levels, CO_2 or bicarbonate on blood work; all are useful markers of cellular aerobic metabolism [27]. In using these other markers of acidosis, however, it is imperative to understand that not all acidosis is derived from lactate, and not all acidosis is directly related to ongoing anaerobic metabolism. For example, patients with severe hemorrhagic shock may have persistence of acidosis related to acute kidney injury despite

resuscitation being completed. In these cases lactate may be normal and acid levels are derived from other sources. There has been recent interest in non-invasive pH monitoring, since it seems to reliably track the success of resuscitation and risk of mortality [28, 29]. Non-invasive monitoring systems are desirable in both combat and civilian arenas where resources for invasive intervention may be lacking.

Lactate, serum bicarbonate, base deficit, hemoglobin, or tissue oxygenation are some of the most crucial lab values in determining metabolic acidosis, which occurs with poor tissue oxygen extraction and indicates shock at the cellular level [30–36]. Lactate, in the pre-hospital setting, may be more predictive of prognosis than are vital signs, which can be fairly stable until hemodynamic collapse ensues [37]. Lactate increases in under-perfused tissues and can be an early predictor of impending shock, and helps differentiate the stable patient from the one in a compensated shock state.

Base deficit is a reflection of metabolic acidosis secondary to unmeasured anions, which is typically assumed to be lactate in the trauma patient [38]. Base deficit, lactate, anion gap, and bicarbonate levels all correspond to metabolic acidosis and have all been shown to predict morbidity and mortality [39–42]. However, bicarbonate is only a single marker of acid–base status, whereas anion gap, base deficit, and lactate all have some dependence on electrolytes, pH, and buffer capacity of blood [43]. There does not seem to exist great consensus in the literature regarding which is the best predictor of mortality [44].

Up to a third of patients in the ICU show discordance between their base deficit and lactate, and in these situations it has been shown that lactate is more predictive of overall outcome, when it differs significantly from base deficit [45]. Authors from this source imply that base deficit on its own does not have the predictive capacity for mortality that lactate has. On the other hand, while lactate is the most helpful in the initial phase of resuscitation, it is not as accurate in determining the ongoing causes of metabolic acidosis in critical situations outside of trauma where lactate may not elevate, such as respiratory alkalosis and diabetic ketoacidosis.

Serum bicarbonate will correlate with base deficit only when the pH is constant, which has clinical implications in the patient whose standard chemistry is drawn from a venous line at a different time than the arterial blood gas is collected [46]. The fluctuating pH may affect the accuracy of either measurement when compared to the other. There may be a significant difference in base deficit when comparing arterial to venous samples. Venous samples may be more sensitive to changes in pH, pCO_2, and pO_2 resulting in earlier changes in base deficit [47].

Coagulopathy, acidosis, and hypothermia portend the downward spiral into fulminant hemorrhagic shock. The key to understanding hemorrhagic shock is to understand the interactions of the lethal triad and the human body's capacity to self-correct versus what must be medically and surgically repaired. Acidosis is a product of poor tissue perfusion and death at the cellular level [48]. Lactic acidosis is a finding associated with cellular anoxia. Free radical release during tissue hypoxia also contributes to overall organ dysfunction and further perpetuates the cascade [49]. The coagulopathy is secondary to dilution, platelet dysfunction, cellular damage, decreased hepatic synthesis of factors, and shunting of proteins away from creating coagulation factors and toward production of acute-phase reactants [50–53]. Hypothermia occurs secondary to decreased metabolism. It is also associated with infusion of cold or chilled blood products and crystalloid, and hypothermia itself contributes to continued perpetuation of coagulopathy [54]. Furthermore it is the mismatch between oxygen delivery and consumption with resultant organ dysfunction that defines the shock state [55]. All three elements of the lethal triad contribute and potentiate the death spiral after substantial bleeding. Interruption of this process is paramount to survival.

Hypothermia

Hypothermia, defined as a core temperature of less than 34°, is a definitive contributor to ongoing shock and ineffectiveness of resuscitation. It must be immediately corrected in the trauma patient who is coagulopathic [56]. Combat trauma physicians have experienced increased morbidity and mortality, likely due to the loss of function of platelets and coagulation factors, in hypothermic patients [57–60]. While the animal model has demonstrated survival benefit from mild hypothermia during initial resuscitation, coagulopathy in humans seems exacerbated by temperatures outside of physiologic range and is not recommended [61–63]. Moreover hypothermia does not have a role in the current resuscitation guidelines for hemorrhage and should not be employed, even if other clinical factors support its use. Heat loss is attributed to time spent in the field, exposure of the patient to external elements, chilled resuscitation fluid including blood product and crystalloid, air temperature in the emergency department and operating room, open body cavities during operation, and transport to a variety of locations without appropriate warming mechanisms. It is advised that the initial examination proceed with cognizance of the rapidity at which body heat is lost, and that patients be covered as quickly as possible with warm blankets. Bair huggers, ambient warming, institution of protocols that enforce use of hotlines or other mechanisms to warm fluid are all adjuncts to maintaining body temperature. Protocols for hypothermia avoidance are helpful in standardizing mechanisms for warming while bringing attention to this very important component of physiologic normalcy [64].

Crystalloid

There is no longer argument on the preferred resuscitation fluid for patients in hemorrhagic shock—it is maintained ratios of FFP, platelets, and blood—not crystalloid [65, 66]. Crystalloid should not be considered first line therapy for resuscitation in hemorrhagic shock in any facility where blood products are available. It seems intuitive that if a person is hemorrhaging, correction of that shock will be contingent on the repletion of blood, and that his or her coagulopathy will respond to transfusion of plasma and platelets. However, replacement of volume by crystalloid represents classical teaching and guidelines for correction of the initial phase of hemorrhagic shock [67]. Advanced Trauma Life Support (ATLS) discusses placing two large-bore IVs and bolusing 1 l of crystalloid for any patient assumed to be in hemorrhagic shock or any patient with significant blood loss [2]. However, recent data suggest that as little as 1.5 l of fluid has negative clinical implications and numerous sources are refuting the benefit of large-volume crystalloid resuscitation in hemorrhagic shock [68].

While many clinicians consider lactated Ringer's and normal saline interchangeable, they are not. Multiple studies in the swine model compare the use of various crystalloid solutions, focusing on lactated Ringer's solution and normal saline. The swine model demonstrates that if shock is induced and maintained for 30 min, followed by resuscitation with either normal saline or lactated Ringer's solution, the animals resuscitated with Ringer's lactate have better improvement in markers of shock, pH, and extracellular lung water [69]. In this study neutrophil activation contributes to cellular damage. Other studies support the neutrophil activation phenomenon; dextran is the biggest activator, followed by normal saline and then lactated Ringer's [70]. Colloid, plasma, and blood have also been implicated as morbid contributors to effects on neutrophil activation, mainly in the pulmonary system [71–73].

Lactated Ringer's, as a resuscitation fluid, yields less acidosis and less coagulopathy than seen with similar volumes of normal saline [74]. Normal saline causes a well-recognized metabolic hyperchloremic acidosis; patients resuscitated with lactated Ringer's do not achieve such levels of acidosis. Furthermore, normal saline-resuscitated patients demonstrate more blood loss than those resuscitated with lactated Ringer's [75]. This has been demonstrated also in the vascular literature. In a study of aortic repairs it was shown that there was more perioperative bleeding and acidosis when normal saline was used as opposed to lactated Ringer's [76]. There was no statistically significant difference in outcome however. Even despite the better physiologic results with lactated Ringer's resuscitation as compared to normal saline, lactated Ringer's still would not be the first choice for resuscitation in a patient with hemorrhagic shock as excessive bleeding is not well controlled with replacement of volume by crystalloid [77].

Another substitute for balanced crystalloid solution is Plasma-lyte, which has been shown to be cost effective and a potentially better crystalloid choice when compared to normal saline [78]. The enthusiasm for this fluid as a carrier and for maintenance may be due to the fact that it does not contain calcium and therefore can be infused with blood product without concern for crystallization of the line and less morbidity than other non-normal saline balanced fluids [79]. Importantly plasmalyte does not have the acidosis inducing profile of normal saline.

Permissive hypotension purposefully maintains mean arterial pressure as low as possible to ensure adequate organ perfusion. If the minimum mean arterial pressure is not exceeded with over-resuscitation, the delicate new clot formation should not be disrupted prior to operative intervention [80, 81]. These authors show that by purposefully maintaining mean arterial pressure no greater than 50 mmHg, the patients in these groups are not afflicted with coagulopathy to the same degree as controls that are resuscitated to a mean arterial pressure of greater than 65 mmHg. Earlier data from animal models show no difference in ultimate outcome when hypotension is maintained; end organ perfusion and prevention of metabolic perturbations that can occur when tissue oxygenation is inadequate are the goals of permissive hypotension [82]. That is to say that when metabolic acidosis is controlled and the mean arterial pressure is minimized on purpose, patients do not show any long-term adverse effects compared to patients whose resuscitation targets a higher mean arterial pressure. It is unclear how long patients can remain hypotensive without deleterious effects. The original descriptions of this concept date to World Wars 1 and 2. The original civilian studies on this topic show less intraoperative bleeding and overall fluid requirement and hence less postoperative morbidity when this strategy is applied [83]. Survival is improved by limiting crystalloid infusion. Furthermore overaggressive resuscitation to a physiologically normal blood pressure may contribute to ineffective hemostasis, termed "popping the clot," shown in an animal study where raising the blood pressure caused re-bleeding and increased mortality [84]. This cycle of repeated resuscitation and bleeding is ultimately detrimental to clot stability and to overall survival [85].

Hypertonic Saline

Crystalloid evaluation would not be complete without consideration of hypertonic saline. Hypertonic saline use is pervasive throughout the literature. Prior to the recent explosion of blood product-based resuscitation, crystalloid resuscitation was the standard of care. Hypertonic saline shows some improvement in blood pressure and arguable survival difference for patients

who receive it in the pre-hospital setting [86]. Interest also exists in combat medicine where space, weight, and facility of transport of medical devices remain an important consideration. There are studies showing decreased pre-hospital fluid requirements in patients who receive hypertonic saline during transport [87]. Immunomodulatory effects are enhanced with single administration of 250 ml of hypertonic saline in the initial phase of resuscitation of hemorrhagic shock, and this could have additional effects on patients with later discovered head injury [88, 89]. A large study of hypertonic saline showed statistical difference in outcome in pediatric head-injured patients when compared with isotonic fluid administration [90]. Hypertonic saline decreases interstitial pressure and consequently decreases bowel edema, which may be a potential benefit of using it on the patient whose abdomen is still open [91, 92]. Animal studies in the 1990s showed that there was no protective effect or difference in outcome for the patient in hemorrhagic shock with a head injury [93]. Since that time several studies examining hypertonic saline as a resuscitative fluid have been terminated secondary to futility and concerns for patient safety [94, 95]. It is still debatable that hypertonic has a physiologic or survival advantage when compared to other crystalloid formulations when used as a primary resuscitation fluid [96].

Table 1.2 Current indications and contraindications for EDT

Indications
Salvageable post-injury cardiac arrest:
Patients sustaining witnessed penetrating trauma with <15 min of pre-hospital CPR
Patients sustaining witnessed blunt trauma with <5 min of pre-hospital CPR
Persistent severe post-injury hypotension (SBP ≤60 mmHg) due to:
Cardiac tamponade
Hemorrhage—intrathoracic, intra-abdominal, extremity, cervical
Air embolism
Contraindications
Penetrating trauma: CPR >15 min and no signs of life (pupillary response, respiratory effort, or motor activity)
Blunt trauma: CPR >5 min and no signs of life or asystole

From Mears G, Glickman SW, Moore F, Cairns CB. Data based integration of critical illness and injury patient care from EMS to emergency department to intensive care unit. Curr Opin Crit Care. 2009;15(4):284–9, with permission

The Role of Cardiopulmonary Resuscitation

One of the great follies occurring during the treatment of hemorrhagic shock is to perform advanced cardiac life support (ACLS) or cardiopulmonary resuscitation (CPR) for patients where source control is not achievable. There will not be meaningful survival for hemorrhagic shock with the institution of CPR alone; CPR has no role in the definitive treatment of hemorrhagic shock [2]. It is costly, resource intense, and potentially dangerous for healthcare workers when it is used for patients without survivable injury pattern. Until the source of the hemorrhage is controlled and intravascular volume restored after hypovolemic arrest, there is no other effective treatment option.

Emergency Room Thoracotomy

Although residents often consider it a rite of passage to perform the emergency room thoracotomy (ERT), the mature surgeon realizes that the ERT has its place in very few clinical circumstances (Table 1.2) [97]. With only a 2% overall survival rate in blunt trauma, and a 35% survival rate for patients with a single penetrating, quickly controllable injury and no or brief loss of vitals, a selective approach to deciding which patient qualifies for such an invasive maneuver is mandatory. Patients who are found down with no signs of life should not be considered for ERT.

If a patient has spontaneous return of vital signs during the critical maneuvers of the EDT, then transportation to the operating room for more definitive surgical management is appropriate.

REBOA

Resuscitative endovascular balloon occlusion of the aorta, REBOA, has recently emerged as a potential adjunct to resuscitative cases of hemorrhagic shock below the diaphragm [98]. While REBOA is not applied universally, there are case series showing a potential benefit in its use [99]. Trauma surgeons are also engaging in training of endovascular techniques and even completing vascular fellowships, thus minimizing human resources for cases of hemorrhagic shock needing embolization. The REBOA is deployed in a similar fashion to an endovascular balloon via femoral access by cutdown or direct puncture, dilatation. In some examples the aortic occlusion time is decreased compared to thoracic aortic cross clamping and the mean arterial pressure is increased until definitive management can occur. Successful deployment of the balloon also can mitigate pelvic packing and violation of the thoracic cavity. In a recent multi-center study published by Moore and colleagues, REBOA was found to have a higher survival rate as compared to resuscitative thoracotomy for patient with non-compressible torso hemorrhage arising from below the diaphragm [100]. The appropriate patient for REBOA consideration is one with high mortality risk, intra-abdominal exsanguination source, pelvic instability, and sustained systolic pressures lower than 70; in essence, REBOA should be considered in a patient who does not require thoracotomy but who would benefit from aortic occlusion [101].

Thromboelastogram (TEG)

TEG is used to guide decisions in goal-directed resuscitation or correction of coagulopathy or fibrinolysis. TEG is a plotted graph of the effectiveness of clot formation and breakdown, and is considered more accurate to identify causes of coagulopathy in the trauma patient than is a coagulation panel [102, 103]. Several reviews have failed to show a mortality difference in patients who are resuscitated using TEG guidance versus those who follow a standardized massive transfusion protocol; however, the authors note poor power of that aggregated data [104]. They also note that TEG can potentially reduce the amount of transfusions if interpreted and applied during hemorrhagic shock, but that the data on this point is not definitive.

The TEG curves can provide information about all aspects of the clotting system, possibly even the interactions with the endothelium, which is currently an ongoing area of research [105]. The initial part of the TEG, which comprises the R time, or the activated clotting time (ACT), illustrates the amount of time to begin forming a clot (Fig. 1.2). The K time shows how long it takes to reach clot strength and quantitates the clot kinetics [106], whereas the alpha angle and the maximal amplitude (MA) show the rate of clot formation and the absolute clot strength indicating a relationship between fibrinogen and platelets, respectively. A low angle reflects a low fibrinogen concentration; a low MA means that the platelet count or function is reduced and the patient would benefit from platelet transfusion or desmopressin (DDAVP). The LY30 indicates the stability of the clot and the degree of fibrinolysis. The G value shows clot strength or firmness [107].

Normal ACT, R time, and K time indicate that clotting factors are intact and functional. Delays in any of these mean that the patient would most benefit from the administration of FFP or factor; additionally, it can reflect a patient on heparin or other medication that impairs clotting. The angle and MA reflect platelet function and an increase in either suggests hypercoagulable state, whereas a decrease in either means that the platelets may not be aggregating properly. In patients with an elevated MA there is argument for administration of a daily aspirin or placement of an IVC filter [108]. It has been shown that an MA greater than 68 correlates with an increase in coagulability, predisposing patients to thromboembolism [109]. LY30 greater than 3 % has significant consequences of increased mortality and use of antifibrinolytic therapy to target hyperfibrinolysis will be discussed below [110–113].

Damage Control Resuscitation

Damage control resuscitation is a term coined in the military [114, 115]. It is a reproducible strategy with reproducible results and it is automatic and continuous until a physician decides that the shock state has resolved and that hemostasis has been achieved. It describes a resuscitation that uses replacement blood product, rather than crystalloid, for hemorrhagic shock. By limiting the crystalloid infused in the initial resuscitation, patients appear to have less complications and morbidity [116, 117] There are fewer reports of compartment syndromes, a higher number of abdomens that can be closed after a damage control laparotomy, less acidosis, and less electrolyte disturbances.

PROPPR shows that using a 1:1:1 ratio for massive transfusion reduced mortality at 3 h in centers where product was immediately available [118]. By mitigating the onset of coagulopathy within the timeframe of predictable hemorrhagic death, mortality can be prevented. Many centers now utilize a strategy of blood product resuscitation and limitation of crystalloid allocation [119]. For example, Cotton and colleagues investigated the success of the trauma laparotomy when damage control resuscitation in a 1:1:1 ratio and limited crystalloid were implemented. This strategy of damage control resuscitation was found to be useful in the field. Patients in the damage control resuscitation group received

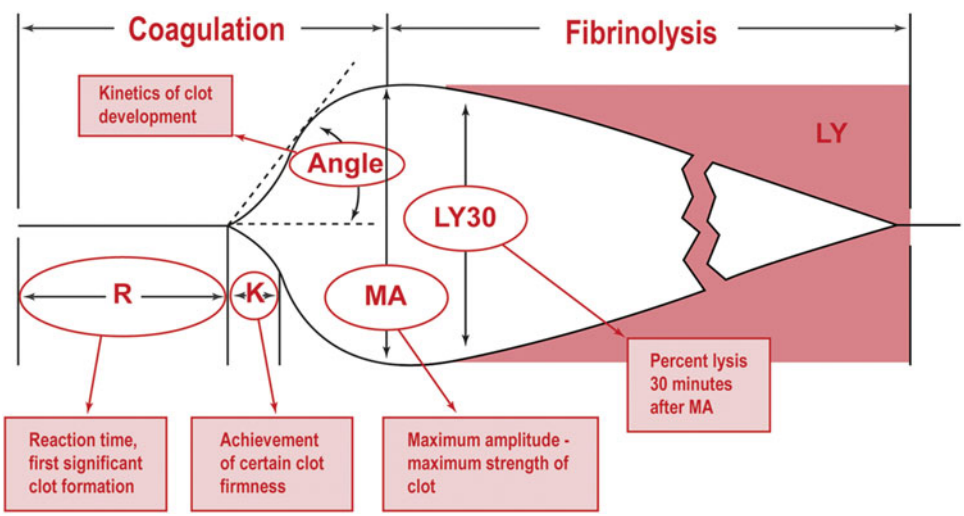

Fig. 1.2 Analytical software graphical representation of a TEG tracing. *R* initial time, *K* time it takes to reach clot strength, *MA* maximal amplitude, *LY* lysis. (From Mark H. Ereth, MD. Uncontrolled bleeding after thoracic aortic aneurysm repair: a case report and interactive discussion. http://www.bloodcmecenter.org, with permission.)

approximately 10 liters less of crystalloid in the first 24 h, had better short- and long-term survival, and showed signs of being less acidodic, less coagulopathic, and less hypothermic on arrival to the ICU than patients who received a traditional resuscitation. The study was a retrospective cohort that examined two similar groups of patients, finding improved morbidity and mortality rates in the group receiving better ratios and colloid. Secondary analyses showed statistically significant differences in multi-organ failure, acute lung and kidney injury, and their effects.

The length of time it takes to get access to FFP plays a role in the success of a massive transfusion protocol. Several studies have examined time factors in receiving product as a way to analyze the effectiveness of a massive transfusion protocol [120–122]. Thawed plasma improved availability and adherence to the 1:1:1 in 12 nationwide trauma centers participating in PROPPR [123]. These data showed an improvement in infusion time interval from 56 min to less than 5 min, which is associated with improved outcomes. Multiple centers are now using never frozen liquid plasma, which has up to 25 day storage at 4 °C [124]. This product combines rapid availability with much longer storage times.

Data is conflicting on the benefit of tranexamic acid (TXA) on outcome in patients with hyperfibrinolysis. While a Cochrane Review in 2012 showed that risk of death in bleeding patients with hypotension is reduced with early TXA, Harvin et al. showed no improvement in 30-day or in-hospital mortality [125, 126]. CRASH-2 showed that TXA was not specifically causative to thromboembolic events. Napolitano et al. review the current data and lingering questions regarding TXA in hemorrhagic shock [127].

Improved overall survival at 30 days and improved hemorrhage related survival without any difference in transfusion requirement was shown in the CRASH 2 trial. The antifibrinolytic was given despite the lack of laboratory data, and when infused more than three h after injury, death was increased. Based on the uncertainty created by the increased death rate, several leading centers have restricted the use of TXA to patients with increased fibrinolysis shown by TEG and presenting early after their traumatic event. Until further randomized data are published this seems like a reasonable approach.

Complications of Resuscitation

Data from the days when trauma patients were resuscitated with multiple liters of saline prior to receiving their first blood product shows complications related to the overwhelming volume of crystalloid infused [128–130]. These types of complications include compartment syndromes, high number of abdomens that cannot be closed, and grossly edematous bowel, all secondary to large volume resuscitation [131]. Complications of transfusion-related acute lung injury (TRALI) and transfusion-associated circulatory overload (TACO) are not seen frequently because the base resuscitative fluid is colloid at relatively lower volumes than a crystalloid based resuscitation [132–134]. Ileus, heart failure, and difficulty with wound healing have all additionally been attributed to over-resuscitation with crystalloid.

All trauma patients who receive a massive resuscitation remain at risk of abdominal compartment syndrome, but this complication appears better mitigated when low ratio of crystalloid to blood product is given. One study claimed that there would be an epidemic if crystalloid resuscitations are continued with such fervor and that patients were threatened by secondary compartment syndrome that occurs solely as the result of excessive crystalloid resuscitation during hemorrhagic shock [135]. Abdominal hypertension is defined as any pressure greater than 12 mmHg without evidence of multi-organ failure. Abdominal compartment syndrome is defined as any one of the following: pressure greater than 20 mmHg; progressive, identifiable organ dysfunction; and improvement following decompression. The trauma population is susceptible, even those who lack abdominal injuries and develop elevated pressures simply due to the amount of fluid they receive. In Houston during the late 1990s the resuscitations during the first 24 h for a group of 128 patients requiring decompression for organ dysfunction averaged the following volumes: (26 ± 2 units PRBC, 38 ± 3 l crystalloid). Seven of these cases required urgent non-abdominal operations, where they likely received several additional units of crystalloid or colloid [136].

It is recommended to check bladder pressures and peak inspiratory pressures routinely and aggressively in patients where massive transfusion has taken place [137]. This practice of serially checking bladder pressures, based on observational data, seems to help in the early identification of intra-abdominal hypertension, perhaps staving off the evolution to abdominal compartment syndrome [138]. Decompression can be done with placement of a temporary dressing and later planned closure with evidence of better results and earlier closure [139, 140].

Keeping the abdomen open after a damage control laparotomy also has its disadvantages. It has been shown that ileus and bowel edema prevent advancement of feeds and definitive closure, and that these phenomena are likely related to an ongoing inflammatory response that occurs as a result of the sustained acute resuscitative phase [141–143]. It is additionally unclear whether ileus is a cause or an effect of bowel edema and vice versa [144, 145]. Administration of 3 % hypertonic saline during the time that the abdomen is open has been shown in a small series to decrease bowel edema. The mechanism is thought to be due to hydrostatic gut edema induced by overaggressive resuscitation with crystalloid. The hypertonic saline gives a smaller volume of more concentrated solution, and pulls extra edematous fluid from the bowel wall. Success has been shown in the rat and subsequently in the human model.

Using Ultrasound to Determine Volume Status

Distinguishing compensated shock from impending complete cardiovascular collapse can be difficult. Understanding physiology and volume status on a global scale seems straightforward—it is the clinical application of these principles to the individual patient that creates a conundrum for identifying the degree of shock. While CVP, monitoring derived from arterial wave forms, intraesophageal echo, urine output and vital signs have all been described for assessment of fluid status, there is also potential benefit in using non-invasive US. Given the application of focused assessment with sonography in trauma (FAST) exam, there has been some interest in examination of the inferior vena cava (IVC) volume during the initial assessment. This is a non-invasive, accurate, and rapid way to assess the patient's overall volume status and is easy to repeat. The technique has been described as placing the patient in the supine position and angling the probe toward the right shoulder from a subcostal view. The IVC can be measured at the entrance of the hepatic veins. Measuring in expiration appears to yield the most accurate measurement. Several small studies demonstrate that measurements of IVC diameter are incredibly fast, non-invasive, accurate measures to determine if shock is present [146–149]. Of note there can be error in measuring the IVC diameter; when accounting for volume variability, the anterior–posterior measurement has been found to be less precise than measurements taken on the oblique axis. In this manuscript the minor axis was defined as the shorter axis when the IVC was viewed as an ellipse shape in horizontal orientation. Trauma patients were included in the study if they were noted to be hypovolemic on the initial ultrasound (minor axis measurement less than 15 mm, consistently measured one cm below the renal vessels) and if they received a computed tomography (CT) scan of their abdomen to further confirm results within 1 h of their diagnosis of hypovolemia. Expected expansion after fluid resuscitation was approximately 7 mm in the minor axis. It remains to be seen if this technique can be widely applied and reliably instituted as a means to identify patients who are volume depleted or dependent and guide resuscitation

Conclusion

Resuscitation is an art and requires attention to detail at all stages including pre-hospital, hospital, operating room, and ICU. The salient points from this chapter focus on understanding shock, providing deficient products, using TEG to guide resuscitation and identifying endpoints. Interested readers are encouraged to focus on several of the resources below to enhance their knowledge and perfect their resuscitation abilities.

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The Evaluation of the Acute Abdomen

2

Marie Crandall

Introduction and Epidemiology

Abdominal pain is one of the most common reasons for visits to the emergency room, comprising 7 % of all visits [1]. Although for the majority of patients, symptoms are benign and self-limited, a subset will be diagnosed with an "acute abdomen," as a result of serious intra-abdominal pathology necessitating emergency intervention [2].

An expeditious workup and Epidemiology is necessary when evaluating patients presenting with acute abdominal pain to determine the most likely cause of their symptoms and determine whether or not emergent operative intervention is necessary. The most appropriate therapy should then be initiated with the patient's clinical status optimized. The workup should first include a thorough but efficient acquisition of the patient's history and physical examination followed by the judicious use of laboratory and radiologic studies. The evaluation of patients with acute abdominal pain can pose a diagnostic challenge for physicians as patients may present with atypical symptoms that interfere with the usual pattern recognition that often guides decision making. These atypical presentations may help account for the over 25 % of abdominal pain cases labeled as "nonspecific" or "undifferentiated" [2].

Additionally, physicians must take into account the patient's age, gender, and comorbidities as conditions associated with the acute abdomen may vary accordingly. Specifically, gastroenteritis, acute appendicitis, and abdominal trauma are common causes of the acute abdomen in children and young adults [3], whereas biliary disease, intestinal obstruction, diverticulitis, and appendicitis are among the most common causes in middle-aged adults and the elderly [4]. Furthermore, pelvic pathology accounts for approximately 12 % of acute abdominal pain presentations and should therefore be considered when evaluating female patients [2].

Finally, there are a variety of nonsurgical causes of abdominal pain that are cardiovascular, metabolic, and toxic in origin that should be considered when evaluating these patients.

Clinical Presentation

A thorough, yet expeditiously obtained, history and physical exam is paramount to developing the differential diagnosis for patients presenting with an acute abdomen. Various laboratory and imaging studies may subsequently be used as adjuncts to help guide decision making.

History

When obtaining a patient history, the physician should avoid questions that are leading and should focus on details of the pain. This includes information on the onset, character, duration, and location of pain as well as the presence of radiation of pain.

Regarding onset, pain that develops suddenly may be suggestive of a perforated viscus or ruptured abdominal aortic aneurysm (AAA). Pain that gradually worsens over time may be the result of conditions characterized by the progressive development of infection and inflammation such as acute appendicitis and cholecystitis.

With regard to character, pain described as "burning" may implicate the pain of a perforated peptic ulcer while a "ripping" or "tearing" sensation typically represents the pain of an aortic dissection. Pain that is intermittent or colicky should be distinguished from pain that is continuous in nature. Colicky pain is typically associated with obstructive processes of the intestinal, hepatobiliary, or genitourinary tract, while pain that is continuous is usually the result of

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_2

underlying ischemia or peritoneal inflammation. The latter may occur primarily or following an initial episode of colicky pain when an obstructive process is complicated by the development of ischemia. Examples of this include cases of biliary colic that progresses to acute cholecystitis or an incarcerated loop of intestine that becomes strangulated and ischemic.

The location of pain is important to consider as various pathologic conditions tend to occur in specific regions or quadrants of the abdomen (Fig. 2.1a, b). Therefore, if the physician is knowledgeable of the disease processes that cause pain in these areas, they may be able to significantly narrow down their differential. This holds true for those with the understanding that certain conditions may result in pain that radiates or is referred to an area beyond the site of disease due to shared innervation. Classic examples of this include biliary pain that is referred to the right subscapular region, the pain of acute pancreatitis that radiates to the back, and genitourinary pain that radiates from the flank down to the groin. Finally, it is important to note any chronological variation in the pain as this may provide helpful clues to the diagnosis. One of the best examples of this is in the case of acute appendicitis, in which pain is initially perceived in the periumbilical region before localizing to the right lower quadrant (RLQ). This phenomenon reflects the transition from visceral to parietal pain as appendiceal inflammation progresses to involve and irritate the peritoneal lining.

The majority of patients presenting with acute abdominal pain have associating symptoms (e.g., nausea, vomiting, diarrhea, constipation, hematochezia) that are often helpful in making a diagnosis. Chronology of nausea is important to consider as vomiting that occurs after the onset of abdominal pain is more likely to be surgical in nature as a result of medullary vomiting centers that are stimulated by pain impulses traveling via secondary visceral afferent fibers. Additionally, constipation or obstipation may point towards an intestinal obstruction, while diarrhea (especially if bloody) is associated with gastroenteritis, inflammatory bowel disease, and intestinal ischemia.

Aggravating or alleviating factors may also provide diagnostic clues. Depending on the underlying etiology, patients may maintain certain positions to help alleviate their pain. For example, patients with peritonitis may find some relief when lying still with their knees bent, while patients suffering from a bout of acute pancreatitis prefer to sit upright and lean forward. The effect of food is also important to consider as eating may alleviate the pain of a peptic ulcer while worsening the pain of an intestinal obstruction, acute cholecystitis, or acute pancreatitis [5, 6].

The patient's past medical and surgical histories may also help to narrow down the differential. A remote history of abdominal surgery may indicate that intestinal obstruction secondary to adhesive disease is the source of a patient's complaints. Furthermore, it is important to consider the impact that coexistent medical conditions, such as diabetes, chronic obstructive pulmonary disease, and atherosclerosis, may have on patient outcomes. The fact that elderly patients are more likely to have significant comorbidities places them at increased risk for end organ damage incited by gastrointestinal emergencies [7].

Physicians should also take into account the effects of medication use. Anticoagulants may predispose to the development of rectus sheath hematomas and precipitate the gastrointestinal bleeding that is a component of the patient's underlying illness or complicating the patient's postoperative or posttreatment course. Chronic use of nonsteroidal anti-inflammatory drugs (NSAIDs) may also promote bleeding episodes along with the development of peptic ulcer disease (PUD) and its complications.

A detailed social history should also be obtained to determine if there is any significant history of tobacco, alcohol, or illicit drug use, as such behaviors can be a source of the patient's symptoms as well as complicate the patient's hospital course. Notably, a history of cocaine abuse may point towards a diagnosis of mesenteric ischemia as the underlying reason for the patient's symptoms.

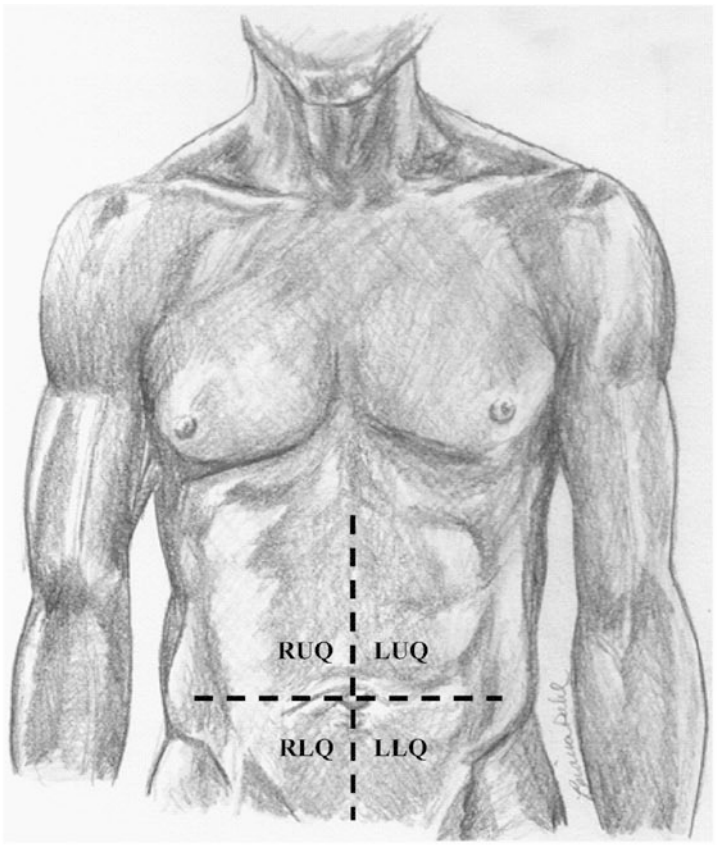
The social history should consist of a detailed gynecologic history, including the date of the last menses, the presence of any vaginal bleeding or discharge, and any history of unprotected sexual activity or intercourse with multiple partners. Such information could indicate pregnancy complications, salpingitis or pelvic inflammatory disease, and other gynecologic conditions as the cause of the patient's acute abdominal complaints. Physicians should also take note of any history of recent travel to implicate infectious enterocolitis. Any exposure to environmental toxins should be determined, as lead and iron poisoning are two well-known, extra-abdominal sources of acute abdominal pain [5, 6].

Finally, the patient's family history may ascertain whether a patient's symptoms are hereditary in origin, as seen in the case of inherited hypercoagulable states, which can cause acute mesenteric ischemia secondary to mesenteric venous thrombosis.

Physical Examination

Examination of the patient presenting with acute abdominal pain should initially begin with overall appearance of the patient and vital signs. Patients who appear diaphoretic, pale, and anxious often suffer from a condition of vascular origin, including dissecting AAA, mesenteric ischemia, or atypical angina. The patient who is lying particularly still on the exam table often has peritonitis from perforated viscus or pancreatitis. Vital signs should always be interpreted knowing the status of the patient's pain, or the influence of any home

a



Right Upper Quadrant (RUQ)
Cholecystitis
Biliary Colic
Cholangitis
Hepatitis
Hepatic Abscess
Pancreatitis
Peptic Ulcer
Appendicitis (pregnancy)
Intestinal Obstruction
Inflammatory Bowel Disease
Pneumonia

Left Upper Quadrant (LUQ)
Gastritis
Peptic Ulcer
Pancreatitis
Splenomegaly
Splenic Rupture
Intestinal Obstruction
Inflammatory Bowel Disease
Diverticulitis (Splenic Flexure)
Pneumonia
Myocardial ischemia
Pericarditis

Right Lower Quadrant (RLQ)
Appendicitis
Inflammatory Bowel Disease
Diverticulitis (Cecal, Meckel's)
Mesenteric Adenitis
Intestinal Obstruction
Hernia
Ectoptic Pregnancy
Salpingitis
Ovarian Torsion
Ruptured Ovarian Cyst
Mittelschmerz
Nephrolithiasis
Pyelonephritis

Left Lower Quadrant (LLQ)
Diverticulitis
Appendicitis
Intestinal Obstruction
Inflammatory Bowel Disease
Ischemic Colitis
Hernia
Ectopic Pregnancy
Salpingitis
Ovarian Torsion
Ruptured Ovarian Cyst
Mittelschmerz
Nephrolithiasis
Pyelonephritis

Fig. 2.1 (**a**) Common causes of the acute abdomen based on quadrant. (**b**) Common causes of the acute abdomen based on region. (Illustrations courtesy of Briana Dahl.)

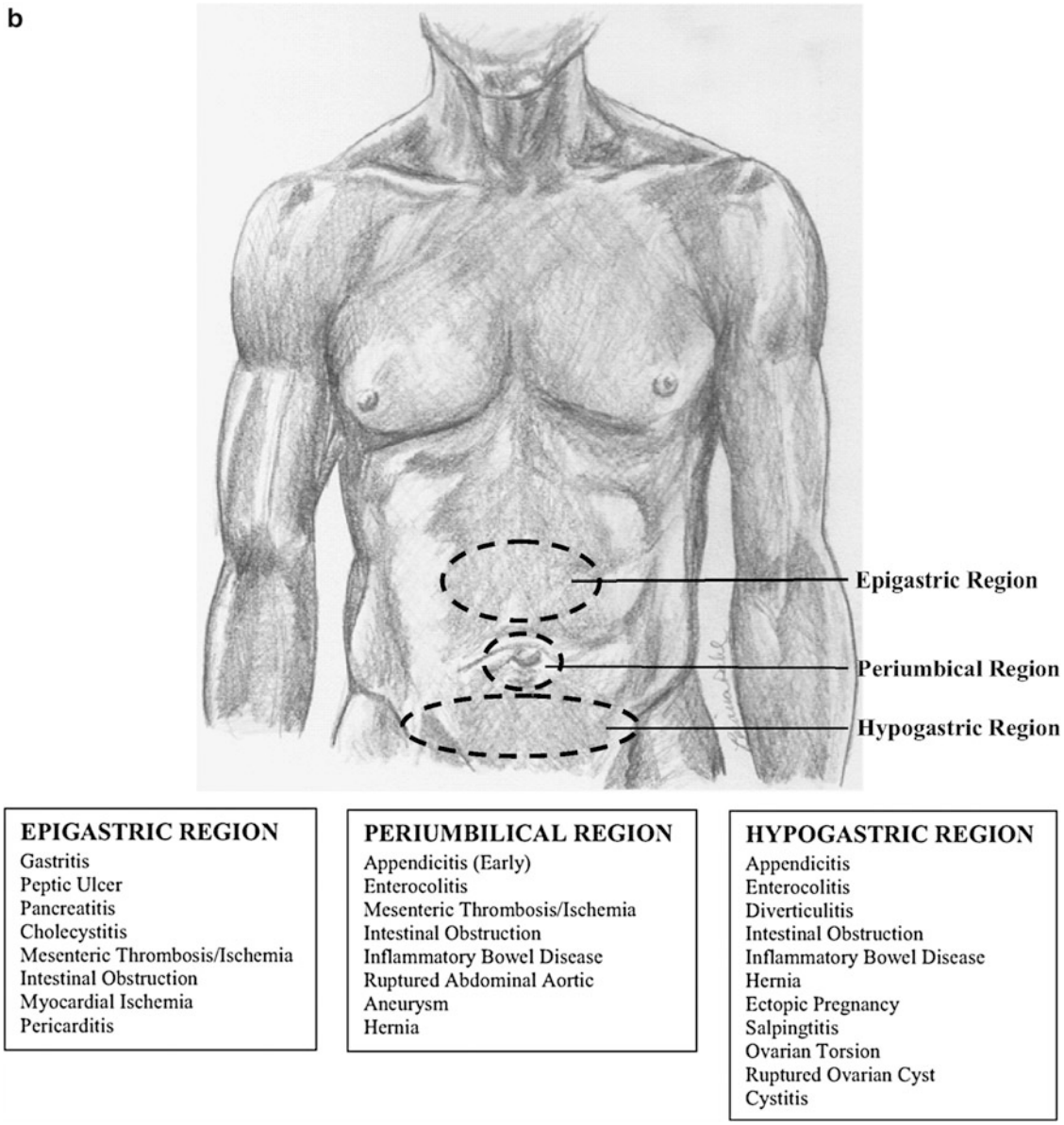


Fig. 2.1 (continued)

medications (beta blockers masking tachycardia, for example). Severity of systemic illness can be graded based on the degree of tachypnea, tachycardia, febrile or hypothermic response, and relative hypotension. Further examination of the lungs and heart could reveal signs representing primary cardiac disease or new-onset arrhythmias, which could lead to mesenteric embolic disease. The remainder of a complete physical examination should proceed expeditiously so that attention can be focused on the abdomen.

Examination of the abdomen should comprise four sequential components: inspection, auscultation, percussion, and palpation. The exam should include all areas of the abdomen, flanks, and groins.

Inspection

Inspection is the initial step of the abdominal examination and consists first of a general assessment of the patient's overall state followed by focus on the abdomen. Patients with peritonitis tend to lie still with their knees flexed as doing so provides some alleviation of their pain. Upon closer inspection of the abdomen, one should note the presence of prior surgical scars, abdominal distension or visible peristalsis, any obvious masses suggestive of an incarcerated hernia or tumor, or erythema or ecchymoses secondary to traumatic injury or hemorrhagic complications of acute pancreatitis. Caput medusa may indicate liver disease.

Auscultation of the abdomen should be performed next and involves listening for the presence or the absence of bowel sounds, for the characteristics of those sounds, and for the presence of bruits. Although this step may be the least valuable overall, as bowel sounds may be completely normal in patients with severe intra-abdominal pathology, it may nonetheless provide some information that assists the physician in making a diagnosis. For example, the absence of bowel sounds may point towards a paralytic ileus, while ones that are high pitched in nature or rushed may indicate the presence of a mechanical bowel obstruction. Finally, bruits that are detected on the abdominal exam suggest the presence of turbulent flow, which is often the case for arterial stenoses.

Percussion

Next, percussion is utilized to assess for any dull masses, pneumoperitoneum, peritonitis, and ascites. A largely tympanic abdomen may indicate the presence of underlying loops of gas-filled bowel typical of intestinal obstructions or a paralytic ileus. If findings of tympany extend to include the right upper quadrant (RUQ) however, it may be suggestive of free intraperitoneal air. Lastly, percussion can be used to detect ascites by the presence of shifting dullness or by the generation of a fluid wave. Percussion may be all that is necessary to elicit pain in the patient who has peritonitis, for whom further palpation should be deferred.

Palpation

Palpation is the final, critical step as it enables the physician to better define the location and severity of pain and confirm any findings made on other aspects of the physical exam. Palpation should always commence away from the area of greatest pain to prevent any voluntary guarding, which should be distinguished from the involuntary guarding that accompanies peritonitis. Palpation can produce various signs commonly associated with specific disease processes. These include Murphy's sign, characterized by an arrest in inspiration upon deep palpation of the RUQ in patients with acute cholecystitis, and Rovsing's sign, observed many times in patients with acute appendicitis in which pain is elicited at McBurney's point upon palpation of the left lower quadrant. Additionally, pain felt with hyperextension of the right hip, or iliopsoas sign, may indicate the presence of a retrocecal appendix, while a pelvic location of the appendix may be suspected in patients exhibiting Obturator sign, or pain created with internal rotation of a flexed right hip.

It is essential that all patients presenting with acute abdominal pain undergo a digital rectal exam as it may reveal the presence of a mass, the focal tenderness of a periappendiceal or peridiverticular abscess, and the presence of gross or occult blood. Finally, a pelvic examination should be performed in female patients presenting with lower quadrant pain to discern whether their pain has a gynecologic or obstetric source like pelvic inflammatory disease or a ruptured ectopic pregnancy. On exam, one should take note of any vaginal bleeding or discharge and any adnexal or cervical motion tenderness [4, 5].

Diagnosis Including Use/Value of Pertinent Diagnostic Studies

Laboratory Studies

Various laboratory studies can be used as adjuncts to help narrow down the differential, or to confirm or rule out a diagnosis. A complete blood count (CBC) with differential, for example, may help detect or confirm the presence of an infectious or inflammatory process by the demonstration of leukocytosis and/or a left shift. The accompanying hematocrit is also of value as it can provide information about one's plasma volume, altered in cases of dehydration and hemorrhage. In addition, serum electrolytes, blood urea nitrogen (BUN), and serum creatinine may provide clues to the extent of any fluid losses resulting from emesis, diarrhea, and third-spacing as can lactic acid levels and arterial blood gases. The latter two tests may also help to confirm the presence of any intestinal ischemia or infarction as well.

Liver function tests (LFTs) can help in determining whether conditions of the hepatobiliary tract are the source of the patient's symptoms, while measurements of serum amylase and lipase may implicate acute pancreatitis or its complications as the cause. Physicians should be mindful of the fact, however, that serum amylase levels may also be elevated in a variety of other acute abdominal conditions including intestinal obstruction, mesenteric thrombosis, ruptured ectopic pregnancy, and perforated PUD to name a few [8].

Finally, with respect to serologic tests, there has been recent interest in measurement of inflammatory markers, such as procalcitonin and C-reactive protein (CRP), to aid in the diagnosis of intra-abdominal pathology. However, at this point in time, the markers are insufficiently sensitive and/or specific to be routinely useful [9, 10]. Urinary tests, namely, urinalysis, should be obtained in patients presenting with hematuria, dysuria, or flank pain to determine if their symptoms are genitourinary in origin. Urine samples can also be used to perform toxicology screens in those whose abdominal pain is thought to be the result of long-standing illegal drug use, as seen in the case of mesenteric ischemia that occurs with chronic cocaine abuse. Finally, human chorionic gonadotropin (Hcg) levels can help in determining whether complications of pregnancy, such as a ruptured ectopic pregnancy,

are to blame. Regardless of whether or not it is the source of the patient's symptoms, Hcg levels should be obtained in all women of childbearing age as it may affect decision making, especially if additional studies or surgical intervention are deemed necessary [5]. Finally, depending on the clinical situation, blood may be obtained for typing and crossmatching.

Radiologic Studies

Radiologic imaging plays a key role in the evaluation and management of the acute abdomen (Table 2.1). Plain films, ultrasound (US), computed tomography (CT), and magnetic resonance imaging (MRI) are the most common imaging modalities employed in the diagnostic workup of these patients.

Plain radiographs are often the initial imaging study performed in patients presenting with acute abdominal pain. The advantages of their use include their rapidity and universal availability. Although patients are subject to ionizing radiation exposure, the dose is significantly lower than that of CT scans [11]. Plain films can be of great utility in patients suspected of a perforated viscus by the detection of a pneumoperitoneum by demonstrating dilated loops of bowel and air-fluid levels consistent with obstruction, or by visualization of a foreign body.

The advantages of abdominal US include the lower cost and the lack of ionizing radiation exposure [12], which is advantageous for the pediatric population and pregnant women. In addition, abdominal US is the imaging modality of choice for those patients presenting with suspected hepatobiliary pathology, with a sensitivity of 88 % and specificity of 80 % in the diagnosis of acute cholecystitis [13]. Features suggestive of acute cholecystitis on US include the presence of gallstones, gallbladder wall thickening, pericholecystic fluid, and an elicited Murphy's sign (Fig. 2.2).

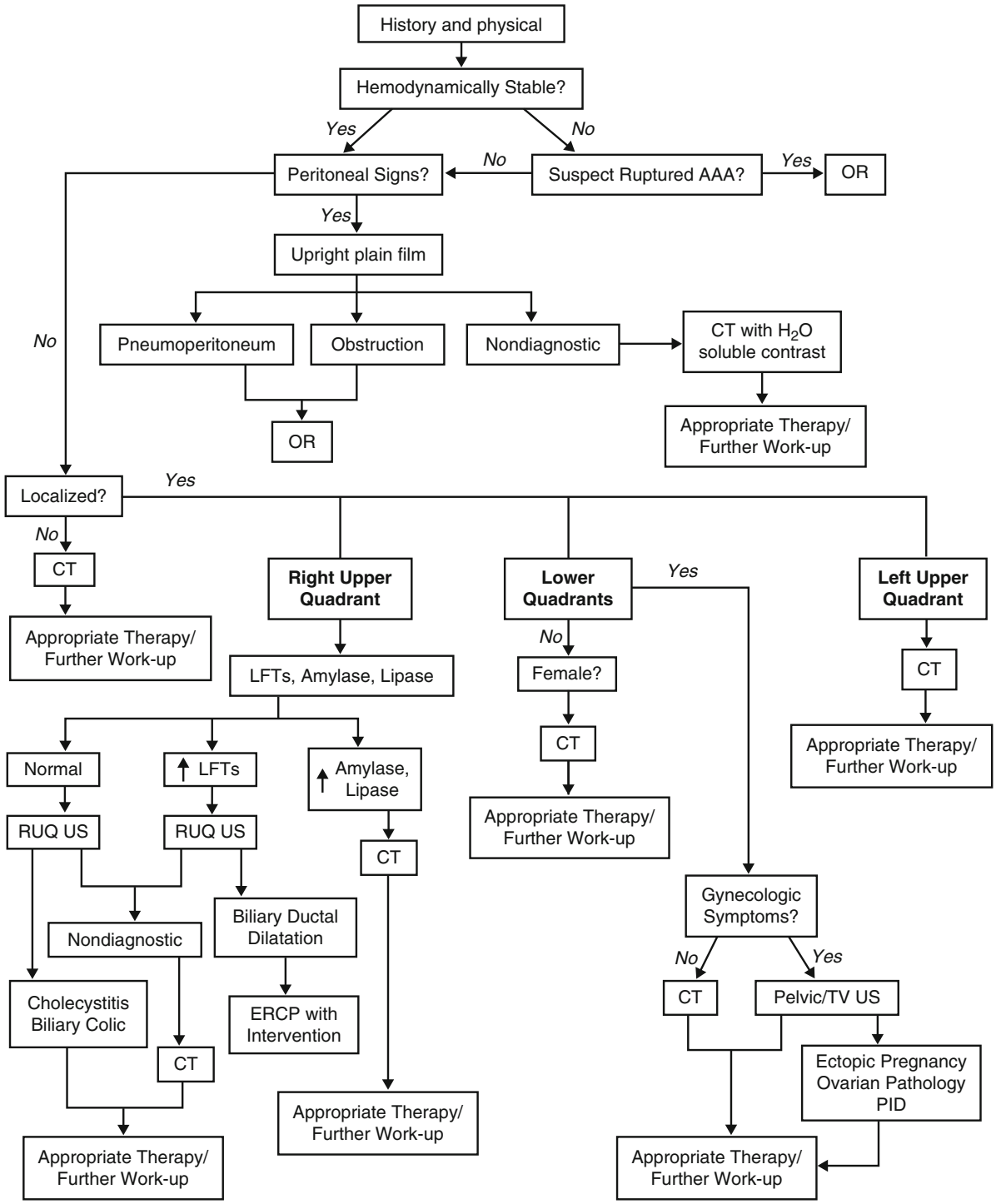
If an obstetrical or gynecologic condition is suspected as the source of a patient's acute abdominal pain, pelvic and transvaginal US are the preferred imaging modalities to assess the uterus and adnexal structures. The presence of free fluid and an empty uterus on US in the setting of a positive pregnancy test is strongly suggestive of a ruptured ectopic pregnancy [14] while an enlarged and edematous ovary with an absence of blood flow is characteristic of a torsed ovary.

Of all the available diagnostic radiologic, the CT scan has emerged as the tool of choice, due to its sensitivity, specificity, and ability to improve work flow and decrease unnecessary hospital admissions [15, 16]. The CT scan has sensitivity of 96 % overall for diagnosing most causes of the acute abdomen, compared to a 30 % sensitivity for plain films [11]. CT scanning has had a significant impact on the diagnosis of acute appendicitis as it has decreased the negative appendectomy

Table 2.1 Diagnostic imaging strategies and treatment options for common causes of acute abdominal pain based on age and gender

	Imaging strategy	Treatment options
Children/young adults		
Acute appendicitis	US, CT	Appendectomy (laparoscopic or open); percutaneous abscess drainage
Gastroenteritis	None	Supportive care
Functional constipation	XR	Manual or pharmacologic fecal disimpaction
Intussusception	XR, US, contrast enema	Contrast enema; operative reduction; resection of ischemic or perforated bowel
Abdominal trauma	FAST, DPL, CT	Exploratory laparotomy; IR
Older adults/elderly		
Acute cholecystitis	US	Cholecystectomy (laparoscopic or open); percutaneous cholecystostomy
Intestinal obstruction	XR, CT	Supportive care; exploratory laparotomy with adhesiolysis, resection of ischemic bowel
Perforated peptic ulcer	XR, CT, or UGI with H_2O soluble contrast	Patch closure with *Helicobacter pylori* treatment if hemodynamic instability
Diverticulitis	CT	Supportive care; percutaneous abscess drainage; resection of involved bowel
Acute appendicitis	CT	Appendectomy (laparoscopic or open); percutaneous abscess drainage
Acute pancreatitis	US, CT	Supportive care; IR or operative pseudocyst drainage; debridement of infected necrosis
Mesenteric ischemia	CTA, MRA	Supportive care; IR; operative bypass, thrombectomy, resection of ischemic bowel
Women		
Acute appendicitis in pregnancy	US, CT, MRI	Appendectomy (laparoscopic or open)
Acute cholecystitis in pregnancy	US	Cholecystectomy (laparoscopic or open)
Ectopic pregnancy	US	Linear salpingostomy or salpingectomy (laparoscopic or open)
Ovarian torsion	US	Ovarian detorsion, possible oophorectomy (laparoscopic or open)
Pelvic inflammatory disease	US, MRI, CT	Supportive care; percutaneous or operative drainage of abscess

US ultrasound, *CT* computerized tomography, *XR* plain radiography, *FAST* focused abdominal sonography for trauma, *DPL* diagnostic peritoneal lavage, *UGI* upper gastrointestinal series, *IR* interventional radiology, *CTA*, *CT* computerized tomographic angiography, *MRA* magnetic resonance angiography, *MRI* magnetic resonance imaging



AAA, Abdominal Aortic Aneurysm; CT, Computerized Tomography; LFTs, Liver Function Tests; ERCP, Endoscopic Retrograde Cholangiopancreatography; RUQ, Right Upper Quadrant; US, Ultrasound; TV, Transvaginal; PID, Pelvic Inflammatory Disease.

Fig. 2.2 Algorithm for the treatment of the acute abdomen

rate from 24 to 3 % [17]. Findings diagnostic of appendicitis on CT scan include an enlarged, nonopacified appendix, appendicoliths, and adjacent fat stranding while the presence of an abscess, phlegmon, and extraluminal gas points towards appendiceal perforation (see Fig. 2.2).

Although MRIs provide excellent visualization of the intraabdominal organs without the need for ionizing radiation, their cost and lack of universal availability make them less ideal for use in the evaluation of the acute abdomen [18]. In addition, some patients have contraindications to undergoing

an MRI or are simply unable to tolerate the test because of claustrophobia. MRI, however, may be of utility for pregnant women in the setting of acute abdominal pain, and has been increasingly been used in diagnostic algorithms with the goal of reducing fetal radiation exposure while still optimizing speedy evaluation and treatment [19, 20].

Diagnostic Laparoscopy

Diagnostic laparoscopy may be of utility in the evaluation of acute abdominal pain, especially in situations in which the underlying etiology remains unclear despite a thorough clinical evaluation and radiologic imaging. The advantages of diagnostic laparoscopy include its ability to make a definitive diagnosis in 90–98 % of cases and determine whether further intervention is necessary [21, 22]. A resultant decrease in the negative laparotomy rate—and the fact that if further treatment is indicated that many acute abdominal conditions can be treated laparoscopically—equates to a decrease in morbidity and mortality, a shorter length of stay, and decreased hospital costs [21]. As experience and skill with advanced laparoscopic techniques increase among surgeons, surgical conditions such as infected pancreatic necrosis, bowel obstructions caused by one or two adhesive bands, and perforated peptic ulcer are now being both diagnosed and treated laparoscopically, with favorable results reported in the literature [23].

Therapeutic Options

In the evaluation of patients presenting with acute abdominal pain, the physician must first determine whether operative intervention is necessary, and if so, whether it should be pursued on an immediate or emergent basis versus urgently or within a few hours of a patient's arrival. Treatment algorithms are beneficial in helping to make such decisions (see Fig. 2.2). In some cases, a short delay to fully correct any fluid and electrolyte abnormalities may prove to be beneficial, whereas in others, immediate operative intervention is necessary for stabilization of a patient's condition. This holds true in the presence of peritonitis, a pneumoperitoneum, intestinal ischemia or infarction, and continued hemodynamic instability despite aggressive resuscitative measures.

Specific treatment strategies for the acute abdomen are largely dependent upon the underlying etiology (see Table 2.1). In the case of acute appendicitis, patients should receive antibiotics and undergo urgent removal of their appendix through either an open or laparoscopic approach, unless their condition is complicated by a perforation with an associated abscess or phlegmon, for which initial nonoperative therapy with interval appendectomy is employed.

For those presenting with acute pancreatitis, however, treatment is largely supportive and includes bowel rest, aggressive fluid and electrolyte repletion, pain control, antibiotic therapy, and nutritional support. Surgery is reserved for the management of complications that may occur subsequently, including the development of infected pancreatic necrosis and large, symptomatic pseudocysts.

Lastly, for patients whose conditions do not warrant emergent surgery, but in whom the underlying etiology remains uncertain, treatment options include diagnostic laparoscopy as previously discussed or observation with frequent monitoring of their hemodynamic status and serial abdominal examinations. Studies have demonstrated that observation in properly selected patients is safe without an increased risk of complications [24].

Special Patient Populations

The Acute Abdomen in the Extremes of Age

Abdominal pain is one of the most common complaints among elderly patients presenting to the emergency department [25]. As the presentation is often different than what is seen in younger patients, the ability to accurately diagnose the underlying cause of their abdominal complaints can be challenging. Elderly patients may lack the febrile response, leukocytosis, and severity of pain expected in those suffering from serious intra-abdominal pathology as a result of the age-dependent decline in immune function [26] along with a well-documented delay in pain perception [27].

The atypical presentation commonly seen in these patients may also be attributed to the effects of other, coexisting medical conditions and medications. For example, beta blockers may blunt the normal tachycardic response to acute abdominal processes while nonsteroidal agents and acetaminophen may prevent the development of a fever. Finally, diagnostic accuracy may be difficult to achieve because of the inability to obtain an adequate history from elderly patients with memory and hearing deficits. Combined, these factors contribute to the increased incidence of complications and increased morbidity and mortality observed in elderly patients presenting with acute abdominal pain. For example, although the incidence of acute appendicitis is lower in this population compared to their younger counterparts, the rate of perforation is significantly higher, reaching almost 70 % in some series [28]. Furthermore, complications of acute cholecystitis occur in more than 50 % of patients aged 65 or older [29].

Although on the opposite end of the age spectrum, the diagnosis of the acute abdomen in children can be equally as challenging, particularly in children who are preverbal or uncooperative. Further adding to the difficulty is the fact that

the etiologies of abdominal pain in children can range from trivial (e.g., constipation) to potentially life-threatening (e.g., malrotation with midgut volvulus) with little to no difference in their presentation [30]. As a result, there are higher rates of misdiagnosis and complications in the pediatric population as well. In fact, the rate of perforation in childhood cases of acute appendicitis is 30–65 %, which is significantly higher than what is reported for adults [31].

Overall, physicians should be mindful of the potential challenges posed to them in the evaluation of acute abdominal pain in these extremes of age and adjust their diagnostic approach accordingly.

The Acute Abdomen in Immunocompromised Patients

The ability to make the diagnosis of an acute abdomen is often challenging for those patients who are immunocompromised as a result of conditions such as cancer requiring chemotherapy, transplantation, human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS), renal failure, diabetes, and malnourishment to name a few. As a result of their body's inability to launch a full inflammatory response, these patients may have a delayed onset of fever and other typical symptoms, experience less pain, and have an underwhelming leukocytosis [5]. As a result, a diagnosis may not be made until the development of overwhelming sepsis, multisystem organ failure, and death.

It is also important to consider that these patients may suffer from a variety of atypical infections—including ones that are viral (in particular, cytomegalovirus and Epstein–Barr virus infections), mycobacterial, fungal, and protozoal in origin—that may affect the pancreas and hepatobiliary, and gastrointestinal tracts. Furthermore, neutropenic enterocolitis is a common source of acute abdominal pain in patients with bone marrow suppression secondary to chemotherapy [32]. As a result of these challenges unique to this subset of patients, physicians should have a high index of suspicion for an acute abdominal process if such patients present with persistent abdominal complaints even if seemingly mild in intensity. These patients should undergo prompt diagnostic imaging and the possibility of operative intervention should be considered early.

The Acute Abdomen in the Critically Ill

The acute abdomen in the critically ill presents a diagnostic challenge as even the history and physical exam is often unattainable or unhelpful, especially in those patients who are obtunded, sedated, or intubated. Physicians should therefore have a high index of suspicion and develop a strategy that will allow them to diagnose and treat acute abdominal illnesses in a timely fashion.

Physicians should initially take note of any recent abdominal surgery, the sudden onset of abdominal pain or distension, as well as any changes in laboratory studies or hemodynamic status as indicated by changes in vital signs, an increase in volume requirements, and the need for pressors.

If not contraindicated because of hemodynamic instability or physical constraints, radiologic imaging should be obtained to search for evidence of an acute abdominal process. As is the case for patients who are not critically ill, the sensitivity and specificity for diagnosing certain conditions may vary amongst imaging modalities.

If contraindicated, however, but clinical suspicion is high, then emergent laparotomy is indicated. If there are still doubts however, a less invasive technique such as diagnostic peritoneal lavage (DPL) may be used to assist in decision making. The advantages of DPL include the ability to perform the test at the bedside and the fact that it prevented unnecessary laparotomy in more than 60 % of patients in a small series [33, 34]. Overall however, CT is the imaging modality of choice for most intra-abdominal processes, unless a biliary process is suspected for which US is the most sensitive and specific [13].

An acute abdominal condition of the biliary tract more commonly observed in the critically ill is that of acute acalculous cholecystitis. Although the exact etiology is unclear, biliary stasis and gallbladder ischemia with resultant bacterial colonization have been implicated in its development [35]. Such a scenario is common in critically ill patients who are typically not enterally fed and who are hemodynamically unstable.

Acalculous cholecystitis tends to have a more fulminant course and is therefore characterized by increased rates of gallbladder perforation and gangrene [35]. While cholecystectomy is the treatment of choice for this condition, for patients who are critically ill and unable to undergo surgery, percutaneous cholecystostomy is therapeutic until the patient is able to undergo cholecystectomy at a later time. Approximately 90 % of patients experience significant improvement after percutaneous cholecystostomy [36].

Another acute abdominal process more prevalent in the critically ill population is that of abdominal compartment syndrome (ACS), which often occurs in the setting of abdominal sepsis coupled with aggressive fluid resuscitation [37]. Characterized by an increased intra-abdominal pressure (IAP) of 20 mmHg or higher, ACS can progress to hemodynamic compromise (due to impaired venous return), difficulties with ventilation and oxygenation (a result of elevated airway pressures), and oliguria (secondary to impaired venous return and renal vein compression) [38]. Treatment involves emergent abdominal fascial decompression.

The Acute Abdomen in the Morbidly Obese

It is often more challenging to diagnose the acute abdomen in morbidly obese patients as a result of the subtle changes in vital signs, atypical symptoms, and underwhelming physical exam findings these patients often present with. A mildly elevated heart rate, fever, nausea, and malaise may be the only indications to the presence of a serious intra-abdominal process. This is further complicated by the constraints created by an obese body habitus that make performing a physical exam and interpreting any exam findings more difficult. By the time the patient is found to have peritonitis, it is often a late finding with the patient at significant risk for the subsequent development of abdominal sepsis, multisystem organ failure, and death [39].

Physicians should also be aware of the fact that an obese body habitus may result in imaging studies being unattainable or more difficult to interpret. Weight limits may render some morbidly obese patients from being eligible to undergo CT or MRI scanning and large amounts of subcutaneous fat can result in poor radiographic and sonographic image quality [40]. As a result of these challenges, a high index of suspicion should be employed when making treatment decisions, in particular, whether to operate or not. Note that with the advent of laparoscopy and the development of bariatric laparoscopic ports and instruments less invasive measures may be taken to both diagnose and treat the source of the patient's symptoms [41].

The Acute Abdomen in Pregnant Patients

When evaluating a pregnant patient who presents with abdominal pain, one must keep in mind that delays in diagnosis and subsequent intervention can result in an increased risk of morbidity and mortality for both the patient and her unborn fetus.

Delays in presentation, diagnosis, and treatment may occur because many of the presenting signs and symptoms may mimic those normally observed in pregnancy, including abdominal pain, nausea, vomiting, and anorexia. In addition, vital signs and laboratory findings may be more difficult to interpret as they are routinely altered in pregnancy. There is notably a "physiologic anemia" in pregnancy in addition to mild leukocytosis. Additionally, there is typically a 10–15 bpm increase in pulse rate as well as relative hypotension as a result of hormone-mediated vasodilation [42].

The examining physician must also take into account that the presentation of certain disease processes and physical exam findings may differ in the pregnant patient as a result of the upward displacement of the gravid uterus. A classic example of this is seen in the case of acute appendicitis, in which tenderness may be palpated in the RUQ. Appendicitis is the most common nonobstetrical cause of the acute abdomen, complicating 1 in 1500 births [43]. Although the overall incidence is similar to that of nonpregnant patients, the rate of perforation is higher at approximately 25 %, presumably due to delays in diagnosis and intervention. If and when perforation occurs, the risk of both fetal and maternal mortality increases significantly [44].

Delays may occur because of hesitancy on the part of the physician to obtain certain radiologic studies like that of plain films or CT scans due to the concerns of the radiation exposure associated with these modalities. Ultrasound is therefore used as the initial imaging study in most evaluations of the pregnant acute abdomen [45]. In addition to fetal evaluation, ultrasound is the imaging study of choice for assessment of the biliary tract, pancreas, kidneys, and adnexa. In addition, multiple studies have shown that when paired with graded compression, ultrasound has a sensitivity between 67 and 100 % and a specificity between 83 and 96 % for diagnosing acute appendicitis in pregnancy [46].

If the diagnosis remains uncertain, CT scan is an acceptable alternative means of imaging the pregnant abdomen if used judiciously in order to minimize ionizing radiation exposure [47]. Although the estimated conceptus dose from a single CT acquisition is 25 mGy [48], as per the 1995 American College of Obstetricians and Gynecologists (ACOG) consensus statement, "Women should be counseled that X-ray exposure from a single diagnostic procedure does not result in harmful fetal effects. Specifically, exposure to less than 5 rad (50 mGy) has not been associated with an increase in fetal anomalies or pregnancy loss" [49]. Ultimately, the use of CT scans as a secondary imaging tool in pregnancy can lead to a more timely diagnosis of acute appendicitis resulting in decreased rates of perforation. This along with the decreased rate of negative appendectomies observed in expectant women undergoing US followed by CT scan [50] likely reduces the risk of mortality for both the mother and fetus significantly.

MRI, which uses magnets instead of ionizing radiation, has also been shown recently to be of use in evaluating abdominal pain during pregnancy when ultrasonography was deemed inconclusive [15, 20]. Despite this however, MRI is not always readily available for emergent evaluations; this plus cost and lack of experienced radiologists to read the studies contribute to barriers to its routine use [51].

Once diagnosed, patients should undergo appendectomy. Despite initial concerns of the safety of such an approach, laparoscopy has been accepted as safe with the same advantages afforded for nonpregnant patients, including shorter hospitalizations and less narcotic medication needs [52]. Of course certain precautions should be taken to ensure safety, including using an open Hasson approach to enter the abdomen, a left tilted position, maintaining a CO_2 insufflation of 10–15 mmHg, and monitoring fetal heart tones during the procedure [53].

After appendicitis, the next most common nonobstetric causes of acute abdominal pain are disorders of the biliary tract, notably acute cholecystitis and gallstone pancreatitis. The incidence of acute cholecystitis ranges from 1 in 6000 to 1 in 10,000 births [42]. Presenting symptoms, diagnostic workup, and treatment are similar to their nonpregnant counterparts. As previously stated, laboratory values may be more difficult to interpret, especially in the case of acute cholecystitis as white blood cell counts and alkaline phosphatase levels are normally elevated during pregnancy [42]. As is the case in nonpregnant patients, acute cholecystitis is usually treated conservatively early on with intravenous fluid hydration, bowel rest, pain control, and antibiotics. If the patient fails to respond to medical management, then surgery is indicated. Failing to operate on these patients in a timely fashion significantly increases the risk of preterm labor and fetal loss [54].

Regardless of whether patients respond appropriately to conservative management, the majority of surgeons still recommend surgery during pregnancy to prevent any recurrence or any complications that may pose a threat to the fetus [54]. In fact, the rate of fetal demise with gallstone pancreatitis has been reported to be as high as 60 % [55]. As is the case with acute appendicitis, laparoscopic cholecystectomy has been deemed safe to perform during pregnancy without any increased risk of morbidity or mortality to the mother or fetus [56].

The Acute Abdomen from a Global Perspective

The acute abdomen can be especially concerning from a global health perspective. In 2010, nearly 900,000 people lost their lives to emergency general surgical conditions, such as peptic ulcer disease, bowel obstruction, and appendicitis, diseases which are widely viewed as treatable and survivable in higher resourced countries [57].

The low density of adequately trained physicians and quality treatment facilities in developing countries means long delays between symptom onset and treatment, resulting in worse outcomes [58, 59]. Proper management of the acute abdomen in these regions may be further complicated by the lack of modern radiographic and other diagnostic modalities, which may render contemporary treatment algorithms unusable. As a result, increased emphasis should be placed on careful history taking and physical exam skills. Findings of abdominal distension, abdominal masses, deranged vital signs, guarding, and a positive vaginal/rectal examination have been associated with worse outcomes in these regions, warranting further investigation [60]. In areas where advanced clinicians are unavailable, a standardized questionnaire may help in establishing a differential diagnosis in patients presenting with acute abdominal pain.

In addition to common causes of abdominal pain, physicians in developing countries must consider other exotic causes of acute abdominal pain, including typhoid enteritis, abdominal tuberculosis, and parasitic infections, which can themselves cause acute intestinal obstructions, appendicitis, cholangitis, and liver abscesses [61]. Typhoid, which usually presents with high fever, abdominal distension, and delirium, remains endemic in impoverished parts of the world [62]. Caused by the bacterium *Salmonella typhi*, typhoid fever is transmitted through fecal contamination of food or water supplies. If not identified and treated in a timely fashion with the appropriate antibiotics, typhoid can result in intestinal hemorrhage or perforation—two potentially fatal causes of an acute abdomen requiring surgical intervention [63]. In one series, typhoid fever complicated by ileal perforation was diagnosed in 16 % of patients in a region of West Africa, making it the second most common cause of the acute abdomen [64].

A large number of acute abdominal cases in developing countries are caused by parasitic infections, which like that of typhoid fever are typically acquired through fecal–oral transmission. In one study originating from West Africa, some 4 % of acute abdominal cases necessitating emergency surgery were attributable to parasites [65]. The majority of these were secondary to infections with members of the amoeba family, which can cause colitis and hepatic abscesses, or *Ascaris lumbricoides*, a species of roundworms that can invade and overwhelm the gastrointestinal and hepatobiliary systems, resulting in intestinal obstruction, appendicitis, pancreatitis, and cholecystitis [66]. In addition to emergent surgical intervention, patients should be treated with antiparasitic medications to ensure complete eradication of disease.

Overall, the acute abdomen poses diagnostic challenges unique to the developing world given the limited access to resources and personnel required to sufficiently treat patients with potentially life-threatening abdominal conditions. Compounding this are the other exotic causes of acute abdominal pain prevalent in these regions that one must consider in their workup. Therefore, in addition to enhancing access to healthcare, health education, and sanitation, attention should be placed on the development of adequate history taking and physical exam skills to improve the outcomes of patients presenting with an acute abdomen in these regions of the world.

Potential Complications

The outcomes of patients presenting with an acute abdomen are influenced by the underlying etiology of their symptoms, age, comorbid conditions, and the time to diagnosis and treatment. In terms of etiology, one could assume that a

patient with a noncontained hollow viscus perforation is likely to have higher rates of morbidity and mortality in the peri- and postoperative period compared to a patient presenting with acute, nonperforated appendicitis. With regard to age and health status, diminished physiologic reserve and an increased incidence of comorbidities place elderly patients at an elevated risk of complications and death compared to their younger counterparts. For example, the age-related decline in pulmonary function is associated with a prolonged need for mechanical ventilation and an increased risk of developing ventilator-associated pneumonias [67]. These issues are compounded by the fact that elderly patients tend to have delays in diagnosis and treatment, further contributing to their increased rates of morbidity and mortality. In the case of perforated PUD, older patients who underwent surgery more than 24 h after perforation were 8 times more likely to die compared to those who were operated on within 4 h [68].

Morbidly obese patients with an acute abdomen are also at an increased risk of poor outcomes due to atypical presentations and the challenges posed by their body habitus that result in treatment delays [39]. Even in cases where surgery is indicated and performed in a timely manner, higher rates of postoperative complications including surgical wound infections and multisystem organ failure are experienced by morbidly obese patients [69].

In pregnant patients, the acute abdomen poses significant risks to both the mother and fetus. Atypical presentations and the inability to distinguish some acute abdominal symptoms from those normally experienced during pregnancy can result in treatment delays and an increased susceptibility for preterm labor and fetal loss [56].

Outcomes

Evaluating outcomes after treatment for an emergent intra-abdominal disease process has been challenged by the lack of risk-stratified data. The American College of Surgeons National Surgical Quality Improvement Project (ACS NSQIP) deliberately focused on elective surgical cases, though there is currently a multi-center pilot project underway that should begin to address this issue. Recently published grading scales which standardize the approach to anatomic severity of disease in emergency surgery should help with risk stratification and, ultimately, comparative analysis of outcomes [70, 71].

In general, regardless of age or health status, patients presenting with an acute abdomen should undergo a thorough yet expeditious evaluation to help establish a diagnosis and initiate the therapeutic interventions necessary to help ensure positive outcomes for these patients.

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Perioperative Considerations for Surgical Emergencies

3

J. Davis Yonge and Patricia Ayoung-Chee

Emergent perioperative care is strikingly different from all other surgical environments. This period requires coordination of care from the unpredictable pre-hospital environment to the sterile conditions of the operating room (OR). In this fluid environment, the acute care surgeon must effectively risk-stratify a potential operative candidate. The following chapter will discuss the appropriate perioperative management of the emergent general surgery patient. Three surgical time frames define this period: emergent, urgent, and time-sensitive. An emergent diagnosis requires operative intervention within 6 h of surgical consultation [1]. Urgent situations require operative intervention within 6–24 h, and time-sensitive situations require surgical management within 1–6 weeks [1]. The critical step for maneuvering through the perioperative period is attention to detail. From resuscitation to OR preparation, the surgical team is responsible for managing all aspects of patient care and careful planning cannot be underestimated in this situation.

The primary surgical assessment begins with the history and physical examination. Initial questioning of the patient or family member will provide valuable information regarding functional capability and physiologic reserve. This encounter will identify all medications, with specific attention paid to anticoagulant and cardiac medications. It will give insight into the patient's mental status and guide a "goals of care" discussion. It will, at times, be integral in determining surgical futility. The accurate assessment and appropriate patient management during this initial phase of care is as important as the intended operative procedure.

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Perioperative Cardiovascular Assessment

Patients undergoing emergent noncardiac surgery have increased morbidity and mortality compared to the elective surgical population (odds ratio (OR) 1.39; 95 % confidence interval (CI) 1.30–1.48) [2, 3]. The purpose of a focused cardiac assessment is early identification of factors associated with increased morbidity and mortality, including cardiac irregularities and classification of functional status. Functional status, as measured in metabolic equivalents (METs), ranges from 1 to greater than 10 METs (Table 3.1). As a patient's functional status increases, there is a reduction in postoperative complications [4, 5]; Girish et al. reported an 89 % "postoperative cardiopulmonary complication rate" in patients who cannot climb 1 flight of stairs prior to high-risk surgery [6].

The American Society of Anesthesiologists (ASA) classification adds to the surgical team's global assessment of patient health. Originally developed in 1941 [7, 8] and subsequently revised and validated in 1962, this 5-tiered system by the American Society of Anesthesiologists is not intended to determine operative risk, but to evaluate a patient's physiological reserve prior to surgery [9–11]:

1. Healthy Patient[a]
2. Mild systemic disease[a]
3. Severe systemic disease[a]
4. Incapacitating systemic disease[a]
5. Moribund patient, not expected to survive operation

[a]The modifier "E" is assigned to any classification between 1 and 4 if the patient is undergoing an emergent operation

The emergent setting rarely permits a complete cardiovascular evaluation; therefore, identification of known independent risk factors is critical. Age, previous or current coronary artery disease, recent myocardial infarction (MI), and need for emergency surgery are independently associated with an increased risk for adverse postoperative cardiac events [12, 13]. Myocardial infarction within the last 6 months is associated

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_3

Table 3.1 Activity and metabolic equivalent

Activity	Metabolic equivalent
Sleeping, desk work	1–3
Intercourse, ascension of two flights of stairs	4–6
Pushups/situps, swimming	7–10

Data from Ainsworth. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc. 2000. PMID: 10993420; and Eagle B et al. ACC/AHA guideline update for perioperative cardiovascular evaluation for noncardiac surgery—executive summary. Anesth Analg. 2002. PMID 11973163

with an eight-fold increase in perioperative mortality [1, 14] and a significantly increased risk of perioperative stroke (OR 13.8 CI: 8.9–19.7) [14].

High risk surgical candidates can undergo a more comprehensive risk assessment using The Revised Cardiac Risk Index (RCRI) and the American College of Surgeons (ACS) NSQIP Surgical Risk Calculator. The RCRI, originally published in 1999, has six components assessing cardiovascular disease, cardiovascular risk factors, renal function, and surgical procedure. Each category is assigned a single point value; greater than 3 points is associated with an 11 % risk of sustaining a "major cardiac event" [15]. Based on an AUC of 0.75 for stratifying low and high-risk patients undergoing mixed noncardiac surgery, the RCRI is a reasonable tool for the general surgeon [16].

The ACS NSQIP Surgical Risk Calculator, developed in 2007, is a web-based application that aims to provide a patient-specific risk assessment and is not just based on general population estimates. Risk is calculated using 21 patient variables and estimates the patient's chance of developing any of the following eleven adverse events following surgery [17, 18]: death, any complication, serious complication, venous thromboembolism, return to OR pneumonia, cardiac event, surgical site infection, urinary tract infection, venous thromboembolism, renal failure, and discharge to rehab or nursing facility. The calculator was developed using data from >1.4 million procedures from approximately 400 hospitals and can be found at www.riskcarculator.facs.org [17, 18].

The widespread use of sensitive biomarkers has increased the diagnostic incidence of perioperative cardiac events. Prior to any emergent operation, the American Heart Association (AHA) recommends obtaining a baseline electrocardiogram (EKG) for comparison with postoperative EKGs (level of evidence B) [1]. Routine postoperative troponin-I or brain natriuretic peptide (BNP) monitoring is recommended only in the setting of patient symptoms [1]. The phenomenon of a "troponin leak" may be significant in the appropriate clinical context. A "troponin leak," as defined by Redfern et al., is "an elevation of troponin below the diagnostic threshold for a perioperative myocardial infarction, without symptoms or ischemic electrocardiography change or echocardiography signs" [19]. A meta-analysis of the vascular literature demonstrated a significant association between all-cause short-term mortality and postoperative troponin elevation (OR 5.03; CI 2.88–8.79) [19]. However, it is difficult to make specific interventions to mitigate "troponin leak" in a population where both cardiac and noncardiac issues contributed to overall mortality. Subsequently, the Vascular events In noncardiac Surgery patIents cOhort evaluatioN (VISION) investigators demonstrated that patients undergoing noncardiac surgery and sustaining a sub-clinical myocardial infarction retain significant long-term adverse clinical implications. Specific outcomes included: 30-day mortality (OR 10.07; 95 % CI 7.84–12.94), stroke (OR 4.66; 95 % CI 2.87–7.58), and congestive heart failure (OR 10.34; 95 % CI 7.99–13.37) [20]. Finally, Mangano reported a "28-fold increase in subsequent cardiac complications within 6 months, 15-fold increase within 1 year, and 14-fold increased within 2 years" for patients suffering perioperative myocardial infarctions [21]. These patients should have appropriate pharmacotherapy initiated and undergo further cardiac evaluation prior to discharge.

With increasing frequency, intensivists and anesthesiologists are using bedside ultrasonography to assess cardiac function in the perioperative period. A focused ultrasound study can evaluate left and right ventricular function, estimate aortic valve gradient, and intravascular volume status. Perioperative transthoracic echocardiography (TTE) is not a routine study; however, guidance at points of clinical uncertainty makes this a valuable tool [22, 23]. As defined by Drs. Cowie and Beaulieu, these particular situations include: "undifferentiated heart murmurs, hemodynamic instability, ventricular function assessment, undifferentiated dyspnea, hypoxemia, tamponade, aortic rupture, and limited functional capacity" [22]. Identification of significant hypovolemia or severely depressed cardiac function would delay if not preclude surgical intervention. In fact, Manasia et al. demonstrated a 37 % change in management following TTE training and implementation for intensivists [24]. Additionally, the average time to TTE study completion was 10 min, making this an efficient technique for use in the perioperative period [24].

Optimization of any emergent surgical patient requires acute management of cardiovascular medications. Rebound hypertension is associated with abrupt discontinuation of alpha-2 antagonists as well as rebound tachycardia when beta blockade is stopped [25–27]. Furthermore, the effects of extended-release metoprolol succinate in patients undergoing noncardiac surgery (POISE trial) demonstrated that the beneficial effects of perioperative beta blockade are tempered by the associated increase in stroke, bradycardia, hypotension, and all-cause mortality (OR 1.33 95 % CI 1.03–1.74) [28]. Due to these adverse events, it is not recommended to initiate beta-blocker therapy for patient's naïve to this class of medications in the immediate perioperative period, specifically the

day of surgery [1]. If the patient's clinical status, specifically blood pressure and mentation will allow for continuation of home beta blockade, then the medication is continued throughout the perioperative period (level of evidence IB) [1, 29, 30]. Of note, continuation of beta blockers is a Surgical Care Improvement Project (SCIP) performance measure [31].

There are few data to guide perioperative angiotensin converting enzyme inhibitor (ACEi) and angiotensin II receptor blockers (ARB). However, ACEi administration compounds the already significant risk of hypotension and renal hypoperfusion in the emergent setting [32]. Therefore, suspension in the perioperative period is appropriate, but should be restarted as soon as clinically appropriate [1].

The adverse events associated with statin use do not limit their use in the perioperative period [1]. Secondary to a reduction in low-density lipoprotein (LDL) and stagnation of coronary plaque, lipid-lowering medications are known to significantly reduce coronary events [33]. In addition, Raju et al. demonstrated a reduction in all-cause mortality at 30 days following intermediate risk noncardiac non-vascular surgery in patients receiving perioperative statin therapy versus non-statin users [34]. Emergent vascular surgery patients and patients with elevated cardiac risk should be started on postoperative statin therapy when clinically appropriate [1, 35].

In summary, early risk factor identification is integral to reducing the incidence of adverse perioperative cardiac events. Appropriate and efficient control of these risk factors should comprise the backbone of the surgeon's initial assessment.

Management of the Patient on Anti-Thrombotic Therapy

The decision to reverse a therapeutically anticoagulated patient in the emergent setting depends on: (1) the surgical procedure, (2) the type of anticoagulant, and (3) the clinical status. Therefore, pharmacologic knowledge of common anticoagulants is advantageous. Warfarin inhibits the carboxylation of vitamin K, thus inhibiting clotting factors II, VII, XI, and XII. Rapid reversal requires both immediate replacement of clotting factors. Current clotting factor preparations include fresh frozen plasma (FFP) and prothrombin complex concentrate (PCC), a dose-dependent four-factor complex that requires less volume for therapeutic effect than FFP [36]. Of note, the normalized international normalized ratio (INR) of FFP is 1.5, and additional transfusions for further reduction in INR are generally ineffective.

New oral anticoagulants (NOAC) which directly inhibit factor Xa include dabigatran and rivaroxaban. Unfortunately, there is no direct reversal agent for either of these medications. In 2013, the Working Group on Perioperative Hemostasis published management recommendations that rely on the ability to check plasma concentrations of the NOACs and the ability to delay surgery for 12 h, depending on plasma drug concentrations [37]. If the plasma concentration for either dabigatran or rivaroxaban is ≤30 ng/mL, the risk of bleeding is acceptably low and surgery should be performed. At concentrations >30 ng/mL it is recommended to delay surgery (if possible) and recheck the plasma concentration in 12 h [37]. Concentrations ≥400 ng/mL are consistent with severe overdose and patients are at risk for major hemorrhagic complications. If plasma drug concentration is not available, the authors give guidance on using PT/PTT values: for dabigatran, a normal aPTT level (≤1.2 times the upper limit of normal) correlates with low concentrations and indicates an acceptable level of bleeding [37, 38]; for rivaroxaban, a normal PT value correlates with a drug concentration between 30 and 50 nL/mL [37, 39]. Therefore, aPTT and PT test are recommended if direct drug concentration measurements are not available [37]. In the emergent setting, delaying surgical intervention is a luxury and if operating in the setting of supra-therapeutic NOACs is mandatory, adjunctive hemostatics including FFP, PCC, and factor eight inhibitor bypass activity (FEIBA) may be necessary [37]. Two additional considerations are important regarding NOACs: (1) dabigatran is renally cleared and its half-life of 12 h is increased significantly in the presence of renal failure (2) the use of the INR is not a part of the laboratory evaluation for these novel anticoagulants [37].

As plasma concentrations for NOACs are not commonly available, and typical coagulation labs (PT/PTT) can be misleading in the critically ill patient [40], investigators have begun using thromboelastography (TEG) to determine the coagulation profile in the acute setting [41, 42]. Thromboelastography allows for investigation of multiple aspects of the coagulation cascade including clot formation time (R), thrombin burst (alpha angle), clot strength (MA), and fibrinolysis (LY30) by providing a real-time tracing of clot formation (Fig. 3.1) [43]. The Surgical Critical Care Guidelines highly recommends the use of TEG for trauma patients in hemorrhagic shock, requiring MTP, or with clinical suspicion for coagulopathy [31]. As data supporting the use of TEG increases, and clinicians become more comfortable with result interpretation, its use will be more widespread.

In July 2014, the AHA published recommendations for the management of antiplatelet therapy in the perioperative period [1]. For patients with cardiac stents who require emergent surgical intervention, all antiplatelet therapy should be continued in the perioperative period unless the clinical "risk of bleeding is greater than the risk of stent thrombosis" (Class I recommendation) [1]. If P2Y12 inhibitors (e.g., clopidogrel) must be stopped, aspirin should be continued in the perioperative period [1]. There are no class I recommendations for patients without coronary stents.

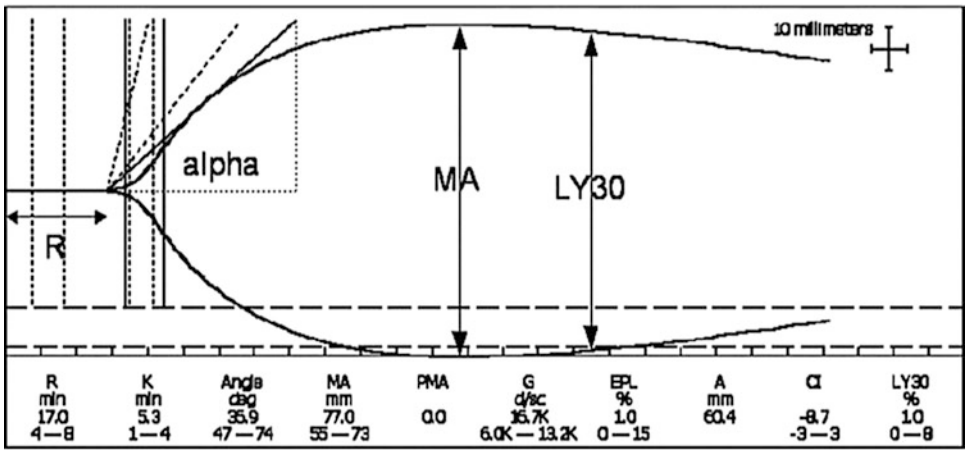

Fig. 3.1 Thromboelastogram tracing with normal parameters. (Courtesy of Martin A. Schreiber, MD.)

For patients without cardiac stents who require non-emergent, noncardiac surgery, the AHA recommends continuing aspirin when the risk of potential increased cardiac events outweighs the risk of increased bleeding" (Class II) [1]. These recommendations were influenced by the Aspirin in Patients Undergoing Noncardiac Surgery (POISE-2) trial that demonstrated no significant reduction in death or nonfatal myocardial infarction at 30 days when aspirin versus placebo was administered in the perioperative period for more than 10,000 patients undergoing elective noncardiac surgery [44].

Following the POISE-2 publication, Gerstein published a critique of participant inclusion as well as methodological structure [45]. Gerstein demonstrates that "only one-third of recruited patients were at high-risk, only two-thirds underwent high-risk procedures (4.9 % of which were vascular), the exclusion of patients undergoing carotid endarterectomy (CEA) or those with a recent coronary stent" left the extrapolation of results difficult in the high-risk population [45]. In the emergent setting, perioperative antiplatelet therapy is addressed on a case-by-case basis, influenced by specific procedure type.

Perioperative Pulmonary Assessment

Perioperative pulmonary complications (PPC) are as prevalent as cardiac complications and contribute similarly to morbidity, mortality, and length of stay [46–48]. The spectrum of complications ranges from atelectasis to fatal pulmonary embolism. The emergent surgical candidate is rarely without elevated risk of PPC and there are a variety of risk factors that influence the development of a PPC, broadly grouped as patient risk factors and procedural risk factors.

The literature clearly identifies the most effective strategy to identify patients at risk for PPC development is a thorough history and physical [46]. The American College of Physicians (ACP) has identified the following patient related risk factors: age, chronic lung disease, cigarette use, congestive heart failure (CHF), ASA class II or greater, functional dependence, obstructive sleep apnea, and impaired sensorium [46]. After adjusting for multiple co-morbidities, age ≥60 years is an independent predictor of PPC (OR 2.09; 95 % CI 1.70–2.58), with increasing risk for every decade over 60 years [46]. A pre-admission diagnosis of CHF is also strongly correlated with the incidence of PPC (OR 1.79; 95 % CI 1.44–2.22) [46]. Cigarette use and impaired sensorium are important to identify but are only weakly associated with increased incidence. Similar to cardiac events, emergent surgery alone is a strong procedure-related risk factor (OR 2.21, 95 % CI 1.57–3.1) [46, 49, 50]. Specifically, abdominal aortic aneurysm repair, foregut surgery, neurosurgery, operative time >3 h, head and neck surgery, and the use of general anesthesia have all been associated with significant increases in the occurrence of PPC [46].

Table 3.2 Risk index for predicting postoperative respiratory failure

Example 1: factors	Points
60 Years old	4
Emergent surgery	11
Upper abdominal surgery	14

Total of 29 points = (10.1 – 11.9 %) risk of postoperative respiratory failure
From Arozullah AM, Daley J, Henderson WG, Khuri SF. Multifactorial risk index for predicting postoperative respiratory failure in men after major noncardiac surgery. The national veterans administration surgical quality improvement program. Ann Surg. 2000;232(2):242–53, with permission

Prediction models for postoperative respiratory failure and pneumonia have been developed using the National Veterans Administration (VA) Surgical Quality Improvement Program (VASQIP). The original model included >81,000 patients and was validated with >99,000 patients undergoing noncardiac surgery [51]. The model scores seven variables with an associated point value ranging from 4 to 27 [51]. The summation value estimates the patient's risk of developing a PPC (Table 3.2) [51].

Ancillary testing for PPC prediction is rarely indicated in the emergent setting, including pulmonary function testing and arterial blood gas [46]. In a recent Cochrane review,

continuous pulse oximetry in the postoperative period has not been shown to reduce the risk of PPCs [52]. The only strong laboratory predictor of PPC occurrence is a preoperative serum albumin <3.5 g/dL [46]. The National VA Surgical Risk Study found an exponentially inverse relationship between albumin and mortality, with a 28 % mortality rate for patients with levels <2.1 g/dL [53]. Preoperative chest radiography should not be used to predict PPC [46, 54] and is only necessary for patients with known PPC risk factors [46].

Postoperative therapies are critical to the prevention of PPCs. However, appropriate counselling on these therapies is mandatory and reliable quantitative reductions are hard to reproduce. In 2013, the I COUGH: Reducing Postoperative Pulmonary Complications with a Multidisciplinary Patient Care Program, trial was published demonstrating a 1.6–2.6 % reduction in postoperative pneumonia with implementation of multiple non-invasive measures including, but not limited to: incentive spirometry, head of bed elevation, and deep breathing [55]. This demonstrated that relatively simple measures are capable of reducing PPCs.

Patients in the perioperative period are at constant risk for aspiration. Patients are at especially increased risk during emergency intubation and proper precautions are necessary. Rapid sequence intubation has become the technique of choice for emergent intubation and has three components: (1) Preventing hypoxia during induction-intubation, (2) Minimizing the time the airway is unprotected, (3) Applying measures to decrease the chances of pulmonary aspiration of gastric contents [56]. In 1961 Sellick demonstrated that backwards pressure on the cricoid cartilage of cadavers would occlude the mid-esophagus and prevent gastric content regurgitation and aspiration [57]. Cricoid pressure subsequently became a crucial step during rapid sequence intubation (RSI). However, over the last two decades the necessity of this maneuver has been questioned. A Best Evidence Topic Report in Emergency Medicine from 2005 reviewed 241 publications from 1950 to 2005, and concluded that there is no clinical reduction in the incidence of aspiration during emergency RSI [58].

In conclusion, the critical aspect of perioperative pulmonary assessment is the history and physical. Evidence elucidated from this initial encounter will direct the necessity or futility of additional imaging and testing. It is important to understand how intraoperative decisions will affect PPCs and plan for aggressive pulmonary rehabilitation following surgery.

Prophylaxis of Venous Thromboembolism (VTE)

The classic risk factors described by Virchow [59] are still relevant in surgical patients today and vascular stasis, coagulopathy, and endothelial injury are nearly always present in the acute care patient. Deep venous thrombosis (DVT) still affects 25 % of hospitalized patients and ≥30 % of those patients will experience one or more complications from DVT [60, 61]. These complications cost $30,000 per patient [60], which combined with its classification as a "never event" by the Joint Commission, has prompted most major medical societies to publish guidelines for prevention. Even with its high priority status, Cohen et al. demonstrated that only 58.5 % of surgical patients at risk for VTE receive American College of Chest Physicians (ACCP)-recommended prophylaxis [62]. Routine screening is not a current recommendation nor is it a widespread practice. However, institutions that do perform routine inpatient screening have higher incidences than institutions without indicating that not all DVTs are symptomatic or clinically significant on physical exam [63]. The SCIP implemented the following performance measures to reduce the incidence of DVT: (1) improve adherence to ACCP guidelines for VTE prophylaxis. (2) Increase the proportion of surgical patients who receive appropriate VTE prophylaxis within 24 h before or after surgery [31]. Publication of these measures has led to numerous quality improvement projects aimed at improving the use of DVT prophylaxis and the results support Electronic Medical Records (EMR) alerts as the most effective measure [64, 65].

Strong risk factors for VTE) occurrence (OR > 10) include: orthopedic fracture (hip or leg), hip or knee replacement, major general surgery, major trauma, and spinal cord injury [66]. Moderate risk factors (OR: 2–9) include: CHF, malignancy, previous VTE, presence of central venous catheter, and hormonal therapy [66]. Weak risk factors (OR < 2) include: obesity, laparoscopic surgery, and bed rest >3 days [66]. These risk factors are easily identified during the history and physical and should prompt initiation of prophylaxis as soon as clinically possible. Two scoring systems have been validated and are in use to stratify VTE risk in non-orthopedic surgical patients. The Rogers score assigns a numerical value of 1, 2, 3, or 5 points to a series of 22 patient variables. The point summation will categorize patients into low, moderate, high risk for VTE [67, 68]. The scope of patient variables is extensive, including: body mass index (BMI) >25 (1 point), laparoscopic surgery (2 points), history of DVT/pulmonary embolism (PE) (3 points), and hip, pelvis, or leg fracture (5 points) [68]. A score >10 is associated with an approximate VTE risk of 0.9 % and an exponential increase as risk increases [68]. The Caprini DVT Risk Assessment is an additive score, assigning increasing values to risk factors associated with increased risk [69]. The total DVT Risk Score is the sum of the points for each factor [67, 69]. Low-risk patients have 1–2 points, moderate-risk patients have from 3 to 4 points, and high-risk patients have greater than 5 points [69]. In 2015, the Caprini score was validated with a retrospective review of 4844 critically ill surgical patients [70].

There is no emergency surgical patient at low or absent VTE risk; this population requires either mechanical or pharmacologic prophylaxis. Mechanical prophylaxis includes graduated compression stockings, mechanical pneumatic compression devices, and walking. Pharmacologic prophylaxis includes low molecular weight heparin (LMWH) or unfractionated heparin (UFH). Based on the Rogers and Caprini scores the following recommendations are made by the ACCP: low-risk patients require at least SCDs; moderate-risk patients, clinically appropriate for anticoagulation, should receive either LMWH or low-dose UFH; high risk patients at high risk for major bleeding should have mechanical prophylaxis) and those at low risk for major bleeding should receive additional prophylaxis with LMWH or low-dose UFH [71]. Regarding the choice of LMWH or low-dose UFH, Geerts et al. showed a 30 % DVT risk reduction in trauma patients who received LMWH versus heparin [72]. Additionally, Greenfield and colleagues developed the Risk Assessment Profile (RAP), a point-based system for the rapid identification of trauma patients at high risk for DVT [73]. Validated by Gearhart et al. in 2000, the RAP variables include Glascow Coma Score (GCS), abbreviated injury scores AISs, and length of operative time. Patients with a score ≥5 are 3-times more likely to develop a DVT [74]. Current investigations are underway to evaluate the use of thromboelastogram for pharmacological dosing of DVT prophylaxis [75]. The ACCP discourages the use of routine perioperative vena cava filter placement for prophylaxis [71].

Transfusion

In 1999, Hebert et al. published the Transfusion Requirements in Critical Care (TRICC) trial, which showed that a restrictive red blood cell (RBC) transfusion strategy (maintenance of hemoglobin (Hb) at 7–9 g/dL) was non-inferior and possibly superior to a more liberal strategy (maintenance of Hb at 10–12 g/dL) [76]. Subsequently, these findings have been corroborated in critically ill children, patients in septic shock, and post-op cardiac and orthopedic surgery patients [77–80]. There are sparse data specifically looking at acute care surgical patients. Current practice follows guidelines published by the American Society of Anesthesiologists: Task Force on Blood Component Therapy: (1) Red blood cell transfusion is rarely indicated when Hb > 10 g/dL and is almost always indicated when <6 g/dL; (2) For patients with 6 < Hb < 10 g/dL, the need for red blood cell transfusion should be based on potential or ongoing bleeding (rate and magnitude), intravascular volume status, evidence of end-organ ischemia, and adequacy of cardiopulmonary reserve; (3) A restrictive transfusion strategy may be safely used to reduce transfusions and administration should be administered unit-by-unit when possible with interval re-evaluation; (4) If possible, autologous blood transfusion (use of intraoperative cell saver) and measures to decrease blood loss (permissive hypotension and use of tranexamic acid [TXA]) may be beneficial [81]. Even with these guidelines in place, the risks associated with blood product transfusion must not be dismissed and include fever, transfusion reaction associated lung injury (TRALI) [82–84], and transfusion related immunosuppression [85]. Infectious disease transmission and blood type incompatibility are rare in the USA due to system-wide checks but are significant when they occur.

The Prospective Observation Multicenter, Major Trauma Transfusion Study (PROMMTT), published in 2013 analyzed 905 patients requiring massive transfusion following trauma [86]. The investigators demonstrated a mortality reduction at 6 h with transfusion ratios approaching a 1:1 for FFP:RBCs and platelets:RBCs in patients with ongoing hemorrhage [86]. Subsequently, the Transfusion of Plasma, Platelets, and Red Blood Cells in a 1:1:1 vs a 1:1:2 Ratio and Mortality in Patients with Severe Trauma study (PROPPR), published in 2015, demonstrated a reduced risk of death from exsanguination at 24 h in patients receiving a transfusion ratio of 1:1:1 (9.2 %) (platelets:FFP:RBC) versus 1:1:2 (14.6 %) (difference −5.4 %; 95 % CI −10.4–0.5 %; p 0.03) [87]. These articles highlight the need for early hemostatic resuscitation in hemorrhaging patients and argue for the expansion of whole blood transfusion therapy research.

Adjunctive hemostatic agents, including TXA, are indicated for select populations [88]. Tranexamic acid is a synthetic analogue of the amino acid lysine and is a potent inhibitor of fibrinolysis. It directly inhibits the conversion of plasminogen to plasmin, thereby preventing the fibrinolytic action of plasmin on formed clot. In a randomized controlled trial of 20,211 patients, TXA was demonstrated to reduce the risk of death in bleeding trauma patients when administered within 60 min (RR 0.68; 95 % CI 0.57–0.82) and 180 min (RR 0.79; 95 % CI 0.64–0.97) [88].

Steroids

The impetus for perioperative glucocorticoid administration stemmed from Dr. Fraser's 1952 publication demonstrating the immediate postoperative circulatory collapse of a patient following cessation of chronic steroid therapy [89]. Buttressing this finding, the recognition of shock, although moderated with the administration of exogenous glucocorticoids, was demonstrated in dog models following bilateral adrenalectomy [90–92]. Recently, the literature has shifted away from empiric "stress dose" steroid administration secondary to demonstrating an appropriate graded stress response of the patient's native hypothalamic-pituitary axis (HPA) [93–96]. Furthermore, the supra-physiologic dosing traditionally used to match the maximal secretion of an adrenal

gland has been soundly disproven [93, 97]. A prospective study from Udelsman, using primate models in the 1980s, demonstrated no difference in outcomes between the group receiving physiologic and supra-physiologic steroid doses [98]. Current literature supports the following approaches for surgical patients on chronic steroid therapy: for patients with primary HPA axis dysfunction, continuation of maintenance dosing is appropriate with the addition of a graded perioperative dose based on the intended procedure; for patients with secondary dysfunction of the HPA axis, routine cortisol testing is not indicated and prophylactic steroid administration should not be routine [93, 95, 97, 99–102]. However, the perioperative and intraoperative manifestations of adrenal insufficiency cannot be dismissed. Hypotension is the major clinical manifestation and is generally responsive to fluid administration [100].

Glucose

As demonstrated by the NICE-SUGAR trial, the effects of hypoglycemia are more detrimental than the effects of transient hyperglycemia [103]. Severe or prolonged hypoglycemia can induce seizure, coma, and irreversible brain damage as well as cardiac arrhythmias [104]. The optimal upper target for blood glucose levels, as defined by the Surviving Sepsis Guidelines, is <180 mg/dL [105]. Of note, there is no lower limit for the recommendation other than "hypoglycemia."

In 2012, The US Department of Health and Human Resources developed a guideline regarding the acute management of blood glucose [106]. The committee recommended initiation of an insulin infusion when blood glucose >150 ml/dL; a ceiling of 180 mg/dL must be maintained with a goal target <150 mg/dL [106]. A thorough history and physical will identify those patients at greatest risk for perioperative hypoglycemia and even in patients without preoperative risk factors, stress-induced increases in cortisol can lead to hyperglycemia.

The Elderly

Patients aged 65 years or older are an increasingly common and complex surgical population. Currently more than half of all operations in the USA are performed on elderly patients and they often present with co-morbidities that increase their perioperative surgical risk [107]. Additionally, the physiological changes that occur in this population put them at increased risk for postoperative complications including pneumonia and urinary tract infections [108, 109]. In order to stratify the challenges associated with this population the Comprehensive Geriatric Assessment (CGA) was created to identify indications associated with frailty [110, 111]. The CGA evaluates seven domains of a patient's life ranging from function to economic resources [110]. Its use in the emergent setting is appropriate, but some components are difficult to ascertain depending on clinical circumstance.

In 2014, Sun-wook et al. published a Multidimensional Frailty Score (MFS) intended for geriatric surgical patients [112]. The score was developed using only elective cases, but its application in the emergent surgical patient is easier than the CGA. The MFS is scored from 1 to 3, and assesses primarily clinical factors of the geriatric patient, including malignant disease, activities of daily living, presence of dementia, and mid-arm circumference [112]. The MFS predicts length of hospital stay, likelihood of discharge to a nursing facility and all-cause mortality at 1-year [112]. In 2015, Kenig et al. published a study on geriatric patients requiring emergent abdominal surgery and found that the Vulnerable Elders Survey (VES-13) had the highest sensitivity and negative predictive value for both postoperative morbidity and mortality, when compared to five other screening tools [113]. The VES-13, developed in 2001 by Saliba et al., is a function-based tool that identifies a vulnerable population in comparison with national averages [114]. A score ≥3 was associated with a four-fold increased risk of death or functional decline in a 2-year period [114]. Overall, the geriatric population is heterogeneous and age alone should never be used as a single predictor of poor outcomes; global assessment of the geriatric patient is a necessary for an accurate and complete evaluation of risk.

Advanced Directives

The emergent setting is fraught with conditions that impede patient autonomy [115]. Prior to any emergent surgical intervention, the surgeon must balance both the desires of the patient and the possible goals of surgical intervention. Not infrequently, these two differ and having an advanced directive is invaluable at this time. Seven states have adopted an approach to identify the wishes of elderly patients prior to hospitalization known as the Physicians Orders for Life Sustaining Treatment (POLST) [116]. This is an outpatient questionnaire completed by individuals with their primary care provider to guide care upon inpatient admission [116]. The questionnaires are stored in an online database, accessible to pre-hospital providers who are required to follow the orders as instructed. Unlike the advanced directive, the POLST form does not appoint a legal health care representative; therefore, it must not be used as a substitute but a supplement to the Advanced Directive [116, 117]. POLST forms, as well as Advanced Directives, are completed by a vast minority of patients, leaving surgeons and loved ones to navigate the "goals of care" discussion at a difficult time. In this setting, communication between the surgeon and loved

ones and patient (when possible) is critical to achieving the best possible outcome [118].

In 2014, the American College of Surgeons (ACS) published a statement on "Advanced Directives by Patients: 'Do Not Resuscitate [DNR]' in the Operating Room". The ACS recommends a "required reconsideration" of any existing DNR order in this situation [119]. This reconsideration takes into account the perioperative and intraoperative risks as well as the patient's goals for advanced care in the perioperative period. Reconsideration maintains patient autonomy by affording the patient the ability to modify, retain, or suspend the DNR order. In the event a patient cannot make his or her own decisions and the health care proxy cannot be reached, the surgeon must "use his or her best judgment as to what the patient would wish" [119]. In these situations, a multidisciplinary approach involving Ethics Committees can provide guidance for the most appropriate course of action.

Conclusion

Patients presenting with surgical emergencies often require rapid intervention and therefore identification and stratification of risk factors must be done expeditiously and sometime with sparse data. The approach must be multidisciplinary and includes: Emergency Medicine, Anesthesia, Surgical teams, patients, and family members. It is important to expand this team when appropriate, including Palliative Care and Ethics consults. Attention to detail and appropriate management of co-morbidities are essential to optimizing outcomes for the acute surgical patient.

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Perioperative Management of the Cirrhotic Patient

4

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Etiology and Clinical Manifestations of Cirrhosis

Cirrhosis is the eventual result of chronic hepatocellular injury resulting from multiple etiologies (Table 4.1) [1, 2]. During the past decade the most common etiologies of cirrhosis have been chronic hepatitis C infection, alcoholic liver disease, and non-alcoholic steatohepatitis (NASH) [3]. As a result of demographic changes, the obesity epidemic, and the recent introduction of novel treatments for hepatitis C, NASH is expected to become the most common cause of cirrhosis in the coming decades [2]. In a recent study, NASH was the most rapidly rising etiology of cirrhosis, increasing in prevalence by 4 fold between 2004 and 2012 [3]. Importantly, 69 % of patients with chronic liver disease are unaware of their disease, and thus a high index of suspicion and vigilance is required by the evaluating surgeon [1].

Clinical manifestations of cirrhosis result from both primary hepatocellular synthetic dysfunction and portal hypertension and affect multiple organ systems in the perioperative setting (Table 4.2). Chronic and repetitive injury to hepatocytes results in diffuse inflammation and fibrosis of liver parenchyma with subsequent development of regenerative nodules. As fibrosis progresses, the intrahepatic vasculature is distorted leading to portal hypertension. In addition, a significant degree of circulatory shunting occurs which deprives hepatocytes from blood exposure, resulting in impaired hepatocyte synthetic function. The combination of portal hypertension and impaired synthetic function leads to the anatomic and metabolic derangements that make the cirrhotic patient a very challenging operative candidate. Each of these complications of liver disease may influence peri- and intra-operative decision making during surgical care of the cirrhotic patient.

Coagulopathy

Hepatocellular synthetic dysfunction results in abnormal production of vitamin-K dependent factors II, VII, IX, and X, as well protein C and S [4–7]. This synthetic dysfunction is compounded by poor absorption of vitamin K in patients with significant cholestasis [8, 9]. As a result, conventional tests of coagulation status such as the International Normalized Ratio (INR) may be significantly abnormal in cirrhotic patients. These conventional tests must be interpreted with caution because cirrhotic patients may in fact be *hypercoagulable* despite an elevated INR due to imbalances in the ratio of pro-thrombotic factors and anti-thrombotic factors [5–7]. Newer tests of coagulation status such as the thromboelastography (TEG) may provide a more accurate reflection of coagulation status prior to invasive procedures [10, 11].

Platelet dysfunction is the most common hematologic abnormality seen in patients with chronic liver disease, and most patients with portal hypertension exhibit thrombocytopenia [11, 12]. The pathogenesis of platelet dysfunction in cirrhotic patients is multifactorial including platelet sequestration due to hypersplenism, decreased platelet production secondary to decreased activity of thrombopoietin and bone marrow suppression, and lastly platelet dysfunction resulting from uremia associated with hepatorenal syndrome (HRS) [11, 12].This underscores the need for more advanced coagulation tests when considering surgery in the cirrhotic patient.

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_4

Table 4.1 Etiologies of cirrhosis in adults

Chronic viral hepatitis	Hepatitis B Hepatitis C
Toxins	Alcoholic liver disease Medications (Isoniazid, Methotrexate)
Metabolic disorders, acquired or inherited	Non-alcoholic steatohepatitis Hemochromatosis Wilson's disease Alpha-1 antitrypsin deficiency Cystic fibrosis
Biliary	Primary biliary cirrhosis Primary sclerosing cholangitis Secondary sclerosing cholangitis
Autoimmune	Autoimmune hepatitis
Vascular	Budd-Chiari syndrome Cardiac cirrhosis

Drug Clearance

Hepatocellular dysfunction results in altered metabolism of many medications, including opioid analgesics, anesthetic agents, and most sedatives [13, 14]. Opioid analgesics, often administered early in the patient's course in the emergency department, are metabolized particularly slowly, and may result in impaired cognition and respiratory depression even in minimal doses [13, 14].

Malnutrition

Malnutrition is often underdiagnosed in patients with liver disease. Several studies show that significant losses occur even in patients with Child-Turcotte-Pugh (CTP) class A cirrhosis [15]. Several factors are involved in this morbid condition which include low appetite, hypermetabolic state, poor absorption of protein nutrients, and impaired protein synthesis [16, 17]. As a result, severe muscle-wasting and hypoalbuminemia are common in cirrhotic patients with potentially significant effects on both wound-healing and maintenance of circulating intravascular volume [16, 17].

Portal Hypertension

Portal hypertension is the result of advanced liver fibrosis, resulting in increased resistance to portal blood flow across the hepatic sinusoids towards the central veins [18]. Portal hypertension results in several medically and surgically relevant changes in both anatomy and physiology.

Varices

Resistance to portal blood flow and the resultant increased portal venous pressure results in enlargement and increased venous flow through extra-hepatic connections between the portal and systemic venous systems (Fig. 4.1). Sites of porto-systemic venous connections within the esophageal and rectal submucosa manifest clinically as varices in these locations. Recanalization of the umbilical vein with subsequent portal blood shunting via the veins of the anterior abdominal wall is common, as are spontaneous spleno-renal shunts with dilatation of the left renal vein. Large varices within the hepatoduodenal ligament as well as throughout the retroperitoneum are also often noted on imaging. These varices have relatively high-pressure and very thin walls, presenting a significant risk of hemorrhage if encountered during laparotomy.

Splenomegaly

Splenomegaly, sometimes massive, often accompanies portal hypertension. The cause of splenomegaly in portal hypertension is multifactorial, with portal outflow congestion, fibrosis, and hyperplasia each playing a role [19, 20]. The increased arterial demand by the large spleen may exacerbate portal hypertension by increasing blood delivery to the portal system. Splenic hemorrhage resulting from trauma or surgical injury may be very difficult to control due to poor venous outflow and spleen fibrosis in the cirrhotic patient with coagulopathy and platelet dysfunction.

Ascites and Hepatic Hydrothorax

Ascites in patients with portal hypertension is the accumulation of transudative fluid within the peritoneal cavity. Ascites of portal-hypertensive origin is confirmed with a high (>1.1 g/dL) serum-ascites albumin gradient (SAAG), indicating low protein content in the transudative ascitic fluid. This high-SAAG ascites contrasts low-SAAG ascites due to malignancy, infection, and other causes. Hepatic ascites is the result of increased hepatic sinusoidal pressure causing fluid transudation into the lymphatic system and eventually the free peritoneal cavity, and becomes exacerbated by hormonal changes including increased aldosterone production and subsequent fluid retention. Complications of ascites include spontaneous bacterial peritonitis (SBP) which will be discussed later in this chapter.

Table 4.2 Clinical manifestations of cirrhosis with assessment and management

System	Pathology	Assessment	Management
Abdomen	Ascites; increased risk of abdominal wound dehiscence, abdominal wall herniation, respiratory compromise, spontaneous bacterial peritonitis (SBP)	Check response to diuretics, pulmonary function tests, diagnostic paracentesis tap	Low sodium diet and diuretics with careful monitoring of creatinine and electrolyte levels; large volume paracentesis for uncontrolled ascites with albumin; antibiotics for SBP
Renal	Renal insufficiency/hepatorenal syndrome (HRS) due to drugs, infections, gastrointestinal bleed	Renal function tests, creatinine clearance, DTPA scan	Avoid nephrotoxic drugs, contract agents for diagnostic studies; combination of terlipressin, albumin in HRS; optimal fluid, electrolyte status
Central nervous system	Hepatic encephalopathy	Clinical assessment, arterial ammonia levels	Use of lactulose, metrogyl, branched chain amino acids; treat infections, avoid diuretics, constipation, CNS depressants, azotemia
Pulmonary	Hydrothorax, hepatopulmonary syndrome (HPS), portopulmonary hypertension (PPH)	Chest imaging; bubble ECHO/ MAA scan for HPS	Optimize pulmonary functions; intravenous epoprostenol, sildenafil has also been tried perioperatively
Cardiac	Cardiomyopathy	Dobutamine stress ECHO; ACC and AHA guidelines for non cardiac surgery	Beta blockers in perioperative period
Homeostasis	Electrolyte disorders (especially hyponatremia)	Regular electrolyte profile and arterial blood gases	Slow correction of serum sodium with fluid restriction, discontinuation of diuretics
Nutrition	Malnutrition, hypoalbuminemia, muscle-wasting, increased need for postoperative ventilation	Methodical nutritional assessment	Preoperative nutritional build-up (high carbohydrate/lipid content, low in amino acid); vitamin B1 in alcoholics
Other systems	Anemia and coagulopathy	Intraoperative thrombo-elastogram	Appropriate blood products perioperatively to maintain desired INR (<1.5), hemoglobin (>9 g %), platelet (>50,000/mm^3) levels
	Glucose intolerance	Laboratory testing	Insulin infusion
	Gastroesophageal varices	Endoscopy, portal pressure measurements	Beta blockers, variceal banding
	Concurrent infections	Screening	Antibiotic prophylaxis
	Autoimmune hepatitis patients developing stress-induced insufficiency	Serum cortisol levels	Stress-dose steroids preoperatively

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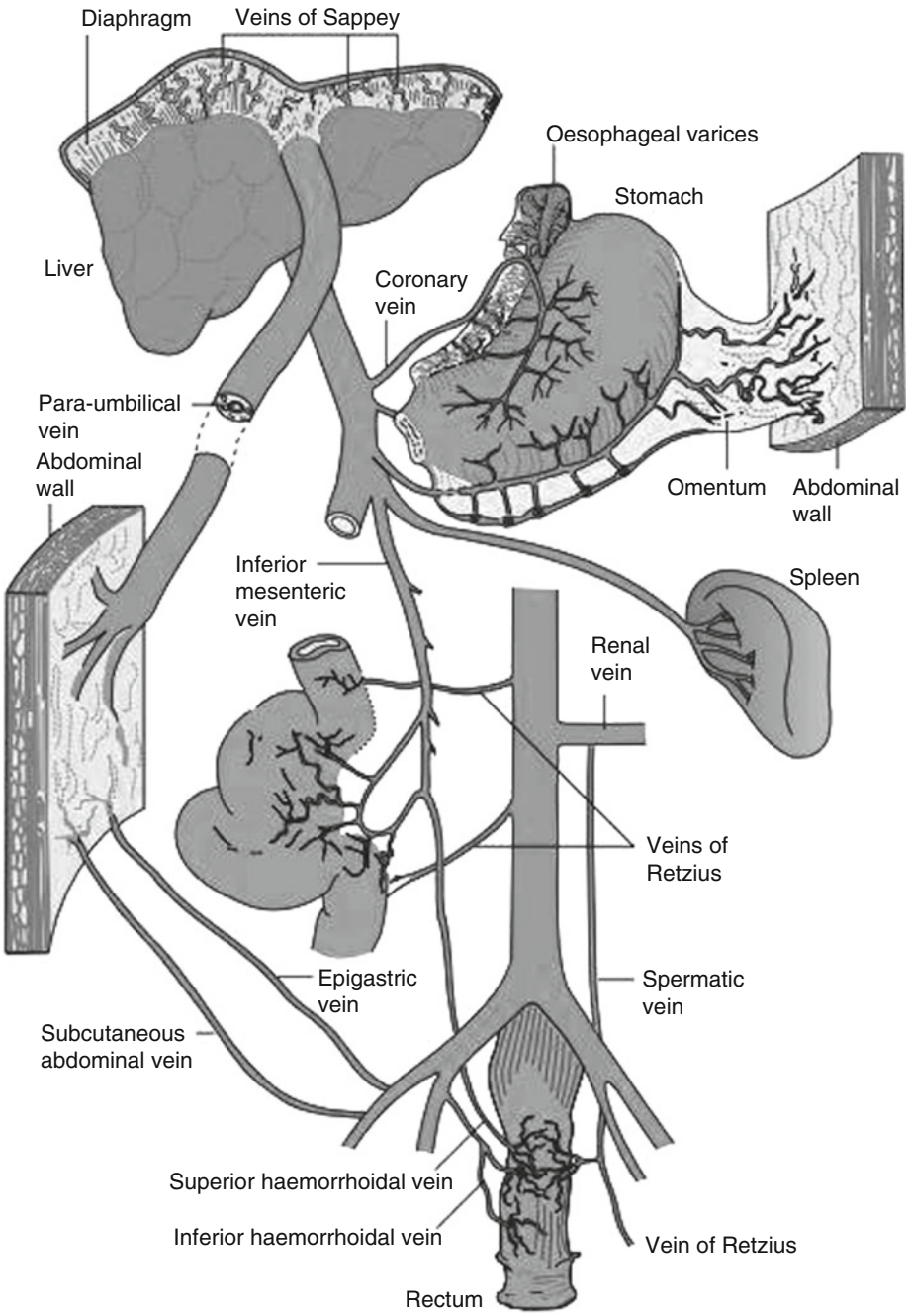

Fig. 4.1 Porto-systemic collateral pathways. (From Dooley JS, Lok A, Burroughts AK, et al., editors. Sherlock's disease of the liver and biliary system. 12th ed. UK: Wiley; 2011, with permission.)

Hepatic hydrothorax, usually on the right side, is believed to be due to micro- or macro-scopic defects in the diaphragm resulting in a transudative pleural effusion in patients with portal hypertension. Negative intra-thoracic pressure forces fluid into the pleural space via even small diaphragmatic defects. Hepatic hydrothorax may be clinically silent, or may present as mild, moderate, or severe respiratory dysfunction. Hepatic hydrothorax may present in the absence of ascites.

Encephalopathy

Hepatic encephalopathy (HE) is a result of decreased hepatic metabolism which results in accumulation of nitrogenous compounds (Table 4.3). The pathophysiology is very complex and includes multiple factors such as elevated ammonia levels, systemic inflammation, oxidative stress, and genetic factors [21]. Elevated serum ammonia levels are often associated with HE, although the relationship is unclear and low

Table 4.3 Clinical grades of hepatic encephalopathy

Clinical grade	Clinical findings
Grade 0	Minimal findings, impairment only detectable with neuro-psychiatric testing
Grade 1	Minor changes in mood/behavior, remains oriented, no asterixis
Grade 2	Increased lethargy and disorientation, + asterixis
Grade 3	Somnolent but arousable, incoherent speech, + asterixis ± clonus
Grade 4	Coma, unresponsive to pain

serum ammonia levels do not exclude HE [21]. Hepatic encephalopathy symptomatology may present on a spectrum ranging from mild personality changes to overt coma, and is often exacerbated by systemic insults such as infection or shock [21, 22]. It may also influence the patient's ability to engage properly in conversations about informed consent. Treatment of HE includes non-absorbable antibiotics such as Rifaximin and non-absorbable disaccharides such as lactulose with the intention of promoting several soft bowel movements per day [21, 22]. Of note, diarrhea associated with lactulose and similar treatments may confound the presentation of surgical diseases.

Hepatocellular Carcinoma

Although considered a rare cancer in western populations (6 cases per 100,000 in the USA), hepatocellular carcinoma (HCC) occurs almost exclusively in patients with chronic liver disease. Hepatocellular carcinoma may be found incidentally on imaging, or may present with portal vein thrombosis, metastatic disease, or rupture into the peritoneal cavity with shock and hemoperitoneum. It is diagnosed primarily by pathognomonic cross-sectional imaging findings of arterial enhancing hepatic lesions with contrast washout during delayed contrast phases. Due to the sensitivity and specificity of these imaging findings, biopsy is rarely indicated for the diagnosis of HCC.

Renal Dysfunction

Renal insufficiency is often seen in cirrhotic patients with an estimated prevalence rate of 20–25 % [23]. The degree of renal insufficiency usually goes unrecognized when using traditional tests such as serum creatinine. Up to 37 % of cirrhotic patients with serum creatinine levels in the normal range have measured creatinine clearance <50 mL/min indicating chronic kidney disease [23]. The degree of renal insufficiency generally correlates with the degree of portal hypertension. Patients with portal hypertension experience a significant increase in endogenous vasodilators which cause splanchnic and systemic vasodilation. The decrease in systemic vascular resistance (SVR), along with the hyperdynamic circulation associated with cirrhosis, results in renal hypoperfusion. These chronically hypoperfused kidneys become very susceptible to slight physiological changes seen with systemic insults such as infection, variceal bleeding, and dehydration [24]. The degree of renal injury can range from a mild reversible acute kidney injury (AKI) to HRS. Hepatorenal syndrome is associated with a high mortality [24].

Circulatory Dysfunction

Portal hypertension leads to the increased production of endogenous vasodilators. These vasodilators cause a decrease in SVR that manifests as hyperdynamic circulation with high cardiac output. Ejection fractions of greater than 70 % and cardiac outputs in excess of 10 L/min are common in decompensated cirrhotic patients. Over time, these hyperdynamic changes cause structural changes in the myocardium as well as the electrophysiology of the heart [25]. Together, this "cirrhotic cardiomyopathy" can lead to compromised heart function that is unable to compensate for any acute hemodynamic changes.

Preoperative Considerations

Preoperative Evaluation

A thorough preoperative history and physical examination is especially essential when evaluating potential surgical pathologies in patients with cirrhosis. Multiple pathologies, both surgical and non-surgical, may present with shock, abdominal pain, and hepatic decompensation, and the importance of a confident diagnosis cannot be overestimated to avoid a nontherapeutic surgical intervention, which may result in high mortality. In addition to standard laboratory tests, diagnostic paracentesis and newer tests of coagulopathy such as TEG may be important to secure a diagnosis or prepare the care team for surgical intervention. If available, previous laboratory results may help establish a baseline level of liver function and indicate the degree of hepatic decompensation brought about by the acute event. We advocate cross-sectional imaging of every patient considered for operative intervention to help secure the diagnosis and to help plan a safe operation.

Table 4.4 CTP classification

Parameter	1 Point	2 Points	3 Points
Ascites	None	Mild–moderate	Severe
Hepatic encephalopathy	None	Grade 1–2	Grade 3–4
Total bilirubin (mg/dL)	<2	2–3	>3
Serum albumin (g/dL)	>3.5	2.8–3.5	<2.8
INR	<1.7	1.7–2.3	>2.3

CTP score is calculated by adding the score for each parameter. CTP class A = 5–6 points, CTP class B = 7–9 points, CTP class C = 10–15 points

Classification of Preoperative Liver Function

The severity of liver disease is one of the most important determinants of surgical outcomes in cirrhotics. As liver function worsens, coagulopathy, stigmata of portal hypertension, and hyperdynamic circulation leave the cirrhotic patient with marginal physiologic reserve and, accordingly, impaired response to surgical stress and general anesthesia [26, 27]. Currently, the CTP system and the Model of End stage Liver Disease (MELD) score are the main classification systems used by clinicians for stratification of patients with cirrhosis (Table 4.4). Current literature suggests that elective surgery can be safely carried out with CTP-A or MELD score less than 8 [26]. On the other hand, patients with CTP-C or MELD score greater than 25 can have perioperative mortality of up to 80–90 %, even in elective situations [26]. In a retrospective study of 53 patients, MELD score was shown to provide a more accurate prediction of patient's outcome compared to CTP system [28]. However, there are no clear recommendations to suggest the use of a single scoring system. The CTP and MELD score are often considered complementary to each other as each provides additional parameters that can lead to a more accurate risk assessment. In addition, the degree of portal hypertension, type of operation, and the urgency of the operation play a major role in predicting postoperative complications and surgical outcome [27].

Discussion of Goals of Care and Advance Directives

Once a cirrhotic patient undergoes general anesthesia and a surgical procedure, the risk of hepatic decompensation, exacerbation of HE, and prolonged intubation may make first-person decision making impossible for patients in the postoperative period. In patients who are alert prior to surgery, a comprehensive discussion of the risk of a poor outcome should be established and the wishes of the patient in the case of significant decompensation should be appropriately documented. If the patient lacks capacity due to HE or other factors, a similar discussion should be held with the patient's family or other responsible parties preoperatively if possible. Knowledge of the patient's CTP class or MELD score will help inform this discussion.

In patients with severely decompensated liver disease and a very high risk of operative mortality, the decision to not proceed with surgery may be a reasonable one depending on the wishes of the patient and/or family. If possible, preoperative discussion with palliative care may help guide the decision to provide comfort measures rather than a surgical intervention which may be unlikely to alter the outcome.

Intraoperative Considerations

Avoiding Hemorrhage

Hemorrhage represents the most immediately life-threatening complication of surgery in cirrhotic patients. Abdominal wall and intra-abdominal venous collaterals are easily ruptured and may bleed catastrophically. Planes that are normally avascular may have significant neovascularization causing bleeding during dissection, and even small veins in normal positions are under significantly increased pressure and may be difficult to control. The liver and spleen may be stiff, friable, and easily fractured, and even minimal traction on these solid organs or structures adherent to these organs can result in small capsular tears that are very difficult to control. The coagulopathy and thrombocytopenia associated with cirrhosis along with the high vascular flow associated with the hyperdynamic state makes hemorrhage more likely, and consumption of sparse coagulation factors in the event of intraoperative bleeding increases the likelihood of further hemorrhage.

The most effective therapy for intraoperative hemorrhage is avoidance. Avoidance of hemorrhage starts with review of preoperative imaging and an understanding of the anatomy of venous collaterals and other anatomic disturbances. The anesthesia team can assist with hemorrhage avoidance preoperatively and intra-operatively by using TEG and other methods to aggressively target therapy for coagulopathy. Additionally, our practice is to utilize octreotide infusion throughout the peri-operative period to reduce hemorrhage potential by decreasing splanchnic blood flow, although this practice has not been rigorously evaluated in the surgical literature.

During incision, venous collaterals that are encountered in the abdominal wall should be definitively controlled with either cautery or suture ligature, as these high-pressure veins will not spontaneously stop bleeding in the presence of coagulopathy. A recanalized umbilical vein may be identified, and if possible should be preserved as it may represent a significant conduit for portal venous shunting in the patient with portal hypertension. If the recanalized vein must be divided, this division should take place between heavy ties far from

the liver and traction on the vein and liver must be avoided. The falciform ligament remains relatively avascular and can be divided with cautery if needed to avoid traction on the liver during retractor placement. It is very important to be certain that the retractor does not place traction on the liver, gallbladder, or spleen either directly or indirectly via adhesions to other structures such as the omentum, or predictable difficult bleeding will ensue.

During the dissection phase of the operation, the importance of gentle technique cannot be over-emphasized. Blunt dissection may be useful in standard patients but can lead to significant bleeding in cirrhotic patients either from inadvertent injury to venous collaterals, oozing from raw surfaces, or traction on solid organs. We advocate the use of cautery and gentle tension on tissues to perform dissection, increasing the power of the cautery when possible and lowering it when dissecting near important structures or mobilizing bowel adhesions. This technique becomes increasingly useful in the patient with ascites and prior SBP, as these patients often have a thick "white rind" of visceral and parietal peritoneum that make blunt dissection nearly impossible.

Controlling Hemorrhage

Should hemorrhage occur, prompt control is mandatory before proceeding to the next step in the operation. In patients with coagulopathy and portal hypertension, venous bleeding does not usually respond to packing. Instead, definitive control with cautery or suture is necessary. If large bleeding collaterals are encountered, attempting to control the hemorrhage with forceps or a hemostat prior to definitive control may lead to tearing of the vessel and further hemorrhage. Instead, we advocate minimal handling of the vessel and prompt control with suture ligature of 4–0 or 5–0 monofilament polypropylene.

Solid organ bleeding from the liver or spleen can be very difficult to control. Surface bleeding from capsular tears can be controlled with a combination of cautery, argon-beam coagulator, and topical hemostatic agents, and may require multiple rounds of treatment. Larger fractures in the liver rarely respond to absorbable gut suture ligature with a large blunt-tip needle. Partial resection of the cirrhotic liver should not be attempted.

Abdominal Closure

The abdomen should be closed using standard techniques. Leaving the abdomen open, even if a "second look" operation is planned, is not advisable, especially in patients with significant decompensation and ascites.

Laparoscopic Surgery

Laparoscopy in cirrhotic patients was previously avoided due to technical issues with hemorrhage control and theoretical concerns about alterations in hepatic blood flow during pneumoperitoneum. Recent experience, however, has demonstrated that laparoscopic surgery using appropriate technique has a similar safety profile compared to open surgery and may offer advantages. Consideration of abdominal wall collaterals and recanalized umbilical vein during trocar placement is important, as is careful inspection of trocar sites during removal to ensure that large-volume bleeding was not tamponaded by the trocar itself. We prefer to use the Hasson technique exclusively in cirrhotic patients for placement of the initial trocar to avoid injury to venous collaterals both within the abdominal wall and within the abdomen itself during abdominal access.

Postoperative Considerations

Cirrhotic patients, even if seemingly stable, should be managed in a monitored unit postoperatively. Close monitoring allows for assessment and management of the early potential complications of bleeding and shock, and late potential complications associated with hepatic decompensation.

Fluid management in the cirrhotic patient, especially the cirrhotic patient with ascites, is of critical importance. It is important to remember that cirrhotic patients normally exist in a vasodilated, hyperdynamic state, and that "hypotension" in a cirrhotic patient may actually be that particular patient's "normal." Instead of blood pressure, more advanced measures of perfusion and oxygen delivery are preferred. Importantly, lactic acidosis may be present despite adequate perfusion due to liver decompensation. In the patient with ascites and peripheral edema, intravascular volume depletion may coexist with generalized volume overload, and accordingly invasive or dynamic monitoring may be useful in guiding therapy. Colloid resuscitation is preferred to crystalloid resuscitation in cirrhotics, and crystalloids that are used should consist of 1/2 or 1/4 NS to avoid excess sodium which may exacerbate ascites.

Renal dysfunction in the postoperative period may be a result of acute tubular necrosis (ATN) from hypoperfusion or HRS. Cessation of diuretics and maintenance of intravascular circulating volume is critical to preventing and treating both causes of AKI. In patients suspected to have HRS the addition of octreotide and midodrine to albumin may improve survival [29].

Coagulopathy is best assessed with TEG rather than conventional coagulation tests to guide blood product therapy. The goal should be hemostasis, rather than correction of

coagulation tests to "normal" values. For example, elevation in INR in a hemostatic patient with relatively normal TEG does not require aggressive treatment with plasma transfusion. In fact, INR is the most sensitive test of hepatic synthetic function, and can be very useful in monitoring for hepatic decompensation if not artificially altered by unnecessary plasma transfusions.

Common Acute Surgical Problems in Cirrhotic Patients

Umbilical Hernia

Umbilical hernia is present in up to 20 % of cirrhotic patients with ascites [30, 31]. Persistently increased abdominal pressure as a result of massive ascites can lead to large umbilical defects and thinning of the overlying skin, leading to the risk of incarceration of abdominal contents and skin rupture with leakage of ascetic fluid.

The elective repair of umbilical hernias in compensated cirrhotics is associated with a low mortality. Elective repair in decompensated cirrhotics is controversial, and is rarely performed outside of specialty centers. In the acute setting, the surgeon may be confronted with two types of emergency consultations for cirrhotics with umbilical hernia complications.

Incarcerated Umbilical Hernia

Small bowel incarceration resulting bowel obstruction is a potentially devastating complication of umbilical hernia in cirrhotic patients. Manual reduction of hernia contents at the bedside may be possible; however, laparotomy with hernia repair is often necessary, despite the increased risk of surgery in this group of patients. If bowel resection is necessary, the surgeon must consider that the bowel is often thickened in patients with portal hypertension, and must also acknowledge the often profound malnutrition associated with cirrhosis. For these reasons we advocate reconstruction of bowel continuity with a two-layer, hand-sewn anastomosis rather than a stapled anastomosis. The choice to use mesh versus primary repair of the hernia defect is controversial. We prefer primary repair to avoid the risk of mesh infection in patients with ascites, although some authors have suggested that mesh placement is safe and reduces future recurrence [32]. With either technique, care must be taken to avoid a recanalized umbilical vein, if present. Skin is closed with interrupted or running full-thickness monofilament sutures rather than staples, and these sutures should be removed only after the skin wound is well-healed. Ascites should be completely suctioned from the peritoneal cavity at the time of surgery and ascites post-operatively should be aggressively controlled with medical management including sodium restriction and diuretics, with transjugular intrahepatic portosystemic shunt (TIPS) placement as a consideration in appropriate candidates for treatment of medically refractory ascites. We do not advocate the use of intraperitoneal drains to divert ascites away from the wound, instead preferring medical management of ascites to prevent wound drainage and subsequent wound complications.

Ruptured Umbilical Hernia (Flood Syndrome)

Ruptured umbilical hernia is often referred to as "Flood Syndrome," named after Frank B. Flood, M.D. who described it rather than for the flood of ascites that follows the spontaneous rupture [33]. Ruptured umbilical hernia is a surgical emergency due to the risk of overwhelming peritoneal infection that may result from contamination, and repair should proceed as above, with excision of devitalized skin prior to closing.

Gallstone Disease

Gallstone disease is more prevalent in cirrhotic patients than in the general population. Hemolysis, biliary stasis, and metabolic changes in the diseased liver all contribute to this higher prevalence of gallstones. Most patients with cirrhosis have black pigmented stones rather than cholesterol stones, and the presence of stones is correlated with both age and severity of liver disease [34]. As in the general population, most gallstones in cirrhotics are asymptomatic, however acute gallstone disease in cirrhotic patients presents a unique challenge to the acute care surgeon.

Symptomatic Cholelithiasis

The first step in evaluation of presumed symptomatic cholelithiasis in a cirrhotic patient is to determine if the symptoms are the result of the gallstones. Multiple pathologies may present as abdominal pain in cirrhotic patients, and a detailed history and physical exam is required to help narrow the differential diagnosis. We advocate the use of cross-sectional imaging as an adjunct to ultrasound in the preoperative evaluation of the cirrhotic patient with presumed symptomatic cholelithiasis, as this information will assist with both exclusion of several other etiologies of pain and surgical planning should cholecystectomy be necessary.

For CTP class A or B cirrhotic patients in whom a confident diagnosis of symptomatic cholelithiasis is possible, laparoscopic cholecystectomy (LC) or open cholecystectomy is advocated as the risk of future complications of

gallstone disease is high. Surgical challenges unique to the cirrhotic patient include the presence of varices within the porta hepatitis. Abdominal wall collaterals must be avoided during port placement as described earlier. The cirrhotic liver is stiff and friable and obtaining an appropriate surgical view may be challenging using the laparoscopic approach. Hemostasis of the gallbladder bed must be complete, and may require extensive cauterization or argon-beam coagulator. Finally, the surgeon must not hesitate to convert to open if the procedure is difficult laparoscopically.

Cholecystectomy in patients with CTP-C cirrhosis is associated with a high risk of mortality. Accordingly, urgent surgery is not recommended and transfer to a liver transplant center should be strongly considered for evaluation and management of these complex patients.

Acute Cholecystitis

Although immediate surgical treatment of acute cholecystitis is now common practice in standard patients, a more cautious approach is indicated in patients with cirrhosis. Early initiation of antibiotic therapy, appropriate imaging, and assessment of the severity of liver disease should all be performed prior to considering surgery. In patients with CTP class A or B cirrhosis, LC can be performed in most cases. In patients with CTP-C cirrhosis, cholecystectomy is associated with a high mortality due to bleeding, liver decompensation, and overwhelming infection. Some centers prefer to use percutaneous cholecystostomy tube decompression along with antibiotics to manage the patient acutely, and then consider LC in a delayed fashion after resolution of the acute illness [35].

Trauma

The incidence of cirrhosis in the trauma population is less than 1 % [36, 37]. When cirrhosis is encountered in the injured patient, however, it is associated with a drastic increase in morbidity and mortality even with minimal trauma burden and absence of operative intervention [38]. Furthermore, cirrhotics are more likely to undergo non therapeutic laparotomy secondary to deranged hemodynamics and ascites which can be confused with shock and hemoperitoneum. When emergent laparotomy is carried out, it further amplifies this drastic increase in morbidity and mortality [38]. The mortality rate of trauma patients with cirrhosis is more than four times greater than those without cirrhosis, and increases according to CTP class with mortality rates of 8 % in CTP-A, 32.3 % in CTP-B, and 45.5 % in CTP- C [32, 37]. Additionally, overall complication rates approach 31.5 % in cirrhotics versus 7.1 % in non-cirrhotics [37]. Hence, the caring team should be aware of the physiologic changes that accompany cirrhosis, have higher vigilance in recognizing complications, and employ early interventions to address these issues. Moreover, these patients should be managed in the intensive care unit despite having low injury burden due to the risk of complications and hepatic decompensation.

In the absence of hemodynamic instability, non-operative management (NOM) is a common strategy for treating blunt injury to intra-abdominal solid organs in most patients. Non-operative management of solid organ injury must be used with caution in cirrhotic patients, particularly when the spleen is involved. In a review of the National Trauma Data Bank patients with blunt liver injury, the presence of cirrhosis was not associated with greater risk for failure of NOM [39]. However, cirrhotic patients with blunt splenic injury did not do as well, with high failure rates of NOM and high mortality [40–42].

Common Non-Operative Problems Which May Provoke Surgical Consultation

Spontaneous Bacterial Peritonitis (SBP)

Spontaneous bacterial peritonitis is defined as intra-abdominal infection in a patient with ascites without a surgically correctable cause (i.e., perforation). It is believed to be the result of bacterial translocation into the ascites fluid, where impaired host defenses permit replication of bacteria and clinical infection. Spontaneous bacterial peritonitis may present in a variety of ways, including fever, abdominal pain, leukocytosis, or shock, or may present as decompensation of liver disease with exacerbation of HE and coagulopathy. It is diagnosed by paracentesis, which should be performed prior to antibiotic administration, and is defined as an ascites fluid polymorphonuclear cell (PMN) count of 250 cells/mm^3, which is calculated by multiplying the total fluid white blood cell count by the percentage of PMNs in the differential. Gram stain and culture commonly demonstrate a single organism rather than polymicrobial flora.

Since SBP may present with abdominal pain and distention, fever, and shock, surgical consultation for a presumed "surgical abdomen" may be requested by the referring provider. It is extremely important to differentiate SBP from secondary bacterial peritonitis from gastrointestinal perforation, as the mortality of missed surgically correctable secondary bacterial peritonitis approaches 100 %, and the morality of patients with SBP undergoing unnecessary laparotomy approaches 80 % [43, 44]. Physical exam may not be helpful, as the presence of ascites separates the visceral from the parietal peritoneum and changes the expected presentation of a "surgical abdomen" on exam. Features that

Fig. 4.2 Runyon's algorithm to distinguish spontaneous form secondary bacterial peritonitis. (From Arkiviadis R. Utility of an algorithm in differentiating spontaneous from secondary bacterial peritonitis. Gastroenterology. 1990;98:128, with permission. Copyright Elsevier.)

suggest secondary peritonitis include pneumoperitoneum on imaging, polymicrobial flora on gram stain, and "Runyon's Criteria" examination of ascitic fluid (Fig. 4.2).

Hepatic Hydrothorax

Hepatic hydrothorax usually presents as a right-sided pleural effusion with variable effects on respiratory function. Surgeons may be asked to place a chest tube in patients with symptomatic hepatic hydrothorax, however this is strongly discouraged. Placement of chest tubes may lead to massive loss of fluid, electrolytes, and protein leading to AKI, and the bleeding risk of placement due to coagulopathy and venous collaterals in the chest can be prohibitive. Furthermore, ongoing re-accumulation of fluid in the pleural space may make it nearly impossible to remove the tube unless TIPS or liver transplantation reverses the offending process. Hepatic hydrothorax should be managed in a similar fashion as ascites with sodium restriction and diuretics, with intermittent small-bore needle thoracentesis in very symptomatic patients.

Variceal Hemorrhage

Surgeons may be consulted to participate in the care of patients with variceal hemorrhage. Patients with variceal hemorrhage present with varying degrees of shock, hematemesis, or hematochezia. The initial treatment of variceal hemorrhage is supportive, with large-bore intravenous access, transfusion, airway management, and intensive care unit monitoring. Octreotide infusion should be started immediately to reduce splanchnic blood flow. Upper endoscopy should be performed by an experienced endoscopist, and most hemorrhage can be controlled by placement of endoscopic variceal bands. Ectopic varices, gastric varices, and uncontrollable varices may require emergent TIPS for portal decompression. In selected cases balloon tamponade of the hemorrhage with a Minnesota or Senstaken-Blakemore tube may serve as a temporary "rescue" treatment while awaiting definitive therapy such as TIPS. The role of surgical portal shunting procedures is minimal in the TIPS era, and even in experienced centers the mortality of emergent porto-systemic surgical shunting is over 50 %. Surgeons without experience in surgical shunt procedures are unlikely to successfully salvage a patient with uncontrolled variceal bleeding.

Ruptured Hepatocellular Carcinoma

Patients with HCC, particularly those with undiagnosed HCC in the setting of poor access to care, may present acutely with hemorrhage from ruptured HCC. Clinical presentation depends on the location of the tumor. Ruptured tumors located deep within the liver may present with pain, mild acute blood loss, and intraparenchymal hemorrhage on cross-sectional imaging. Tumors located near the surface, however, may present with free rupture into the peritoneal cavity and overt hemorrhagic shock. The primary mode of treatment for ruptured HCC is trans-arterial embolization. Hepatic decompensation may occur to varying degrees after the procedure, depending on the preexisting hepatic function and the geographic size of the embolized area. Surgical hemostasis or resection is rarely indicated, in the emergent setting, and is associated with a high mortality. After control of hemorrhage, semi-elective resection by an experienced liver surgeon may be indicated depending on functional hepatic reserve and tumor anatomy. Patients who survive ruptured HCC are believed to have a high incidence of subsequent disseminated disease, although this notion has been recently challenged [45].

Conclusion

Surgical management of cirrhotic patients in the pre-operative, intra-operative, and post-operative phases of care is highly complex. Distinguishing between operative and non-operative pathologies is critical. Due to the complexity of care, working with a multidisciplinary team, including a hepatologist if available, is essential to achieving a good outcome. If the patient is stable preoperatively or in the immediate postoperative setting, early transfer to a tertiary care center or liver transplant center may be beneficial.

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Surgical Procedures in the Intensive Care Unit

5

Emmanuel Sonnaike and Jeremy L. Ward

The operating room is the preferred location for surgeons to perform procedures. The sterile environment, trained and experienced support staff, readily available equipment, and superior lighting make it a desired location for surgeons. However, in many situations the intensive care unit (ICU) may offer advantages as a procedural location, and many procedures that are usually performed in a dedicated environment can safely be performed in the ICU. The focus of this chapter is on those procedures that are often required of the acute care surgeon in the ICU.

Background

The practice of the acute care surgeon is overwhelmingly dedicated to the acute care setting, providing services to patients in the emergency department, ICU, and operating room. The surgeon should be not only procedurally adept, but also adaptable to the various locations in which procedures are performed. The ICU is one of the most common locations in which the acute care surgeon's procedural services are required, and this location offers many advantages as well as limitations.

Why the Bedside Instead of the Operating Room?

Critically ill patients are best served in an environment that is controlled and has the necessary equipment and resources for emergencies. There are risks involved in transporting patients, and hemodynamic instability sometimes precludes safe travel. If the interventions or diagnostics can be brought to the patient, as opposed to having the patient transport to a different location, this potential benefit is worth considering. Eliminating the risk of transporting the patient is one of the key factors in the decision to perform a procedure in the ICU.

Bronchoscopy

Common indications for performing bronchoscopy include the management of a mucus plug, to evaluate for bleeding, and to perform a bronchoalveolar lavage (BAL) or biopsy [1]. There are two types of bronchoscopes: rigid and flexible. The rigid bronchoscope is best suited for foreign body removal, stent placement, and debulking large tumors [2]. Use of the flexible bronchoscope is more common, utilized over 95 % of the time [2].

Early BAL in tracheostomy patients with increased secretions may prevent pneumonia and decrease ICU length of stay [3]. A retrospective cohort study suggested that early bronchoscopy could decrease morbidity and mortality in aspiration pneumonia patients [4].

The application of lidocaine as a topical anesthetic in the laryngopharynx will decrease patient discomfort and may suppress the gag reflex when performing bronchoscopy on awake and spontaneously breathing patients. For intubated patients or those with a tracheostomy, the application of topical lidocaine at the carina will reduce the cough reflex and agitation. Atropine may be used to pretreat asthmatic patients. Its anticholinergic effect in decreasing secretions can provide better visualization. The morbidity and mortality of bronchoscopy are 0.5 % and 0.8 %, respectively [5].

Major complications associated with bronchoscopic procedures include respiratory depression, pneumothorax, airway obstruction, hypoxia, cardiorespiratory arrest, arrhythmias and pulmonary edema. Continuous cardiopulmonary monitoring should be utilized during bronchoscopy in order to quickly identify critical changes in a patient's condition. Some complications such as severe bleeding and pneumothorax are more commonly seen after biopsy. The incidence of pneumothorax

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_5

after biopsy increases from 3 to 14 % when the patient is mechanically ventilated [1].

It is beneficial to have a respiratory therapist assisting during bronchoscopic procedures. The therapist can focus on the patient's airway, and protect the endotracheal tube from accidental dislodgment during the procedure. The ventilated patient should have the FiO_2 increased to 100 % prior to the procedure, and the ventilator should be placed on a mode with a set ventilator rate, as sedatives and paralytics may preclude effective spontaneous respirations. For patients with severely impaired oxygenation, manual bag ventilation may be required during the bronchoscopy to maintain oxygen saturation. A bronchoscopic adapter should be connected to the endotracheal tube and the bronchoscope should be lubricated with aqueous or petroleum-based jelly. Additional supplies required include sterile saline in slip tip syringes, a suction trap connection (for collection of lavage specimens), and a bite block. Two suction setups are preferred, with one connected to the bronchoscope and the other connected to a Yankauer tip for oral suctioning if needed. Participants in the procedure should be cognizant of the patient's oxygenation status, as occasionally the bronchoscope may need to be withdrawn to allow the patient's oxygenation to improve. Avoid unnecessary and excessive suctioning and lavage, as these maneuvers cause de-recruitment of alveoli affecting the patient's ventilation and oxygenation.

Tracheostomy

The subcricoid tracheostomy technique was first performed by Chevalier Jackson in 1909 [6]. The procedure has undergone innumerable modifications leading to the percutaneous dilatational approach refined by Ciaglia, commonly used today [7]. Respiratory failure is the most common indication for a tracheostomy, with the benefits including better pulmonary toilet and oral care, avoidance of the complications of prolonged intubation, expediting ventilator weaning [8], and increasing patient comfort [9]. Tracheostomy is also commonly performed on patients with significant neurological deficit, such as post-cerebrovascular accident or traumatic brain injury, where there is a permanent concern for airway protection.

The main choices to consider when performing a tracheostomy include location (operating room (OR) vs. bedside in the ICU) and approach (open vs. percutaneous). Multiple studies have underscored the safety and cost-effectiveness of bedside tracheostomy. However, one would be challenged to find studies that make equal comparisons among the four different tracheostomy options, especially with regard to ideal patient and ideal procedure [9–20].

Rates of complications are similar when comparing OR tracheostomy to open bedside tracheostomy [13, 14] as well as when comparing percutaneous dilatational tracheostomy (PDT) to open tracheostomy in general [21]. However, the benefits of open bedside tracheostomy include eliminating the OR associated costs and wait times. In the ICU, the respiratory therapists are utilized for airway monitoring and the critical care physician manages the sedation and airway [9, 10, 15].

With the decision to proceed with bedside tracheostomy comes the discussion of what approach to use. As mentioned earlier, both open bedside tracheostomy and PDT have been shown to be safe, with similar outcomes. The cosmetic appearance, with smaller incision and its subsequent scar, is the only reproducible benefit to PDT [16, 17]. Percutaneous dilatational tracheostomy tends to be a more expensive procedure because of use of the disposable kits as well as the recommended use of bronchoscopy [10, 19].

Relative contraindications to PDT include a high positive end-expiratory pressure (PEEP) (PEEP > 10 cm H_2O), calcified tracheal rings, active cervical infection, poor anatomic landmarks (morbid obesity, thyromegaly, or abnormal thyroid anatomy), unstable cervical spine, uncorrected coagulopathy, or the need for an emergency airway [7, 15, 16, 22, 23]. The problem with a high PEEP is that an incision into the trachea will cause a drop in pressure, leading to atelectasis and hypoxemia. This problem, however, is partially mitigated with the use of single dilation kits, decreasing the number of passes in and out of the trachea, and reducing the time associated with the dilatational aspect of the procedure; these kits have allowed practitioners to safely perform the procedure with PEEP as high as 15 cm H_2O [22].

A survey of multiple countries revealed that there is no uniform guideline regarding the performance of ICU tracheostomies across various geographical locations [24]. Given that performance of PDT is a multidisciplinary process with various steps and equipment needed, it makes sense that a pre-procedural checklist would be beneficial in decreasing procedure-related adverse events. This premise was validated in a recent prospective study showing a 580 % reduction in adverse events after adjusting for age, vital signs, risk factors, and post-procedure ICU duration [25].

Tube Thoracostomy and Pigtail Catheters

Common indications for tube thoracostomy include pneumothorax, hemothorax, chylothorax, pleural effusion, and empyema [26]. Formal chest tubes have long been placed at the bedside, and placement is part of the core training of general surgeons. Large bore (32–36 Fr) tubes are traditionally placed in the setting of trauma in order to decrease the risk of malfunction from a clotted tube; however, recent studies have demonstrated that smaller bore chest tubes are as effective as the larger ones in draining hemothoraces [27]. Equally important is the fact that the smaller bore pigtail catheters are better tolerated by patients.

Analgesia is an important component to consider when placing a thoracostomy tube, especially in conscious patients. Both an opioid analgesic, such as fentanyl, and local anesthetic should be administered. A low dose sedative may be used for its anxiolytic effects, but care should be taken to avoid respiratory depression in patients who are not mechanically ventilated. Ketamine is useful in this regard. Supplemental oxygen and continuous pulse oximetry are recommended.

Small bore thoracostomy tubes can be placed for pneumothoraces in unusual locations such as basilar. In such instances where the typical landmarks may result in lung parenchymal injury, ultrasound guidance may be useful for more accurate placement [28]. In experienced hands, ultrasound is more sensitive than supine anteroposterior chest X-ray in detecting pneumothorax in the blunt trauma patient [29].

Some immediate complications of tube thoracostomy include misplacement (kinked, advanced too far, not sufficiently advanced, retroperitoneal placement) and intercostal vessel injury. Additionally, misplacement of the tube into the abdomen or into the intrathoracic viscera should clearly be avoided. Delayed complications include pneumonia, empyema, persistent or re-accumulation of pneumothorax, hemothorax, or pleural effusion, and insertion site infection [30].

Paracentesis

Paracentesis is a relatively rare procedure in most surgical ICU's. Indications include the treatment of ascites refractory to medical therapy, tense ascites, and diagnosis of spontaneous bacterial peritonitis (SBP). Paracentesis catheter placement is also placed for palliation in patients with symptomatic malignant ascites, avoiding repeat procedures in cases of rapid re-accumulation [31].

Relative contraindications include severe uncorrected coagulopathy, ileus or bowel obstruction causing distended bowel, pregnancy, abdominal wall inflammation/infection, and intraabdominal adhesions. After the skin site is prepped and anesthetized, the access needle is inserted with the skin pulled down; the needle is advanced partially, the skin is then released, and the needle is advanced the rest of the way into the peritoneum. This method (Z technique) creates a tunneled path that prevents direct communication from the peritoneum to the atmosphere when the catheter is removed. Care should be taken to avoid injury to the inferior epigastric vessels upon entry. Use of ultrasound can be helpful in preventing injury to abdominal wall vessels and the avoiding injury to bowel or other intraabdominal structures during the procedure.

The most common complication following paracentesis is an ascitic leak, occurring about 5 % of the time. The Z technique is one method to reduce this risk. Other risks include severe hemorrhage, infection, and death, which occur at a rate of less than 1 % each [32–37]. Coagulopathy is common in cirrhotic patients. This may need to be corrected preprocedure if the platelet count is less than 50,000 or if the prothrombin (PT) or partial thromboplastin (PTT) time is greater than 2 times normal as they are associated with increased the risk of bleeding [34]. If an indwelling catheter is left in place, it should be removed at the earliest possible time in order to decrease the rate of infection.

Inferior Vena Cava Filter

Inferior vena cava (IVC) filters are indicated in patients who have had complications or failure of anticoagulation in the treatment of venous thromboembolism (VTE) to include deep venous thrombosis (DVT) and pulmonary embolism (PE). Prophylactic placement in high risk patients without the diagnosis of VTE is controversial, but may be acceptable, especially if anticoagulation is contraindicated and the VTE risk is deemed high. Rogers et al. documented a decreased incidence of PE in high risk patients when prophylactic IVC filters were utilized [38]. That being said, prophylactic IVC filters have not been associated with a survival benefit in trauma patients; in fact, they have been shown to be associated with an increased incidence of DVT when risk adjusted for pharmacologic anticoagulation and patient factors [39].

Some complications of IVC filter placement include contrast induced nephropathy, IVC penetration, filter erosion, filter fracture, filter malposition, and access site thrombosis. Filter embolization and death secondary to the procedure are relatively rare (0.1 %) [40]. Bedside placement of IVC filters has been shown to be feasible using intravascular ultrasound (IVUS) [41]. This approach eliminates the risks associated with administering intravenous contrast and avoids radiation exposure to the ICU.

In patients who have no contraindication to anticoagulation, there is no reduction in the risk of recurrent PE when anticoagulation and retrievable IVC filters were used versus anticoagulation alone [42] (Table 5.1).

Gastrointestinal Endoscopy

Nasoenteric Feeding Tubes

Malnutrition is common in critically ill patients, and nutritional support is important in order to reduce complications and optimize recovery. It is well known that the enteral route is preferred for supplemental nutrition secondary to decreased mucosal atrophy and reduced risk of bacterial translocation [43]. If the gastrointestinal tract is functional, it should

Table 5.1 Indications for inferior vena cava filter placement

Therapeutic	Prophylactic
Absolute or relative contraindication to anticoagulation	Severe trauma without documented PE or DVT
Complication of anticoagulation	Closed head injury
Failure of anticoagulation	Spinal cord injury
Recurrent PE despite adequate therapy	Multiple long-bone or pelvic fractures
Inability to achieve/maintain adequate anticoagulation	Patient at high risk (e.g., immobilized or in an intensive care unit)
Propagation/progression of DVT during therapeutic anticoagulation	
Massive PE with residual DVT in a patient at risk for further PE	
Free-floating iliofemoral or IVC thrombus	
Severe cardiopulmonary disease and DVT	

From Caplin DM, Nikolic B, Kalva SP, et al. Quality improvement guidelines for the performance of inferior vena cava filter placement for the prevention of pulmonary embolism. J Vasc Interv Radiol. 2011;22:1499, with permission

be utilized. In a patient who is unable to swallow, whether secondary to mechanical ventilation, aspiration risk, or otherwise, a nasoenteric tube may be used. It is ideal for patients predicted to require less than 30 days of supplemental nutrition. Risks of nasoenteric tubes include aspiration, misplacement, displacement, and pharyngeal injury [44].

Gastric versus postpyloric feeding tube placement is commonly debated. That being said, multiple studies have demonstrated that critically ill patients have similar aspiration risk when fed either gastrically of post-pyloric [45–47]. However, small intestinal feeds (jejunal) are associated with decreased infectious complications compared to gastric feeds [48]. The nasoenteric tube may be placed at the bedside without the use of endoscopy; however, care must be taken to avoid placement of the tube into the lungs which can result in a pneumothorax or the administration of tube feeds into the thoracic cavity. Initial placement of the tube to approximately 35 cm followed by chest X-ray can confirm esophageal placement (tube remains midline and descends below the carina) or bronchial placement (tube angles off midline at the level of the carina following the bronchus), while preventing the deep positioning that results in alveolar rupture. Once esophageal location is confirmed, the tube can safely be advanced. When the goal is nasojejunal placement, endoscopy may be required if this is unsuccessful. There are numerous methods for the endoscopic placement of nasoenteric feeding tubes:

1. The endoscope may be used to snare a blindly placed feeding tube in the stomach, and then position the tube into the duodenum.
2. A small caliber nasoenteric feeding may be passed through the working channel of the gastroscope into the duodenum.
3. A wire may be passed through the working channel of the endoscope into the duodenum and the nasojejunal tube can then be passed over the wire. The third technique is most difficult, but allows for the use of larger bore tubes and nasojejunal tubes with gastric ports.

Percutaneous Endoscopic Gastrostomy

Percutaneous endoscopic gastrostomy (PEG) tubes are placed when the need for supplemental enteral nutrition is expected to last for longer than 30 days. The percutaneous approach is more commonly used than the open surgical approach.

Indications for PEG placement include recent cerebrovascular injury, other neurological impairment, pharyngeal or esophageal obstruction, and general debility with difficulty swallowing [49]. Percutaneous endoscopic gastrostomy tube placement is contraindicated if the patient cannot withstand the sedation necessary for the procedure, if transillumination and finger indentation are not achieved, or if the surgeon is unable to appose the stomach to the anterior abdominal wall. Conditions which inhibit transillumination can include ascites, prior gastric resection, obesity, and hepatomegaly. Relative contraindications include inflammatory and neoplastic diseases of the gastric and abdominal walls [49–51].

There are two techniques for PEG placement: push and pull. The pull technique is more popular among surgeons and is associated with reduced cost and complication rate [52]. However, the push technique has been shown to have lower infection rate [53–55].

The "pull" technique requires two elements prior to placement: (1) transillumination from the endoscope transgastrically to the abdominal wall and (2) indentation on the stomach by finger compression on the abdomen (as previously stated). The Seldinger technique is then used to introduce the guidewire which is then snared and then pulled retrograde exiting the mouth. The PEG tube is then affixed to the guidewire, which is then pulled at the skin until the PEG tube exits the abdominal wall and its bumper is seated snuggly, approximating the stomach to the abdominal wall.

The push technique is similar in that one must first identify the insertion site via transillumination [53, 54, 56]. A specially designed t-fastener is used to secure the stomach to the anterior abdominal wall. The gastrostomy tube is then placed either through Seldinger technique or using a trocar and

introducer sheath. The balloon is inflated to secure the tube inside the stomach. The push technique is ideal for situation where the oropharyngeal diameter is small, or there is a stricture in the esophagus preventing the PEG bumper from passing via the "pull" method. For patients with oropharyngeal cancers, this method may reduce the risk of the development of abdominal wall and peritoneal metastasis.

Evidence does not support the need for prophylactic antibiotics for push technique, given the low incidence of infectious complications. The higher infection rate associated with the pull technique is likely secondary to passage of the tube through the highly colonized oropharynx, thus periprocedural antibiotics may be beneficial.

A slight modification, the percutaneous endoscopic gastrostomy/jejunostomy (PEG/J) may be placed when small bowel enteral nutrition is preferred (e.g., gastroparesis or significant aspiration risk) and placement of the jejunal extension is feasible.

Endoscopy for Upper Gastrointestinal Bleeding

Gastrointestinal (GI) bleeding is categorized as upper or lower. Upper GI bleeding is considered as that which originates proximal to the ligament of Treitz, and can further be classified as variceal and nonvariceal.

Endoscopy is the primary diagnostic and therapeutic method for upper GI bleeding. Erythromycin may be administered pre-procedure as a promotility agent to empty the stomach for improved visualization [57]. The subset that most benefits from erythromcycin are those who have a large amount of blood in the stomach or who have had a recent meal [58].

Causes of nonvariceal bleeding include peptic ulcer disease and transpapillary hemorrhage [59]. The use of hemoclips is as successful as thermocoagulation in managing these types of hemorrhage. Hemoclips are also associated with decreased rates of re-bleeding and operation compared with the use of sclerosing agents alone [60].

Portal hypertension is the main cause of variceal bleeding [61]. Infusion of octreotide, a somatostatin analogue, is as effective as sclerotherapy in controlling variceal bleeding [62, 63]. Additionally, octreotide has fewer side effects. However, endoscopic variceal band ligation has been shown to be more effective than 48-hour somatostatin infusion for acute variceal bleeding [64]. With regard to the initial control of variceal bleeding, a combination of both sclerotherapy and somatostatin has improved outcomes compared to endoscopic management alone [64–66]. A combination of octreotide and endoscopic banding is most commonly employed. Though infrequently used, the Sengstaken-Blakemore tube [67] can be helpful when bleeding is too brisk for endoscopic management. It is appropriate for bleeding in the GE junction. It has an 80–94 % success rate when correctly placed.

When clot is seen on endoscopy, an attempt may be made at dislodging the clot with irrigation to better assess the base of the bleeding area. If unable to dislodge the clot with irrigation, two options are available (1) leave the clot alone as there is a low rate of re-bleeding from adherent clot, or (2) inject epinephrine then snare with cold guillotine technique [58]. When bleeding cannot be controlled endoscopically, clips should be placed to help guide IR embolization. Angiographic embolization has equal success rates with operation when endoscopy is unsuccessful [58, 59].

Factors predicting re-bleeding (both variceal and nonvariceal) include hemodynamic instability, active bleeding seen on endoscopy (or the evidence of a recent bleed), ulcer size >2 cm, a visible vessel, and bleeding from the posterior wall of the duodenum [61, 68]. These patients may benefit from repeat endoscopy. Recurrent bleeding is associated with increased mortality [69, 70]. The continuous intravenous administration of a proton pump inhibitor is associated with a decrease in need for endoscopy and lower re-bleeding rates [58, 71, 72]. A 2010 meta-analysis indicates that combined beta-blocker and endoscopic band ligation are associated with reduced re-bleeding and mortality rates compared to endoscopic treatment alone [73].

Lower GI bleeding originates distal to the ligament of Treitz. It accounts for 20 % of major GI hemorrhages. Common causes include diverticular disease, malignancy, irritable bowel disease (IBD), anorectal disease, and vascular ectasias [74–76]. Diverticular disease is the most common, and most diverticular bleeding resolves spontaneously [77–80]. Right-sided diverticular disease is usually more severe than left-sided, and has greater tendency to require an operation.

Lower endoscopy is ideal to evaluate lower GI bleeding when the patient is hemodynamically stable, the bleeding is minor or moderate, and most importantly, bowel preparation is possible [78]. Therapeutic methods include thermocoagulation, sclerotherapy, epinephrine injection, and hemoclip placement [81–83]. If the bleeding is severe, then angiography is indicated, with subsequent embolization if bleeding can be localized [78]. When embolized for non-diverticular bleeding, recurrence rate is greater than 40 % [84]. Emergency operation for lower GI bleeding is associated with a 20–50 % mortality rate [85]. Angioembolization can allow for resuscitation of the patient prior to operation, decreasing the risks associated with an emergency operation [84].

Bedside Laparotomy

While patients who are selected for bedside laparotomy are inherently unstable, and have a high risk of mortality, bedside laparotomy should still be considered as a last resort [86]. These procedures are usually done on patients who are too unstable for transport to the OR. They are ergonomically challenging, and operating over the patient's bed rather than an OR table puts significant strain on the back. Additionally, instrument sets and disposable equipment are not as readily available. The team should be prepared with necessary instruments and supplies prior to opening the abdomen, and must work expeditiously. Utilizing portable overhead lights and/or a headlight is particularly helpful in these cases. Common procedures include laparotomy for the management for abdominal compartment syndrome, evaluation in patients with suspicion for ischemic bowel, or for abdominal washouts in patients with intraabdominal sepsis. While more complicated intraabdominal procedures can be undertaken at the bedside, the previously discussed constraints generally preclude this. In addition to preparation with appropriate equipment, full sterile precautions should be employed as in the OR, and the use of the OR team during the procedure can be highly beneficial.

Conclusion

As advances in technology continue to allow for more procedures to be done in ICU, surgeons should adapt to the changing practice, and take full advantage of the benefits that bedside procedures afford.

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Hemodynamic Monitoring in the ICU

6

David Evan Meyer

Management of the unstable patient is one of the greatest challenges in medicine. At stake is the very life of the patient: treat wisely and your patient will benefit; choose poorly and your patient may suffer. Ultimately, the management of any critically ill patient returns to a single, central question: "What is making my patient unstable?" Unfortunately, this very question is one of the most difficult to answer. In part, it is a difficult question because our patients may be unstable for a variety of competing reasons. Even more challenging, a few patients are unstable for a combination of these reasons. Understanding the vectors of the forces that affect a patient's hemodynamics is the key to selecting the management strategy that will provide the most benefit (and do the least harm).

In order to make the most intelligent choices possible, a clinician must always seek to better understand the forces at work inside the body. The delicate interplay between intravascular volume, cardiac function, and vasomotor tone can be difficult to assess. Scientists and engineers have been working for decades to develop a device that can accurately and easily measure a patient's hemodynamic profile. Unfortunately, as of the publication of this textbook, that technology does not exist. Each device or technique is victim to its own specific set of strengths, weaknesses, and complications of use. Critical measurements are often made indirectly or with some degree of estimation. It is imperative that the clinician understands the capabilities of each instrument and when to apply it to a particular patient.

The histories, techniques, and limitations of the three most commonly used strategies are discussed in the following chapter. This is not intended to be an all-inclusive list. Rather, it seeks to describe in detail the devices and techniques that are most commonly encountered in everyday clinical practice.

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Pulmonary Artery Catheterization

History

Prior to the 1970s, the only way to reliably observe and measure the properties of the central circulation was via semi-rigid right heart catheterization. This technique was invasive and required guidance under fluoroscopy. The procedure was technically difficult and required skill with catheter and guidewire manipulation. As such, it was not appropriate for routine monitoring of critically ill patients in the intensive care unit. However, in August of 1970, Jeremy Swan and William Ganz published a description of a flow-directed balloon-tipped catheter that could be placed without the use of selective catheterization under fluoroscopy [1]. The catheter design was the result of the casual observation that yachts in the waters off of Santa Monica, California rigged with a spinnaker type of sail performed better than those without [2]. The development of this technique made right heart catheterization and cardiac output monitoring possible at the bedside in the intensive care unit (ICU).

Technique

Placement of a pulmonary artery (PA) catheter requires access to the central venous circulation. While this can technically be obtained at any site, subclavian or internal jugular access is usually preferred. Ideally, access is obtained via the right internal jugular vein, as the route to the right atrium is nearly straight, and this approach confers the lowest risk of complication.

Once central venous access is obtained, usually through an introducer catheter, the pulmonary artery catheter is prepared. This involves flushing the line and all ports, as well as testing the distal balloon to verify that it inflates and deflates properly. It is also important to ensure that the balloon inflates beyond the tip of the catheter, thereby protecting the

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_6

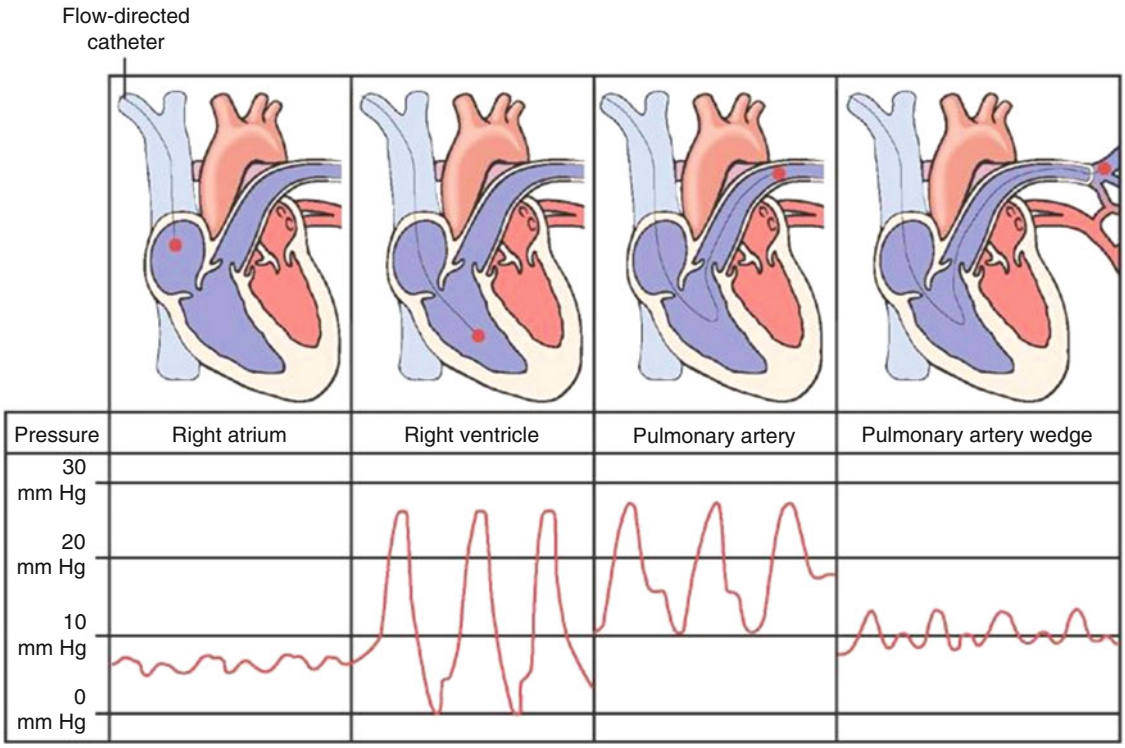

Fig. 6.1 Changes observed in the pressure waveform relative to catheter tip position within the heart. Since the catheter tip cannot be visualized during advancement, understanding how the pressure waveform changes is critical for safe and accurate placement. (From Urden LD, Stacy KM, Lough ME. Thelan's critical care nursing: diagnosis and management. 4th ed. St. Louis: Mosby; 2002, with permission.)

fragile walls of the pulmonary artery from injury during initial placement. Primed pressure tubing should be connected to the port corresponding to the most distal channel (i.e., the one terminating at the tip of the catheter) so that the pressure measurements and waveform accurately reflect the environment distal to the balloon and the catheter. Once prepared, the PA catheter is placed through the introducer catheter. The PA catheter is advanced slowly into the central circulation until respiratory variation is noted in the waveform (thus suggesting that the tip of the catheter has traversed the extrathoracic portion of the vein and entered thoracic cavity). The balloon is then inflated and advancement is continued. With the balloon inflated, the tip of the catheter is borne along with the flow of blood through the tricuspid and pulmonic valves and into the pulmonary outflow tract. Relative position of the tip of the catheter can be determined by observing the change in the pressure waveform transduced through the tip of the catheter (Fig. 6.1).

Once the waveform matches the pulmonary artery occlusion (or "wedge") pressure, the balloon is deflated and the PA catheter is secured in position. When pulmonary artery occlusion pressure (PAOP) measurements are necessary, the balloon is briefly reinflated to allow for calculation at the end of the respiratory cycle. Care must be taken to minimize the number and duration of these measurements, as recurrent or prolonged balloon inflation increases the risk of pulmonary infarction and pulmonary artery injury.

PA Catheter Measurements

When properly positioned, the PA catheter provides a number of directly measured and indirectly derived parameters (Table 6.1).

Additionally, some catheter designs may provide information about continuous mixed venous oxygen saturation and right ventricular end diastolic volume/ejection fraction.

Determining Cardiac Output

Prior to the advent of the modern pulmonary artery catheter, few methods were available to directly measure cardiac output. One method involved right heart catheterization and laborious calculation using the direct Fick method. This required determination of a patient's oxygen consumption (usually using a spirometer), as well as the oxygen concentrations of arterial (oxygen-rich) and mixed venous (oxygen-poor) blood. With this information, cardiac output could be calculated using the equation $\dot{V}O_2 = (CO \times C_a) - (CO \times C_v)$.

Alternatively, cardiac output can be determined using a dilutional technique. By injecting a known volume and concentration of indicator into the central circulation and then measuring the concentration of that indicator over time at a downstream location, cardiac output can be measured by determining the area under the time/concentration curve.

Table 6.1 Measured and derived values from a pulmonary artery (PA) catheter

Direct measurements	Derived parameters
CVP	SV
PAP	SVR
PAOP	PVR
$S\nabla O_2$	$\dot{D}O_2$
Q_T or Q_T*	$\dot{V}O_2$

CVP central venous pressure, *PAP* pulmonary artery pressure, *PAOP* pulmonary artery occlusion ("wedge") pressure, $S\nabla O_2$ mixed venous oxygen saturation, *QT* cardiac output, *QT** cardiac index, *SV* stroke volume, *SVR* systemic vascular resistance, *PVR* pulmonary vascular resistance, $\dot{D}O_2$ systemic oxygen delivery, $\dot{V}O_2$ systemic oxygen utilization

A variety of different indicators have been used for the purpose of determining cardiac output (e.g., hypertonic saline, indocyanine green, iodide, lithium), each with its own accuracy, benefits, and drawbacks.

Today, temperature is the most common indicator used in determining cardiac output (the thermodilution method). Using a known volume of room temperature crystalloid solution injected through the proximal port (usually positioned at the right atrium), a time/temperature curve can be generated as the relatively cooler crystalloid passes a thermistor in the downstream tip of the catheter. Computerized software is used to determine the area under the curve and, thereby, the cardiac output. More recently, a related technique has been employed to measure cardiac output continuously. In specially designed PA catheters, a proximal filament is used to heat the blood intermittently. By monitoring the amount of current supplied to the proximal filament and the temperature of the blood downstream at the thermistor, the average flow of blood across the system can be estimated [3, 4]. Both the bolus and continuous thermodilution methods have been well validated, and bolus thermodilution is considered to be the "gold standard" technique for determining cardiac output today.

Interpretation

Once the catheter has been appropriately positioned and the data from the central circulation gathered, it must be interpreted. Different types of shock affect the heart and blood vessels differently. For example, in neurogenic shock, a loss of sympathetic tone causes a loss of systemic vascular tone resulting in a decrease in the arterial blood pressure. However, this same loss of sympathetic tone impairs the body's usual compensatory mechanism of increased heart rate and contractility. In this setting, cardiac output declines and tissue oxygenation is impaired. Conversely, early stages of septic shock are associated with massive systemic vasodilatation and impaired tissue oxygenation but an *increase* in cardiac output. The ability to differentiate between types of shock or identify coincident competing forms of shock (e.g., the presence of tamponade physiology in the presence of cardiogenic shock following revascularization surgery for myocardial infarction) in critically ill patients provides a major advantage and minimizes unnecessary or potentially harmful treatment modalities. To be effective, a clinician must understand the normal ranges for selected hemodynamic data (Table 6.2) and be able to extrapolate from an underlying knowledge of how the cardiovascular system is affected by different types of shock (Table 6.3).

Table 6.2 Normal ranges for hemodynamic variables

Parameter	Normal range
CVP	0–6 mmHg
Right ventricular systolic pressure	20–30 mmHg
Right ventricular diastolic pressure	0–6 mmHg
PAOP	6–12 mmHg
Systolic arterial pressure	100–130 mmHg
Diastolic arterial pressure	60–90 mmHg
MAP	75–100 mmHg
Q_T	4–6 L/min
Q_T*	2.5–3.5 L min^{-1} m^{-2}
SVR	800–1400 dyne s cm^{-5}

CVP central venous pressure, *PAOP* pulmonary artery occlusion (or "wedge") pressure, *MAP* mean arterial pressure, *QT* cardiac output, *QT** cardiac index, *SVR* systemic vascular resistance

Table 6.3 The effect of different types of shock on cardiovascular properties measured by the pulmonary artery catheter

Type of shock	CVP	PAOP	Q_T	SVR
Hemorrhagic	↓	↓	↓	↑
Septic	↓	↓	↑	↓
Neurogenic	↓	↓	↓	↓
Pulmonary embolism	↑	Normal	↓	↑
Cardiac tamponade	↑	↑	↓	↑

CVP central venous pressure, *PAOP* pulmonary artery occlusion pressure, *QT* cardiac output, *SVR* systemic vascular resistance
From

Limitations

Despite the wealth of information provided by a pulmonary artery catheter, it has not consistently been demonstrated to improve outcomes. The PAC-Man study, a prospective, randomized trial published in The Lancet in 2005, concluded that there was no difference in outcomes (including hospital mortality and 28-day mortality) in a group of over 1000 medical and surgical ICU patients [5]. Likewise, a 2006

JAMA meta-analysis of thirteen randomized, controlled trials involving over 5000 patients failed to demonstrate a benefit in PA catheter placement [6]. An even larger meta-analysis (5686 patients) published by the Cochrane Collaboration in 2013 concluded that placement of PA catheters did not alter mortality, hospital or ICU lengths of stay, or cost [7]. In fact, due to the inherent risks involved in placing PA catheters and the tendency of clinicians to misinterpret the data, some investigators have suggested that PA catheter placement might actually be associated with *worse* outcomes. A prospective, multi-institutional cohort study published in JAMA in 1996 showed an increase in the mean cost and 30-day mortality when PA catheters were used [8].

One potential criticism of these studies is that the insertion of a PA catheter alone does not improve outcome. Rather, it is the physician interpretation of the variable(s) derived from the catheter and the subsequent change in management that has the potential to impact patient care. While the above reference studies did not demonstrate improved outcomes, it is difficult to know if this was solely due to PA catheter insertion or the subsequent interventions (or lack of interventions) performed by the clinician. One consequence of these studies has been a marked decrease in the routine use of PA catheters in the ICU. However, in experienced hands these catheters can still provide useful information. In the wake of this downfall, physicians have explored a variety of invasive and semi-invasive monitoring alternatives, including pulse contour analysis and transesophageal echocardiography.

Pulse Contour Analysis

History

The rise and fall of the arterial blood pressure around a mean value is caused by the blood ejected from the heart during the cardiac cycle [9]. The magnitude of the difference between the systolic and diastolic pressures (i.e., the pulse pressure) varies directly with the volume of blood being ejected (i.e., the stroke volume). Simply, larger volumes of blood ejected from the heart during systole result in larger differences between the systolic and diastolic blood pressures. If one can calculate the stroke volume given the variation between the systolic and diastolic blood pressure, cardiac output can be determined.

This concept is ultimately an expansion of the *Windkessel* (loosely translated from German as "air chamber") theory, which was first articulated by Otto Frank in 1899 [10, 11]. It is drawn from observations that the elastic proximal aorta is similar in some ways to air chambers used in water pumps on eighteenth century fire engines [12]. Both function like capacitors in the way that they absorb the energy from the forward flow of fluid during the pumping phase (systole) and then use that energy to augment the continuous forward flow of fluid during the filling phase (diastole). Several assumptions are made in this theory:

1. The aorta functions like an elastic reservoir that fills only during systole
2. Drainage from the aorta occurs during both systole and diastole
3. Drainage from the aorta occurs more slowly than filling due to the resistance of the peripheral arteries

Windkessel was expanded by Erlanger and Hooker in 1904, who suggested that the pulse pressure is proportional to the stroke volume [9]. After realizing that the relationship between stroke volume, pulse pressure, and aortic compliance is not a linear one, the Windkessel theory was modernized to propose that the *waveform* of the pressure in the aorta during systole varies with the volume of blood being ejected from the heart.

Modern Application

The specific challenge in moving this theory from concept to practical application resides in developing a mathematical formula that accurately translates the pulse pressure and contour to cardiac stroke volume. Initial attempts at developing a mathematical model were the result of work published by Otto Frank himself. His model uses two terms: one for arterial resistance and one for compliance (a so-called two-element Windkessel). However, the two-element Windkessel model does not perform well when compared to indicator dilution methods of measuring cardiac output. Until the 1970s, attempts to define a linear relationship between pulse pressure and stroke volume were unsuccessful, largely due to the later realization that their relationship to the compliance of the aorta is not a linear function (i.e., the compliance of the aorta at a high blood pressure is less than at a low blood pressure). Improved techniques in correcting for the nonlinear compliance paved the way for the discovery that integrating the area under the systolic arterial pressure curve provided better correlation with the stroke volume [13]. The technique was further refined in the 1969 to include a third Windkessel element (characteristic aortic impedance) and again in 1999 to include a fourth element (total arterial inertance) [14, 15]. Due to the inherent and increasing complexity of these mathematical models, it was not until the development of the microprocessor in the 1970s that minute-to-minute variations in the arterial pressure waveform could be interpreted rapidly enough to offer useful hemodynamic monitoring.

Technique

Measurement of the arterial pulse contour requires only insertion of a standard peripheral arterial catheter, most commonly using a percutaneous Seldinger technique in the radial or femoral artery. Once the catheter is placed, it is connected to and transduced by one of a number of commercially available devices. Each device uses its own proprietary algorithm to model the pulse contour. Each algorithm makes some estimation of the arterial compliance, the second element in the Windkessel model. This is accomplished either by calibrating the device externally using indicator dilution or by using a table of "normal" biometric values obtained from extensive cadaver study. Every device generally provides continuous estimations of the stroke volume, cardiac output, and systemic vascular resistance.

Externally calibrated devices include LiDCO-Plus® (LiDCO), PiCCO® (Pulsion Medical Systems), and VolumeView® (Edwards Lifesciences). PiCCO® and VolumeView® use transpulmonary thermodilution for calibration, which requires concomitant central venous catheterization for delivery of the indicator. LiDCO-Plus®, however, uses lithium ion indicator dilution and does not require central venous catheterization [16].

"Uncalibrated" or "autocalibrated" devices include LiDCO-rapid® (LiDCO), ProAQT® (Pulsion Medical Systems), MostCare® (Vytech), and FloTrac® (Edwards Lifesciences) [9]. Uncalibrated devices tend to be somewhat less reliable, especially when used in critically ill patients [17]. Reliability is further degraded in the presence of significant valvular disease or dramatic changes in vasomotor tone [18, 19]. As a result, uncalibrated devices are generally felt to be less accurate than their externally calibrated counterparts [20].

Limitations

The major drawback to pulse contour analysis remains the accuracy. Since each device must make some kind of estimation of the arterial compliance (a variable that cannot be directly measured in vivo), minute-to-minute changes in the arterial compliance (i.e., by administration of vasoactive medications) can confound these estimates and thereby the estimation of cardiac output. When evaluating accuracy in the literature, pulse contour analysis is usually compared to thermodilution. Unfortunately, thermodilution itself is an imperfect measurement, as it carries an inherent percentage error of ±10–20 % [21]. However, thermodilution is the most accurate measurement currently available and is generally accepted as the gold standard.

In evaluating new minimally invasive cardiac output monitoring devices (e.g., pulse contour analysis), a threshold for accuracy was proposed by Critchley and Critchley in 1999. Their meta-analysis study established a semi-arbitrary threshold of percentage error ±30 %. In short, to be considered accurate, cardiac output measurements obtained by a pulse contour analysis device should agree with the measurements obtained by thermodilution to within ±30 %. However, evaluation of multiple pulse contour devices in a variety of clinical settings demonstrates an average percentage error of ±41.3 %, which is outside the established threshold [22]. Additionally, since each device utilizes a proprietary algorithm, there is significant inter-device variability [23].

Transesophageal Echocardiography

History

Transesophageal echocardiography (TEE) has been a well-established method of monitoring hemodynamics in the operating room during cardiac surgery since the 1980s. However, early sonography equipment was complicated and expensive, the image resolution was relatively poor, and the sonographic technique required extensive and specialized training. For these reasons, transesophageal echocardiography was too cumbersome for routine hemodynamic monitoring in the ICU. However, TEE has been demonstrated to provide important hemodynamic data that is not appreciated in the pressure measurements obtained from a pulmonary artery catheter. Importantly, because pressure measurements are only an indirect measure of the volume of a chamber, the true volume status may vary significantly [24].

Despite the limitations, TEE has occasionally found its way into the intensive care unit for evaluation of the critically ill over the last two decades. For the most part, these are described in smaller pilot studies performed at single centers. For example, a 2005 study evaluated the use of TEE in 25 trauma patients with ongoing hypotension in the absence of surgical bleeding. The majority had pulmonary artery catheters already indwelling. Echocardiography demonstrated inadequate preload in about half of the patients, despite large-volume resuscitation and normal pulmonary artery occlusion pressures. The study also found that the information determined by TEE resulted in alterations in resuscitation strategies in about two-thirds of the patients [25]. Similarly, TEE was demonstrated to provide new and clinically significant diagnoses in 17 patients in a 1995 study of 45 mixed medical and surgical ICU patients with unexplained and sustained hypotension [26]. In fact, this very theme was echoed yet again by a larger study of 255 mixed medical and surgical ICU patients where TEE findings led to novel diagnoses and significant changes in management in about 32 % of all TEE studies [27].

As sonographic technology improves, however, newer generations of ultrasounds display images with improved resolution using smaller machines and even smaller transducers.

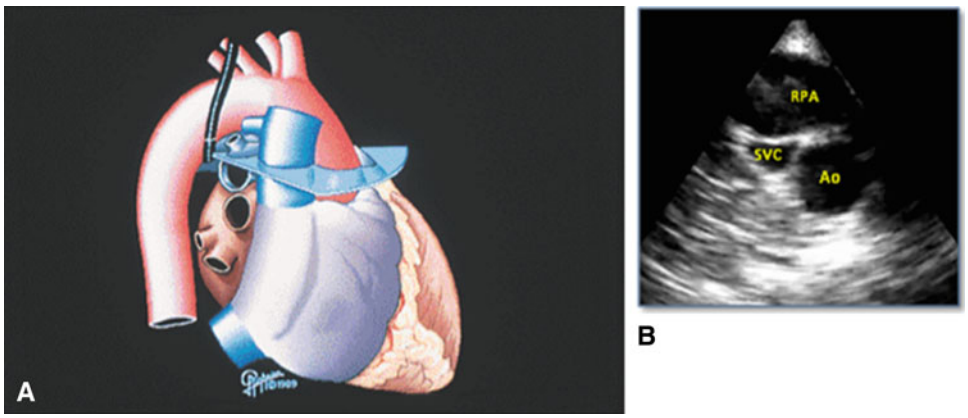

Fig. 6.2 (**a** and **b**) Superior vena cava acoustic window as seen by the ultrasound probe. (**a**, From Nanda NC, Domanski MJ, Atlas of transesophageal echocardiography. Philadelphia: Lippincott Wolters Kluwer; 2007, with permission; **b**, from Hastings HM. Transesophageal echocardiography: guided hemodynamic assessment and management. ICU Director. 2012;3:38–41, with permission.)

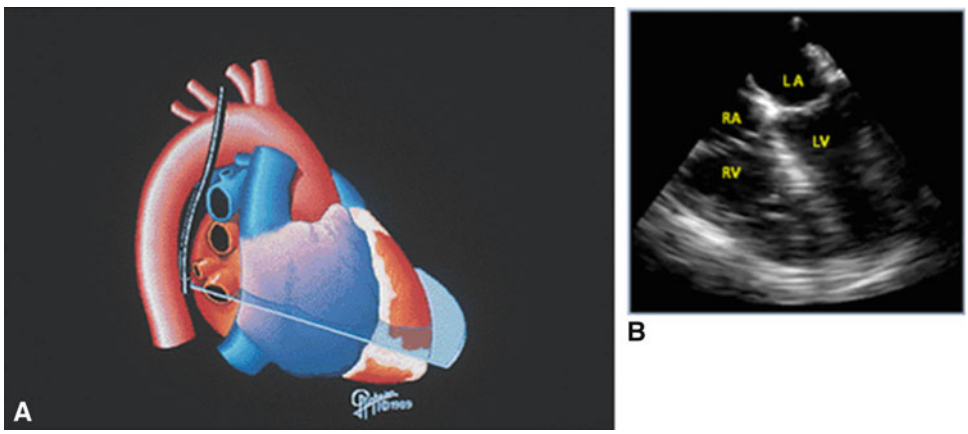

Fig. 6.3 (**a** and **b**) Four chamber acoustic window as seen by the ultrasound probe. (**a**, From Nanda NC, Domanski MJ. Atlas of transesophageal echocardiography. Philadelphia: Lippincott Wolters Kluwer; 2007, with permission; **b**, from Hastings HM. Transesophageal echocardiography: guided hemodynamic assessment and management. ICU Director. 2012;3:38–41, with permission.)

Recently, flexible, disposable TEE probes roughly the size of an adult nasogastric tube have been developed, which provide images with sufficient resolution for hemodynamic monitoring (ClariTEE®, ImaCor, Inc.). These disposable probes can be left indwelling for up to 72 h, providing continuous cardiac and hemodynamic monitoring.

Technique

Whether using a standard, reusable ultrasound transducer or the indwelling, disposable transducer, placement is generally done blind in the manner of orogastric tube placement. For this reason, there is a small risk of trauma related to placement, including injury to the hypopharynx and piriform sinuses, esophagus, and stomach [28]. The presence of naso/orogastric catheters or feeding tubes can obstruct passage of the transducer or provide interference during image acquisition.

Acoustic Windows

Once positioned within the esophagus, a brief cardiac examination can be performed that focuses on global cardiac function and volume status (a hemodynamic TEE or hTEE exam). A full cardiac examination can also be performed; however, this exam is time-consuming and requires significant additional training. In the hTEE exam, three standard acoustic windows (or views) are obtained. The superior vena cava window allows for evaluation of the cross-sectional SVC diameter during the cardiac cycle. Increased variability in SVC diameter over the cardiac cycle suggests responsiveness to fluid resuscitation (Fig. 6.2). The mid-esophageal four chamber window provides a global cardiac picture and allows for comparisons to be made in the sizes of the atria and ventricles (Fig. 6.3). It also provides an overview of global systolic and diastolic function. The transgastric short axis window offers a cross-sectional view of the ventricles and allows for estimation of the ventricular ejection fraction (Fig. 6.4).

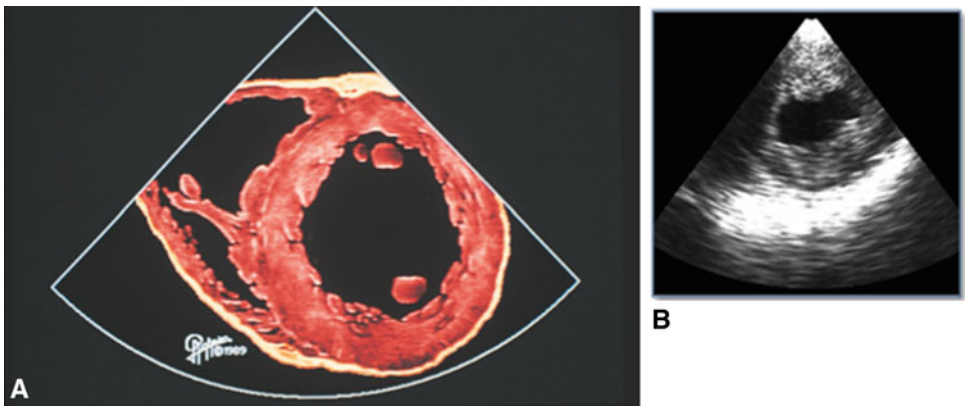

Fig. 6.4 (**a** and **b**) Transgastric short axis acoustic window as seen by the ultrasound probe. (**a**, From Nanda NC, Domanski MJ. Atlas of transesophageal echocardiography. Philadelphia: Lippincott Wolters Kluwer; 2007, with permission; **b**, from Hastings HM. Transesophageal echocardiography: guided hemodynamic assessment and management. ICU Director. 2012;3:38–41, with permission.)

Validation

Validation studies for indwelling TEE are only just beginning to appear in the literature. Generally, these are studies of small cohorts of patients at single centers. No robust, multicenter study of indwelling TEE has been published to date. However, there are increasing numbers of retrospective cohort studies that demonstrate an evolving role for TEE in the critically ill patient for the purpose of hemodynamic monitoring. In one recent study, 148 echocardiographic examinations were made in 55 ICU patients at a single center. The 14 intensivists, none of whom had prior training in TEE, were provided a 6-h course in performing hTEE exams. Their interpretations of the images were compared to those of an experienced cardiologist with specialized TEE training. The study found good inter-reliability between the intensivists and the expert cardiologist [29].

Limitations

First, transesophageal echocardiography is semi-invasive, not unlike endoscopy. For this reason, it is generally not appropriate for an unstable patient who is not already intubated and sedated. Most awake patients do not tolerate the repetitive manipulation of a probe within the esophagus well. For this reason, monitoring techniques like pulmonary artery catheterization or pulse contour analysis are probably more appropriate in this patient subset. Second, as with all ultrasound applications, results are user-dependent. Probe placement, image acquisition, and accurate interpretation are directly impacted by the comfort and experience of the clinician. Furthermore, measuring cardiac output (which is not generally included in the brief hemodynamic exam) is cumbersome and difficult and requires significant additional expertise [30]. Finally, there are no strong, prospective studies that demonstrate either equivalence to or superiority over traditional hemodynamic monitoring techniques (i.e., with a pulmonary artery catheter). As with all of the techniques described in this chapter, TEE has not been shown to specifically improve outcomes or affect overall mortality.

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Early Management of Sepsis, Severe Sepsis, and Septic Shock in the Surgical Patient

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Michelle H. Scerbo and Laura J. Moore

Despite advances in surgical critical care, sepsis continues to be a common and serious problem. It is currently the leading cause of death in non-cardiac intensive care units (ICUs) and the tenth leading cause of death in the USA [1]. Surgical patients account for nearly one-third of these sepsis cases [2]. When septic shock occurs in surgical patients, it has an associated mortality of 39 % in emergent cases and 30 % in elective cases [3]. It is estimated that in the USA, there are greater than 1.1 million cases of sepsis per year at an annual cost of $24.3 billion and 17 % of all in-hospital deaths [4, 5]. The incidence of sepsis among hospitalized patients continues to increase as the population ages, with the rate of sepsis related hospital stays increasing by 153 % from 1993 to 2009 [6]. The current incidence of severe sepsis among hospitalized patients in the USA is 208 cases/100,000 patients [7] with an associated mortality rate higher than 30 % [2]. But subsequent studies have shown this estimate to be low, with increases in sepsis rates subsequently reported to be as high as 10 % per year [8, 9]. These epidemiologic studies document that severe sepsis remains a major challenge and an increasing burden on healthcare systems worldwide.

Among surgical patients, sepsis is a leading cause of morbidity and mortality. Surgical patients account for nearly one-third of sepsis cases in the USA, as determined in a large epidemiologic study from Angus et al. [2]. An analysis of the National Surgical Quality Improvement Project (NSQIP) Database determined that sepsis and septic shock are ten times more common than perioperative myocardial infarction and pulmonary embolism [10]. Risk factors for both the development of sepsis and death from sepsis included age older than 60 years, the need for emergency surgery, and the presence of comorbid conditions. Colon perforation was the predominant source of sepsis, and the incidence of sepsis was highest among patients requiring emergency surgery. The development of septic shock was associated with a 39 % mortality rate among emergent surgical patients and a 30 % mortality rate among elective surgical patients [3].

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Definition of Sepsis, Severe Sepsis, and Septic Shock

A clear and accurate definition of sepsis is essential for clinicians and researchers. A standard definition allows for the identification of patients, leads to a better understanding of the disease process, and facilitates clinical research. The sepsis syndrome was first defined in the literature by Roger Bone in 1989 [11]. Subsequently, the American College of Chest Physicians and the Society of Critical Care Medicine Consensus Conference in 1991 defined the systemic inflammatory response syndrome (SIRS) (Table 7.1) and multiple organ dysfunction syndrome (MODS) [12]. A second consensus conference was convened in 2001 to revise the original definitions in response to ongoing criticism from experts in the field. The updated consensus conference definitions included an expanded list of the signs and symptoms of sepsis [13]. While the definitions included in the 2001 update are widely accepted, they do not specifically define the concept of *surgical* sepsis. Additionally, the consensus conference definitions remain nonspecific and allow for some variability, especially with regard to defining organ dysfunction.

Definition of Surgical Sepsis

To better define the categories of sepsis, severe sepsis, and septic shock with regard to the surgical patient, we have

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_7

Table 7.1 SIRS criteria

Systemic inflammatory response syndrome (SIRS) criteria
Two or more of the following criteria must be present:
• Body temperature less than 36 °C or greater than 38 °C
• Heart rate greater than 90 beats per minute
• Tachypnea, with greater than 20 breaths per minute; or, an arterial partial pressure of carbon dioxide less than 4.3 kPa (32 mmHg)
• White blood cell count less than 4000 cells/mm^3 (4×10^9 cells/L) or greater than 12,000 cells/mm^3 (12×10^9 cells/L); or the presence of greater than 10 % immature neutrophils (band forms)

modified the American College of Chest Physician/Society of Critical Care Medicine Consensus Conference definitions. We have defined *surgical sepsis* as systemic inflammatory response syndrome (SIRS) plus an infection requiring surgical intervention for source control or SIRS plus an infection within 14 days of a major surgical procedure. Major surgical procedure is defined as any procedure requiring general anesthesia for >1 h.

Severe sepsis is defined as SIRS plus infection plus acute organ dysfunction. Qualifications of acute organ dysfunction are defined as follows:

1. Neurologic: Glasgow Outcome Score (GCS) <13 upon recognition of sepsis or deteriorating GCS to <13 during first 24 h.
2. Pulmonary: PaO_2/FiO_2 ratio <250 (<200 if lung is the primary site of infection) and pulmonary capillary wedge pressure (PCWP) (if available) not suggestive of fluid overload.
3. Renal (one of the following): urine output (UOP) <0.5 ml/kg for ≥1 h despite adequate volume resuscitation, increase in serum creatinine ≥0.5 mg/dl from baseline (measured within 24 h of starting sepsis resuscitation) despite adequate volume resuscitation or increase in serum creatinine ≥0.5 mg/dl during first 24 h of sepsis management despite adequate volume resuscitation. Adequate volume resuscitation is defined as a minimum intravenous fluid infusion of 20 ml/kg/ideal body weight (IBW) or central venous pressure (CVP) ≥8 mmHg or PCWP ≥12 mmHg.
4. Coagulation (one of following): INR >1.5, platelet count <80,000 or ≥50 % decrease platelet compared to 24 h before instituting sepsis resuscitation or in the 24 h after starting sepsis resuscitation in the absence of chronic liver disease.
5. Hypoperfusion: lactate level >4 mmol/l. Septic shock is defined as SIRS plus infection plus acute cardiac dysfunction. Acute cardiac dysfunction is defined by the requirement of vasopressors to increase mean arterial pressure (MAP) ≥65 mmHg despite intravenous fluid (IVF) challenge ≥20 ml/kg/IBW of isotonic crystalloid infusion or CVP ≥8 mmHg or PCWP ≥12 mmHg.

Initial Assessment and Evaluation of the Septic Patient

Early Identification of Sepsis

Sepsis is a major cause of morbidity and mortality in general surgery patients [3]. Early signs of sepsis are often missed and subsequent interventions are delayed as bedside nurses and other team members focus on multiple priorities and tasks involved with patient care [14]. Many of the early signs and symptoms of sepsis are often subtle and in the surgical population may be attributed to other problems. For example, oliguria is commonly seen in surgical patients and is often attributed to under resuscitation in the operating room or volume loss from the gastrointestinal tract. However, oliguria can also be an early finding in patients with sepsis. Alterations in mental status are often attributed to narcotic administration or ICU psychosis, but can also be an early warning sign of sepsis. Likewise, acute hypoxia on the surgical wards spurs a workup for pulmonary embolism but acute hypoxia may herald the onset of severe sepsis or septic shock.

Identifying patients in the early stages of sepsis is imperative, but remains difficult. Progression to septic shock is associated with prohibitively high mortality (>30 %) despite aggressive interventions [15]. Considering the adverse outcomes associated with this progression, the benefit of routine, accurate screening of patients for sepsis quickly becomes apparent. In an attempt to increase the early identification of sepsis, a sepsis screening tool for use in the author's surgical ICU was developed (Fig. 7.1) [16]. The initial experience with the implementation of this mandatory sepsis screening tool in the SICU showed promising results. The screening tool yielded a sensitivity of 96.5 %, a specificity of 96.7 %, a positive predictive value of 80.2 %, and a negative predictive value of 99.5 %. Subsequent expansion and statistical validation of the screening on the surgical floor yielded similar results [14]. Since implementing mandatory sepsis screening, a significant decline in the author's institution severe sepsis and septic shock related mortality has been observed (from 35.1 to 23.3 %). Regardless of the method utilized to screen patients, all members of the patient care team must be aware and vigilant in the detection of the early signs and symptoms of sepsis.

Initial Assessment

A clinical suspicion for the presence of sepsis should prompt further evaluation of the patient. This initial evaluation should focus on determining the degree of physiologic derangement exhibited by the patient. It is especially important to assess for the presence and degree of tissue hypoperfusion.

There are several clinical and laboratory variables that can be used to evaluate the state of tissue perfusion. The following are indicators that the patient is experiencing tissue hypoperfusion: (1) urine output <0.5 ml/kg of ideal body weight, (2) mean arterial pressure <65 mmHg, (3) Glasgow Coma Score <12, and (4) serum lactate ≥4 mmol/l. The detection of tissue hypoperfusion should prompt aggressive resuscitative measures focused on restoring tissue perfusion. Based upon the definitions outlined previously those patients that do not have evidence of tissue hypoperfusion would fall into the category of sepsis. Those patients that do have evidence of tissue hypoperfusion would be categorized as having severe sepsis/septic shock. The initial resuscitation and management of these patients is discussed as follows.

Initial Resuscitation of Sepsis

The initial resuscitation phase of sepsis should begin immediately upon recognition of sepsis and should not be delayed until the patient is transferred to a higher level of care. The goals of the resuscitation include restoration of intravascular volume, diagnosis of the source of infection, initiation of broad spectrum antimicrobial therapy, and source control. Many institutions have developed order sets that specifically address each of these issues. The utilization of standardized protocols for the initial management of sepsis has been demonstrated to improve patient outcomes in multiple settings [17–22].

The major tenets of initial resuscitation can be initiated in any area of the hospital and should not be delayed pending transfer to the ICU. Establishing intravenous (IV) access is a critical first step as this allows for the administration of resuscitative intravenous fluid and antimicrobials. For those patients without evidence of tissue hypoperfusion, a large bore peripheral IV should be sufficient. In the event that peripheral IV access is not attainable, a central venous line should be inserted in a timely fashion.

Fluid resuscitation should be guided with the following goals in mind:

1. CVP (if available) of 8–12 mmHg in non-intubated patients and a target CVP of 12–15 mmHg in mechanically ventilated patients [23]
2. MAP of ≥65 mmHg [24]
3. Urine output of ≥0.5 ml/kg/h

a

SICU Bedside Nurse SIRS score

patient label

04162007

current heart rate _____ time _____
T min _____ time _____
T max _____ time _____
current resp rate _____ time _____
latest WBC count _____ date, time _____

points	0	1	2	3	4
heart rate (bpm)	70 - 109		55 – 69 110 – 139	40 - 54 140 - 179	≤ 39 ≥ 180
T (°C) min max	36 – 38.4	34 – 35.9 38.5 – 38.9	32 – 33.9	30 – 31.9 39 – 40.9	≤ 29.9 ≥ 41
resp rate (br / min)	12 - 24	10 – 11 25 - 34	6 - 9	35 – 49	≤ 5 ≥ 50
latest WBC (kcell / mm^3)	3 – 14.9	15 – 19.9	1 – 2.9 20 – 39.9		≤ 1 ≥ 40
score (total points)					

If SIRS score ≥ 4, then notify SICU Nurse Practitioner to complete sepsis screening form.

□ SICU
□ overflow □ MICU □ NICU □ CCU

Completed by: _____, RN Date / time: _____

Fig. 7.1 Sepsis screening tool. (**a**) Sepsis screening score. (**b**) Midlevel/Physician sepsis screening assessment for source of infection. *SICU* Surgical Intensive Care Unit, *SIRS* Systemic Inflammatory Response Syndrome, *resp* respiratory, *WBC* white blood cell count, *MICU* Medical Intensive Care Unit, *NICU* Neuro Intensive Care Unit, *CCU* Cardiac Care Unit, *PICC* peripherally inserted central catheter, *IV* intravenous, *art* arterial, *ARDS* acute respiratory distress syndrome, *UTI* urinary tract infection

b

SICU Nurse Practitioner/Resident Physician Sepsis Screening

1. Vascular access? Yes No

type	dialysis	triple / quad	PICC	port	tunneled	other (IV, art)
date placed						
site						
local finding						
blood culture finding						

Suspicion of: line infection? Yes No

2. Clinical pulmonary infection score (CPIS)

Variable	points	score
temperature (°C) time (hhmm)		
36.5 – 38.4	0	
38.5 – 38.9	1	
>39.0 or <36.0	2	
blood leukocyte count (# per mm^3) time (hhmm)		
4,000 – 11,000	0	
<4,000 or >11,000	1	
tracheal secretions time (hhmm)		
small	0	
moderate	1	
large	2	
purulent (add 1 point if purulent)	+1	
oxygenation (PaO_2/FiO_2) time (hhmm)		
≥240 or presence of ARDS	0	
<240 and absence of ARDS	2	
chest radiograph time (hhmm)		
no infiltrate	0	
patchy or diffuse infiltrate	1	
localized infiltrate	2	

Intubated / mech vent support? Yes No

date intubated:

pneumonia? Yes No

3. Abdomen

recent abdominal surgery?	Yes	No
abdominal pain?	Yes	No
abdominal distention?	Yes	No
purulent drainage from surgical drains?	Yes	No
intolerance to enteral nutrition?	Yes	No

abdominal infection? Yes No

4. Skin / soft tissue

erythema / drainage from other surgical site?	Yes	No
site		

cellulitis / soft tissue infection? Yes No

5. Urinary tract

urinary catheter?	Yes	No
date placed		
latest urinalysis / urine culture results		

UTI? Yes No

6. Other site

site	

other infection? Yes No

Completed by: _____ Date / time: _____

Fig. 7.1 (continued)

4. Central venous ($ScvO_2$) oxygen saturation of ≥70 % or mixed venous (SvO_2) oxygen saturation of ≥65 %(if available) [25]

Per the guidelines outlined by the Surviving Sepsis Campaign, these endpoints of resuscitation should be achieved within 6 h of the recognition of sepsis [26].

In addition, a baseline serum lactate should be sent upon the identification of sepsis. A repeat serum lactate level should be sent 4 h later to monitor the progress of the initial resuscitation.

Fluid Resuscitation: Crystalloid Versus Colloid

Since the early 1940s, the restoration of intravascular volume has been embraced as a pivotal intervention in shock resuscitation. Considerable controversy has persisted since this time concerning the optimal resuscitation fluid to use, largely due to conflicted evidence within the literature. There are several essential differences between crystalloid (lactated ringers, normal saline) and colloid (albumin, hydroxyethyl starch, hypertonic saline) as resuscitation fluid. The volume of distribution of crystalloids is significantly larger than that of colloids. Because of this, the ratio of crystalloid to colloid infusion is approximately three to one. Proponents of crystalloid resuscitation cite improved expansion of the extracellular compartment, minimal risk of anaphylactoid reaction, replacement of volume loss with physiologically balanced solution, and decreased costs. Proponents of colloid resuscitation cite faster restoration of intravascular volume due to the decrease in volume required and reduced risk of interstitial edema secondary to the high oncotic pressure. If colloids are used for resuscitation, one must be particularly vigilant about monitoring cardiac filling pressures and avoiding fluid overload. Additionally, the expense and availability of albumin may be a factor dissuading use in some settings.

Trials Comparing Crystalloid to Colloid

There are no prospective, randomized controlled trials evaluating crystalloid versus colloid resuscitation specifically in surgical patients with sepsis. Further, no trial to date has clearly demonstrated the benefit of crystalloid over colloid or vice versa in any patient population, however all results vary based on study design and outcomes. The current trials that have evaluated crystalloids and colloids, either compared against each other or in addition to one another, for resuscitation of sepsis include the Colloids Versus Crystalloids for the Resuscitation of the Critically Ill (CRISTAL), Effects of Voluven on Hemodynamics and Tolerability of Enteral Nutrition in Patients with Severe Sepsis (CRYSTMAS), Saline versus Albumin Fluid Evaluation (SAFE), Volume Replacement with Albumin in Severe Sepsis (ALBIOS), Early Septic Shock Fluid Resuscitation (PRECISE), and Early Albumin Resuscitation during Septic Shock trials. It should be noted that these studies were conducted in both medical and surgical populations, with varying inclusion criteria, ranging from hypovolemic shock due to all causes (including sepsis) to specifically severe sepsis or septic shock (Table 7.2).

The CRISTAL trial randomized 2857 medical and surgical (~30 %) ICU patients with hypovolemic shock secondary to sepsis (54 %), trauma, or neither, to volume resuscitation with either colloids or crystalloids. The primary outcome of all-cause 28-day mortality was similar between the two groups. Colloids were associated with a reduction in all-cause 90-day mortality (30.7 % vs. 34.2 %; Number Needed to Treat 29). Although this suggests a lack of harm with the use of colloids as the resuscitation fluid in septic shock, the authors caution interpreting these findings as anything other than exploratory, mainly because of the null findings at 28 days [27]. The similar mortality outcomes were additionally found in the CRYSTMAS trial, conducted in 196 patients with septic shock, which demonstrated no difference in mortality with hydroxyethyl starch (HES) compared with 0.9 % Normal Saline (NS) (31 % vs. 25.3 %, $p=0.37$), however this study was underpowered to detect the 6 % difference in absolute mortality observed [28].

The SAFE study randomized 6997 medical and surgical (~43 %) ICU patients (18 % with severe sepsis) to receive either 4 % albumin or NS for fluid resuscitation. No difference in mortality was identified between the two groups (20.9 % vs. 21.1 %, Relative Risk 0.99 95 % Confidence Interval 0.91–1.09). Evaluation of the patients with severe sepsis revealed a non-significant trend towards reduced mortality in the albumin group (30.7 % versus 35.3 %; Relative Risk of death 0.87, 95 % Confidence Interval 0.74–1.02) [29]. Following the results from this subgroup analysis, the PRECISE trial (2012) was designed to evaluate the impact of 5 % albumin versus NS in early septic shock on 90-day mortality [30]. At the time of publication of this text, the PRECISE trial has been completed but results have not yet been published.

Trials Evaluating Addition of Colloid to Crystalloid

The trend of improved mortality with the use of albumin as adjunctive resuscitation fluid suggested by the SAFE study has been subsequently investigated in two trials. In the ALBIOS trial, 1818 medical and surgical (43 %) ICU patients with severe sepsis or septic shock were randomized to receive both 20 % albumin and crystalloid or crystalloid alone. The patients receiving albumin continued to receive daily IV albumin to maintain a goal serum albumin of ≥3 g/dL while both groups received crystalloid for further volume expansion as necessary. The authors found no difference in all-cause 28- or 90-day mortality, incidence of acute kidney injury, or duration of mechanical ventilation with the administration of albumin to maintain target serum levels, however the patients receiving albumin had a shorter duration of vasopressors or inotropes by 1 day (3 versus 4 days, $p=0.007$) [31]. The Early Albumin Resuscitation during Septic Shock study (France) was aimed to determine whether 3 days of

Table 7.2 Studies to date evaluating the use of crystalloid and colloid for ICU patients with severe sepsis and/or septic shock

Trial (year)	N, population	Inclusion criteria	Randomized groups	Primary outcome	Result—primary outcome	Result—secondary Outcomes						Result—subgroup analysis
						28-Day survival	90-Day mortality	Organ failure	MV	RRT	LOS	
SAFE (2004)	6997, ~43 % Surgical	Requiring IV fluids (18 % severe sepsis)	4 % Albumin versus 0.9 % NS	All-cause mortality at 28 days	ND		–	ND	ND	ND	ND	28-Day mortality in *severe sepsis*: 30.7 % versus 35.3 % (RR 0.87; 95 % CI 0.74–1.02; $P=0.09$)
CRYSTMAS (2012)	196, 27 % Surgical	Severe sepsis, requiring fluid resuscitation	6 % Hydroxyethyl Starch (HES) versus 0.9 % NS	Volume (mL) to achieve hemodynamic stability	HES: less volume required to reach hemodynamic stability (1379 ± 886 ml versus and 1709 ± 1164 ml, $p=0.02$)	ND in 28-day mortality	ND	Renal failure: ND				
CRISTAL (2013)	2857, ~30 % Surgical	Hypovolemic due to sepsis (54 %), trauma or other	Colloid versus Crystalloid	All-cause mortality at 28 days	ND		30.7 % versus 34.2 % NNT 29, ($p=0.03$)			ND		Sepsis: 27.8 % versus 29.0 % (HR 0.95; 95 % CI 0.78–1.10)
ALBIOS (2014)	1818, 43 % Surgical	Severe sepsis or septic shock	20 % Albumin to maintain serum albumin ≥3 g/dL versus no albumin	All-cause mortality at 28 days	ND		ND	ND	ND	ND	ND	Decreased time to suspension of vasopressors/inotropes (3 versus 4 days $P=0.007$)
Early Albumin Resuscitation during Septic Shock (2011)	(Completed, not yet reported)	Septic shock	20 % Albumin versus NS	All-cause mortality at 28 days								
PRECISE (not completed)			5 % Albumin versus NS	All-cause mortality at 90 days								

ND no statistical difference, *SAFE* Saline versus Albumin Fluid Evaluation, *CRYSTMAS* Effects of Voluven on Hemodynamics and Tolerability of Enteral Nutrition in Patients with Severe Sepsis, *CRISTAL* Colloids Versus Crystalloids for the Resuscitation of the Critically Ill, *ALBIOS* Volume Replacement with Albumin in Severe Sepsis, *PRECISE* Early Septic Shock Fluid Resuscitation, *IV* intravenous fluids, *NS* 0.9 % Normal Saline, *AD* absolute difference

Not all secondary outcomes are reported in this table

Table 7.3 Surviving sepsis campaign 2012 fluid therapy guidelines

Crystalloids should be used as the initial fluid of choice for the resuscitation of severe sepsis and septic shock (Grade 1B)
HES should not be used for fluid resuscitation of severe sepsis and septic shock (Grade 1B)
Albumin should be used in the fluid resuscitation of severe sepsis and septic shock when patients require substantial volume of crystalloid (Grade 2C)

Adapted from Dellinger RP et al. Surviving Sepsis Campaign: international guidelines for management of severe sepsis and septic shock, 2012. Intensive Care Med. 2013;39:165–228, with permission

20 % albumin compared to NS (100 ml/hour for 8 h) improves 28-day mortality. As of 2011, the trial has been completed, but outcomes had not been reported at the time of publication of this text [32].

Fluid Resuscitation: Current Consensus

While the benefit of colloids or crystalloids continues to be investigated, it is well understood that the use of hydroxyethyl starch (HES) solutions should be avoided. The 6S Trial is a multicenter, parallel-group, blinded trial in which 804 patients with severe sepsis were randomized to receive either 6 % HES 130/0.42 (Tetraspan) or Ringer's acetate. The 6 % HES group had increased 90-day mortality (51 % vs. 43 % $p=0.03$) and renal-replacement requirements (22 % vs. 16 % $p=0.04$). The increased need for renal replacement therapy in patients that received 6 % HES was further demonstrated in a trial randomizing 7000 patients to 6 % HES vs. 0.9 % normal saline (7.0 % vs. 5.8 %; Relative Risk 1.21; 95 % Confidence Interval 1.00–1.45; $p=0.04$) [33]. Finally, a Cochrane Review of 42 studies including 11,399 patients concluded that HES solutions increase the risk of acute kidney injury and the need for renal replacement therapy [34].

Therefore, initial fluid resuscitation of a patient with severe sepsis or septic shock should begin with a bolus of 30 mL/kg (IBW) of crystalloid. Albumin may be considered if the patient continues to have high volume requirements for resuscitation. HES should not be used for fluid resuscitation in severe sepsis and septic shock as it has been demonstrated to have an increased risk of death and the need for renal replacement therapy. A summary of the results of these trials and resulting Surviving Sepsis Campaign (2012) recommendations are outlined in Table 7.3.

Initial Resuscitation of Severe Sepsis and Septic Shock

For those patients presenting with severe sepsis and septic shock the timely correction of tissue hypoperfusion is critical. The concept of early goal directed therapy (EGDT) in severe sepsis and septic shock was initially developed and validated in the emergency department (ED) setting in a single-center trial [25]. The ED is frequently the point of entry for many septic patients into the hospital. Unfortunately, many of these patients may wait for prolonged periods of time in the ED. The end result is often a delay in the implementation of early sepsis resuscitation.

The implementation of EGDT has been shown to improve survival in patient presenting with severe sepsis and septic shock [20, 25, 35, 36]. The basic principles of EGDT therapy are to recognize tissue hypoperfusion and initiate therapies to reverse global tissue hypoxia by optimizing oxygen delivery. Tissue perfusion can be monitored by measuring mixed venous hemoglobin oxygen saturation (SvO_2), central venous hemoglobin oxygen saturation ($ScvO_2$), or peripheral muscle hemoglobin oxygen saturation (StO_2). An SvO_2 of ≤65 %, an $ScvO_2$ of ≤70 %, or an StO_2 of ≤75 % are considered indicators of tissue hypoperfusion. Once tissue hypoperfusion is identified, specific therapies should be instituted to reverse tissue hypoxia by restoring adequate perfusion. The factors affecting oxygen delivery are cardiac output (CO), hemoglobin ([Hb]), and percent arterial hemoglobin oxygen saturation (SaO_2). EGDT attempts to restore tissue perfusion by addressing these variables. The evidence-based Sepsis Resuscitation Bundle was established with a goal to accomplish all indicated tasks, 100 % of the time, within 6 h of the diagnosis of sepsis was established, and is used to assist with the administration of prompt resuscitation efforts in the treatment of sepsis (Table 7.4).

Table 7.4 Sepsis bundles: the goal is to perform all indicated tasks 100 % of the time within the first 6 h (Sepsis Resuscitation Bundle) or first 24 h (Sepsis Management Bundle) of the diagnosis of severe sepsis

Sepsis resuscitation bundle—(to be started immediately and completed within 6 h)
• Serum lactate measured
• Blood cultures obtained prior to antibiotic administration • Broad spectrum antibiotics administered within 3 h for ED admissions and 1 h for non-ED ICU admissions
• In the event of hypotension and/or lactate >4 mmol/L:
– Deliver a minimum of 30 ml/kg of crystalloid (or colloid equivalent)
– Apply vasopressors for hypotension not responding to initial fluid resuscitation to maintain mean arterial pressure (MAP) ≥65 mmHg
• In the event of persistent arterial hypotension despite volume resuscitation (septic shock) and/or initial lactate >4 mmol/L (36 mg/dl):
– Achieve central venous pressure (CVP) of ≥8 mmHg
– Achieve central venous oxygen saturation ($ScvO_2$) of ≥70 %[a]
Sepsis management bundle—(to be started immediately and completed within 24 h)
• Low-dose steroids administered for septic shock in accordance with a standardized ICU policy • Glucose control maintained ≥ lower limit of normal, but <150 mg/dl (8.3 mmol/L)
• For mechanically ventilated patients inspiratory plateau pressures maintained <30 cm H_2O

[a]Achieving a mixed venous oxygen saturation of 65 % is an acceptable alternative

To restore intravascular volume and enhance cardiac output, an initial crystalloid fluid bolus of 30 ml/kg of ideal body weight is recommended. This fluid bolus can be administered initially through existing peripheral IVs, however, placement of a central venous line for monitoring of CVP is recommended. An arterial line should be placed in patients with hypotension that do not rapidly respond to volume challenge. The use of noninvasive blood pressure monitoring for patients in septic shock often produces inaccurate measurements and should be avoided for titration of vasoactive medications. A Foley catheter should also be inserted to allow for close monitoring of urine output. Bladder pressures should be monitored in patients requiring aggressive volume loading.

The goals of resuscitation remain the same as those listed previously:

1. A target CVP (if available) of 8–12 mmHg in non-intubated patients and a target CVP of 12–15 mmHg in mechanically ventilated patients [23]
2. MAP of ≥65 mmHg [24]
3. Urine output of ≥0.5 ml/kg/h, and
4. Central venous ($ScvO_2$) oxygen saturation of ≥70 % or mixed venous (SvO_2) oxygen saturation of ≥65 % [25].

In the event that an $ScvO_2$ of ≥70 % or SvO_2 ≥ 65 % cannot be achieved with restoration of intravascular volume and mean arterial pressure of 65–90 mmHg, red blood cells should be transfused to achieve a hematocrit of ≥30 %.

Having achieved the goal CVP, the goal MAP, and the goal hematocrit, if there is still evidence of tissue hypoperfusion, inotropic agents should be administered to improve cardiac output. In patients presenting with septic shock, the initial fluid bolus may not restore their MAP to ≥65 mmHg. A repeat fluid bolus of 20 ml/kg of ideal body weight can be given to correct hypovolemia. However, transient vasopressors therapy may need to be initiated, even if volume resuscitation is still ongoing.

Vasopressor Therapy

Septic shock is primarily a vasodilatory shock, associated with a high cardiac output and a low systemic vascular resistance. Therefore, initial vasopressors therapy should be targeted at restoring vascular tone when adequate fluid resuscitation cannot maintain a goal MAP of at least 65 mmHg. Norepinephrine is primarily an α(alpha)-receptor agonist that promotes widespread vasoconstriction and has little effect on heart rate or stroke volume. Dopamine has dose dependent effects on α(alpha), β(beta), and dopaminergic receptors. The initial increase in blood pressure seen with dopamine is related to increasing cardiac output. At higher doses (>7.5 μ[mu]g/kg/min), dopamine does activate α(alpha)-receptors with resultant vasoconstriction. Both norepinephrine and dopamine were initially viewed as acceptable first-line agents for treatment of septic shock, however recent evidence has demonstrated norepinephrine to be superior to dopamine as it is associated with less cardiac arrhythmias [37]. An additional meta-analysis by Oba et al. of 2811 patients demonstrated an improvement in 28-day mortality with norepinephrine alone compared to dopamine for the treatment of hypotension in septic shock (Odds Ratio 0.8, 95 % Confidence Interval 0.65–0.99) [38].

In patients with septic shock that is refractory to norepinephrine, the addition of vasopressin may be beneficial. Vasopressin is a stress hormone that has vasoactive effects. The use of vasopressin is supported by recent work by Landry et al. who suggest that in states of septic shock there is a relative deficiency of vasopressin [39]. The administration of vasopressin in this patient population has been shown to improve responsiveness to catecholamines and potentially reduce the amount of catecholamine needed to maintain blood pressure [40]. The previously mentioned meta-analysis by Oba et al. additionally showed a mortality benefit of adjunctive vasopressin with norepinephrine compared with dopamine (Odds Ratio 0.69, 95 % Confidence Interval 0.48–0.98) [38].

The Vasopressin and Septic Shock Trial (VASST) randomized 779 patients in septic shock requiring norepinephrine (5 μg/min) for at least 6 h and at least one organ system dysfunction present for <24 h to vasopressin (0.01–0.03 U/min) versus higher dose norepinephrine (5–15 μg/min) [41]. No difference in 28-day or 90-day mortality was identified. In the prospectively defined stratum of less severe septic shock, the mortality rate was lower in the vasopressin group than in the norepinephrine group at 28 days (26.5 % versus 35.7 %, $p = 0.05$), which persisted to 90-day mortality (35.8 % versus 46.1 %, $p = 0.04$). In a post hoc analysis of the VASST study, it was identified that the combination of low-dose vasopressin and corticosteroids was associated with decreased mortality and organ dysfunction as compared with norepinephrine and corticosteroids [42]. Based on the results of studies to date, clinicians should consider the addition of low-dose continuous infusion vasopressin (up to 0.04 U/min) in individual septic shock patients who are still requiring high doses of vasopressors despite adequate resuscitation.

The authors therefore recommend initiating a vasopressin drip at a rate of 0.03 U/min in patients requiring norepinephrine infusion at ≥15 μg/min. The dose of vasopressin should not exceed 0.04 U/min because of the possibility of decreased cardiac output and myocardial ischemia at higher doses [43].

Phenylephrine, a central α-adrenergic vasoconstrictor, has been demonstrated to decrease stroke volume. For this reason, phenylephrine is only recommended when norepinephrine has caused serious arrhythmias or when target blood pressure is not maintained despite first-line vasopressor and inotrope therapy and the patient has maintained their cardiac output [26].

While most patients with sepsis initially present with increased cardiac output, a subset of patients will develop

myocardial depression from sepsis. The exact mechanism for this reversible myocardial dysfunction is still under investigation. B-type natriuretic peptide (BNP) is secreted in response to stretching of myocardium and is used clinically to assess volume overload and predict death in acute congestive heart failure. More recently, BNP has been demonstrated to be elevated in early septic shock and likewise predict death. We have recently shown that BNP increases with initial sepsis severity and is associated with early left ventricular (LV) dysfunction that is itself associated with later death [44]. Monitoring BNP in early sepsis to identify occult LV dysfunction may prompt earlier use of inotropes, which are not commonly used in early sepsis resuscitation. For those patients with suspected or known cardiac dysfunction, the addition of inotropic therapy is recommended. Dobutamine is the first-line agent for treatment of cardiac dysfunction in patients with sepsis [26]. The management of patients with a cardiac component to their shock state presents a unique challenge to the clinician since they require the titration of vasopressors and inotropic agents. In this subset of patients, the utilization of a pulmonary artery catheter can be useful. This allows for the specific titration of vasopressors based upon systemic vascular resistance and inotropic agents based upon cardiac output. There is no evidence to support increasing cardiac index to predetermined supranormal levels [45].

In summary, septic shock is a vasodilatory shock that results in an initial high cardiac output and decreased vascular resistance. The goal of vasopressor use in septic shock is to restore vascular tone. The first-line of therapy is norepinephrine, which is preferred over dopamine due to the decreased association of norepinephrine with cardiac arrhythmias. If the patient continues to be hypotensive, vasopressin can be helpful, up to a maximum dose of 0.04 U/min, as higher doses are associated with myocardial ischemia. The intensivist should be aware that persistent septic shock may result in myocardial depression, which may be detected with monitoring of BNP. Patients with identified myocardial depression may benefit from monitoring via a pulmonary catheter and ionotropic support with dobutamine. Finally, phenylephrine should be reserved for cases when norepinephrine has caused arrhythmias or the combination of vasopressor and ionotropic therapy fails to maintain target blood pressure despite adequate cardiac output.

Steroids in Septic Shock

The use of steroids and the definition and diagnosis of relative adrenal insufficiency in patients with septic shock has been debated for several decades. The adrenal gland produces sympathetic hormones and glucocorticoids, including cortisol. Cortisol has immunologic and anti-inflammatory effects including inhibition of many proinflammatory cytokines (IL-1, IL-2, IL-3, IL-6, INF-γ[gamma], and TNF-α[alpha]). Cortisol also stimulates the production of anti-inflammatory mediators such as IL-10 and decreases the local inflammatory reaction. Cortisol plays a vital role in maintaining vascular tone and endothelial integrity. Additionally, cortisol augments the vasoconstrictor effect of catecholamines. During critical illness, the normal physiologic response stimulates the adrenal glands resulting in a nearly sixfold increase in cortisol production. However, in septic shock, the capability of the adrenal gland to increase cortisol production may be blunted. Multiple factors contribute to this including high levels of circulating inflammatory cytokines, decreased glucocorticoid sensitivity of receptors, and suppression of the hypothalamic–pituitary–adrenal axis by various medications. The end result is a state of relative adrenal insufficiency, requiring exogenous catecholamines to maintain vascular tone.

Diagnosing Adrenal Insufficiency in Septic Shock

Relative adrenal insufficiency in critical illness can be defined as either a baseline total cortisol level of <10 μg/dL or a delta cortisol of ≤ 9 μg/dL after administration of 250 μg of cosyntropin (ACTH) [46]. Additionally, a random cortisol level of <18 μg/dL is an indication for initiating steroid therapy in a patient with shock [26].

While it had previously been a common practice to perform a low-dose cosyntropin stimulation test on all patients with septic shock as a means to identify those with relative adrenal insufficiency, this method has been abandoned due to its limited accuracy [47, 48], and the use of medications (i.e., etomidate) in septic shock that suppress the hypothalamic–pituitary–adrenal axis. Etomidate causes a transient (approximately 24 h) suppression of the hypothalamic–pituitary–adrenal axis [49], although the mortality impact of this transient adrenal insufficiency is not well understood [50–52]. In addition, patients that have received steroids at any time during the previous 6 months should not undergo testing of their adrenal function. Rather, these patients should be empirically initiated on steroid therapy.

Evidence Supporting the Use of Steroids in Septic Shock

The administration of steroids in septic shock has been debated for decades. In the 1960s, high dose steroid replacement therapy was found to improve survival in animal models of septic shock. A clinical study by Bennet et al. found no benefit to the use of steroids in sepsis and the practice was largely abandoned. In the 1970s, high dose steroids were widely used for patients with septic shock. Schumer et al. demonstrated significant improvement in survival among patients that received high dose steroids [53]. This practice

continued into the 1980s, at which point new evidence emerged suggesting that high dose steroids were associated with an increased risk of death and a higher frequency of secondary infections. Because of these discrepancies in the medical literature regarding the use of steroids in sepsis, there was no clear consensus at the time. The 1990s produced several meta-analyses evaluating the use of high dose steroids in septic shock. The conclusion of these studies was that high dose steroids provided no survival benefit and in fact they were associated with increased mortality. As a result of these studies, the use of high dose steroids for patients with septic shock has been largely abandoned. However, the use of low-dose steroids for the management of septic shock remains a topic of intense discussion.

Recently, numerous trials have been undertaken to evaluate the use of low-dose steroids in sepsis. Low-dose steroid use is defined as ≤300 mg of hydrocortisone (or an equivalent steroid) over duration ≤5 days. In 2002, Annane published a multicenter, randomized, double-blind, placebo-controlled trial evaluating the use of low-dose steroids in 300 patients with septic shock [54]. All patients with septic shock were randomized within 3 h of the onset of septic shock to either placebo or 50 mg of hydrocortisone IV every 6 h and 50 μg of oral fludrocortisone PO. Patients receiving low-dose steroids showed a decreased mortality (Hazard Ratio 0.67, 95 % Confidence Interval 0.47–0.92, $p=0.02$) and decreased duration of vasopressor therapy (Hazard Ratio, 1.91; 95 % Confidence Interval, 1.29–2.84; $P=.001$) compared to placebo. These findings that low-dose steroid use in patients septic shock with relative adrenal insufficiency significantly improves time to shock reversal and mortality were additionally supported by a meta-analysis of eight (6 randomized) smaller studies [55] as well as a systematic review of a 12 (subgroup of 17) randomized/quasi-randomized trials with prolonged (≥5 days) low-dose (≤300 mg hydrocortisone or equivalent) steroid treatment [48].

However, a follow-up study published in 2008 brought the use of low-dose steroids in septic shock back into question. The Corticosteroid Therapy of Septic Shock (CORTICUS) trial was a multicenter, randomized, double-blind, placebo-controlled trial that also evaluated the use of low-dose steroids in patients with septic shock [47]. The results from this study failed to show a difference in 28-day mortality between the two groups, however it was again displayed that the steroid group had a decreased time to shock resolution by approximately 2 days.

Unlike the Annane study, patients in the CORTICUS trial were randomized up to 72 h after the diagnosis of septic shock to receive either hydrocortisone 50 mg IV every 6 h or placebo. No difference in 28-day all-cause mortality was identified, however earlier shock resolution was confirmed in the steroid group. However, it is important to note that the patients enrolled in this trial had a lower placebo group mortality (63 % in Annane study; 31 % in CORTICUS trial). The Annane study enrolled only patients with vasopressor-dependent septic shock, while the CORTICUS trial enrolled all patients with septic shock. In the Annane study, patients were randomized within 3 h of the onset of septic shock. In the CORTICUS trial, patients were randomized up to 72 h after the onset of septic shock. Additionally, patients in the Annane study received both hydrocortisone and fludrocortisones as opposed to only hydrocortisone in the CORTICUS trial. The CORTICUS trial patients differed as well, with more abdominal sepsis and more surgical patients, and fewer patients diagnosed with pneumonia. The CORTICUS trial documented that 46.7 % of patients did not have a response to corticotropin-stimulation test, and these patients had a higher mortality rate. CORTICUS was, however, underpowered for the primary outcome measure, death within 28 days in patients who did not respond to corticotropin. Therefore considerable controversy still remains. An important contribution of the CORTICUS trial was the identification that hospital-based immunoassays are not accurate for cortisol measurements in critically ill patients.

Despite the ongoing debate over the optimal use of low-dose steroids in patients with septic shock, the Surviving Sepsis Campaign Guidelines still recommend consideration of hydrocortisone in patients with septic shock not responsive to volume resuscitation and vasopressor therapy. The dose of hyrdrocortisone given should not exceed 300 mg/day and should be administered in divided doses. The use of fludrocortisone is still considered optional. Optimal duration of steroids also remains in question, however most would agree that steroid administration should continue until the patient is weaned from vasopressor therapy.

Initiation of Empiric Antimicrobial Therapy

Another key component of the initial resuscitation of the septic patient is the administration of intravenous antimicrobial therapy. Antimicrobials should be administered after appropriate cultures have been collected but within 1 h of sepsis recognition. Difficulty with specimen collection should not delay the initiation of antibiotic therapy beyond the 1 h mark. The time to antimicrobial administration has been identified as a critical factor in survival of patients presenting with sepsis. A recent study by Kumar et al. found that each hour in delay of antimicrobials was associated with an average decrease in survival of 7.6 % [56]. Delayed administration of antifungal therapy in patients with Candida bloodstream infections was an independent predictor of hospital mortality [57]. Maintaining a supply of commonly used antimicrobials in the ED and ICU can assist in the timely administration of these agents. The Surviving Sepsis guidelines recommend initiation of intravenous broad spectrum antibiotics within the first hour of recognizing severe sepsis and septic shock.

The selection of antimicrobial therapy should take into account the patient's history (including drug allergies and recent antimicrobial exposure), suspected source of infection, and hospital-specific antibiograms. Within our surgical ICU, our multidisciplinary sepsis team has developed antimicrobial regimens based upon suspected source of infection and the current institution specific antibiogram (Table 7.5). When choosing empiric antimicrobial therapy, a few general

Table 7.5 Recommendations for source-specific empiric antibiotic selection

Pneumonia	Antibiotic	Regimen
Community acquired (CAP)	1. Ceftriaxone +	1 g IV q24h
	Levofloxacin	750 mg IV q24h
	2. Aztreonam +	2 g IV q8h
	Levofloxacin	750 mg IV q24h
Aspiration (not chemical pneumonitis)	Piperacillin/Tazobactam	4.5 g IV q6h
Ventilator associated (VAP)		
Early VAP (<5 day)	1. Cefepime	2 g IV q12h
	2. Ciprofloxacin	400 mg IV q12h
Late VAP (≥5 day; pseudomonas risk: previous hosp or broad spectrum antibiotic exposure +pseudomonas culture)	1. Cefepime +	2 g IV q8h
	Vancomycin +	15 mg/kg IV q12h
	Tobramycin	7 mg/kg IV
	2. Ciprofloxacin +	400 mg IV q8h
	Vancomycin +	15 mg/kg IV q12h
	Tobramycin	7 mg/kg IV
Catheter related infections		
Catheter-associated urinary tract infection (CAUTI)	1. Cefepime	1 g IV q12h
	2. Ciprofloxacin	400 mg IV q12h
IV, art cath; bloodstream	Vancomycin	1 g IV q12h
Candidemia high risk (TPN, steroid Tx, diabetes, hepatic failure)	Fluconazole	800 mg IV q24h
Wound/soft tissue infections		
Necrotizing soft tissue infection (NSTI)	1. Piperacillin/Tazobactam +	4.5 g IV q6h
	Vancomycin +	15 mg/kg IV q12h
	Clindamycin	900 mg IV q8h
	2. Ciprofloxacin +	400 mg IV q8h
	Vancomycin +	15 mg/kg IV q12h
	Clindamycin	900 mg IV q8h
Surgical Site Infection (SSI)	1. Ertapenem +	1 g IV q24h
	Vancomycin	15 mg/kg IV q12h
	2. Ciprofloxacin +	400 mg IV q12h
	Vancomycin	15 mg/kg IV q12h
Intra abdominal infections		
Pseudomonas—low risk	1. Ertapenem +	1 g IV q24h
	Vancomycin	15 mg/kg IV q12h
	2. Ciprofloxacin +	400 mg IV q8h
	Metronidazole +	500 mg IV q8h
	Vancomycin	15 mg/kg IV q12h
Pseudomonas—high risk (previous hospitalization or broad spectrum antibiotic exposure; positive pseudomonas culture)	1. Imipenem/Cilastatin +	500 mg IV q6h
	Vancomycin	15 mg/kg IV q12h
	2. Ciprofloxacin +	400 mg IV q8h
	Metronidazole +	500 mg IV q8h
	Vancomycin	15 mg/kg IV q12h
Candidiasis—high risk (TPN, steroid treatment, diabetes, hepatic failure, upper GI perforation + H2 blocker, age ≥75, prolonged antibiotic, long-term care)	Consider Fluconazole	800 mg IV q24h

Special Considerations
1. indicates preferred therapy, *2.* alternative for severe β lactam allergy
Dosing adjustments should be made if evidence of renal dysfunction
If Vancomycin allergy (not intolerance), then use Linezolid 600 mg IV q12hr

rules should be applied. Chiefly, the initial antimicrobial coverage should be broad enough to cover all potential pathogens. There is substantial evidence that administering inadequate initial antimicrobial coverage is associated with increased morbidity and mortality [58–61]. Any antimicrobial that the patient has recently received should be avoided. Vigilant monitoring of culture data and de-escalation of the antimicrobial regimen based upon culture results and sensitivities will reduce the risk of superinfection and the emergence of resistant organisms.

Importance of Early Broad Spectrum Antimicrobials

The timely administration of empiric antimicrobial therapy is perhaps the most beneficial pharmacologic intervention in patients with sepsis. While antimicrobial therapy has always been a mainstay in the treatment of infection, not until recently has the importance of antimicrobial choice and rapid administration been demonstrated to significantly impact patient mortality. In a landmark study by Kumar et al. the relationship between time to antimicrobial administration and patient mortality was clearly illustrated [56]. This multicenter, retrospective study evaluated 2154 patients with septic shock over a 15-year period. The primary objective was to determine the prevalence of delays in antimicrobial administration from initial onset of septic shock and its impact on mortality. The results of this study demonstrated a 7.6 % decrease in survival for each hour of delay in antimicrobial administration after the onset of shock [56]. In addition, patients that received effective antimicrobial therapy within 1 h of the onset of septic shock had the highest survival rate at 79.9 %. The results of this study have subsequently been corroborated by other studies [62, 63].

Despite convincing evidence that early antimicrobial administration significantly improves outcomes in patients with sepsis, compliance with this recommendation remains problematic. In Kumar's previously mentioned study, >50 % of septic shock patients experienced a delay in antimicrobial administration of at least 6 h. A recent multicenter prospective analysis of compliance with antimicrobial administration revealed that only 60 % of patients were receiving antimicrobials within 1 h [64]. After a 2-year educational campaign for performance improvement programs compliance only reached 67 %. Clearly, significant clinical hurdles exist that we must overcome in order to implement this seemingly straightforward intervention.

Several barriers to the timely administration of antimicrobials have been identified. One critical issue is the availability of intravenous access in a timely manner. During active sepsis resuscitation, intravenous access is needed for fluid administration as well as antimicrobial therapy. In addition, appropriate cultures, typically from various sites, must be sent prior to antimicrobial administration. Many antimicrobials are not readily available in patient care areas and must be transported from the pharmacy to the bedside. Most patients receive at least two empiric antimicrobials, which can result in additional delays if adequate IV access is not available. Performing this multitude of tasks, particularly in an unstable septic shock patient, can quickly overwhelm the clinical team. The end result is a significant delay in antimicrobial administration.

While each institution has their own specific barriers to implementation, it is important to recognize the importance of administering IV antimicrobials within 1 h. This one simple task of administering antimicrobial agents can significantly improve patient survival. In order to minimize the time to antimicrobial administration, there are a few basic clinical practices that can be implemented to help overcome these barriers. Rapidly establishing IV access is critical to the success of the initial resuscitation. If peripheral IV access is not easily attainable, central venous access should be secured promptly. Central venous access has the benefit of providing the clinical team with multiple infusion ports as well as a means of monitoring central venous pressure. Working in conjunction with pharmacy to establish a rapidly available, pre-mixed supply of commonly administered antimicrobials will also help to minimize delays. Many institutions have developed a "sepsis toolbox" containing IV fluids, culture materials, blood tubes for measuring serum lactate, and a premixed supply of antimicrobials. This toolbox can be taken to the bedside of septic patient at any location in the hospital, avoiding potential delays in the initiation of resuscitation.

The choice of empiric antimicrobial therapy is equally as important as administering antimicrobials within 1 h. Antimicrobial selection can be a complex process and should take into include consideration of the patient's history and comorbid conditions, recent antimicrobial exposure, and probable source of infection. With the recent emergence of several virulent, drug resistant pathogens, the length of the patient's hospital course and the potential for infection with such organisms should be considered. Failure to provide effective antimicrobial coverage for the causative organism significantly increases the risk of death from sepsis. The best practice is to provide broad coverage initially and de-escalate antimicrobial therapy based upon culture data as it becomes available.

Identifying the Source of Infection

Identifying the source of infection is essential to the initial management of sepsis. Whenever possible, cultures should be obtained prior to initiation of empiric antimicrobial therapy. Current recommendations include obtaining a minimum of two blood cultures, including one blood culture from each

vascular access device and one blood culture from a peripheral puncture. Additional cultures from other sites (respiratory, urinary tract) and radiographic imaging should be dictated by clinical suspicion. In the surgical population, this may include obtaining cultures from surgical drains and performing pertinent imaging to identify an undrained abscess. Despite the importance of source identification, difficulty in the collection of cultures should not generate a significant delay in the administration of antimicrobial therapy.

In order to improve the chances of detecting bacteremia it is crucial to obtain the appropriate volume of blood for the culture medium. Several studies have demonstrated that the volume of blood cultured is the single most important factor in the detection of bacteremia [65–67]. The recommended volume of blood per culture tube is ≥10 ml. Obtaining blood cultures from all vascular access devices along with simultaneous collection of blood cultures from a peripheral site is beneficial in diagnosing catheter related infections. Differential time to positivity is defined as the difference in time necessary for blood cultured drawn simultaneously from a peripheral site and a central venous catheter to become positive [68, 69]. The differential time to positivity is considered to be positive if the blood culture that is drawn through the vascular access device becomes positive at least 120 min before the peripheral culture. If a patient has an indwelling vascular access device and the cultures drawn from that device become positive at least 120 min before the peripheral cultures, it is recommended that the device be removed as it is likely infected [68].

Obtaining Source Control

The final component of the initial resuscitation bundle is identification and control of the source of infection. This can be as simple as removing an infected vascular access device. However, the abdomen is the site of infection in nearly half of the patients with surgical sepsis. This is usually due to hepatobiliary disease, appendicitis, diverticulitis, inflammatory bowel disease, infected pancreatic necrosis, perforation of a gastric or duodenal ulcer, or large or small bowel perforation from obstructive carcinoma. Additionally, intra-abdominal infections can occur post-operatively due to injury to the bowel, anastomotic leak, or contamination of the peritoneal cavity. These patients often require diagnostic imaging to identify the source and an operative procedure to attain source control. This includes, but is not limited to, emergent debridement of necrotic tissues, abscess drainage, removal of infected vascular access devices, and exploratory laparotomy. In the setting of septic shock, these procedures, although necessary, can present a unique challenge to the surgical team.

The concept of damage control laparotomy (DCL) was first recognized for the care of critically injured trauma patients [70–72]. Damage control is defined as rapid, initial control of hemorrhage and contamination followed by intraperitoneal packing as needed, and temporary abdominal closure. This concept was utilized on those patients that presented with severe physiologic derangements such as coagulopathy, acidosis, and hypothermia. Rather than persisting for hours performing the definitive operation, these patients have their critical surgical issues addressed in an abbreviated manner so they may be taken to the ICU for continued resuscitation. Once the physiologic derangements have been corrected the patient is taken back to the operating room for a definitive surgical procedure. The decision to utilize DCL should not be viewed as a bailout. Instead, it is a deliberate decision to truncate the surgical procedure in order to minimize the time away from the ICU. The decision to perform DCL is often made prior to arriving in the operating room and is based on the severity of the patient's physiologic derangements at the time of presentation.

The concept of DCL has now evolved to include critically ill patients with surgical sepsis. Like the trauma patient with the lethal triad of acidosis, hypothermia, and coagulopathy, many patients with septic shock present in a similar fashion. For those patients presenting with septic shock and an identified source of infection requiring surgical intervention, the utilization of DCL can be lifesaving.

The first priority is to initiate resuscitation. The patient needs to undergo preoperative optimization during which time the airway is secured, central venous and arterial lines are placed, volume resuscitation and broad spectrum antimicrobial agents are administered, and if needed, vasopressors are titrated to the appropriate endpoints. Within 6 h the patient is taken to the operating room for emergent laparotomy and potential damage control procedures. The surgeon needs to assess the degree of physiologic derangement early in the operation and if the severe physiologic derangements exist, then the operative interventions need to be abbreviated. The primary aim is to control the source of infection, e.g., resect dead bowel, manage bowel perforations (resection versus primary closure), drain abscesses, and wash out the abdomen. During this initial operation, source control is the primary goal, therefore ostomies are not created and bowel is left in discontinuity. The abdomen is then managed with a temporary abdominal closure device (via a variety of techniques) and the patient is rapidly returned to the ICU to undergo continued physiologic optimization. This includes optimizing volume resuscitation and mechanical ventilation, correction of coagulopathy and hypothermia, and monitoring for abdominal compartment syndrome. Over the next 24–48 h, abnormal physiology is corrected so that the patient can safely return to the OR for a definitive operation and abdominal closure. Septic shock is a formidable metabolic insult and it is very important to provide optimal nutritional support (via combined enteral and parenteral nutrition) and

early mobilization to prevent the loss of lean body mass and resultant impaired recovery.

One of the problems with the "damage control" strategy is the frequent difficulty encountered when trying to close the midline fascia due to bowel distention and edema. This results in multiple additional laparotomies for definitive abdominal wall closure. The midline fascia is progressively closed with the use of a vacuum-assisted closure (VAC) device. For this technique to work it is important that the bowel not become adherent to peritoneum of the anterior abdominal wall out to the lateral paracolic gutters otherwise the abdomen becomes "frozen" and the fascia cannot be brought to midline. The VAC device actively removes fluid and decreases edema, provides medial tension which helps to minimize fascial retraction and loss of domain, and protects the abdominal contents by providing separation between abdominal wall and viscera, with no fascial damage since it does not require fascial suture placement. Traditionally, abdominal wall defects in these "frozen" abdomens were closed by mobilizing skin/subcutaneous tissue flaps to cover the defect (i.e., accepting a large hernia defect and need for delayed reconstruction) or by bridging the defect with mesh with later split thickness skin grafting once granulation tissue has developed. This is associated with a 20 % gastrointestinal fistula rate, which is an extremely morbid complication. Additionally, many of these patients required delayed complex abdominal wall reconstructions. Recently, there has been significant enthusiasm for acute reconstruction with biological mesh. Unfortunately the long-term follow-up studies show that many of these patients still require delayed hernia repairs of large defects [73]. In our published experience of treating the open abdomen with the VAC device, we achieved primary fascia closure in 87 % at a mean 7 days with a 2 % fistula rate and no intra-abdominal abscesses [74, 75]. These results are nearly identical to the results reported by Miller et al. from Wake Forest University who taught us how to do this type of closure [76]. More recently, Cothren et al. have reported 100 % primary fascial closure rate using a modified VAC device technique [77]. The long-term outcomes are not known but in short-term follow-up (mean 180 days) ventral hernia rate was 2.3 %. However, as is true with all emergency laparotomies, this rate will without a doubt increase with time but the hernia defects will be small and more easily repaired.

In addition to "damage control" scenarios, there are other reasons that we leave the abdomen open and plan for a staged laparotomy:

1. Patients with ischemic bowel that have undergone a resection will be taken back the next day to assess viability of the remaining bowel before attempts at anastomosis or ostomy creation. We have been quite successful in completing the small bowel to colon anastomosis at the second operation and thus these patients have avoided the need for a temporary ileostomy.
2. Patients with infected necrotizing pancreatitis. We attempt to avoid operative interventions in this group of patients but are occasionally forced to do so.
3. Patients who have massive bowel distention that cannot be closed without causing significant intra-abdominal hypertension (IAH) will undergo temporary abdominal closure. IAH sets the stage of abdominal compartment syndrome (ACS) which occurs with subsequent ICU resuscitation [78]. Avoiding ACS significantly improves survival.
4. Patients who develop ACS and require a decompressive laparotomy. As a result of advances in trauma care starting in the 1980s, this entity emerged as an epidemic in the mid 1990s in trauma centers worldwide. As we begin to understand this new entity, it has been increasingly recognized to occur in non-trauma ICU patients as well [79–81]. Unfortunately, if you do not look for ACS by monitoring bladder pressures, you will not diagnose it and these patients will die of refractory shock.

Within our SICU we have been utilizing DCL for our patients with septic shock. Over 2 years, we had 22 septic patients who underwent DCL for source control. Sources of intra-abdominal infection were colon (11 patients), small bowel (4), stomach (2), and pancreas (1). Four patients had peritonitis with no identified source. Of the 22 patients, 6 died from multiple organ failure, for an actual mortality rate of 27 %. The mean Portsmouth-Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity (P-POSSUM) predicted mortality was significantly higher at 69.4 % ($p < 0.02$), as was the predicted mortality of 76 % based on a mean APACHE II score of 31.8 ($p < 0.02$) [82]. This data suggests that the implementation of DCL for patients with surgical sepsis is decreasing mortality and is a viable option for patients with septic shock and the need for immediate operative source control.

Planned Laparotomy for Established Peritonitis Is Not Damage Control

The treatment strategy for patients with established peritonitis has been debated for three decades. After an initial emergent laparotomy, relaparotomy is frequently necessary to eliminate persistent peritonitis or a newly developed infectious focus. There are two widely used strategies for relaparotomy including relaparotomy when the patient's condition demands it ("on-demand") and "planned" relaparotomy. In the planned strategy, a relaparotomy is performed every 48 h

for inspection, drainage, and peritoneal lavage of the abdominal cavity until findings are not suspicious for ongoing peritonitis. The "planned" strategy may lead to early detection of persistent peritonitis or a new infectious focus which reduces the risk for MOF but harbors the risk of potentially unnecessary reexplorations in critically ill patients. The on-demand strategy, while minimizing the number of surgical interventions, harbors the risk of a potentially harmful delay in the detection of intra-abdominal infection with increased risk for MOF. Additionally there is a risk that the need for a delayed laparotomy will occur at a time when intra-abdominal adhesions (day 10–14) create a hostile operative environment. Over the years, there have been number of case series that have offered conflicting results. The consensus and meta-analysis conclusion is that for the non-critically ill patient, (APACHE II <10) use of the "on-demand" strategy is preferred. Newer developments in CT scan technology can accurately detect intra-abdominal infections in patients who clinically deteriorate or fail to improve. With aggressive interventional radiology, greater than 95 % of the infections can be successfully treated without a repeat laparotomy. More recently, Ruler et al. has performed a prospective randomized controlled trial in patients with severe peritonitis (defined as APACHE II >10) which confirmed that the practice of "planned" relaparotomy was associated with no difference in outcome compared with "on-demand" laparotomy and was associated with increased expenditure of hospital resources and length of hospital stay [83]. It is important to emphasize that this recent trial is not relevant to the previous discussion of "damage control" in patients with septic shock. Patients randomized into this trial had a mean APACHE II score of 15 (with predicted mortality of <25 %) while the patients we described had a mean APACHE II score of 32 (with a predicted mortality of >75 %). We use damage control in patients in the "persistent septic shock cycle," who require an expedient procedure to attain source control, and continued resuscitation prior to the definitive procedure. The rationale is to appropriately time and limit the duration of source control to break the cycle and then optimize resuscitation in the ICU. Planned and on-demand laparotomy are considered in the case of patients requiring surgical source control, who are not exhibiting severe metabolic derangements.

Effect of Sepsis on Coagulation

Proper function of the coagulation system is of critical importance, particularly in the surgical patient as it plays an essential role in hemostasis. Extensive laboratory research has advanced our understanding of the relationship between inflammation and coagulation. In the septic patient, dysregulation of the coagulation system can result in derangements in laboratory tests of coagulation, increased bleeding risk, and DIC. A basic understanding of this relationship is important to understanding the pathophysiology of sepsis.

A key factor in the interaction between coagulation and inflammation is tissue factor (TF) expression. Under normal circumstances, TF is found only on adventitial structures, myocytes, and fibroblasts. When tissue injury occurs, these subendothelial structures that express TF are exposed and the clotting cascade is initiated by TF binding with circulating factor VII. In a septic state, proinflammatory mediators induce the expression of TF on the endothelium. The expression of TF by the endothelium activates the coagulation cascade and is additionally a potent stimulus for excess thrombin generation. Thrombin is a procoagulant molecule that converts fibrinogen to fibrin and promotes platelet activation. The formation of fibrin is followed by consumption of clotting factors and the formation of fibrin clots in the microcirculation. These fibrin clots serve as filters, trapping platelets to form larger clots. All of these actions combined shift the coagulation system into a procoagulant state. Additionally, there is a loss of anticoagulant factors such as thrombomodulin. Proinflammatory cytokines downregulate the production of thrombomodulin on the surface of the endothelial cells. Thrombomodulin is an essential cofactor in the conversion of protein C into activated protein C. Clinically, this imbalance in the coagulation system is reflected as tissue hypoxia secondary to microvascular thrombosis. This disruption in the coagulation system and the resulting microvascular thrombosis has been the target of potential pharmacologic interventions.

Activated Protein C for Severe Sepsis and Septic Shock

In the normal physiologic state, anticoagulation predominates. The major anticoagulant factors are protein C, protein S, antithrombin, and tissue factor pathway inhibitor. Protein C is activated by the binding of thrombin to thrombomodulin on the surface of the endothelium. Once activated, protein C directly inhibits factor Va and factor VIIIa in the clotting cascade. In patients with severe sepsis and septic shock there is a decreased expression of thrombomodulin on the vascular endothelium. As a result, there is decreased production of activated protein C (APC). This results in a shift toward the procoagulant state. This shift to a procoagulant state results in microvascular thrombosis, impaired fibrinolysis, and endothelial dysfunction. The microvasculature becomes occluded with resultant tissue hypoxia and direct tissue damage, which ultimately results in organ dysfunction/failure. The extent of coagulation disturbance ranges from mild laboratory abnormalities to disseminated

intravascular coagulation (DIC). This underlying disruption of the intrinsic production of APC served as the physiologic impetus for the administration of APC as a means to reverse the procoagulant state seen in severe sepsis and septic shock. Following the 2001 Prospective Recombinant Human Activated Protein C Worldwide Evaluation in Severe Sepsis (PROWESS) study, recombinant human activated protein C was used for the treatment of severe sepsis and was advocated by the Surviving Sepsis Campaign. The PROWESS study was a phase 3 international, randomized controlled trial that was stopped early (after enrolling 1690 patients with severe sepsis) due to its efficacy; absolute mortality in the intention-to-treat population was reduced by 6.1 % [84]. A subgroup analysis suggested the mortality benefit was limited to patients with an APACHE II score >24 or with at least one organ system dysfunction. Following the results of this study, the Food and Drug Administration approved the use in patients with a high risk of death. However, subsequent placebo-controlled trials were unable to produce the same results as the PROWESS trial [85]. Therefore, a decade later, the Prospective Recombinant Human Activated Protein C Worldwide Evaluation in Severe Sepsis and Septic Shock (PROWESS-SHOCK) trial was undertaken to evaluate the efficacy of recombinant human activated protein C specifically in patients with septic shock. There was no benefit in mortality in the drug group compared with placebo [86]. Following the results of the PROCESS-SHOCK trial, recombinant human activated protein C was removed from the market and is no longer included in the Surviving Sepsis Guidelines [26].

Pathophysiology of Sepsis: A Complex Process

The clinical manifestations of sepsis are the result of a complex series of interactions between the inciting organism and the host's innate immune response. This intricate cellular interaction involves numerous signaling pathways as well as the production of cytokines and chemokines. A detailed discussion of each of these pathways is beyond the scope of this text; however, a few key elements are discussed.

Characteristics of the Pathogen

The host response to infection can be triggered by bacterial, viral, and/or fungal infection. The specific characteristics of the inciting organism have a role in the body's response to the infectious stimuli. Each organism has specific virulence factors that enable the organism to evade the host's defenses. These virulence factors include antigenic variation of surface molecules, inhibition of complement activation, resistance to phagocytosis, production of exotoxins, and scavenging of reactive oxygen intermediates [87]. Cell to cell communication between organisms allows for signaling and upregulation of virulence factors. Perhaps one of the best described virulence factors is lipopolysaccharide (LPS), also known as endotoxin, a component of the outer cell wall of all gram-negative bacteria. The presence of LPS provokes local and systemic inflammation, including proliferation of cytokines and activation of macrophages. The presence of LPS is essential to maintaining the integrity of the outer membrane of gram-negative bacteria, acting as a protective barrier against lysozymes, antimicrobial agents, and host phagocytic cells.

Characteristics of the Host

The human body is equipped with a variety of defense mechanisms against microorganisms. These include physical barriers such as the skin and mucosal surfaces, the innate immune response, and the adaptive immune response. Dysfunction of any of these components can lead to the development of sepsis. The recognition of pathogens by the innate immune response initiates a complex cascade of events with the intent of removing the pathogen from the host. This includes the release of reactive oxygen metabolites to destroy the pathogen, release of chemokines to recruit additional lymphocytes, and the generation of a variety of systemic cytokines to further activate the host immune response. We are just beginning to understand the potential impact of genetic polymorphisms and the impact on patient survival [88, 89].

Sepsis Screening: Increasing Awareness and Improving Outcomes

The early identification and management of sepsis remains a significant challenge to healthcare providers. In the recent past, multiple organizations have focused their efforts on providing evidence-based guidelines in an attempt to decrease the morbidity and mortality associated with sepsis. Several recent studies in the literature have highlighted the correlation between early sepsis intervention and patient survival. The use of EGDT therapy as described by Rivers et al. has emphasized the importance of early intervention during the "golden hours" of sepsis [25]. A recently published study by Kumar et al. demonstrated a significant correlation between time to appropriate antimicrobial administration and patient survival [56]. In this study of 2154 patients with septic shock, administration of effective antimicrobial

therapy within the first hour of document hypotension was associated with a survival rate of 79.9 %. Each hour of delay in administration of effective antimicrobial therapy was associated with an average decrease in survival of 7.6 %.

Despite strong evidence that the early implementation of evidence-based, sepsis-specific interventions save lives, the early identification of sepsis remains a challenge. The signs and symptoms of sepsis are nonspecific, particularly in its early phases. As bedside nurses and other health care providers focus on multiple priorities and tasks, early signs of sepsis are often missed resulting in the delay of time critical interventions. Lack of awareness of the signs and symptoms of impending sepsis may contribute to the severity of the problem. In the surgical patient, the early signs of sepsis can often be attributed to other common postoperative problems. A recent audit of ward nurses' knowledge of sepsis demonstrated lack of awareness of the standard definitions of sepsis, severe sepsis and septic shock, the significance of increased blood lactate concentration as an indicator of severe sepsis, and the basic principles of early goal directed therapy [90]. The conclusion of this audit was that these deficits could result in the missed or delayed diagnosis of severe sepsis or septic shock, and seriously delayed therapy. This lack of awareness seems universal, as physicians too struggle with the early identification and evidence-based management of sepsis. A recent international survey of physicians regarding their knowledge regarding sepsis reported that 83 % of physicians surveyed had missed the diagnosis of sepsis [91]. The reasons listed for missing the diagnosis of sepsis included lack of monitoring, lack of a common definition for sepsis, and lack of knowledge. Of the 1058 physicians surveyed, only 140 (13.2 %) were able to provide the definition of sepsis as stated in the ACCP/SCCM consensus statement.

Our experience with the sepsis screening tool in the SICU has prompted us to expand our evaluation of sepsis in general surgery patients within our own institution. We conducted a quality improvement review of patients admitted to our SICU over a 5-month period with an admitting diagnosis of sepsis, severe sepsis, or septic shock. Of the 55 patients with these diagnoses, 26 (47 %) were admitted to the SICU from an inpatient surgical ward. Of these, 26 patients admitted from the surgical ward, 15 (58 %) presented to the SICU with severe sepsis or septic shock. Out of the 15 patients who presented to the SICU in severe sepsis/septic shock, 6 died (40 %). There were no deaths among the 11 patients that presented with sepsis. For each of these 26 patients, the first step of our sepsis screening tool was performed in a retrospective fashion. Of the 26 patients, 20 (77 %) had a positive retrospective SIRS screen (SIRS Score $\geq$4). On average, the screen became positive 25 h before the diagnosis of sepsis was made (range 30 min to 114.75 h, standard deviation 35.8, interquartile range 33.75). The Surviving Sepsis Campaign Guidelines place great emphasis on the speed with which sepsis specific interventions are initiated secondary to the impact this has on sepsis related mortality. This is supported by our data. The average delay of 25 h between the initial recognition of sepsis using this screening tool and the initiation of appropriate therapy is well beyond the recommended time for intervention. These findings would indicate that the use of this nurse initiated sepsis screening tool could significantly improve sepsis recognition and subsequent initiation of therapy on the inpatient surgical floor.

We subsequently implemented and validated our sepsis screening tool on the inpatient surgical ward [14]. The screening tool yielded a sensitivity of 99.9 %, specificity of 91.3 %, a positive predictive value of 16.3 %, and a negative predictive value of 99.9 %. The sepsis related mortality in those patients that screened positive for sepsis was 6.3 %. Of the 16 patients that developed sepsis, 4 (25 %) required transfer to the SICU. Of the 16 true positive screens, 14 (87.5 %) had sepsis and 2 (12.5 %) had severe sepsis at the time of the screen. These results underscore the importance of sepsis screening in order to identify sepsis before the patient progresses into septic shock.

Disputes of Early Goal Directed Therapy

Rivers et al. conducted a landmark study which demonstrated that early goal-directed therapy (EGDT) reduced mortality from septic shock from 46.5 to 30.5 % [25]. The results of this single center study propagated the use of EGDT and the Surviving Sepsis Campaign. However, there have been challenges to both the necessity and safety of EGDT, which started with a retrospective, cohort study of 405 medical ICU patients with severe sepsis or septic shock suggested that EGDT may increase the risk of fluid overload, the need for subsequent medical inventions and mortality [92]. Following this study, there have been three trials in the academic, community, and National Health Service (England) settings to compare EGDT to "usual care."

The Protocolized Care for Early Septic Shock (ProCESS) trial was a multi-center trial which randomized 1341 adult patients presenting to academic emergency departments with septic shock. The patients were randomized to 3 arms: EGDT, protocol-based standard therapy without invasive monitoring (i.e., no central venous access), and usual care. The protocol-based therapy group was administered intravenous fluids to goal systolic blood pressure and shock index (ratio or heart rate to systolic blood pressure). The usual care group was at the varied discretion of the bedside physician. There were no significant differences between either

group with respect to 60- or 90-day mortality, however the EGDT group did receive more vasopressors, inotropes, and blood transfusions [93]. This led to the conclusion that perhaps, in academic emergency departments in the USA, patients presenting with septic shock can be safely managed with an approach that focuses on patient response to resuscitation, early antibiotic use, and continued observation [12]. Of note in this study, randomization occurred after the initiation of volume resuscitation, making the "6 hour" initial resuscitation bundle of EGDT [25] longer than 6 h. Additionally, more than 75 % of the patients received antibiotics prior to randomization.

In a similar effort, the Australasian Resuscitation in Sepsis Evaluation (ARISE) randomized 1600 patients with severe sepsis or septic shock in both academic and community centers throughout Australia, New Zealand, Finland, Hong Kong, and Ireland to EGDT therapy or variable physician-guided care. Similar to the ProCESS trial, no survival benefit at 90 days was appreciated (RR 0.98, 95 % CI 0.80–1.21, $P=0.90$). Additionally, no differences in ICU length of stay or in-hospital mortality were appreciated [94]. In this study, the mortality was only approximately 18 % in both groups, which is considerably lower than the overall mortality from sepsis. Also, due to the widespread acceptance of EGDT, it was difficult to ascertain how different the usual care was from the EGDT protocol. Finally, the Protocolized Management in Sepsis (ProMISe) Trial randomized 1260 patients in 56 hospitals in England to EGDT or usual care. There was no difference in all-cause 90-day mortality (OR 0.95, 95 % Confidence Interval 0.74–1.24, $p=0.73$). Additionally, this trial demonstrated a greater mean Sequential Organ Failure Assessment (SOFA) score at 6 h, a greater proportion of patients receiving cardiovascular support, and a greater median length of stay in the early goal-directed therapy group [13]. Comparable to the ProCESS trial, all patients did receive antibiotics prior to randomization.

The comparison of these three randomized controlled trials to the original study by Rivers et al. is not simple as the original trial had a higher mortality, consistent with epidemiological descriptions of mortality from sepsis [2, 8], despite having similar APACHE II scores and baseline lactic acid values. The ProCESS, ProMISe, and ARISE trials all administered approximately 2 L of fluid and most patients received antibiotics prior to randomization (Table 7.6), which was not included in the 6 h resuscitation bundle.

In addition to these three randomized controlled trials, two meta-analyses have been conducted to compare EGDT to usual care. The first consisted of ten randomized controlled trials over 10 years (2004–2014) including 4157 patients. The authors found that EGDT did not show a survival benefit in patients with severe sepsis or septic shock (RR 0.91, 95 % CI 0.79–1.04, $p=0.17$). In addition, patients receiving EGDT compared to their controls received more inotopic agents, and a greater volume of fluid, including red cell transfusion. EGDT did not benefit patients by decreasing vasopressor support, ICU length of stay, hospital-free days, or ventilator-free days [97].

Table 7.6 Comparison of Rivers et al. [25] with ProCESS [95], ARISE [94], and ProMISe [96] study characteristics

	Rivers EGDT (2001)	ProCESS (2014)	ARISE (2014)	ProMISe (2015)
APACHE II				
Usual care	20.4 ± 7.4	20.8 ± 8.1	15.8 ± 6.5	18.0 ± 7.1
EGDT	21.4 ± 6.9	20.7 ± 7.5	15.4 ± 6.5	18.7 ± 7.1
Serum lactate mmol/L (baseline)				
Usual care	6.9 ± 4.5	5.0 ± 3.6	6.6 ± 2.8	6.8 ± 3.2
EGDT	7.7 ± 4.7	4.8 ± 3.1	6.7 ± 3.3	7.0 ± 3.5
IV Fluids (mL) in 1st 6 h				
Usual care	3499 ± 2438	2279 ± 1881[a]	1713 ± 1401[b]	1784 (1075, 2775)[c]
EGDT	4981 ± 4984	2805 ± 1957[a]	1964 ± 1415[b]	2000 (1150, 3000)[c]
28-Day mortality				
Usual care	49 %	18.9 %[d]	15.9 %	24.8 %
EGDT	33 %	21 %[d]	14.8 %	24.5 %

Plus–minus values are means ± standard deviation

[a]Patients in the ProCESS trial received 2083 ± 1405 mL in the usual care group and 2254 ± 1472 mL in the EGDT group prior to randomization

[b]Patients in the ARISE trial received an additional 2591 ± 1331 mL in the usual care group and 2515 ± 1244 mL in the EGDT group prior to randomization

[c]Values are expressed as median (interquartile range). Patients in the ProMISe trial received an additional 1790 (1000, 2500) mL in the usual care group and 1600 (1000, 2500) mL in the EGDT group prior to randomization

[d]60-Day mortality

The second meta-analysis included 13 trials with 2525 patients and discovered that the mortality benefit of goal-directed therapy was only appreciated when applied early (within 6 h, RR 0.77; 95 % CI, 0.67–0.89; $P = 0.0004$; $I^2 = 40\,\%$) and not when the timing was outside of the 6 h or unclear (RR 0.92; 95 % CI, 0.69–1.24; $P = 0.59$; $I^2 = 56\,\%$) [97].

There have not yet been updates to the Surviving Sepsis Guidelines in light of these new studies. What these studies do emphasize is that while all components of EGDT may not be necessary, they do not definitively display any harm. This could be a limitation of only assessing mortality as an outcome. The work of Rivers and colleagues over a decade ago revolutionized the way that sepsis is considered, leading to increased awareness, earlier identification, and earlier administration of therapies. Perhaps the biggest contribution of EGDT is the earlier recognition of sepsis and earlier administration of antimicrobial therapy.

Implementing Evidence-Based Guidelines: The Use of Computerized Clinical Decision Support

In the recent past, multiple organizations have focused on providing evidence-based guidelines (EBGs) in an attempt to decrease the sepsis associated morbidity and mortality [26, 98, 99]. These EBGs provide a comprehensive list of therapies and include several time sensitive interventions. Despite strong evidence that the early implementation of evidence-based, sepsis-specific therapies saves lives, the complexity of these recommendations makes bedside implementation difficult and compliance poor. A recent study by McGlynn et al. which evaluated compliance with implementation of evidence-based care in a variety of acute and chronic health conditions found that only 55 % of patients currently receive appropriate evidence-based care [100]. This failure of health care providers to consistently implement evidence-based care is multifactorial. Busy clinicians struggle to keep up with the information overload that has resulted from the recent explosion in health care related guidelines. As a result, it often takes 15–20 years for a newly proven therapy to become standard of care [101]. Additionally, guidelines are often difficult to implement at the local level because they are not patient specific and rarely provide explicit directions for use at the bedside. These factors result in a significant hurdle that clinicians must overcome in order to provide current, evidence-based care.

In the case of EBGs for sepsis management, the number and complexity of the recommendations makes it difficult to consistently implement these interventions. In addition, many of the interventions are time sensitive and require prioritization. Patients with an intra-abdominal source of surgical sepsis are at particularly high risk due to severity of illness and treatment complexity. These patients often require emergent operation for source control, with damage control techniques employed for the most severely ill. Integration of surgical intervention with ICU resuscitation introduces even more variables in sepsis management paradigm. This necessitates a system which ensures adequate and timely resuscitation, adherent to EBGs for sepsis.

Our previous experience with computerized clinical decision support (CCDS) has proven valuable in implementing other complex EBGs for critically ill patients [102]. A computer-based algorithm has the ability to accurately and precisely manage clinical interventions, frequently more consistent than the bedside clinician. Prior studies evaluating the use of CCDS in implementing EBGs for ARDS management and hemorrhagic shock resuscitation have demonstrated that the utilization of CCDS improves compliance with EBGs at the bedside [103–106]. Based upon this experience we developed a CCDS protocol for the management of sepsis. This bedside CCDS program includes an algorithm for goal-directed volume resuscitation, with subsequent real-time prompts for specific therapies such as antimicrobials, vasopressors, and further modalities within the initial 24 h after sepsis identification (Fig. 7.2). Acknowledgement of administered therapies allows the computer logic to proceed to the next step, ensuring compliance with all aspects of the EBGs.

Implementation of CCDS for the management of sepsis has significantly improved our ability to consistently implement EBGs in our SICU. Since implementing our CCDS sepsis management protocol we have increased our compliance with all components of the 6 h resuscitation bundle has increased from 29 to 79 %. In addition, our overall severe sepsis/septic shock mortality has declined from 24 to 12 %. We attribute this significant decrease in sepsis related mortality to increased compliance with the EBGs, a finding that is consistent with other reports in the literature [19, 25, 56, 64, 107].

Conclusion

Sepsis continues to be a common and potentially lethal problem for surgical patients. The early identification and management of surgical patients with sepsis presents a significant challenge to the surgical team. The implementation of rapid, evidence based care in conjunction with timely surgical source control improves survival.

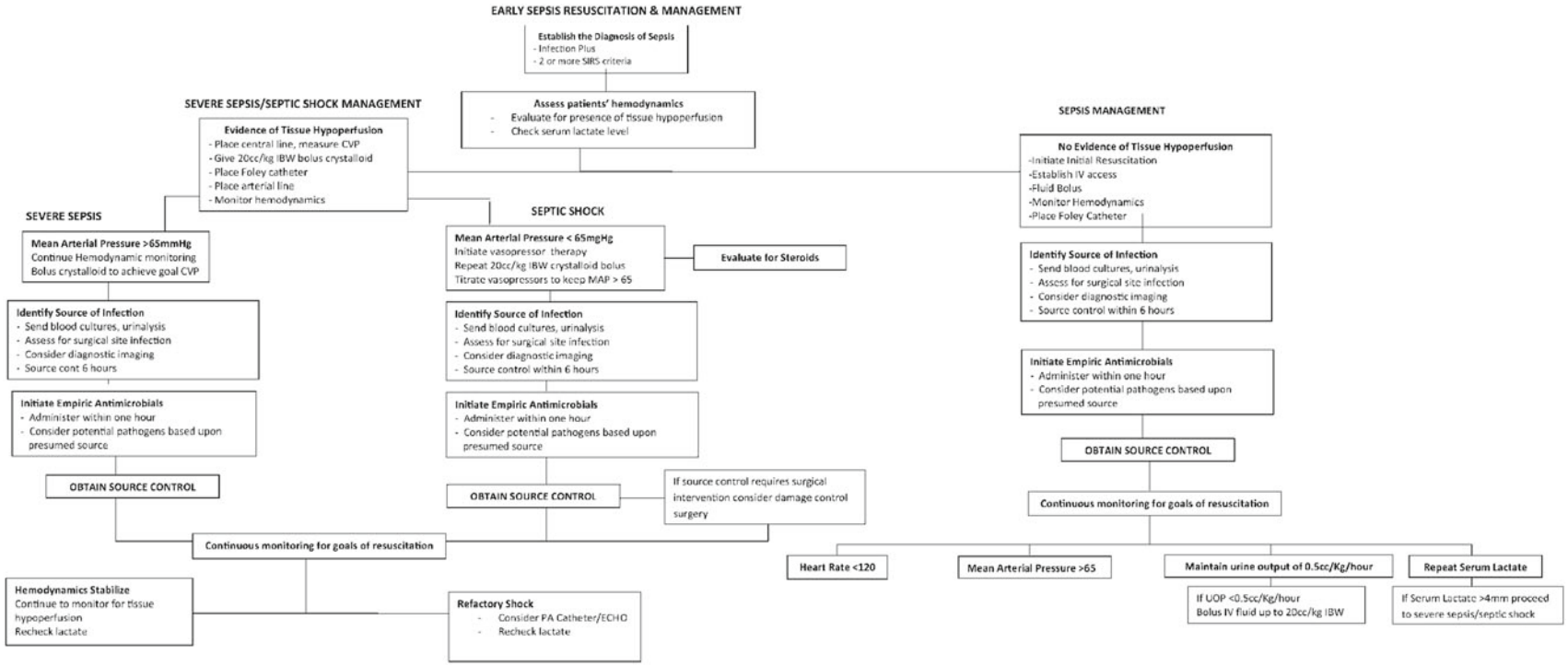

Fig. 7.2 Treatment algorithm for early sepsis resuscitation and management, severe sepsis/septic shock management, and severe sepsis

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Multiple Organ Failure

8

Stephanie Gordy

While traumatic brain injury and uncontrolled hemorrhage remain the leading causes of death after trauma, sepsis followed by multiple organ failure (MOF) are leading contributors to mortality in critically ill surgical and trauma patients. Multiple organ failure is the leading cause of morbidity in the intensive care unit (ICU) following trauma and represents the endpoint of the spectrum of SIRS and sepsis [1]. Despite the identification of this disease process in the early 1970s, our understanding of the pathophysiology and the ensuing treatment of this syndrome remains a perplexing entity which entire books have been dedicated to. This chapter will provide a brief overview of the evolution of the disease, the clinical presentation; discuss the epidemiology and salient pathophysiology, as well as current treatment options and future considerations of this disease.

Historical Perspective

Military conflicts have historically been the impetus for knowledge advancement in the arena of care of the critically injured patient. The evolution of the medical communities' knowledge of morbidity and mortality from a single organ injury to multiple organ failure is an example of such a process. In WWI, death of the injured was primarily due to hemorrhagic shock and infections. During World War II the lessons learned from prior conflicts, including control of hemorrhagic shock and expeditious evacuation to a surgical treatment facility greatly reduced the immediate death rate to half of what it had been for the U.S. Army in early World War II [2, 3]. Transfusions in WWII aided resuscitation in stabilizing hemodynamic parameters but delayed renal failure was a significant morbidity. In the Korean War, delayed deaths in resuscitated patients were most often as a result of acute renal failure [4]. The increased resuscitation with crystalloid improved the renal failure but resulted in acute lung injury. This emerging constellation of symptoms is now known as acute respiratory distress syndrome (ARDS) [5]. These serial improvements were beneficial in the understanding of resuscitation of severely injured patients. However, the survival of these patients revealed the damage that multiple end organs had sustained as manifested in a new syndrome now known as multiple organ failure. Multiple organ failure is at the severe end of the severity of illness spectrum of both SIRS and sepsis.

The term "multiple organ failure" (MOF) was used by Shoemaker in a 1973 editorial to describe the circulatory, respiratory, renal, cerebral, and cardiac complications that ensued after the initial resuscitation of a trauma patient [6]. Around the same time, Tilney described a similar syndrome of sequential organ failure in 18 patients following surgical repair of their abdominal aortic aneurysms [7]. In 1975, Baue expanded on the organ systems affected and recognized that when more than one organ system failed, the knowledge and ability to care for the patient was stretched. Additionally, Baue offered suggestions to prevent further damage as well as potential therapeutic options which included prevention of respiratory failure, volume resuscitation, early vasopressor use, source control, and early nutrition (Table 8.1). It is salient to point out that these principles are still very central to the treatment of this disease process. Currently, the terms MODS (multiple organ dysfunction syndrome) and MOF are often used interchangeably [8]. The nuances of the two words effectively describe the syndrome of organ impairment at the point where expeditious treatment might prevent overt organ failure (MODS) versus established coexisting MOF as described in numerous organ failure scores [9]. Effectively, MOF is the end of a continuum that ranges from SIRS to severe organ dysfunction.

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_8

Table 8.1 Goals to prevent MOF

• Prevent ventilatory failure by early support, not allowing the lungs to fail and produce hypoxemia
• Avoid fluid overload, maintaining a urine output of 25–50 mL/h and no more
• Avoid excess sodium and sodium bicarbonate
• Filter blood before transfusion
• Insist on sighing and deep breathing during operation, during resuscitation, and afterward
• Maintain adequate cardiac output by circulatory support using inotropic agents early such as isoproterenol, dopamine, and epinephrine
• Empty the stomach, keep it empty and instill antacids after operation or injury
• Continue controlled ventilation after operation if ventilatory problems are anticipated
• Follow a sigh-suction-sit treatment program for ventilation
• Prevent renal failure by maintaining renal blood flow and urine output
• Use diuretics or dialysis early
• Provide for early nutritional support of such patients
• With tissue injury, use antibiotics before operation to reduce invasive sepsis
• Drain septic foci and eliminate continuing peritoneal contamination

Definitions

In the mid-1980s, after the recognition of sequential organ failure as a syndrome was recognized, multiple terms were used inconsistently by the medical community [10]. These disparate definitions attempting to describe the same physiologic phenomena led to the 1991 consensus conference. The societies of the American College of Chest Physicians (ACCP) and the Society of Critical Care Medicine (SCCM) were present. The goal of this conference was to establish a definition to describe what is now known as the spectrum of physiologic response to infection and/or inflammation. The term "systemic inflammatory response syndrome" (SIRS) was introduced at this conference. Additionally the terms sepsis, severe sepsis, septic shock, and multiple organ dysfunction were defined as a result of this meeting (Table 8.2). The term "SIRS" was established to differentiate sepsis from a noninfectious, inflammatory state [11]. Systemic inflammatory response syndrome (SIRS) was defined as two or more of the following conditions: Core body temperature >38 °C or <36 °C, heart rate >90 beat/min, respiratory rate >20 breath/min; or $paCO_2 < 32$ mmHg or white blood cell count >12,000 or <4000, or >10 % bands. SIRS could represent the symptoms from an infectious or noninfectious source. Infection was described as the invasion of normally sterile tissue by organisms. The term "sepsis" was defined as SIRS in conjunction with a confirmed infection. "Severe sepsis" was defined as sepsis associated with organ dysfunction, hypotension, or hypoperfusion as evidenced by: elevated lactate, acute renal failure, liver failure, altered mental status, and/or hematologic abnormalities. "Septic shock" was the term established as a subset of severe sepsis with the added additional clinical information of persistent hypotension, despite adequate fluid resuscitation. Hypotension was defined as systolic blood pressure (SBP) <90 mmHg, mean arterial pressure (MAP) <70 mmHg or a decrease in SBP >40 mmHg from baseline. "Multiple organ dysfunction syndrome" (MODS) was defined as the presence of altered organ function in an acutely ill patient such that homeostasis cannot be maintained without intervention and is the culmination of septic shock and multiple end organ failure [12]. The 2001 Consensus Conference further expanded on these definitions [13]. A problem similar to the disparate use of the word "sepsis" in the early 1980s remains a problem in regard to the definition of MOF. This is evidenced by a lack of consensus with regard to the innumerable scoring systems available to assess mortality.

Table 8.2 Term definitions

SIRS
• Two or more of the following conditions and can result from infectious or noninfectious causes: • Temperature >38 or <36 °C • Heart rate >90 beat/min • Respiratory rate >20 breath/min or $paCO_2 < 32$ mmHg • White blood cell count >12,000 or <4000, or >10 % bands
Sepsis
• SIRS in conjunction with an infection is termed sepsis
Severe sepsis
• Sepsis associated with organ dysfunction • May include hypotension, elevated lactate, acute renal failure, liver failure, altered mental status, and/or hematologic abnormality
Septic shock
• Subset of severe sepsis with the addition of hypotension manifested by • Systolic blood pressure (SBP) <90 mmHg • Mean arterial pressure (MAP) <70 mmHg • Decrease in systolic blood pressure (SBP) >40 mmHg from baseline
Multiple organ dysfunction (MODS)
• Presence of altered organ function in an acutely ill patient such that homeostasis cannot be maintained without intervention

Epidemiology

Sepsis, severe sepsis, septic shock, and MOF are commonplace in intensive care units and afflict 1.1 million people annually. Moreover, MOF results in 215,000 deaths in the USA alone. Mortality from the spectrum of sepsis is estimated to be 9.3 % of all deaths in the USA [14]. The individual costs

of treating a single patient with MOF can be upwards of $150,000 per patient [15]. In the USA alone the cost of treating sepsis and its related sequelae is approximately $24 billion annually [16]. Additionally, the cost of critical care can account for as much as 1 % of the gross national product of some countries. The resultant morbidity from this disease and consequent loss of wages and quality of life are difficult to quantify. These costs illustrate the substantial financial and societal burden this disease process inflicts. The irony of MOF is that it emerged as a result of improvements in critical care but that it has remained a substantial encumbrance in terms of morbidity, mortality, and cost despite numerous improvements made in critical care in regard to resuscitation and supportive measures.

The overall mortality ranges between 40 and 60 % for MOF in all patients and this mortality increases as more organ systems are affected [17, 18]. The incidence of any organ failure in all intensive care units ranges from 30 to 60 % [19]. In a 1985 study of intensive care patients by Knaus, single organ failure occurred in approximately one third of all patients at some point during their ICU stay and MOF occurred in 15 % of these patients [20]. MOF following septic shock remains the leading contributor to mortality in intensive care unit patients. In a study by Mayr that looked at causes of death in 3700 ICU patients, the most common cause of death in a single ICU was multiple organ failure (47 %) [19]. Specifically regarding trauma patients, traumatic brain injury and uncontrolled hemorrhage remain the leading causes of early death after trauma. Multiple organ failure is, however, the number one cause of late deaths in trauma patients [21]. Despite our improved understanding of the pathophysiology of this disease, the use of antibiotic agents, and more innovative therapies, there continues to be a high mortality rate for MOF.

Regarding the demographics of sepsis and organ failure, a study by Martin et al. in 2003 elucidated some important differences. This study revealed that men are more likely to have sepsis and are more frequently enrolled in clinical trials despite the predominance of women in the population of the USA. Additionally, African-American men had the youngest age of onset in this study as well as the highest mortality. The reason for these demographic differences is not known, however genetic differences and socioeconomic factors most likely contribute to these disparities [22]. Recently, research has confirmed a lower overall incidence of multiple organ failure [23]. The incidence of early single organ dysfunction has not changed but there has been a decrease in early MOF from 22 to 7 %. The incidence of MOF in 1992 was 1.8 times the incidence in 2002 [24, 25]. A similar study of trauma patients by Durham also revealed a lower overall mortality for single organ failure as well as a decrease in the overall incidence of multiple organ failure [26].

Risk Factors for the Development of Organ Failure

Multiple organ failure resides at the most severe end of a spectrum of illness that includes SIRS, sepsis, severe sepsis, and septic shock. Any point along this constellation of criteria puts the patient at risk for MOF. The risks of organ failure are multiple and due to lack of consensus regarding a scoring system, it is difficult to ascertain which risk factors are most specific. MOF was originally thought to be catalyzed by an infectious process. While the majority of patients with MOF will have an infectious source, it is also known that MOF occurs without an infection per se, and can be solely due to unregulated inflammation, as occurs with severe pancreatitis, trauma, or burns [27]. Immunosuppression, pneumonia, blood transfusions, and bacteremia are all associated with increased risk for developing sepsis, severe sepsis, or septic shock and therefore also increases a patient's risk for MOF [28, 29]. Additionally, Zolin et al. showed that early elevations and increasing testosterone levels over initial 24 h after injury are associated with an exaggerated inflammatory response and a significantly greater risk of MOF. High estrogen levels at 24 h are independently associated with an increased risk of MOF. The current analysis suggests that an early evolving testosterone to estrogen hormonal environment is associated with a significantly higher independent risk of poor outcome following traumatic injury [30].

A demographic risk factor for MOF includes advanced age. Advanced age, defined as greater than 65, has likewise been associated with worse quality of life indicators in survivors of sepsis. These patients more often require extensive rehabilitation as well as skilled nursing facility admission upon their hospital discharge from their acute septic event [31]. In a multivariate analysis, adjusted for age, sex, and severe head injury, patients with MOF had 4 times greater odds of requiring assistance from others in activities of daily living more than 2 years after trauma as compared to trauma patients without organ failure. There was no statistically significant difference regarding self-care between patients who did not have a history of organ failure when compared with those patients who had a history of a single organ failure [32]. Obese patients, in general, have been found to have higher post traumatic morbidity and mortality. Obesity is defined as BMI > 30 kg/m and as the BMI goes up, the incidence of MOF increases as well [33]. Moreover, when age, ISS, and transfusions are adjusted for, obesity is associated with an 80 % increased risk of MOF [21, 34]. This is likely associated with the pro-inflammatory state that obesity confers to patients [35]. Additionally, patients with non-operative diagnoses, for example patients admitted post-acute myocardial infarction, have also been found to have a higher likelihood of developing MOF [20].

In trauma patients, Balk and colleagues aptly identified several major risk factors for the development of post injury MOF (Table 8.3). These included prolonged periods of hypotension, trauma, bowel infarction, hepatic insufficiency, advanced age, and alcohol abuse [36]. Additionally, Injury Severity Score (ISS), number of units of packed red blood cells transfused, base deficit, and lactate levels are all associated with an increased risk of developing MOF [37, 38]. Blood transfusions have independently been shown to be predictors of SIRS, MODS, and mortality [39]. Furthermore, Durham et al. also validated that total blood products infused in the first 24 h after injury in addition to higher APACHE III scores amplified the risk for MOF occurrence [26].

Genetic factors also play a role in determining the severity and progression of organ failure. Genetic variants, particularly single-nucleotide polymorphisms (SNPs), are critical determinants for individual differences in both inflammatory responses and clinical outcomes in trauma patients [40]. Individuals who possess specific genetic polymorphisms in genes controlling the synthesis of cytokines or toll like receptors (TLR) may be predisposed to excessive inflammatory response to sepsis which increases their risk for the development of MODS [41]. For example, toll like receptor 9 (TLR9) signaling plays an important role in the innate immune response. Trauma patients with SNPs of TLR9 have been found to have a greater responsiveness of their peripheral blood leukocytes as well as a higher risk of sepsis and multiple organ dysfunction [42]. Henckaerts and colleagues furthermore showed that these functional polymorphisms involved in innate immunity predispose patients to severe infections and death. Further study and elucidation could contribute to formation of a risk model where patients could be stratified as to who could benefit from specific preventative or therapeutic options [43].

Scoring Systems

Multiple organ failure does not have a consensus definition and there are a variety of scoring systems used to categorize the severity of organ dysfunction. Trending these scores during a patient's hospital course enables physicians to prognosticate the patient's risk of mortality [8]. There is also a direct relationship between the number of organ failures and ICU mortality. Moreover, improvements in cardiovascular, respiratory, and renal function during an ICU course can predict a better survival [44].

Scoring systems like the Acute Physiology and Chronic Health Evaluation (APACHE) score are based on measured laboratory values that enable staging of the severity of organ dysfunction. One of the most commonly used scoring systems is the sequential organ failure assessment score (SOFA) (Table 8.4). Clinical and laboratory variables in six organ systems (respiratory, hematologic, liver, cardiovascular, CNS, renal) are utilized to calculate a total score [45]. Patients with no organ failure defined by a SOFA score below or equal to 2 for each organ at admission have an ICU mortality rate of 6 % compared to 65–100 % for those with four or more organ failures [34]. The Denver MOF score is also a frequently used and well-validated score. It is defined as two or more organ systems failing greater than 48 h after injury. The Denver score looks at dysfunction in the cardiac, respiratory, renal, and hepatic systems [25] (Table 8.5). When comparing the Denver post injury MOF score with the SOFA score, the SOFA score is very sensitive but not as specific as the Denver MOF score, whereas the Denver post injury MOF score is more specific and less sensitive than the SOFA score when dealing with the trauma population. This distinction is important when analyzing epidemiologic data as more sensitive scores will have a higher incidence of

Table 8.3 Major risk factors for the development of post injury MOF

Risk factors for early MODS <72 h of injury	Risk factors late MODS >72 h after injury
• ISS > 24	• Age > 55
• SBP < 90	• >6 units of blood transfused within 12 h of injury
• >6 units of blood transfused within 12 h of injury	• Base deficit >8 mEq/l within first 12 h of injury
• Lactate > 2.5	• Lactate > 2.5 mmol/l within 12–24 h of injury

Table 8.4 SOFA score

System	Grade 0	Grade 1	Grade 2	Grade 3	Grade 4
Respiratory P_aO_2/FiO_2	>400	<400	<300	<200 with respiratory support	<100 with respiratory support
Coagulation platelets (Ã-103/mm^3)	>150	<150	<100	<50	<20
Liver bilirubin (mol/L)	<20	20–32	33–101	102–204	>204
Cardiovascular	No hypotension	MAP <70 mmHg	Dopamine >5 or any dobutamine dose	Dopamine >5 or epi_0.1	Dopamine >15 or epi >0.1
Renal creatinine (mol/L)	<110	110–170	171–299	300–440	>440
Central nervous system Glasgow Coma Scale	15	13–14	10–12	6–9	<6

Table 8.5 Denver postinjury multiple organ failure score

Dysfunction	Grade 0	Grade 1	Grade 2	Grade 3
Pulmonary P_aO_2/FiO_2 ratio	>250	250–200	200–100	<100
Renal creatinine (mol/L)	<159	160–210	211–420	>420
Hepatic total bilirubin (mol/L)	<34	34–68	68–137	>137
Cardiac	No inotropes	Only 1 ionotrope at small dose	Any ionotrope at moderate dose or >1 agent at small dose	Any ionotrope at large dose or >2 agents at moderate doses

MOF, while a more specific score will have a higher mortality rate [46–48]. Recently, Dewar et al. compared the Denver versus the SOFA scores with respect to mortality, ICU length of stay, and ventilator days. Both scores had similar performance predicting mortality; however, the Day 3 SOFA score outperformed the Denver score when predicting ICU LOS and ventilator days [49]. Regardless of what score is used to evaluate the various physiologic and clinical parameters, it is an underlying theme in all organ failure scores, that as the number of organ systems that are affected increase, so does the mortality [45, 50]. Moreover, these scoring systems were developed to quantify the severity of illness and the risk of mortality in ICU patients. These prognostic scores will not tell how a patient will respond to therapy and are best utilized to predict outcomes in certain homogenous groups of patients. Additionally, these scores are unable to provide details regarding how a patient will respond to treatment. However, they can be repeatedly assessed to evaluate a patient's progress and used to identify patients for enrollment and to assess morbidity in clinical trials [51].

Clinical Presentation, Evaluation, and Diagnosis

The common clinical manifestations leading to multiple organ dysfunction are included in the ACCP-SCCM guidelines and can fall anywhere within the continuum of SIRS to MOF. These most commonly include alterations in body temperature (hyper or hypothermia), tachypnea or hypocarbia, tachycardia, leukocytosis, leukopenia or bandemia, hypotension, thrombocytopenia or coagulopathy, and alterations in mental status [52]. Fever is the most common presenting symptom of sepsis and should be an impetus for further evaluation the patient as well as identification of a source. Elderly patients with sepsis or those that are immunosuppressed may not mount a febrile response or conversely may be hypothermic [53]. In sepsis, common sites of infection are the pulmonary, gastrointestinal, and urinary tract systems. Other nosocomial causes of sepsis are intravenous catheter infections, ventilator-associated pneumonia, and sinusitis. As approximately 20 % of patients will not have an identifiable source, noninfectious etiologies for SIRS should be considered [54]. These may include surgery, trauma, hematoma, subarachnoid hemorrhage, venous thrombosis, pancreatitis, myocardial infarction, transplant rejection, thyroid storm, acute renal or adrenal insufficiency, lymphoma, tumor lysis syndrome, transfusion reaction, opiates, benzodiazepines, anesthetic related malignant hyperpyrexia, and neuroleptic malignant syndrome [55].

A thorough physical examination should include a head to toe exam as well as inspection of indwelling catheters, a rectal exam, and examination of all wounds, including those under casts/fixation devices. Potential atypical causes of sepsis should be given consideration when an obvious source is identified. These potential causes of sepsis include sinusitis, meningitis, septic joint, acalculous cholecystitis, septic thrombophlebitis, deep muscular abscess, or a viral infection. Corresponding laboratory values based on the suspected differential diagnoses should be obtained.

Infections leading to sepsis can also arise in surgical sites from the skin to the deep muscle layers. Physical examination should be repeated if no source is identified. An investigation of all organ systems should be thorough and systematic. Subtle findings of end organ hypoperfusion such as altered mental status, tachypnea, hypoxia, hypotension, oliguria may be missed if the physician does not have a high index of suspicion and an incomplete exam is performed, i.e. failure to remove a dressing to inspect a wound. Failure to investigate thoroughly can lead to a delay in diagnosis and increased morbidity and mortality. Physical examination should include a rapid review of the patient's hemodynamic condition and should include continuous monitoring. Patients in shock should have arterial catheters placed for blood pressure monitoring. Persistent clinical signs of SIRS may suggest ongoing inflammation or infection. In addition to the patient's hemodynamic status, clinical signs of poor end organ perfusion, such as change in mental status, low urine output, mottling, and poor capillary refill, should be taken into consideration and used to guide resuscitation [56]. Initiation of resuscitation should take place immediately upon recognition of SIRS or sepsis symptoms and should not wait for transport to the next level of care.

Laboratory Evaluation

While no laboratory value will diagnose sepsis or MOF, they may assist in narrowing the differential diagnosis, localizing the source and guiding appropriate antibiotic therapy.

Laboratory studies should include a complete blood count with differential, chemistry profile, arterial blood gas with lactic acid, prothrombin time and partial thromboplastin time, fibrinogen, and urinalysis [54]. Utilizing lactic acid level trends to guide resuscitation has been shown to be helpful in septic patients. For prognostication purposes, resolution of lactic acidosis with resuscitation efforts is associated with improved outcomes [57].

Pan cultures of the urine, blood, and sputum should be collected. The SCCM guidelines recommend that one pair of blood cultures be obtained at the onset of symptoms and another set obtained again at 24 h [11]. When taking blood cultures, two sets of blood cultures should be drawn from peripheral sites. If this is not possible, then one set should be drawn peripherally and the other from a recently inserted central catheter after careful cleansing of the port site. Every effort must be made to draw the first cultures before the initiation of antimicrobial therapy. They can be drawn consecutively or simultaneously, unless there is suspicion of an endovascular infection, in which case separate peripheral blood draws separated by timed intervals can be drawn to demonstrate continuous bacteremia [58].

Based on physical exam, additional body fluids may be sampled if the patient exhibits localized symptoms of infection. For example, cerebrospinal fluid, pleural fluid, joint aspiration, and ascites can all be sampled to localize the source of infection and help guide antibiotic therapy. Radiographic images should be tailored to the most likely source. If plain films are nondiagnostic, CT scans can assist in elucidating a suspected source and used to guide therapy, for example, abscess drainage.

Pathophysiology

The pathophysiology of MOF is at best a nebulous interaction of multiple inflammatory mediators. Our understanding of this process and the innumerable interactions is in its infancy. A complete discussion of the immunology of this process is beyond the scope of this chapter as entire books have been dedicated to this task [59–61]. This section will highlight some salient points regarding the pathophysiology of MOF.

Initially, SIRS was thought to be an overwhelming, uncontrolled response to infection. While MOF frequently is the end point of the spectrum of SIRS and severe sepsis, severe inflammation is also a mitigating factor and can result in the same endpoint of organ failure. This indicates overlap in the pathophysiology between inflammation and infection. The progression to MOF from SIRS from either cause is likely the result of an unbalanced interaction between the pro- and anti-inflammatory mediators. In most patients, the initial SIRS response is physiologically followed by a compensatory anti-inflammatory response syndrome (CARS). This acts to limit the SIRS response so that it is not counterproductive. The subsequent balance between the pro-inflammatory (SIRS) and anti-inflammatory (CARS) response has been referred to as the mixed antagonistic response syndrome or MARS [36]. If the balance of these two systems is disturbed, the inflammatory response becomes systemic and deregulated. The result is whole-body activation of the inflammatory response, with resultant disruption of normal cellular metabolism and microcirculatory perfusion. Both of these responses, if unchecked can result in complications, the former leading to MOF and the latter secondary infections. At the site of injury, endothelial cells and leukocytes coordinate the local release of mediators of the inflammatory response, including cytokines interleukins, interferons, leukotrienes, prostaglandins, nitric oxide, reactive oxygen species, and products of the classic inflammation pathway. It is this usually functional biologic response that becomes unregulated and leads to MOF [62].

In 1996, Moore and colleagues recognized MOF is not necessarily related to an infectious process and follows a bimodal distribution. Early MOF is now defined as organ failure that develops within 72 h of the initial diagnosis of sepsis**.** Late MOF was defined as organ failure that develops after 72 h after the initial diagnosis of sepsis [63]. When compared to the late MOF group, patients with early organ failure died sooner, had more cardiac dysfunction, and had greater evidence of hyper inflammation. In contrast, patients with late MOF were older, had greater evidence of hepatic failure, and were more likely to have an infection as a "second hit" [64].

Multiple theories exist regarding the cause for MOF and it is likely that these pathways overlap to cause initially organ insufficiency which, unless reverses, ultimately leads to failure. Four overlapping categories have been proposed to the complex pathophysiology of MOF. These are the cytokine hypothesis, the microcirculatory hypotheses, the gut hypothesis, and the two-hit hypothesis [60].

The Cytokine Hypothesis of MOF

In the cytokine hypothesis, the immune response to infection or inflammation results in excessive or prolonged activation or stimulation of mediators. These include interactions between polymorphonuclear neutrophils (PMNs), endothelial cells, and macrophages. PMN stimulation results in "priming" of the neutrophil and can lead to overzealous production, surface expression, and liberation of cytokines [65]. These mediators often have an exaggerated response and the products of these cascades exert damaging local and systemic effects. A temporal relationship between cytokine production and time of injury was recognized. Cytokines

predictive of MOF in trauma patients include inducible protein (IP)-10, macrophage inflammatory protein (MIP)-1B, interleukin (IL) IL-10, IL-6, IL-1Ra, and eotaxin [66]. Several lines of evidence support the central role of inflammatory cells in the pathogenesis of lung and systemic organ injury. Tumor necrosis factor (TNF) has been considered one of the most potent pro-inflammatory cytokines identified in SIRS and sepsis. Administration of TNF to experimental animals creates the hemodynamic and metabolic observations consistent with SIRS. Analysis of cytokine serum biomarkers has shown that patients with MOF show a biphasic elevation of IL-6 and significantly higher soluble TNF receptor (sTNF-R) concentrations [67]. Activation of leukocytes and their subsequent inappropriate sequestration in organs appears to additionally be one of the key events in the development of early MOF. Once activated, leukocytes have the capacity to release their cytotoxic factors including nitric oxide and lysosomal granules, which aid in polymicrobial killing. These factors can cause necrosis and inflammation of organs such as the lung despite a lack of an infectious stimulus [68]. Additionally, PMN stimulation provokes endothelial and epithelial injury through up-regulation of adhesion molecules on these cells. This prompts changes in the cell wall, increased permeability cell swelling and culminates in cellular dysfunction. Neutrophil elastase is a key marker of severity of injury and has also been found to be a prognostic marker [69].

The Microcirculatory Hypothesis of MOF

The microcirculatory hypothesis proposes that organ injury is related to ischemia or vascular endothelial injury [70]. Some authors have speculated that even though adequate blood flow may reach the various tissue beds, there may be an inability of the mitochondria or cells to take up or use the delivered oxygen and substrate. Although prolonged tissue hypoperfusion and hypoxia leads to inadequate ATP generation and potentially irreversible cell damage, this shock period is not long enough in most clinical conditions for that to occur. This damage is relieved by reperfusion and thus pro-inflammatory factors and oxygen radicals are introduced and lead to injury [71]. In vitro studies have found that nitric oxide (NO) up-regulates the production of pro-inflammatory cytokines (TNF-a, IL-8 and prostaglandins) and can lead to injury of the lung and intestine. Additionally, the superoxide anion and hydrogen peroxide can interact with NO and form peroxynitrite which is toxic to cells [69]. During shock, these mediators, such as reactive oxygen species, are released to destroy the offending bacteria and to inactivate toxins. The unintended effects are that when unregulated, they also result in damaging the patient's organ systems [72].

Gut Hypothesis of MOF

The gut is considered an immunologically active organ and a main in the burden of infection induced systemic inflammation [25]. Gut barrier dysfunction can occur for a variety of reasons including, trauma, shock, infection, and malnutrition. It is proposed that, as a result of the loss of the gut barrier function, intestinal bacteria and endotoxin cross the mucosal barrier and lead to exposure of the intestinal immune cells. The production of gut-derived toxins and inflammatory products reach the systemic circulation through the intestinal lymphatics, leading to SIRS, ARDS, and MOF[656] These translocating bacteria are phagocytosed by intestinal immune cells and contribute to the intestinal inflammatory response. Some of these translocating bacteria or their toxic products are trapped in the intestinal lymph nodes, causing inflammatory reaction [69]. This hypothesis is supported by the demonstration of circulating levels of endotoxin in the peripheral blood of critically ill patients with sepsis and SIRS. Reports of endotoxemia in these critically ill patients, even without clinical or microbiologic evidence of infection with gram-negative organisms support the potential role of translocation in the production of MODS/MOF [36]. The phenomenon of bacterial translocation, however, is not sufficient to explain the development of MODS in ICU patients. The development of MODS in these high-risk patients is likely due to intestinal injury and the resultant inflammatory cascade that reaches the systemic circulation via the intestinal lymphatics [73].

Two-Hit Phenomenon in MOF

The phrase "two-hit phenomenon in MOF" is used to describe the biologic phenomenon in which an initial insult primes the host such that on a second or subsequent insults, the host's response is greatly amplified. Primers to the subsequent insult can be infection, shock, inflammation, or trauma. Despite the decreasing incidence of MOF, the rate of PMN priming has not changed. PMN priming increases elastase release, IL-8 production, L-selectin expression, and CD-18 expression, and delayed apoptosis. This is evident by a lack of change in the incidence of early lung dysfunction post injury, which is a surrogate marker of PMN priming [74]. The timing of the second hit phenomenon was shown in laboratory experiments evaluating abdominal compartment syndrome (ACS). If subjects had early decompressive laparotomy (<2 h) or late (>18 h), they had a lower mortality than those having a decompressive laparotomy at 8 h. This correlates with the clinically identified time frame of the development of postinjury ACS, which manifests 8–12 h window after trauma. Severely injured patients who develop ACS have a four-fold increase in their chance of developing MOF

compared to the non-ACS patients with similar demographics, shock parameters, and injury severity[251] These insults prime the immune system to mount an exaggerated response when exposed to a second physiologic insult. Botha described the observation that the first hit primes and activates PMNs within 3–6 h after injury. This primer creates a vulnerable window during which a second insult activates excessive cytokine release. This second hit results in an elevated risk of developing MOF [75]. This exaggerated immune response then results in end organ injury [70]. In summary, MOF results from an excessive host response to an infectious or inflammatory stimulus. Any or all of the above hypotheses can coexist and each overlaps with the other. The cytokine, endovascular, and systemic storm that ensues thereafter predisposes to additional infections and can lead to organ failure [44].

The temporal series of events in MOF is usually predictable and is independent of the etiology. Multiple studies have demonstrated that the respiratory system is usually the first to fail and is the most commonly affected [14]. This is typically followed by hepatic, intestinal, and renal failure, in that order. As the number of organ systems affected increases from 1 to 4, the mortality increased from 21 to 100 % [76]. Hematologic and myocardial failures are usually later manifestations of MOF, whereas the onset of central nervous system alterations can occur either early or late [25]. Physiologically, these patients are hypermetabolic and they have a hyper dynamic circulation, which is characterized by an increased cardiac output and a decreased systemic vascular resistance. This classical sequential pattern of organ failure may be modified, however, by the presence of pre-existent disease or by the nature of the precipitating clinical event. For example, renal failure may precede hepatic or even pulmonary failure in patients with intrinsic renal disease or in patients who have sustained prolonged periods of shock, whereas hepatic or myocardial failure may be an early or even the initial manifestation of this syndrome in the patient with cirrhosis or myocardial damage [59]. The exact sequence of organ failure however is not always predictable and can be influenced by the patient's preexisting morbidities as well as their acute process. However, as the number of organs that fails increases from one to four, the mortality rate progressively increases from 30 to 100 % [26].

Multiple Organ Failure by System

Pulmonary Dysfunction

The sequence of organ dysfunction is predictable and the lung is usually the first organ to show signs of failure. Initial pulmonary insufficiency and renal impairment are followed by circulatory failure and then metabolic dysfunction and liver failure. Respiratory failure can range from mild hypoxia and tachypnea to acute respiratory distress syndrome (ARDS)

Table 8.6 Berlin definition of ARDS

Timing	Within 1 week of a known clinical insult or new or worsening respiratory symptoms
Chest imaging	Bilateral opacities—not fully explained by effusions, lobar collapse or nodules
Origin of edema	Respiratory failure not fully explained by cardiac failure or fluid overload
	Need objective assessment (echo) to exclude hydrostatic edema if no risk factor present
Oxygenation mild	200 mmHg < P_aO_2/FIO_2 < 300 mmHg with PEEP or CPAP >5 cm H_2O
Moderate	100 mmHg < P_aO_2/FIO_2 < 200 mmHg with PEEP >5 cm H2O
Severe	P_aO_2/FIO_2 < 100 mmHg with PEEP >5 cm H_2O

[77]. The classic American-European Consensus Conference (AECC) definition of acute respiratory distress syndrome is defined as a P_aO_2/FIO_2 ratio lower than 200 mmHg in association with bilateral fluffy pulmonary infiltrates and a pulmonary capillary wedge pressure lower than 18 mmHg [78]. In 2012, the ARDS Definition Task Force, using a consensus process developed the Berlin Definition of ARDS (Table 8.6). The Berlin definition proposed three mutually exclusive categories of ARDS based on degree of hypoxemia: mild (200 mmHg; $P_aO_2/FIO_2 \leq 300$ mmHg), moderate (100 mmHg; $PaO_2/FIO_2 \leq 200$ mmHg), and severe ($P_aO_2/FIO_2 \leq 100$ mmHg). An additional four ancillary variables for severe ARDS were also included: radiographic severity, respiratory system compliance (≤40 mL/cm H_2O), positive end-expiratory pressure (≥10 cm H_2O), and corrected expired volume per minute (≥10 L/min). Compared with the classic AECC definition, the final Berlin definition demonstrated better predictive validity for mortality [79].

Increased capillary permeability and neutrophil influx are the earliest pathologic events in ARDS. As the acute inflammatory process resolves, further lung injury results both from the process of repair, which involves fibrosis and the deposition of hyaline material, and from further lung trauma, resulting from positive pressure mechanical ventilation [80]. Acute respiratory distress syndrome may occur within a few days of admission or after the development of SIRS and sepsis. Sepsis-induced ARDS is associated with the highest mortality rates. Additionally, the data suggests that approximately 40 % of patients with severe sepsis develop ARDS. Historically, 10–12 mL/kg tidal volumes were commonplace and resulted in alveolar damage due to over distention. Parenchymal injury appears to be due primarily to oxidative damage from the activated neutrophils in the lung. Endotracheal intubation and a controlled mode of ventilation are the mainstays of support for respiratory failure. Lung protection ventilation strategies, with low tidal volumes (4–6 mL/kg) for patients with ARDS, are recommended and showed a decreased mortality from 40 to 31 %. Due to the smaller tidal volumes, patients typically will have a rise in carbon dioxide [81]. This permissive hypercapnia

has been shown to have a protective effect in critically ill patients [82]. Some patients with refractory hypoxemia may require alternative therapies such as extracorporeal membrane oxygenation (ECMO), high-frequency oscillation, or inhaled nitrous oxide.

Gastrointestinal and Hepatic Dysfunction

The gastrointestinal tract is a crucial component of the SIRS response. Shock is associated with obligatory gut ischemia due to vasoconstriction. With resuscitation efforts, reperfusion results in a local inflammatory response that can set the stage for abdominal compartment syndrome (ACS). Abdominal compartment syndrome is a syndrome that occurs either primarily or secondarily [83]. Primary ACS occurs in patients undergoing damage control laparotomy. The presence of laparotomy pads, blood products, and resuscitation fluid increases the pressure in the abdomen to a tipping point, usually 25 mmHg. Secondary ACS occurs after a non-abdominal injury that requires massive transfusion. The products of resuscitation result in edematous bowel and fluid sequestration and the same impaired end organ perfusion [84]. This pressure elevation is higher than the mesenteric and splanchnic arterial beds resulting in ischemia. Respiratory physiology is impaired due to elevated peak pressures and vena cava compression results in impaired cardiac filling. This constellation of symptoms requires an investigative clinician. Once the diagnosis is made, the abdominal pressure is usually relieved by emergent laparotomy. Clinical studies have clearly documented the poor outcome of patients developing ACS and the frequent association of ACS and MOF [85].

Risk factors for hepatic insufficiency include perfusion deficits, persistent foci of dead or injured tissue, an uncontrolled focus of infection, the presence of the respiratory distress syndrome, and preexisting fibrotic liver disease [86]. In patients with septic shock, transaminitis is a common laboratory finding in patients. The catecholamine, norepinephrine induces injury to hepatocytes by activating adrenergic receptors on Kupffer cells. In turn, norepinephrine enhances chemokine and NO production, resulting in mitochondrial damage [48]. This process is usually transient and limited to a laboratory abnormality that corrects once the patient is resuscitated. However, if hemodynamics are not restored, a secondary hepatic dysfunction may occur and can lead to bacterial product spillover, amplified inflammation and may lead to multiple organ failure and death [87].

Renal Dysfunction

Acute kidney injury is a common dysfunction in patients with sepsis. It confers its own mortality risk and when it develops in association with MOF [88]. In a recent review by Wohlauer et al., early acute kidney injury was present in 2.13 % of severely injured patients and was associated with a 78 % MOF incidence and 27 % mortality. Both rates were higher than those associated with early heart, lung, or liver failure [89]. The causes of renal dysfunction are multi-factorial and can be due to inadequate perfusion, nephrotoxic medications, acute tubular necrosis, contrast induced nephropathy, abdominal compartment syndrome, and obstruction. Activation of the renin–angiotensin system may contribute to reduced perfusion as vasoconstriction exacerbates ischemia. This is clinically manifested as oliguria (<30 mL/h) or anuria and as an increased serum concentration of creatinine and urea [77]. The vasoconstrictive shunting due to compensatory mechanisms or concomitant vasopressors agents can exacerbate the injury and results in further nephron ischemia. Additionally, tumor necrosis factor has been shown to be directly injurious to nephrons by inducing apoptosis [48]. Treatment is aimed at identifying the source and provision of supportive care. Moreover, up to 70 % of patients with severe sepsis require some form of renal replacement therapy [55]. While intermittent and continuous hemodialysis are equivalent, continuous dialysis avoids the hemodynamic instability often seen with intermittent dialysis [90]. The typical indications for dialysis are volume overload, refractory acidosis, uremia, and electrolyte derangements.

Although common, AKI is often underdiagnosed. Several scoring systems exist for identifying acute kidney injury (AKI) and aim to predict the prognosis of affected patients. The RIFLE score (Risk, Injury, Failure, Loss of kidney function, and End-stage renal failure) and the Acute Kidney Injury Network (AKIN) are staging systems that are used to grade acute kidney injury and predict mortality. Recently, the Kidney Disease: Improving Global Outcomes (KDIGO) proposed a new definition and classification of acute kidney injury (AKI) on the basis of the RIFLE and AKIN criteria (Table 8.7). A higher incidence of AKI was diagnosed according to KDIGO criteria. Patients diagnosed as AKI had a significantly higher in-hospital mortality than non-AKI patients, no matter which criteria were used. Compared with the RIFLE criteria, KDIGO was more predictive for in-hospital mortality, but there was no significant difference between AKIN and KDIGO [91, 92].

Cardiovascular Dysfunction

Myocardial depression is a well-recognized manifestation of organ dysfunction in sepsis. Due to the lack of a generally accepted definition and the absence of large epidemiologic studies, its frequency is uncertain. Cardiac dysfunction in sepsis is characterized by decreased contractility, impaired ventricular response to fluid therapy, and ventricular dilatation. Cardiac echocardiograms suggest that 40–50 % of patients with prolonged septic shock develop myocardial

Table 8.7 Acute kidney injury staging

Urine output	Stage	KDIGO stage Serum creatinine	Stage	AKIN stage Serum creatinine	Class	RIFLE class Serum creatinine or GFR
<0.5 mL/kg/h for 6 h	1	Increase of 1.5–1.9 times baseline or >27 μmol/L increase	1	Increase to >150–200 % from baseline or > increase	Risk	Increase in serum creatinine × 1.5 or GFR decrease >25 %
<0.5 mL/kg/h for 12 h	2	Increase of 2–2.9 times baseline	2	Increase to 200–300 % from baseline	Injury	Increase in serum creatinine × 1.5 or GFR decrease >25 %
<0.3 mL/kg/h 24 h or anuria for 12 h	3	Increase of >3 times baseline or increase in creatinine to >354 μmol/L or initiation or RRT	3	Increase to >300 % or >354 μmol/L with an acute increase of >44 μmol/L or initiation of RRT	Failure	Increase in serum creatinine × 1.5 or GFR decrease >25 %
					ESRD	ESRD >3 months

depression, as defined by a reduced systolic and diastolic ejection fraction. Additionally, peroxynitrite has a direct damaging effect on myocyte mitochondria and causes reduced contractility [93]. Troponin elevation is also seen and correlates to the severity of illness and dysfunction [94]. Sepsis-related changes in circulating volume and vessel tone inevitably affect cardiac performance. The principal hemodynamic profile shows elevated cardiac output, but substantially reduced systemic vascular resistance [95]. Mitochondrial dysfunction, another feature of sepsis-induced organ dysfunction, will also place the cardiac myocytes at risk of adenosine triphosphate (ATP) depletion. However, clinical studies have demonstrated that myocardial cell death is rare and that cardiac function is fully reversible in survivors. Hence, functional rather than structural changes seem to be responsible for intrinsic myocardial depression during sepsis [96]. Current studies support that myocardial depression is due to a complex underlying physiopathology with a multiple overlapping pathways. Cytokine release and circulation such as TNF-alpha, IL-1, and endothelin-1 directly inhibit myocyte contractility contributing to the overall cardiac dysfunction [97]. Nitric oxide production additionally has a complex role in sepsis-induced cardiac dysfunction and may have a deleterious as well as a beneficial role [98].

Endocrine Dysfunction

Endocrine abnormalities are common during sepsis and MOF and include hyperglycemia and insulin resistance. Hyperglycemia is common in critically ill patients, with approximately 90 % of patients treated in an ICU developing blood glucose concentrations >110 mg/dL [99]. Historically, hyperglycemia was not treated until the blood glucose level rose above 200 g/dL. In a randomized controlled study, Van den Berge and colleagues used insulin infusions to maintain tight control of blood sugars in critically ill surgical patients. The strictly controlled group had their blood glucose maintained between 80 and 110 g/dL. The more liberal threshold was only treated at >180 g/dL. A mortality benefit, from 8 to 4.6 %, was identified in the surgical patients that had strict control of their blood sugar. This survival benefit was largely related to a reduction in deaths due to MOF [100]. Due to tighter control utilizing insulin drips, patients were noted to more episodes of hypoglycemia requiring treatment. Subsequently, follow-up studies have shown that hypoglycemia is an increased risk factor for mortality [101]. Conversely, the Normoglycemia in Intensive Care Evaluation-Survival Using Glucose Algorithm Regulation (NICE-SUGAR) study reported increased mortality with a tight blood sugar control approach [102]. Recent meta-analyses do not support intensive glucose control for critically ill patients and more moderate recommendations to target a blood glucose concentration between 144 and 180 mg/dL (8–10 mmol/L) are now in effect [103].

In addition to hyperglycemia, a relative state of adrenal insufficiency is common in critically ill patients [48]. This is defined as an abnormally low level of the patient's endogenous cortisol at the time of physiologic stress. In response to hypotension and following trauma or surgery, circulating cortisol concentrations should exceed 25 μg/dL. Marik et al. discovered that 70 % of ICU patients had inappropriately low levels of cortisol. This low level of cortisol can result in a blunted response to hypoglycemia and hypotension [104]. The Surviving Sepsis Campaign suggests giving intravenous hydrocortisone to adult septic shock patients after their hypotension is identified to be poorly responsive to fluid resuscitation and vasopressor therapy. If one suspects adrenal insufficiency, corticosteroids should be administered without waiting on results of a cosyntropin stimulation test [103].

Hematologic Dysfunction

Thrombocytopenia is the most common hematologic dysfunction and is present in 20 % of patients and is associated with an increased mortality [105]. The causes are multifactorial but include bone marrow suppression from sepsis,

sequestration, consumption, and heparin induced thrombocytopenia (HIT). As critically ill patients are often immobilized and mechanically ventilated, they are at elevated risk for deep vein thromboses. If no contraindication exists, critically ill patients should be on daily chemical thromboprophylaxis. This chemical prophylaxis can lead to HIT by production of antibodies against the heparin-platelet factor 4 complex. The antibody-platelet complex is then removed prematurely from the circulation leading to thrombocytopenia [105].

Anemia is also a common finding in patients who are critically ill. The etiology is usually multi-factorial and can result from direct inhibition by cytokines, deficiency of erythropoietin, blunted erythropoietic response, acute blood loss, nutritional deficiencies, as well as renal insufficiency [106]. Leukocytosis is also common within hours after injury or the onset of sepsis. Typically, the number of leukocytes markedly increases and the number of lymphocytes and monocytes decreases. This post injury leukocytosis is primarily due to increased PMN numbers, and several studies have shown a link between high number of PMNs during the first hours after injury and an increased risk of organ failure and mortality [75].

Neurologic Dysfunction

CNS dysfunction occurs in as many as 70 % of critically ill patients. The brain plays a pivotal role in sepsis, acting as both a mediator of the immune response and a target for the pathologic process. Sepsis-associated encephalopathy is associated with increased mortality and morbidity [107]. Its pathophysiology remains insufficiently elucidated, although there is evidence for a neuroinflammatory process sequentially involving endothelial activation, blood–brain barrier alteration and cellular dysfunction and alteration in neurotransmission [108]. Increased permeability to cytokines, neuroamines, as well as endotoxemia has all been implicated in septic encephalopathy [94]. It is difficult to quantify neurologic impairment as there are no specific biomarkers of neuronal injury and bedside evaluation of cognitive performance is difficult in an intensive care unit [109]. The Glasgow Coma Scale is frequently utilized by organ failure scoring systems to evaluate the severity of a patient's neurologic failure but sedatives and analgesics can make this score unreliable. New delirium in a critically ill patient should raise the suspicion of the physician to the possibility that this is the first presentation of infection.

Furthermore, a substantial number of patients admitted to the ICU because of an acute illness, complicated surgery, severe trauma, or burn injury will develop a de novo form of muscle weakness during the ICU stay that is referred to as "intensive care unit acquired weakness" (ICUAW). This ICUAW evoked by critical illness can be due to axonal neuropathy, primary myopathy, or both. Underlying pathophysiological mechanisms comprise microvascular, electrical, metabolic, and bioenergetic alterations, interacting in a complex way and culminating in loss of muscle strength and/or muscle atrophy. ICUAW is typically symmetrical and affects predominantly proximal limb muscles and respiratory muscles, whereas facial and ocular muscles are often spared. The main risk factors for ICUAW include high severity of illness upon admission, sepsis, multiple organ failure, prolonged immobilization, and hyperglycemia, and also older patients have a higher risk. Recovery usually occurs within weeks or months, although it may be incomplete with weakness persisting up to 2 years after ICU discharge. Prognosis appears compromised when the cause of ICUAW involves critical illness polyneuropathy, whereas isolated critical illness myopathy may have a better prognosis. In addition, ICUAW has shown to contribute to the risk of 1-year mortality [110].

Treatment

Initial Resuscitation

Current strategies are aimed at preventing organ failures and supporting failing organ systems in critically ill patients. Once MOF has developed therapies are aimed at supporting failed organ systems and preventing secondary example infection. Currently there is no specific pharmacotherapy for ARDS or MOF.

A crucial component in preventing the progression of septic shock to multiple organ failure (MOF) is early recognition and expeditious implementation of goals of therapy. Initial resuscitation should include establishing intravenous access and prompt initiation of fluid resuscitation. In 2001, Rivers et al. found that in patients with septic shock, early goal-directed therapy conferred a substantial reduction in mortality from 46.5 to 30.5 %. This study also demonstrated the importance of the urgency of resuscitation. Once sepsis is recognized, whether it's in the Emergency Department or the hospital ward, early goal-directed therapy should be initiated. Studies in which aggressive resuscitation was delayed until after transfer to the ICU failed to show improved outcome or a reduction in MODS [111]. Patients that have septic shock should be admitted to an intensive care unit that is conducive for invasive hemodynamic monitoring and frequent reassessment. In 2014, a follow-up study was conducted by the Protocol-based care for early septic shock (ProCESS) group in 31 emergency departments in the USA. Patients with septic shock were randomized to one of the three groups for 6 h of resuscitation: protocol-based EGDT; protocol-based standard therapy that did not require the placement of a central venous catheter, administration of

inotropes, or blood transfusions; or usual care. The primary end point was 60-day in-hospital mortality. The goal was to elucidate whether protocol-based care (EGDT and standard-therapy groups combined) was superior to usual care and whether protocol-based EGDT was superior to protocol-based standard therapy. The protocol based resuscitation group did not show improved outcomes but this may be a reflection that "usual care" in sepsis is treated with Rivers' early goal-directed therapy [112].

Vascular access with two large bore intravenous (IV) catheters is adequate for initiating resuscitation but if hemodynamic compromise is present, central venous access should be established. The optimal type of fluid is an ongoing controversy in the critical care literature, but crystalloid should be given at an initial bolus of 20 mL/kg of ideal body weight. Fluids should be bolused to attain a goal central venous pressure (CVP) of 8–12 mmHg, mean arterial pressure (MAP) >65 mmHg, urine output >0.5 mL/kg/h, and a SvO_2 >70 %. Recognition of the sequelae of each IV fluid should be recognized and tailored to the patient's specific pathophysiology, i.e., resultant hyperchloremic acidosis with normal saline administration [48]. If hypotension is still present after the CVP goals are attained, vasopressor assistance should also be initiated.

The Surviving Sepsis Campaign established resuscitation and management bundles that emphasize the prompt initiation of therapy for sepsis. The resuscitation bundle describes tasks that should begin immediately, and must be accomplished within the first 6 h of presentation for patients with severe sepsis or septic shock.

Some items may not be completed if the clinical conditions described in the bundle don't apply, but clinicians should assess their patients for them. The goal is to perform all of the indicated tasks 100 % of the time within the first 6 h of identification of severe sepsis. The management bundle provides evidence-based goals that similarly must be completed within 24 h for patients with severe sepsis, septic shock, and/or lactate >4 mmol/L (36 mg/dL). For patients with severe sepsis, as many as four bundle elements must be accomplished within the first 24 h of presentation. Again, some items may not be completed if the clinical conditions described in the bundle do not apply but a high index of suspicious by physicians should exist to rule them out. The goal is to perform all indicated management tasks, 100 % of the time, within the first 24 h of presentation [13].

Along with the aforementioned endpoints of resuscitation, measurement of blood lactate has also been used as a means to assess prognosis and is inversely proportional to survival [113]. As the lactate concentration increased from 2.1 to 8 mM/L, the estimated probability of survival decreased from 90 to 10 % [114]. Abramson et al. also revealed the importance of lactate clearance and survival following traumatic injury. If a patient's lactate normalized (lactate <2 mmol/L) within 24 h their survival rate was 75 % versus 14 % if the lactate level did not return to normal by 48 h [115].

Vasopressors

Once fluid resuscitation has been initiated and hemodynamic monitoring established, if the patient's MAP remains <65 mmHg, vasopressor therapy should be initiated. The Surviving Sepsis Campaign Guidelines (SSCG) recommends norepinephrine or dopamine as the first line vasopressor agents. Due to a relative deficiency of vasopressin in septic shock, consideration should be given to adding a low dose vasopressin drip (0.04 Unit/min) which may assist in correcting refractory hypotension [116]. Additionally, the SSCG guidelines regarding vasopressors also recommend using epinephrine as an alternative if blood pressure is poorly responsive but it should not be used as a first line agent. Volume resuscitation should be occurring simultaneously but if hypotension is refractory, vasopressors should be initiated to maintain MAP >65.

Source Control and Antibiotic Therapy

Once the suspicion for SIRS or sepsis is present, a thorough physical exam, laboratory studies and radiographic evaluation of the patient should ensue to identify the causative agent. Ongoing sources of infection are known to "prime" the host immune system so that a second insult can cause an exaggerated systemic inflammation ultimately culminating in MOF [51]. Laboratory values that should be sent were mentioned earlier. Indwelling catheters should be inspected for signs of infection or outright removed if the clinical suspicion is high. A positive blood culture from a centrally placed catheter is considered infected if the culture becomes positive at least 2 h before the peripherally obtained culture does [117]. Antibiotics should be administered within 1 h of suspicion of sepsis and the urgency should be conveyed to the ICU pharmacist to assist in expediting the administration of the antibiotics to the patient. A study by Kumar et al. demonstrated that patients had a survival rate of 79 % if antibiotics were given within 1 h of the development of hypotension. Conversely, the same study showed a decrease in survival of 7.6 % for every hour antibiotic administration was delayed [118]. This illustrates the importance of having a high index of suspicion and initiating antimicrobial therapy. According to the SSCG antibiotics should be broad spectrum and active against bacterial/fungal pathogens. Therapy should be limited to 7–10 days unless a mitigating circumstance is present and once susceptibilities return, de-escalation of therapy is appropriate.

Should a surgical source of infection be identified, utilization of damage control techniques is appropriate to prevent further injury. Originally described in trauma patients as an abbreviated laparotomy, this involves making a decision, to address only the critical issues at the first surgery and to return the patient to the ICU for further resuscitation [119]. Depending on the intracavitary findings, a conscious decision to leave bowel in discontinuity or to leave the abdominal wall open may be made with a planned returned once the patient is further resuscitated. This technique has been used in trauma and emergency general surgery and should be considered for any surgical patient with ongoing resuscitation needs or who has preexisting or is at risk for, acidosis, coagulopathy and hypothermia.

Corticosteroids

Relative adrenal insufficiency is often seen in septic shock due to what is hypothesized as suppression of the hypothalamic–pituitary–adrenal axis. The debate regarding the benefit of giving corticosteroids is ongoing and multiple studies have had conflicting results. Annane et al. performed a multicenter, double-blind, placebo-controlled trial study that administered hydrocortisone plus fludrocortisone to patients with septic shock [120]. This landmark study showed improved survival in patients and decreased vasopressor requirements. In contrast, the Corticosteroid Therapy of Septic Shock (CORITCUS) trial was a multicenter, randomized, double-blind, placebo-controlled trail that also evaluated the use of hydrocortisone in patients with septic shock. This study failed to show a mortality benefit but did show a statistically significant benefit of faster shock reversal [121]. Despite the ongoing controversy and presence of multiple conflicting studies, the current Surviving Sepsis Guidelines recommendations include administering corticosteroids to septic patients if hypotension is refractory to fluid resuscitation and vasopressor initiation. Cosyntropin (ACTH) stimulation test is not required and clinical suspicion of adrenal insufficiency should be the impetus to start steroids rather than waiting on the stimulation test to be resulted. Once the patient's vasopressor requirements have subsided, the steroid therapy may be weaned [103].

Activated Protein C

Activated protein C (APC) directly inhibits clotting factors Va and VIIIa and restores the fibrinolytic system by blocking plasminogen activator inhibitor. In sepsis, there is decreased production of APC resulting in a procoagulant state [122]. APC also has anti-inflammatory effects that include limiting leukocyte chemotaxis and reducing thrombin production. However, the levels of endogenous APC are depleted during sepsis [123]. In 2001, the protein c worldwide evaluation in severe sepsis (PROWESS) study found that when patients with APACHE scores >25 received activated protein C for sepsis, they had a relative and absolute risk reduction of 19.4 % and 6.1 %, respectively. The PROWESS study also demonstrated that patients that received APC had a statistically significant increase in serious bleeding events (3.5 % versus 2.0 %). In 2004, the first Surviving Sepsis Campaign guidelines included the use of drotrecogin alfa on patients at high risk of death, APACHE II ≥25, sepsis-induced multiple organ failure, septic shock, or sepsis-induced ARDS and no absolute contraindication related to bleeding risk or relative contraindication that outweighs the potential benefit of activated protein C [124]. The 2008 guidelines suggested that consider its use in the patients that met the above criteria but that it should not be used on patients with a low risk of death. Of note in 2011, a Cochrane review in 2011 and 2012 found no evidence to suggest that APC reduced the risk of death in any patient [125]. Moreover, heightened risk of bleeding precluded its use and the drug was pulled from the market [126].

Nutrition

The past few decades have led to considerable interest regarding nutritional support of critically ill patients. Sepsis and organ failure are hypermetabolic states and increase the patient's metabolic demand. If the caloric needs are not met by supplemental nutrition, muscle breakdown and weakness can ensue. The intestinal tract is now recognized as an immune organ and the intact intestinal wall acts as a barrier. It has been recognized that loss of this barrier can potentially lead to bacterial translocation, progressive shock, and ultimately organ failure. The use of enteral nutrition is known to reduce infectious complications in subpopulations of patients with trauma and burns [127]. No single formula matches every patient's needs thus formulas should be tailored to match the pathophysiology of the individual patient. Formulas containing linoleic acid, antioxidants, and omega-3 fatty acids may reduce the incidence of organ failure in patients with acute lung injury and may reduce mortality rates in mechanically ventilated patients [128, 129]. Arginine and glutamine containing formulas have shown benefit in trauma and burn patients [130, 131]. Arginine containing formulas, however, may be detrimental to patients with septic shock [132].

Current guidelines strongly recommend early use of enteral nutrition, with parenteral nutrition being reserved for patients in whom enteral nutrition fails to provide sufficient nutrition [133]. While enteral feeding is preferred, ileus due to ongoing infection or inflammation may prohibit enteral feeding. In these patients, parenteral nutrition is the preferred option.

Innovative Therapies

The overlap of inflammatory cells, cytokines, endothelial cells, and organ systems offers numerous potential locations to intervene by enhancing or blocking specific receptors and halt the damaging effects of the deregulated immune system. Potential targets for therapy have been anti-endotoxin antibodies, anti-tumor necrosis factor monoclonal antibodies, interleukin-1 receptor antagonists, antioxidants, dialysis and activated protein C [58]. A better understanding of the dynamic of interactions at the cellular level is needed to direct therapy and more research is ongoing. Thus far, supportive care is the mainstay once sepsis has progressed to MOF.

Conclusion

Multiple organ failure remains a major cause of morbidity and mortality in the trauma and surgical intensive care units. Due to improvements in recognition of sepsis and early institution of therapy, the incidence of MOF has decreased. Further research is needed to obtain a better understanding of the pathophysiology of this disease and how the inciting event progresses to organ failure. This understanding will afford more potential targets for therapy. Thus far there is not one "magic bullet" therapy and the mainstay of critical care should be prompt recognition of SIRS and the sequelae of sepsis, expeditious treatment and prevention of end organ damage.

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Acute Respiratory Distress Syndrome

9

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Historical Perspectives

The earliest official clinical description of acute respiratory distress syndrome (ARDS) appeared in 1967; however, this phenomenon has been identified since the eighteenth century. Interestingly, low tidal volume strategies for the management of respiratory failure, which are the mainstay of today's therapy for ARDS, were described as early as 1745 by Fothergill.

Mild ARDS, formerly acute lung injury, in critically ill or injured patients is characterized by the acute onset of diffuse bilateral pulmonary infiltrates, normal pulmonary capillary wedge pressure (<18), and hypoxemia (PaO2:FiO2 < 300). It represents the pulmonary manifestations of the systemic inflammatory response syndrome (SIRS). The definition of ARDS is evolving to represent it more as a spectrum of disease rather than a strictly defined entity. The most recent iteration of the clinical criteria for ARDS was described in 2012 by the European Society of Critical Care Medicine (Table 9.1). These criteria, known as the *Berlin criteria*, take into account the relative rarity of pulmonary artery catheters in clinical practice. They have been widely accepted internationally by both the American Thoracic Society and the Society of Critical Care Medicine. Acute respiratory distress syndrome is increasingly recognized as a single disease with a spectrum of presentations. The use of acute lung injury as a descriptor of this clinical phenomenon continues to be widely used, however this should be updated to reflect the current lexicon.

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Pathophysiology

It is important to note that ARDS is the sequelae of an initial physiologic insult rather than a primary pulmonary problem. Therefore it stands to reason that ARDS can result from both direct and indirect mechanisms of pulmonary injury. Sepsis is overwhelmingly the most common underlying pathology that precedes the development of ARDS. Sepsis can be considered both a direct and indirect mechanism of lung injury for the development of ARDS. Risk factors for direct lung injury include aspiration pneumonitis, near drowning, fat or amniotic fluid embolus, pulmonary contusion, and inhalational injury. Clinical conditions associated with indirect lung injury include pancreatitis, shock, burns, disseminated intravascular coagulation, head injury, and thrombotic thrombocytopenic purpura. Interestingly, massive transfusion has been implicated in ARDS, the phenomenon called *transfusion-related acute lung injury* (TRALI), although current data would suggest another underlying cause.

The importance of identifying the precipitating cause of ARDS cannot be stressed enough as mortality rates are dependent on proper identification and treatment of the underlying cause. The reported mortality rate for ARDS ranges from 20 to 60 % overall. Certainly the severity of ARDS, the patient's underlying performance status, and the inciting physiologic insult determine the mortality of ARDS. As stated previously, sepsis is the most common cause of ARDS in the elderly patient, while trauma leads the field in younger patients. Sepsis with multi-organ failure is the most common cause of death in patients with ARDS.

The underlying pathophysiology of ARDS develops in three phases. The *exudative phase* occurs between days 0 and 5 after injury to the Type 2 pneumocytes, resulting in decreased surfactant production. The histology of the ARDS lung can be characterized by diffuse alveolar hemorrhage and edema. This often manifests as the classic "pink, frothy" secretions seen in early ARDS. Recovery and proliferation of the Type 2 pneumocytes is initially identified on days 5–7,

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_9

Table 9.1 Berlin criteria vs. previous criteria for ARDS diagnosis

	Previous criteria	Berlin criteria 2012
Acute onset		Within 1 week of apparent clinical insult
Bilateral pulmonary opacities	Sparing of costophrenic angles	Opacities not explained by other pathology
Respiratory failure	PCWP < 18, if not available then lack clinical evidence of left atrial hypertension	not explained by heart failure or volume overload
PaO2:FiO2		
201–300	ALI	Mild ARDS
101–200	ARDS	Moderate ARDS
<100		Severe ARDS

The Berlin criteria were created by the European Society of Intensive Care Medicine and have subsequently been endorsed by the American Thoracic Society and the Society for Critical Care Medicine

a period known as the *proliferative phase*. The initial exudates organize in the airway leading to thicker secretions. The compliance of the airway begins to decrease in response to fibroblast proliferation. The more chronic phase, or *fibrotic phase*, of ARDS is characterized by collagen deposition and formation of the classic hyaline membranes. Throughout all phases microvascular thrombi are readily identified resulting in obliteration of the vasculature. This appears to result from damage to the pulmonary capillary epithelium resulting in an unopposed pro-thrombotic milieu. The entire alveolar epithelium is damaged in ARDS, resulting in increased permeability, decreased surfactant production, decreased water tension, and ultimately alveolar collapse.

Clinical Presentation

It must be understood that ARDS is a sequelae of an inciting clinical event rather than an independent entity. The features of ARDS classically presented between 6 and 72 h of this inciting event (e.g., trauma, sepsis, burn), but currently ARDS may be diagnosed within 1 week of the inciting clinical event with rapid clinical deterioration accompanied by worsening of the imaging findings associated with ARDS.

Diagnostic Evaluation

The astute physician clinically diagnoses ARDS based on a focused history and physical examination combined with a chest radiograph and ABG. ARDS should be clinically suspected in any patient with acute onset hypoxia and bilateral pulmonary infiltrates on chest radiograph. Other diagnostic criteria include the absence of cardiogenic pulmonary edema and PaO2:FiO2 < 300. An exhaustive search for the underlying cause of ARDS should occur immediately after the diagnosis is suspected as early identification and treatment improves outcome.

In settings where the diagnosis is unclear or concern exists for multifactorial etiology of hypoxia or pulmonary edema, echocardiography and electrocardiography should be performed to rule out cardiogenic causes. Abnormal findings can be supplemented with brain natriuretic peptide levels and right heart catheterization as needed.

Basic blood work, including complete blood count, combined with lavage airway specimens can help to distinguish underlying infectious etiology or malignant etiology. Further workup can include computed tomography in truly difficult cases.

Ultimately, patients who are found to be hypoxic or have an alteration in the alveolar-arterial oxygen gradient should be intubated early to prevent worsening of their underlying disease process while definitive diagnosis is sought. After confirmation of a diagnosis of ARDS, the acute management is critical in attempting to prevent worsening of the disease. The rest of this chapter will focus on management of patients with ARDS.

Treatment

Initial therapy for ARDS is supplemental high flow oxygen therapy. For patients with mild ARDS, treatment with non-invasive oxygen therapy may suffice. This population is easily treated as long as early recognition occurs.

Lung Protective Ventilation

As the severity of ARDS increases, endotracheal intubation is the foundation of therapy in ARDS with concurrent low tidal volume ventilation. As mentioned previously, the Berlin Consensus guidelines recently re-characterized and defined ARDS. As such, the majority of data on the management of ARDS was performed with the previous consensus definition. While it is unlikely to affect the outcomes significantly, it is impossible to say that with certainty. However, the majority of the therapy that will be discussed in the remainder of this chapter will be based on the previous definitions unless otherwise noted. When available, the relevant P/F ratio will be presented to avoid issues with nomenclature and allow the reader to focus on the severity of disease.

The workhorse of ARDS treatment after intubation is low tidal volume ventilation. Decreasing tidal volumes from the traditional value of 12 mL/kg to 6 ml/kg resulted in a 9 % reduction in mortality. These results, originally reported by the ARDS Network, have been repeated and validated and stand as one of the most important breakthroughs in the treatment of ARDS. This low tidal volume ventilation represents part of the current standard of care. In addition, combining low tidal volume with increased positive end expiratory pressure (PEEP) has repeatedly shown an improvement in oxygenation in the setting of ARDS when compared to low PEEP strategies. The higher PEEP group also was noted to have a decreased need for rescue therapies. These data should not be extrapolated to non-ARDS patients as meta-analysis has shown that there may be a slightly higher incidence of mortality in non-ARDS patients treated with high PEEP.

Opponents of lung protective ventilation cite the acidemia and hypercapnia associated with low tidal volume ventilation as potential problems in systemically ill patients. Patients with unrelenting acidosis or intolerable levels of CO_2 might require other therapeutic strategies as discussed later in this chapter. It has also been observed that there may be a population of patients that are "non-responders" to increased PEEP. Other potential problems with increased PEEP include hyperinflation of the lung, barotrauma, and increased inflammation. Despite these potential problems, the data produced by the ARDS Network is sufficiently compelling that most clinicians will implement low tidal volume ventilation with increasing levels of PEEP as a first line strategy when faced with a patient with ARDS.

Fluid Management

When considering therapy for ARDS it is mandatory to reconsider the underlying physiology of ARDS. The pulmonary edema of ARDS is not hydrostatic in nature. Hydrostatic pulmonary edema related to cardiogenic causes requires different consideration of diuretic therapy and fluid management that are beyond the scope of this chapter. Therefore, when reviewing this discussion the clinician must be cautious with the broad application of fluid management strategies discussed herein.

When considering surgical patients the management of fluid is certainly paramount to many aspects of recovery. Within this population the liberal use of intravenous fluids continues to demonstrate poor outcomes. The notion that overall positive fluid balance is associated with worse outcomes in ARDS has been consistently demonstrated for nearly 3 decades [1–3]. However, standardized protocols for conservative fluid management have failed to materialize in that time. The ARDSnet group has recently generated a series of protocols driven at fluid restriction that are associated with improvement in ventilator-free days, ICU days, and overall fluid balance. While there was no difference in overall mortality between a fluid liberal and fluid conservative approach, the astute clinician will be thrilled to recognize the benefits of decreasing the overall fluid balance by 5 liters [4]. Fluid restriction is not without consequence. While the long-term neurocognitive deficits associated with ARDS are discussed later in this chapter, it bears mentioning that the fluid conservative group shows a trend towards increased impairment in long-term survivors. This data is in its infancy and will certainly be explored further in the future.

Many practitioners besmirch the use of colloid in resuscitation. While the data on dextran and starches should limit their use by most practitioners, albumin is an alternative colloid with some success. In fact, the use of albumin in conjunction with continuous furosemide infusions has been shown to improve the hemodynamics, P/F ratio, and weight gain in ICU patients with hypoalbuminemia [5]. The consideration of protein levels in the setting of acute illness is difficult as albumin is a negative acute phase reactant and the accurate measurement of serum levels is challenging [3].

Neuromuscular Blockade

When conventional therapies fail many practitioners turn to neuromuscular blockade in order to completely control ventilation. Full paralysis has been used in as many as 55 % of all ARDS patients studied in recent literature. The beneficial effect of neuromuscular blockade in the treatment of patients with ARDS is explained by two different mechanisms. The first is elimination of patient-ventilator dyssynchrony which results in shunt related atelectasis. The second appears to be anti-inflammatory effects related to the use of neuromuscular blockade. Lavage specimens of patients with ARDS demonstrate decreased levels of inflammatory mediators when comparing patients on neuromuscular blockers than non-paralyzed patients for 48 h.

Like so many aspects of the treatment of ARDS, optimal timing and duration of neuromuscular blockade remains controversial. Additionally, selection of appropriate paralytic regimens is also debated. The use of cis-atracurium, a benzylisoquinolinium, is thought to have decreased risk of long-term complications. The underlying physiology is related to the pharmacokinetic properties of the drug: benzylisoquinoliniums undergo Hoffman degradation instead of the standard renal and hepatic elimination. Compared to the 400 min required for clearance of aminosteroid paralytics (i.e., vecuronium, pancuronium, and rocuronium), cis-atracurium is cleared in about 70 min. Hypothetically, judicious use of cis-atracurium may be associated with decreased risk of ICU-acquired weakness. For the clinician facing persistent hypoxia in a patient with ARDS, neuromuscular blockade may be a useful adjunct while escalating care.

Prone Positioning

In patients with severe ARDS the use of prone positioning has been shown to improve mortality. In 2013, the PROSEVA trial demonstrated that the early application of prone positioning for 16 h per day decreased all cause mortality by half in patients with a P/F ratio <150 [6]. At publication, this trial was unique in this data. Prior randomized controlled trials repeatedly showed improved oxygenation without improvement in mortality. However, a recent meta-analysis re-demonstrated an improved survival in patients with P/F ratio less than 100 but not greater than 100 [6].

Controversy still exists in the use of prone positioning. Optimal timing and duration of prone therapy remain an area of research. While prone positioning has been shown to be safe in patients with ARDS due to trauma, its use is precluded by unstable spine fractures. Relative contraindications to prone positioning include painful or unstable facial and thoracic fractures. Additionally, one of the limitations of prone positioning is the increased nursing demands required for monitoring prone patients, as well as the specialty equipment required for the application of prone positioning. Prone therapy should be considered in select patients in centers with expertise and staffing. A more important controversy surrounding this therapy in ARDS is whether prone positioning should be considered in the primary armamentarium rather than strictly as a rescue therapy, as it is commonly considered. As the PROSEVA data enters the lexicon of critical care practitioners the use of prone therapy will likely evolve to be an adjunct primary therapy in centers where the technology and expertise are available.

High Frequency Oscillatory Ventilator (HFOV)

Another advanced recruitment maneuver technique in patients with ARDS is high frequency oscillation (HFOV). HFOV is performed with ultra low tidal volumes (1–4 ml/kg) at a very high rate. At this volume there is hardly more tidal volume than physiologic dead space, in many cases not more at all. Therefore, the mechanism of oxygenation in HFOV is something unique to the other strategies that we have discussed previously. While the exact mechanism of oxygenation is not completely clear, convection within the conducting bronchi seems to play a role in delivery of oxygen to the alveoli.

HFOV has been shown to be an effective method of ventilation in many patient populations; however, two trials published in 2013 have brought into question the safety of HFOV. The results of the OSCAR and OSCILLATE trials demand that close attention be paid to patient selection prior to initiation of oscillatory ventilation [7, 8]. Further research is required prior to abandonment of the technique completely.

Airway Pressure Release Ventilation (APRV)

Airway pressure release ventilation is a specialty mode of ventilation gaining acceptance and popularity at multiple centers around the country. While the data comparing APRV to conventional modes of ventilation is in its infancy, the increasing use of APRV warrants discussion. APRV is a type of bi-level ventilation wherein high airway pressures are maintained for a period of time in which the patient is allowed to breathe spontaneously. The pressure is then released for a short period of time. Within APRV, the airway pressures (high and low) can be adjusted as well as the time spent at each pressure.

Theoretical advantages of this mode of ventilation include recruitment of atelectatic lung through the use of continuous high airway pressure; decrease in cyclic de-recruitment associated with prolonged expiratory time, and decreased risk of barotrauma secondary to lower peak airway pressures. Spontaneous breathing during APRV may improve hemodynamic performance by increasing venous return and decreasing diaphragm dysfunction.

Centers with expertise in the use of APRV advocate its use as a primary mode of ventilation. However, until the data has been rigorously reviewed it is unlikely that most centers would rely on APRV as more than a rescue therapy.

Steroids

The use of steroids in ARDS remains a source of controversy. Several studies have demonstrated mixed results regarding the use of steroids [9–12]. Due to the heterogeneity of timing, dosing, and treatment protocols, it is difficult to draw broad conclusions regarding their use. Within the early phases of ARDS (<7 days), the data are unclear. Powerful steroid protocols with prolonged tapers seem to allow earlier extubation and discharge from the ICU if instituted between days 7 and 14 [8]. However, there does seem to be a higher re-intubation rate in patients on steroid protocols. Use of steroids after day 14 of refractory ARDS has been associated with an increased mortality rate. The clinician facing a challenging patient with refractory ARDS may reasonably consider the use of high dose steroids with a prolonged taper after the first week of conventional management.

Inhaled Therapies

While inhaled nitric oxide transiently improves oxygenation in early ARDS, which may allow sufficient time for alternative therapies to take effect, nitric oxide is a very costly therapy with no mortality benefit. Epoprostenol, an inhaled prostaglandin, was demonstrated to provide equivalent

improvement in P/F ratio at a fraction of the cost compared with inhaled nitric oxide [8]. While broad application of nitric oxide or epoprostenol is unlikely, when faced with extreme hypoxia and refractory ARDS these may be considered as viable salvage therapies.

Extracorporeal Membrane Oxygenation

Extracorporeal membrane oxygenation (ECMO) is a form of heart lung bypass that is indicated in the setting of hypoxic respiratory failure. The use of ECMO is reserved for specialized tertiary centers and patients with refractory ARDS should be referred to such centers. While such transfer may not necessitate initiation of ECMO, the CESAR trial demonstrated that referral to ECMO centers was beneficial [13]. ECMO should be considered as a second line rescue therapy in patients with severe refractory ARDS.

Long-Term Sequelae

Discussion of ARDS is not complete without mentioning the long-term multisystem consequences and disabilities associated with ARDS and persistent hypoxia. Survivors of ARDS face consequences related to long-term intubation including dysphagia. Patients with ARDS that undergo ECMO frequently face serious neurological consequences including stroke, hemorrhage, coma, and death. Long-term cognitive impairment in ARDS is an area of active research. Several cross sectional studies have demonstrated that survivors of ARDS are persistently debilitated from a physical and pulmonary standpoint. Patients are noted to have decreased pulmonary function tests, muscle weakness, and functional performance [14–21]. In addition, patients are also found to have a post-traumatic stress disorder type syndrome after surviving ARDS [22–27]. The data on this topic lack significant controls relative to patients with similar injury patterns prior to the development of ARDS. Further exploration of the downstream consequences of ARDS is warranted. Patients must survive a disease to develop long-term complications. Heightened awareness and investigation of neurocognitive and pulmonary deficits associated with ARDS is the result of advances in critical care that have converted ARDS from a highly lethal disorder to a survivable condition.

Conclusion

Cases of ARDS represent a broad spectrum of disease from simple shortness of breath managed by supplemental oxygen to life threatening hypoxia. Recent changes in nomenclature notwithstanding, the treatment of ARDS continues to evolve and more evidence continues to develop optimal therapeutic strategies. Early ARDS should be managed with intubation, low tidal volume ventilation strategies, and conservative fluid administration. Escalation of care can progress within institutional guidelines and available expertise. In cases of severe or refractory ARDS, referral to a tertiary center with expertise in advanced management techniques should be considered. Long-term survivors of ARDS seem to face problematic sequelae both neurologically and functionally. Full elaboration of these complications remains an area of active research.

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Nutrition in the Surgical Patient

10

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Nutrition in the surgical patient is a multifactorial, complex subject. Beyond the decision to feed enterally or parenterally, a surgeon must consider specific patient characteristics that interfere with the delivery of nutrients for useful and purposeful digestion and metabolism. The patient with postoperative ileus, a previous bowel obstruction, short gut, an open abdomen after damage control, or discontinuous bowel, to mention only a few special circumstances, has energy requirements beyond what is provided by maintenance or resuscitative fluids. These examples comprise situations in which early feeding would inherently be of benefit. Certainly the patient with an enteric fistula deserves focused discussion as this patient population, more than the standard surgical patient or even the patient with an open abdomen after damage control, has the additional complexity of nutrient and digestive component loss.

Attention should also be given to the consideration of nutritional access as many patients with these special circumstances do not have the ability to take food orally. Surgeons must decide how they will provide nutrition to their patients and many times this requires surgical or endoscopic placement of lines and tubes that can be used to administer nutrients into the body. Timing of feeding and location of feed entry into the body are further decisions that the surgeon faces. This chapter serves to discuss and present data regarding the differences in parenteral, enteral, gastric, and post-pyloric feeding, and includes algorithms for instituting early nutritional support in the acute and traumatic patient populations.

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Rationale for and Types of Nutritional Support

The rationale for providing nutritional support is to prevent acute protein malnutrition, to modulate the immune response, and to promote normal gut function [1].

Enteral Versus Parenteral Nutrition

In the 1970s total parenteral nutrition (TPN) was introduced, but despite its availability, enteral nutrition (EN) was still more economical and convenient to provide. However, the practice at that time was to hold EN until the gut proved to be completely functional, which could take days or even weeks, for surgical and trauma patients. By the 1980s enough data had been collected to support the use of EN in these surgical populations. Enteral nutrient provisions were functional and processed effectively in the critically ill patient with maladapted gut mucosa [2, 3]. In fact it was shown in multiple studies that introducing enteral feeds into the gut stimulated immunologic response and competence [4–7]. The 1990s introduced data that TPN may be harmful in patients who could otherwise tolerate enteral feeds. There were more infections, including catheter-related sepsis, seen in the parenteral group [8, 9]. Meta-analyses confirmed that early enteral feeding, compared to parenteral nutrition, reduced postoperative infections and complications [10, 11].

Enteral Nutrition

Enteral nutrition is the preferred form of nutritional supplementation in surgical patients who have enteral access [12–14]. Absolute contraindications to enteral feeds include functional complications such as bowel obstruction, peritonitis, progressive ileus, massive gastrointestinal hemorrhage, and gastrointestinal ischemia associated with shock and

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_10

vasopressors. Relative contraindications include proven intolerance to enteral nutrition and intolerance associated with short gut syndrome, high-output fistula, pancreatitis, and inflammatory bowel disease.

Early enteral feeding supports gastrointestinal structure and function, and in the critically ill surgical patient can reduce gut hyper-permeability, enhance gut blood flow, promote gastric emptying, and stimulate gut-associated immunity. Multiple studies have shown tolerance of trophic feeds in critically ill and mechanically ventilated patients, and in patients with recent bowel surgery [15]. While there are studies that show some increased infectious complications with early goal enteral feeds, there is more convincing data to the contrary [13, 14, 16]. Based on 14 Level 2 studies, early EN was shown to reduce infectious complications and mortality and is overwhelmingly recommended in mechanically ventilated patients after adequate resuscitation [17, 18].

Parenteral Nutrition

Total parenteral nutrition is appropriate in situations in which enteral feeds cannot be used. Its disadvantages include need for vascular access, infection of vascular access and associated bloodstream infection, sepsis, cost, need to monitor electrolytes and adjust formula, and hyperglycemia. Several types of amino acid-specific formulas for TPN are available and there is evidence to support the use of glutamine for both enteral and parenteral nutrition, regardless of the formula used [19, 20]. Glutamine shows decreased complications and increased survival when added as a supplement to TPN [21].

Whenever possible, the gastrointestinal track should be utilized for nutritional support. The algorithm (Fig. 10.1) reviews the decision process for starting EN and for the administration of TPN. In general, TPN should be started by 7–10 days postoperatively if the patient is well nourished at baseline and unable to tolerate adequate EN. Unlike early enteral feeding, there is no clear benefit to early TPN. There is equally no difference in outcomes for patients who take enteral and parenteral nutrition in combination [22]. Patients with persistent ileus, bowel obstruction, short gut, high-output fistulas, and malabsorption may all benefit from TPN. Additionally, patients unable to tolerate EN or who are at risk for non-occlusive bowel necrosis (hypoperfusion, vasopressor, or paralytic requirements) may benefit from TPN. There is new data that indicates that the risk of infection with the parenteral route may have been overestimated as a recent randomized trial performed in the UK and involving 33 English intensive care units and 2400 patients [23]. This study showed no significant difference in the mean number of treated infectious complications or in the 30-day mortality among patients receiving early parenteral nutrition compared to patients receiving early EN. Another Australian randomized single-blind clinical trial involving 31 hospitals with 1372 patients even demonstrated significantly fewer days of invasive ventilation but not significantly shorter intensive care unit (ICU) or hospital stays with early parenteral nutrition when compared with no nutrition in the presence of relative contraindications for EN [24]. Parenteral nutrition thus remains a valuable and necessary tool in specific patient populations.

Determining Caloric Needs

Caloric needs can be calculated using one of many formulas such as the Harris–Benedict equation or measured with indirect calorimetry.

Harris–Benedict Equation

The Harris–Benedict equation estimates basal energy expenditure (BEE) to determine caloric requirements. The Harris–Benedict equations are specific to men and women based on weight, body mass index (BMI), and height and are as follows:

$$\text{Men:}\quad \text{BEE} = 66 + (13.7 \times \text{weight}) + (5 \times \text{height}) - (6.8 \times \text{age})$$

$$\text{Women:}\quad \text{BEE} = 665 + (9.6 \times \text{weight}) + (1.9 \times \text{height}) - (4.7 \times \text{age}).$$

Weight is in kilograms (kg), height in centimeters (cm), and age in years. The BEE represents energy requirements in the fasting, resting, and non-stressed state, so it may not be completely accurate in trauma or surgical patients. In the presence of metabolic stress, the BEE must be multiplied by an empirically derived stress factor; this factor may grossly overestimate the true caloric needs of the individual and remains the source of controversy in using this formula in the critically ill. Overestimation of caloric needs results in complications such as overfeeding, hypercapnia, hyperglycemia, and hepatic steatosis. The new multiplication constants to estimate the stressed caloric needs range from 1.2 to 1.6 times the BEE. These new recommendations better estimate the caloric needs of even the most stressed patient scenarios, such as burns.

Indirect Calorimetry

Indirect calorimetry is a tool used to measure resting energy expenditure (REE) and relies on the relationship of oxygen consumption and carbon dioxide production. Because of the

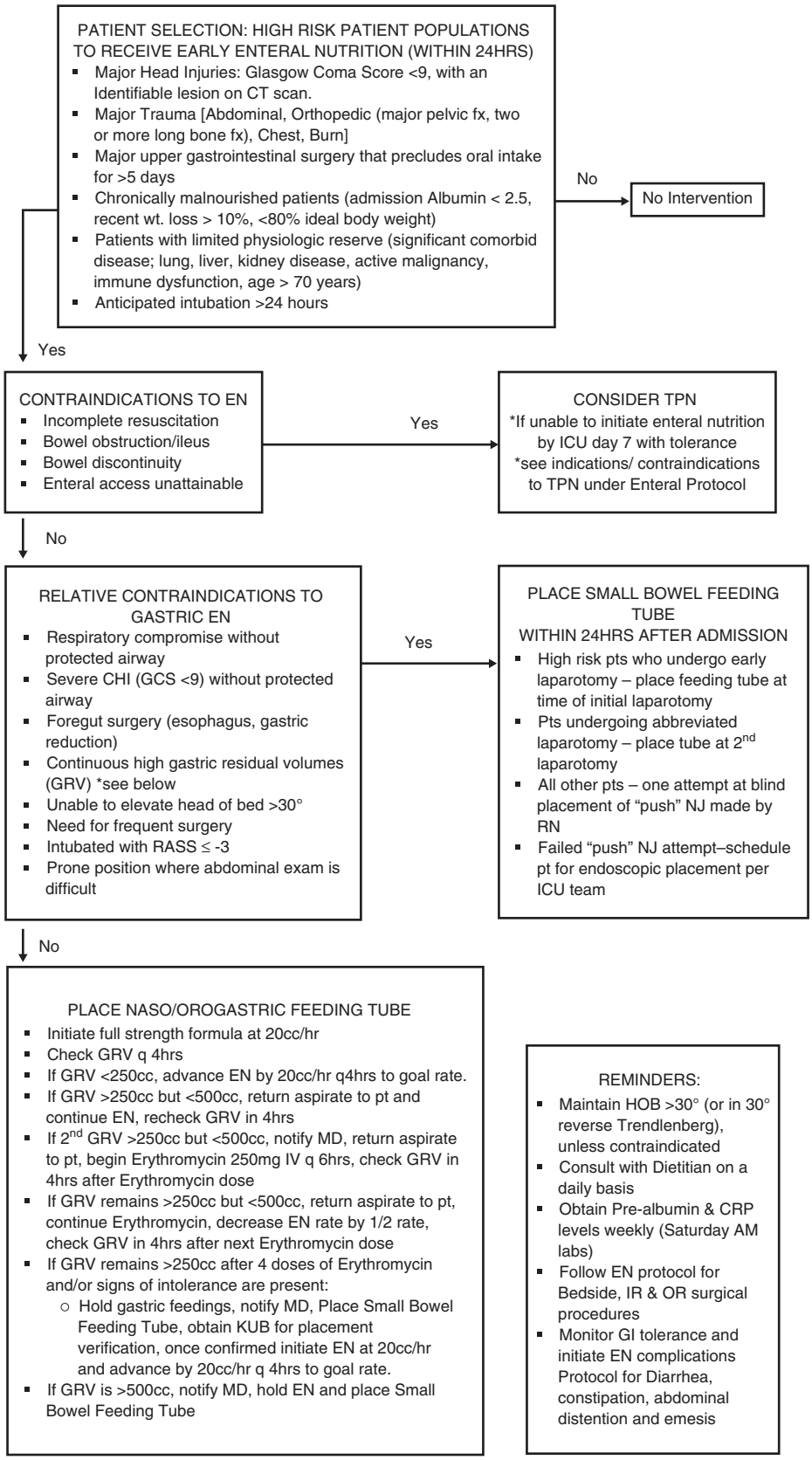

Fig. 10.1 Example of an enteral nutrition protocol algorithm

components necessary to calculate the REE, patients should be ventilated for best accuracy, although there is support to use it even in spontaneously breathing patients. It is recommended that steady state be achieved, defined as a change in either parameter of less than 10 % over 5 min or more [25]. The REE obtained should then be used to estimate the patient's baseline nutritional goal. Indirect calorimetry may be helpful when overfeeding would be undesirable (as in diabetes, obesity, or chronic obstructive pulmonary disease), underfeeding would be especially detrimental (renal failure, large wounds), physical or clinical factors promote energy expenditure that deviates from normal, drugs are used that may significantly alter energy expenditure (paralytic agents, beta-blockers, corticosteroids), patient response to calculated regimens is suboptimal, or body habitus makes energy expenditure predictions challenging (morbid obesity, quadriplegia).

The respiratory quotient is another derivative from the components of the indirect calorimetry. The formula is below:

$$\text{Respiratory quotient}\left(\text{RQ}\right)=\frac{V_{O2}}{V_{CO2}}=\frac{CO_2\,\text{production}}{O_2\,\text{consumption}}$$

The RQ is a gross measurement of substrate utilization [26]. When an RQ value ≥1 is obtained, CO_2 production may be increased by one of the two mechanisms: either a high proportion of non-protein calories are being supplied as glucose (carbohydrates have RQ of 1) or less commonly, the patient is being provided excess calories. Failure to wean with a persistently elevated PCO_2 on an arterial blood gas should prompt measurement of the RQ. An RQ of 0.85 provides optimal utilization, while <0.7 suggests gross underfeeding and ketone utilization.

Calculating TPN

Components of TPN include dextrose, fatty acids, amino acids, electrolytes, vitamins, and trace minerals. Dextrose is the carbohydrate at a caloric density of 3.4 kcal/g. Dextrose solutions of 50 or 70 % dextrose are readily available, but any carbohydrate percentage and volume can be mixed according to the patient's need. Protein provides 4 kcal/g and is provided as amino acids. Standard amino acid solutions contain a balance of essential and nonessential amino acids and are available as either 10 g/100 ml or 15 g/100 ml. Fat emulsions are 2.0 kcal/cm^3 of 20 % lipid and are the source of essential fatty acids, linoleic, linolenic, and arachidonic acids. The electrolyte cations, which include sodium, potassium, magnesium, phosphorus, and calcium, are mixed into the TPN solution using one of several anions. Acid–base status may be affected by the amount of chloride or acetate used in providing sodium and potassium. The concentrations of calcium and phosphorus are limited to avoid precipitation of a calcium phosphate salt. Vitamins included are A, C, D, E, and B vitamins, including folate, but not vitamin K, which must be added separately. Mineral product is added to provide copper, chromium, manganese, zinc, and selenium. The basic steps in calculating TPN are as follows: (1) establish the kilocalories and protein desired, (2) select the appropriate amino acid formula and quantity, (3) calculate 10 % of kcal as lipid emulsion, and (4) tally the kcal from amino acids and fat and subtract from goal, which is the amount of dextrose kcal needed. Divide this number by 3.4 to get the grams of dextrose required [27].

Types of Formulas

The primary categories of enteral formulas include polymeric, elemental, immune-enhancing, and specialty formulas.

Standard Enteral Diet versus Immune-Enhancing Diets

Both basic and clinical research suggests that the beneficial effects of enteral nutrition can be amplified by supplementing formulas with specific nutrients that exert immune-enhancing effects, including glutamine, arginine, nucleotides, and omega-3 fatty acids. There are numerous prospective randomized controlled trials comparing immune-enhancing enteral diets to standard enteral diet and most, but not all, demonstrate improved outcomes. The majority of trials are in trauma and cancer patients, though a few trials include mixed ICU and septic ICU patients.

Pharmaconutrition

The concept of pharmaconutrition allows the separation of nutritional support from the provision of key nutrients that may modulate the inflammatory and immune response associated with critical illness. This came about after the realization that the greatest benefit in clinical outcomes was from studies utilizing specific nutrients [16]. This is likely due to their effects on the enteric inflammatory response and the way in which they work to block inflammatory stimulation. Any event that stimulates a gastrointestinal inflammatory response and a change in gut perfusion alters the way that the gastrointestinal tract utilizes nutrients. Providing intraluminal alimentation to stressed mucosa of the gut improves intestinal transit [28]. Pharmaconutrients alone or as supplementation have been shown to decrease infectious complications and complication-associated length of hospital stay [29].

Glutamine is the primary fuel source for the enterocyte and is preferred to glucose as a fuel source in times of stress [30]. It is released from muscle during the stress response and then exploited as a signal mechanism, promoting immune regulation and cellular protection, and as a nutrient and source of energy [31]. But in addition, glutamine has anti-catabolic and antioxidant properties that enhance its use and its receipt at enterocytes. Furthermore it increases plasma concentration of arginine [32]. Although glutamine can be provided both enterally and parenterally, it demonstrates the most benefit of barrier to infection and control of the immune response when given enterally [32]. Meta-analysis and prospective randomized trials for trauma and burn patients showed benefit of glutamine in these patient populations in terms of decreasing infectious complications and enhancing the gut's use of other enteric nutrients [33–37]. Based on the available data, glutamine, despite the administration route, appears to lower infectious complications, decrease hospital length of stay, and enhance nutrient use in the critically ill patient [38, 39]. Heat-shock proteins, which serve as molecular regulators of denatured proteins, are induced by glutamine, which may be another way in which glutamine modulates the cyto-protection and inflammatory response [40–42]. Equally important is the lack of data showing adverse effect of using glutamine in either form.

Arginine is another modulator of immune response of the enteric system. It is produced both endogenously from glutamine and the urea cycle, and obtained from the diet. When there is normal physiology without ongoing stress response, arginine serves to enhance immune function, contribute to wound healing, and stimulate anabolic hormones. L-arginine is a substrate for nitric oxide, which itself enhances the inflammatory response. L-arginine and its pathway to creating nitric oxide is a potential target for modification of immune activation. Specifically in trauma patients it has been shown that the release of IL-4, IL-10, and transforming growth factor beta increases arginase I expression, which corresponds to increased immune cell arginase activity and decreased plasma arginine and citrulline levels [43, 44]. By shunting arginine use in this way, it can no longer be used as a substrate for nitric oxide synthase dimerization and nitric oxide production. Therefore, administration of supplemental arginine in the critically ill patient may reduce the amount of nitric oxide produced in the post-injury period. Arguing against this data is work from another group suggesting that arginine supplementation increases nitric oxide production, thereby amplifying the systemic inflammatory response syndrome (SIRS) response and increasing mortality in the trauma or critically ill patient [45, 46]. There exists data supporting and refuting the use of arginine supplementation for both enteral and parenteral routes of administration [47–50]. It is clear, however, that arginine supplementation in elective surgical patients is beneficial. A recent meta-analysis by Drover et al. demonstrated a significant decrease in postoperative complications and hospital length of stay when patients undergoing gastrointestinal surgery received pre-, peri-, or postoperative arginine supplementation [51]. The effect was greatest when the supplementation included arginine as well as omega-3 fatty acids and nucleotides.

Nucleotides play an active role in cellular proliferation and immune modulation and are building blocks for several intrinsic cellular molecules. They are produced de novo and by salvage pathways. T cell proliferation and appropriate recognition of antigen are thought to be dependent on the presence of nucleotide because it has been shown that artificial decrease in interleukin-2 is corrected by addition of supplemental nucleotide [52]. They are either purine or pyrimidine derived with a ribose and one or more phosphate groups [53]. Similar to glutamine and arginine, intravenous (IV) and enteral forms are available. Infusions of nucleotides decrease bacterial translocation and decrease graft rejection [52, 54]. These references also show that parenteral doses of nucleotides, administered with TPN, decrease associated gut atrophy.

Omega-3 fatty acids are the active components of fish oils and have significant anti-inflammatory properties [55], the mechanism of which is likely a combination of functions including arachidonic acid displacement from cellular membranes, production of prostaglandins, and reduced activation of various nuclear factors [56]. Specifically, they target and down-regulate NF-kB and AP-1 [54] on the nuclear membrane and they down-regulate iNOS, thereby reducing production of nitric oxide. While there are no studies of critically ill patients who received only omega-3 fatty acid and no additional supplementation, there are three prospective randomized studies that included omega-3 fatty acid in the supplementation package and had a significant improvement in respiratory function of their critically ill patients [57–59].

Beyond activation of the immune system, the critically ill and traumatic patient suffers damage at the cellular level secondary to the effects of oxidation-induced injury. Antioxidants have been found to catalyze the breakdown of the substances that are implicated in causing this damage. Superoxide dismutase, catalase, and glutathione peroxidase have been identified as antioxidants; cofactors include selenium, zinc, manganese, and iron. Supplementation of these substances decreases the inflammatory response and halts oxidative stress [60–62]. Similar to nucleotides, it has been shown that the number of days on mechanical ventilation and overall mortality can be reduced by supplementation of antioxidants and their cofactors [62–64].

The value of vitamin supplementation has also been studied and it has been suggested that intravenous ascorbic acid addition in patients with severe sepsis is safe and results in reduction of pro-inflammatory markers such as C-reactive protein and procalcitonin although the effect on patient outcomes has not been proven [65]. The same findings could not be extended to other vitamins such as Vitamin D supplementation in Vitamin D deficient patients with sepsis [66].

Despite numerous studies demonstrating benefit from supplemental nutrients, a recent prospective randomized trial comparing enteral and parenteral glutamine and antioxidants in critically ill patients with established organ failure, parenteral and enteral glutamine supplementation resulted in a nonsignificant trend toward increased mortality. Therefore, the administration of glutamine is no longer recommended for patients with organ failure. [67]. A post hoc analysis did, however, suggest that glutamine may be safe for trauma and burn patients when administered prior to the development of distant organ injury [68].

Optimal Route of Delivery of Enteral Nutrition

Access can be divided into gastric (and duodenal) and jejunal with push, endoscopic, radiologic, and surgical options all available. For patients to be fed gastrically, a soft, non-sump nasogastric tube can be placed. There are also blindly placed nasojejunal tubes. If blind placement is unsuccessful, an endoscopically placed nasojejunal tube is an option. Nasojejunal feeding may be done indefinitely, but if the need for long-term access becomes apparent, either a percutaneous endoscopic gastrostomy (PEG) or a PEG with a jejunal extension limb (PEG-J) can be placed. For those patients identified as candidates for jejunal feeds and undergoing laparotomy, either a standard open jejunostomy or a needle catheter jejunostomy (NCJ) can be placed.

The largest study examining the safety of needle catheter jejunostomies in patients undergoing major elective and emergency abdominal operations documented an incidence of major complications of 1 % and minor complications of 1.7 % [69]. When feeding jejunostomy-related complications in trauma patients were reviewed by Holmes et al. [70] the overall major complication rate was 4 %. However, the majority of complications occurred in patients with a Witzel tube jejunostomy (10 %), with only a 2 % rate with NCJs. In fact, the only difference between patients with and without major complications was the type of feeding access. Major complications included small bowel perforation, volvuli with infarction, intraperitoneal leaks, and non-occlusive small bowel necrosis. The first three of these complications can be minimized by improved technique and the latter minimized by more judicious feeding.

Gastric Versus Small Bowel Feeding Controversy

While gastric and post-pyloric nutrition have been compared, statistically no difference is noted in the time to reach caloric goal, length of stay in the ICU, or length of ventilator time between the two [71]. There is a consistent delay in initiating gastric feeds when compared to post-pyloric feeds in surgical patients, but again, the ultimate outcomes data do not differ. The early initiation of pro-kinetic agents may also be of benefit. In fact gastric feeds and post-pyloric feeds can achieve the same caloric supplementation in the same amount of time in the critically ill patients [72]. It has also been shown that initiating early enteric feeds (within 36 h) improves survival and decreases infectious complications [73].

If feeds are provided past the ligament of Treitz, enteral feeds do not need to be held for the operating room [74]. This is important in the surgical population where frequent trips to the operating room might otherwise greatly hamper uninterrupted full caloric nutrition in these patients. Aspiration during intubation remains a risk for patients who have been gastrically fed [75]. This same risk does not appear as evident even for patients who have continuous jejunal tube feeds running during their operations. There is no difference in aspiration risk in gastric or post-pyloric feeds with respect to aspiration risk or residuals [76]. Furthermore, there does not seem to be a significant difference in rates of pneumonia or ICU mortality among adult ICU patients fed intra-gastric or through a jejunal tube [77].

Additionally the question of gastrointestinal prophylaxis in the patient who is ventilated and fed into the small bowel is significant. Gastric pH must be addressed in any patient intubated more than 48 h and undergoing non-gastric nutritional support. This is to prevent stress ulceration, which is a known complication of ICU patients. Because gastric tubes can be placed nasally and blindly by push technique easier than jejunal tubes, the natural tendency is toward placing nasogastric (NG) tubes for decompression and to pass a nasojejunal tube and feed it even if gastric. There may be a need for recommendations on post-pyloric feeds in ICU-level patients secondary to their frequent trips to the operating room, need for continuous uninterrupted feeds to prevent malnutrition, and prevention of aspiration. Equally one could argue for gastric feeds with head of bed elevation, which might cut the number of stress ulcers and reduce the number of procedures and sedation that ICU patients are getting for placement of endoscopic tubes. The type of stress ulcer prophylaxis is another matter of debate. A systematic review of 14 trials enrolling a total of 1720 patients in 2013 favored the use of proton pump inhibitors over histamine 2 receptor antagonists in critically ill patients [78]. The former were found to be more effective in preventing clinically significant upper gastrointestinal bleeding. Nonetheless the heterogeneity of the trials included did limit the strength of that recommendation.

Effectiveness of Nutritional Delivery

Once the provision of nutrition has been started at goal, it is equally important to measure the effectiveness of that nutrition. Several ways of assessing caloric use in the critically ill and surgical patient have been described. Updated BMI, 12-h

urinary urea nitrogen, prealbumin, and C-reactive protein (CRP) levels are obtained weekly after recording a baseline measurement and starting nutrition. Indirect calorimetry is also available as required for further assessment. The urinary urea nitrogen serves to estimate the protein need and loss in patients who have a creatinine clearance greater than 50 ml/min. A normal range is 6–24 g/day. A negative result indicates excessive muscle shunting for energy. (Total urinary nitrogen is more accurate in the critically ill, but is less readily available [79]. In addition, spinal cord-injured patients must be excluded because loss is tremendous and ongoing [80]).

C-reactive protein is an acute-phase protein that directly correlates with injury and ongoing inflammatory states. Elevation above 15 mg/dl indicates that the liver is unable to synthesize other types of proteins such as albumin, prealbumin, and transferrin. It therefore can be used to measure whether there is still acute inflammatory response preventing anabolism, appropriate, expected use of nutrients, and healing.

Prealbumin has a 2–4-day half-life, and its level indicates anabolic activity. Normal response during the critical phase would be an increase of 0.5–1 mg/dl/day.

Indirect calorimetry measures expired carbon dioxide to extrapolate energy consumption in the ventilated patient. Patients must be on a FiO_2 of less than 60 % with a PEEP of less than ten. The usefulness of the measurement is apparent for patients where over- or underfeeding would be clinically undesirable based on their known medical comorbidities [81].

Consequences of Inadequate Feeding

Though the precise caloric requirements for critically ill patients is not well defined and is dependent on numerous factors, it is well recognized that adequate caloric intake is important. In a prospective observational study of critically ill patients, an increase of 1000 cal/day significantly reduced mortality, with the most pronounced effects in those patients with a BMI less than 25 or greater than 35 [17]. In a recent study of more than 7000 intubated ICU patients, there was a significant association between the percent of prescribed calories received, and 60-day mortality [82]. Patients receiving more than two-thirds of prescribed calories were less likely to die than those receiving less than one-third of prescribed calories. The optimal percent of prescribed calories was approximately 80–85 %.

Early delivery of adequate calories to critically ill surgical patients, however, can prove challenging. Vasopressor use, bowel in discontinuity after damage control surgery, and ileus can all impede adequate early delivery of feeds. Nutritional adequacy is defined as the actual 24-h caloric or protein intake/prescribed 24-h caloric or protein intake and has been studied in the trauma adult and pediatric populations [83]. For both patient age groups, adequacy was ≤ 60 %. Therefore early placement of feeding access and a focus on the importance of early nutritional delivery are paramount. In fact, adequacy of nutrition in the ICU seems to play an important role in discharge destination. In a recent study by Yeh et al. of critically ill surgical patients, inadequate macronutrient delivery was found to be associated with lower rates of discharge to home [84].

Open abdomens and recent bowel anastomosis are not contraindications to early feeding [85]. In a recent meta-analysis of early versus traditional postoperative feeding in patients with bowel anastomosis, there was a significant reduction in total postoperative complications in patients receiving some type of nutritional support (either enteral feeds or diets) within 24 h of surgery, even if it was provided proximal to the anastomosis [86]. The use of enteral glutamine during shock may also be safe [87].

In an attempt to improve nutritional adequacy, the PEP uP Protocol has been proposed by Heyland et al. [88]. In a single center feasibility trial, enteral feeds were started at 25 ml/h, motility and protein supplements were started immediately, and the target was a 24-h volume of enteral nutrition rather than an hourly rate. If a patient missed feeds, "makeup" feeds were provided. They found a significant improvement in caloric and protein delivery, with no increase in complications.

On the other hand, there are some studies that suggest caution needs to be exerted in intensely feeding certain populations with critical illness. A prospective randomized trial conducted by Braunschweig et al. showed increased mortality in ICU patients with acute lung injury who are provided with more than 75 % of their estimated energy and protein needs per day as non-volitional infusional EN when compared with patients who received standard EN. It was postulated that intense nutrition leads to that effect by interfering with autophagy and altering gut microbiota [89]. These results were not replicated in a separate Australian study and further trials are warranted. [90]

Parenteral Supplementation of Enteral Nutrition

If critically ill patients are not receiving adequate enteral nutrition and adequate delivery of calories and protein is important, the question arises as to whether supplemental TPN should be added until full needs are met by the enteral route. This was recently investigated by Casaer et al. in a prospective randomized multicenter trial [91]. All patients received early EN but were randomized to either early (<48 h) or late (>day 7) parenteral nutrition. Survival was equal between groups but the late parenteral group had fewer ICU infections and a greater likelihood of being discharged alive.

Though the study demonstrated that the early use of supplemental TPN is not beneficial, there were several limitations of the study. The majority of patients were not malnourished at ICU admission, the severely malnourished were excluded, the patient population was that requiring primary cardiac surgery, and approximately half the patients were extubated by day 2, suggesting that those patients who may have benefited from supplemental nutrition were not included in the study. There is a completed pilot study by Wischmeyer et al. that is examining the efficacy of supplemental parental nutrition in under and overweight patients (personal communication). Patients must be candidates for EN but not receiving their nutritional goal on enteral feeds alone. Results of this study are currently being analyzed. However, until the time supplemental TPN is shown to have proven benefit, it is not recommended in the surgical patient when EN can be used.

Complications of Nutritional Support

Refeeding

The refeeding syndrome can occur in any nutritionally deplete individual regardless of the manner in which he or she is being fed. The syndrome is most frequently seen in patients who are alcoholics, have eating disorders, suffer from hyperemesis gravidarum, or who have experienced excessive, rapid weight loss following bariatric surgery. Symptoms are not limited to cardiac arrhythmias, organ failure, and death. The crux of the syndrome is that fat metabolism, which predominated in the unstressed, starved state, now with refeeding, switches to a primarily carbohydrate-based metabolism. The carbohydrate-based metabolism is responsible for a rapid uptake of electrolytes causing intra- and extracellular levels to drop quickly creating disturbances and related effects. Prevention is by recognizing inherent risks and repleting electrolytes before the syndrome can ensue. An additional strategy is to start feeds at one-third to one-half of goal and increase gradually. Electrolytes should be serially checked in high-risk patients.

Non-occlusive Mesenteric Ischemia

There is no decisive data regarding feeding the gut for patients on pressor therapy. Based on primarily retrospective data, it appears that if vasopressors may be safe, though there is no high quality evidence to date. In examining different pressor agents and doses, a norepinephrine dose less than 12.5 mcg/min, utilization of phenylephrine, and the exclusion of dopamine and vasopressin were associated with enteral nutrition tolerance in a large retrospective study [92]. In a small prospective observational study of cardiac surgery patients with circulatory failure (2 or more vasopressor agents utilized and/or mechanical circulatory support), investigators sought to assess the feasibility of providing nutrition via the enteral route [93]. Enteral nutrition was successfully instituted though only 40 % of patients achieved adequate delivery. Complications were identified in 62 % of patients, 46 % of whom developed constipation. There were no reported cases of mesenteric ischemia.

The major concern in feeding patients on vasopressors is the risk of bowel ischemia. A non-occlusive pattern would involve the entire length of the bowel, and, if it were from feeds, would be expected to begin at the site wherever feeds came in contact with the bowel mucosa. For example, if the stomach is the point of nutritional entry, then any non-occlusive bowel necrosis would be expected to involve the stomach, even despite its robust blood supply. Patchy areas may result if the period of ischemia were short. However, the data appear to be lacking for definitive recommendations in such situations. The mortality for fulminant non-occlusive bowel necrosis approaches 50 % [94].

Nutritional Support in Specific Surgical Patients

Pancreatitis

Pancreatitis, though not strictly a surgical disease, demands special attention. There is some debate in the literature of whether post-ligament of Treitz feeding prevents continued inflammation. Placement of endoscopic or push nasojejunal tubes has allowed the patient with pancreatitis to be fed enterally. There are several well-documented populations where outcomes have shown a positive benefit to enteral feeds as compared to nutrition provided by TPN [95, 96]. Enteral feeds are thought to decrease the expression of endotoxin, TNF-a, IL-6 as well as APACHE II scores, pancreatic sepsis and overall mortality in patients with severe acute pancreatitis [97]. Of special interest, is that early EN seems to moderate the excessive immune response without leading to subsequent immunosuppression [98]. Despite previous concern that small bowel enteral feeds would still have some, even if minimal, effect on pancreatic stimulation, this has proven to be unfounded [99]. The time to start of feeds continues to be an area of research and debate. A recent Dutch randomized controlled trial by Bakker et al. did not show any superiority of early nasoenteric tube feeding as compared with an oral diet after 72 h in reducing the rate of infection or death in patients with severe pancreatitis at high risk for complication [100]. Furthermore, the role of glutamine was recently investigated and oral glutamine administered early to patients with pancreatitis was not shown to have any significant effect on gut permeability, degree of inflammation,

infectious complications, or length of ICU or hospital stay. Mortality was also noted to be unaffected [101]. The role of very early nutritional and additive supplementation in pancreatitis continues to be unclear, though the initiation of feeds does not seem to cause any harm to these patients.

Chylothorax/Chyloperitoneum

Although an uncommon phenomenon, chylothorax and even chyloperitoneum do require special attention. While overall this complication is more likely seen as a result of malignancy or operative management of malignancy, they are also seen in the trauma population, after central line placements, with lumbar spine fractures, and iatrogenic. Recommendations include attempting nonoperative management with dietary modification and TPN, chest tube drainage to quantify the volume, followed by surgical ligation if the output continues of 1500 ml/24-h periods or for more than 2 weeks [102]. When the volume of this problem is uncontrollable, TPN or enteral feeds with medium-chain fatty acids seem to be most effective in decreasing the output. Typically elemental formulas are recommended to expedite adequate seal of the lymphatic chain. When conservative treatment fails, there may be a role for percutaneous thoracic duct embolization or percutaneous destruction of lymphatic vessels which are reportedly successful in 70–80 % of cases in controlling the lymphatic leak [103]. These therapies are more popular in Europe but present an alternative route for management. Substantial loss of protein and albumin occurs during the leak and this can lead to significant malnutrition and immunologic derangement if allowed to continue [104, 105].

Enterocutaneous Fistulas

Enterocutaneous fistulas drain bowel content to the atmosphere and are the bane of surgical complication. They are thought to be caused by anastomotic failure and breakdown, intra-abdominal abscesses, foreign body erosion (for example, drains), malignancy, or inflammatory processes, and there is some data that they can be due to prolonged wound vac usage [106, 107]. They additionally can occur without identifiable cause. The biggest problems are damage and excoriation to the skin, loss of electrolytes and fluid with dehydration risk, and challenges in providing effective and usable nutritional support [108]. Spontaneous closure is more likely if the output is low, the surrounding bowel is healthy, and the fistula resulted as a postoperative complication [109]. There is no definitive data in the literature regarding medications or supplements that will decrease fistula output and promote ultimate closure; glutamine, use of TPN with avoidance of enteral nutrition, and specific dressings have all been credited with enabling closure [110–114]. Spontaneous closure does not occur often, and if does not occur, indicates need for planned, delayed, surgical closure [115–117]. Mortality is directly correlated with output volume and additional related complications [109]. High-output fistula is defined as volume loss greater than 500 ml per 24-h period. This fluid contains significant electrolytes, mimicking the makeup of the specific fluid in that part of the gastrointestinal system. These electrolytes must be accounted for and appropriately replaced to prevent dehydration and complications related to specific electrolyte loss [118, 119]. Significant albumin wasting is associated with increased morbidity and mortality [120, 121].

Short Bowel Syndrome

Short bowel is more associated with the clinical outcomes of having insufficient length to perform effective digestion, than defined by the actual length, since there is evidence that the bowel has some ability to adapt function over time [122, 123]. Providing long- and short-chain fatty acids, immunomodulators, and trophic feeds or elemental formulas may play a role in gut adaptation [124–126]. It should be noted that the adaptation of the bowel includes adaptation of each of the enterocytes, overall function, motility, secretion, and absorption [127, 128]. Short bowel implies inadequate length to enable all the necessary components of digestion without the ability to maintain nutritional support. It is a spectrum, with some patients still able to maintain some degree of enteral support. Less than 100 cm of missing length of small bowel is extremely well tolerated; total remaining lengths of less than 100 cm are poorly tolerated and typically require complete replacement of nutrition by the parenteral route [129]. Those with true short bowel are TPN dependent, which of course introduces the risks of line sepsis, intra-abdominal sepsis from gut overgrowth, and bowel disuse. There is also increased cost of the TPN itself and of hospitalization necessary for placement of lines and treatment of infections. The most likely cause of short bowel is from resection, the majority of these cases resulting from resections in childhood [130, 131]. Treatment focuses on nutrition. Pharmacologic treatment includes transit slowing medications (loperamide, diphenoxylate-atropine, cholestyramine, narcotics, pancreatic enzymes), drugs that reduce gastrointestinal secretions (acid-reducing medications, octreotide, clonidine), drugs that provide trophic effect and growth factors (glutamine, teduglutide) as well as drugs to treat small intestinal bacterial overgrowth [132]. Surgical management includes preserving any remaining length, reversing small segments to enhance absorption and motility, and intestinal transplants [133–139]. No surgical intervention has been shown to have overwhelming benefit.

Conclusion

The delivery of early, appropriate nutritional support is a critical component of the comprehensive care of the surgical patient. An understanding of the various options for EN, the indications for enteral versus parenteral nutrition, and the complications of the various modalities of nutrition delivery are fundamental for delivering optimal care.

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Renal Replacement Therapy

11

Kevin W. Finkel

Acute kidney injury (AKI) occurs commonly in critically ill patients and independently increases morbidity and mortality [1, 2]. Despite impressive gains in the understanding of the basic pathophysiologic principles underlying renal injury, there are no therapeutic options to prevent or ameliorate AKI; treatment consists of supportive care and avoidance of nephrotoxic agents such as radiocontrast and non-steroidal anti-inflammatory agents. At a certain point in the disease course the use of renal replacement therapy (RRT) may be considered. Although RRT has been available since the 1950s, several critical issues regarding the use of RRT remain controversial as outlined in Table 11.1.

Timing of Initiation

The classic "indications" for initiating RRT in a patient with AKI are listed in Table 11.2. However, it is misleading to refer to these clinical conditions as indications because it implies that RRT should only be started when such criteria are met. Using such criteria could delay appropriate therapy resulting in serious deleterious effects in critically ill patients. Rather, the conditions listed should necessitate emergent RRT unless only comfort care measures are planned.

In the case of lesser degrees of renal injury, the timing of RRT remains a controversial issue. On the one hand, early initiation would certainly avoid the development of any serious complication of AKI; however, the early use of RRT could expose patients to the potential harm of RRT when otherwise they would not have received it (Table 11.3). Currently, there are no randomized controlled trials addressing this issue. Such trials are difficult to perform since we do not have a reliable method to ascertain which patients would progress to requiring RRT if we avoided "early" RRT and therefore allow proper randomization.

Two retrospective studies partitioning patients into "early versus late" initiation groups based on having started RRT when above or below the entire group's median blood urea nitrogen (BUN) concentration found a survival advantage in the early dialysis group [3, 4]. Although other studies report conflicting conclusions, a recent meta-analysis of all studies to date suggests a benefit to earlier initiation of RRT [5, 6]. Unfortunately, the overall data quality is poor and doesn't actually outline when RRT should be started.

Therefore, initiation of RRT should be individualized to each patient taking into consideration several factors including fluid balance, severity of multi-organ dysfunction, urinary output, age, and co-morbid conditions. For example, an otherwise healthy young person with traumatic rhabdomyolysis and non-oliguric AKI may warrant delayed initiation of RRT compared to an elderly patient with oliguric AKI and multi-organ dysfunction from biliary sepsis that might benefit from earlier RRT.

Type of Metabolic Clearance

There are two basic methods of solute removal from the blood with RRT: diffusion via dialysis, and convection, or solvent drag, using hemofiltration (Table 11.4). Dialysis relies on the diffusion of solute across a semipermeable membrane (dialyzer) based on a concentration gradient. It provides excellent acid–base control and small molecule removal such as BUN and creatinine. It is also relatively inexpensive since the dialysis solution can be produced in bulk using processed local water and does not need to be ultra-pure because bacterial products do not cross the dialyzer membrane. However, as the molecular weight of solute increases there is a significant decrease in clearance regardless of the concentration gradient because larger molecules move more slowly in an aqueous environment compared to smaller ones. This reduced clearance of so-called middle molecules, which includes

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_11

Table 11.1 Considerations when initiating renal replacement therapy

Timing of initiation
Early versus late
Method of clearance
Diffusion (dialysis)
Convection (hemofiltration)
Means of delivery
Intermittent
Continuous
Intensity of dialysis
High versus usual dose
Non-renal indications
Sepsis
Liver failure
Volume overload

Table 11.2 Mandatory indications for initiating renal replacement therapy

Uremic symptoms
Severe hypervolemia unresponsive to diuretics
Refractory hyperkalemia
Severe metabolic acidosis
Uremic pericarditis
Uremic bleeding
Certain poisonings/intoxications

Table 11.3 Potential complications of renal replacement therapy

Dialysis catheter associated
Pneumothorax
Hemothorax
AV fistula
Line related sepsis
Bleeding
Anti-coagulant related
Bleeding
Heparin induced thrombocytopenia (HIT)
Citrate toxicity (liver failure)
Procedure related
Hypotension
Dialyzer reaction (anaphylactoid)
Blood loss (clotting)
Cardiac arrhythmias
Seizures
Air embolism
Hemolysis
Thrombocytopenia
Severe electrolyte abnormalities
Prolonged acute kidney injury

Table 11.4 Comparison of hemodialysis and hemofiltration

	Hemodialysis/ Diffusion	Hemofiltration/ Convection
Fluid type	Dialysate	Replacement fluid
Ultra-pure solutions necessary	No	Yes
Acid–base control	++++	++++
Small solute removal	++++	++++
Middle molecule removal	+	+++
Cost	$	$$$$

inflammatory mediators such as interleukin-6 and tumor necrosis factor-alpha, could be significant in critically ill patients, particularly those with sepsis or shock.

Hemofiltration, on the other hand, works by removing large volumes of plasma water across the dialyzer membrane using a pressure gradient, or transmembrane pressure (TMP). The lost plasma volume is replenished with concurrent intravenous administration of a physiologic replacement fluid. The removal of plasma water under pressure essentially "drags" solute with it leading to solute removal. By this mechanism, middle molecule clearance is superior to dialysis; hence, many clinicians have proposed that hemofiltration is the preferred method of RRT in septic AKI. The major disadvantage of hemofiltration is cost. Replacement fluid, since it is administered intravenously, needs to be ultra-pure and is therefore more expensive compared to dialysis fluid.

Despite the hypothetical advantage of hemofiltration over dialysis in septic AKI, there currently are no randomized trials demonstrating its potential benefit [7]. In some countries, hemofiltration is even used as a treatment for sepsis without AKI, so-called cytokine dialysis. Again, there is no credible evidence that this practice is beneficial [8, 9]. Furthermore, hemofiltration increases middle molecule clearance indiscriminately as it removes both "good" and "bad" solutes equally.

Based on the foregoing information, there is no absolute evidence favoring the use of one form of clearance over the other. Therefore, the choice becomes one of personal opinion considering ease and cost of therapy. At our institution if intermittent RRT is started we use dialysis. If patients are started on continuous RRT (CRRT), since the therapy fluid is the same whether used as dialysis or replacement fluid and there is no cost difference, we perform hemofiltration.

Method of RRT Delivery

Once the decision has been made on when to start RRT and what form of clearance will be used (no small undertaking), it must be determined what type of delivery method will be utilized (Table 11.5). Typically, RRT is divided into two major categories, intermittent hemodialysis (IHD) and CRRT. Using a double-lumen venous catheter, CRRT can be performed as either continuous veno-venous hemofiltration or hemodialysis (CVVH and CVVHD, respectively). Although CRRT on a minute by minute basis is less efficient than IHD because of lower flow rates, it provides excellent volume and solute removal due to its continuous application.

Table 11.5 Comparison of different modalities of renal replacement therapy

	Intermittent hemodialysis	Continuous renal replacement therapy[a]	Hybrid therapies (SLED/EDD)
Time (h/day)	3.5–4	24	8–12
Blood flow rate (ml/min)	350–400	200–300	200–300
Dialysate flow rate (ml/min)	800	30–50	100
Replacement fluid flow rate (ml/min)	N/A	30–50	N/A
Hemodialysis	Y	Y	Y
Hemofiltration	N	Y	N
Cost	$	$$$$	$$

SLED Slow, low efficiency dialysis, *EDD* Extended daily dialysis
[a]In continuous dialysis the flow rates are determined by ml/kg/h. In the table it is converted into the typical flow rates in ml/min for easier comparison

Table 11.6 Complications of continuous renal replacement

Enhanced antibiotic removal
Persistent hypophosphatemia
Reduced 2, 3 DPG levels
Excess blood loss from repeated filter clotting
Need for continuous anticoagulation
Increased amino acid loss
Increased vitamin loss
Increased trace mineral loss
Prolonged membrane exposure

Table 11.7 Indications for continuous renal replacement therapy

Hemodynamic instability
Cardiac SOFA Score > 2
Atrial fibrillation with rapid ventricular response
Poor metabolic control
Rhabdomyolysis
Tumor lysis syndrome
Hypercatabolism
Anasarca
Fulminant hepatic failure
Cerebral edema/hemorrhage
Post-cardiothoracic surgery
Poisoning and intoxications
Ethylene glycol
Lithium

It has been suggested that CRRT is the preferred RRT modality in critically ill patients because of improved hemodynamic stability, safer volume removal, better acid–base and electrolyte balance, and the ability to give more nutritional supplementation. It is expected that these attributes of CRRT would lead to improved outcomes in critically ill patients compared with IHD. However, despite these apparent advantages, several randomized controlled trials were unable to demonstrate any benefit to CRRT [10]. It has been argued that this lack of superiority was due to study design where the sickest patients were excluded from participation thereby creating bias. On the other hand, another interpretation is a failure to recognize the potential negative effects from CRRT that could negate its positive attributes as listed in Table 11.6 [11]. In fact, in a study from the Cleveland Clinic, 27 % of patients on CRRT experienced hypophosphatemia and its development was associated with a significantly increased risk of respiratory failure necessitating tracheostomy [12]. For now, the debate on CRRT versus IHD continues although CRRT certainly has a role in the care of a select group of patients. Reasonable guidelines for selecting CRRT are listed in Table 11.7.

Intensity of Dialysis

Other than control of metabolic and volume disturbances in patients with AKI, there is the issue of how much dialysis does a patient need, or the concept of dialysis dose. An early study of dialysis intensity in stable outpatient IHD patients showed that the amount of solute clearance (as measured by the percentage decline in the initial BUN concentration) was more predictive of morbidity and mortality than duration of dialysis [13]. This landmark study led to the concept of urea kinetic modeling as a means to assess "adequate dialysis." In essence, it showed that simply looking at the BUN concentration as a marker of "good" dialysis was severely flawed since BUN levels are affected by numerous non-renal factors such as protein intake, catabolic rate, and medications. What mattered was the percent reduction in the BUN concentration. Adequate dialysis is a > 65 % reduction in the BUN level at the end of treatment regardless of whether the initial value is 50 mg/dl or 100 mg/dl. Lesser amounts of reduction in stable outpatient IHD patients are associated with significantly higher morbidity and mortality rates. In fact, urea reduction ratios (URR) are mandatorily followed in dialysis clinics as a measure of quality care.

If the URR is a good measure of adequate dialysis in end stage renal disease (ESRD) patients, what about unstable or critically ill patients with AKI needing RRT? In other words, if "dose" matters in ESRD, does it matter in AKI and how do you measure it? Inherent in the issue is that the URR was only validated in the ESRD population and not patients with AKI.

With this as a background, in the early 2000s there arose great interest in assessing the "dose" of RRT in critically ill patients with AKI. In a trial by Ronco et al. patients receiving CVVH for intensive care unit (ICU) acquired AKI were randomized to low dose (20 ml/kg/h) or high dose (35–45 ml/kg/h) replacement fluid rates [14]. Patients in the higher dose group had significantly better survival rates. In another trial of patients receiving IHD for AKI, Schiffl et al. showed that patients receiving daily dialysis had better survival rates compared to those who received dialysis on an every other day basis [15]. Based on these findings, as well as other supportive retrospective studies, higher doses of RRT for critically ill patients were strongly encouraged. However, there were several problems with this recommendation: 1) control groups may have been "underdialyzed." For example, in the Schiffl study, the mean URR during each treatment was below 60 %; 2) demographics of the study patients were not reflective of those usually seen in the ICU; in the Ronco trial 85 % of patients were surgical and only 15 % had sepsis; 3) volume control was not standardized; and 4) most studies had small numbers of patients and were underpowered.

Based on clinical equipoise, the VA/NIH Consortium embarked on an ambitious study (ATN Study) to address the question of RRT adequacy in ICU patients with AKI [16]. Patients were randomized to either high dose or usual dose dialysis until death, recovery, discharge, or day 30 of hospitalization. Furthermore, modality (CRRT or IHD) was determined by the cardiac sequential organ failure score (SOFA). If patients were considered hemodynamically unstable (cardiac SOFA score of 3 or 4), they received CRRT. Otherwise IHD was performed. Patients switched between modalities as their cardiac SOFA score changed; however, they remained in the same dosing arm. High dose CRRT was 35 ml/kg/h of dialysate/replacement fluid while usual dose was 20 ml/kg/h. High dose IHD was six treatments weekly and usual dose was 3 weekly treatments. Each treatment was required to achieve a URR of >65 %. The study randomized over 1000 patients with a 90 % power to detect a 10 % absolute reduction in mortality rate with an expected mortality rate of 55 %. The study found there was no survival benefit to intensive dialysis in either the entire group or in any predefined subgroup of patients. It is important to note that all patients achieved a URR >65 % during IHD treatments and the CRRT dose (defined as either hours on machine or quantity of used fluids) was achieved in 90 % of cases. Therefore "under dosing" of dialysis did not occur.

Likewise, in the RENAL trial with over 1000 patients with AKI in the ICU with similar demographics to the ATN study, randomization to high (45 ml/kg/h) versus usual (25 ml/kg/h) dose CRRT did not confer any survival benefit [17].

What do we make of these results given the power of these two randomized controlled trials as compared to much smaller previous studies? The preponderance of the evidence does not prove that dose doesn't matter, it does! Rather, that if an adequate dose of dialysis is delivered, then more is unnecessary. Adequate dosing is not what is prescribed but what is achieved. Barriers to achieving the prescribed dose include poor catheter function, filter/blood line clotting, competing procedures (abdominal washouts, radiology procedures), and morbid obesity. Therefore, patients with ICU associated AKI can be safely treated with thrice weekly IHD (as along as the URR is measured and a target of >65 % is achieved) or CRRT with a dose of 25 ml/kg/h as long as they receive at least 22 h (90 % of dose) of therapy per day.

Conclusions

Acute kidney injury occurs commonly in critically ill patients and independently increases morbidity and mortality rates. Despite increasing understanding of the basic pathophysiologic processes in AKI, there currently are no effective therapies that can reverse or ameliorate renal injury necessitating the use of RRT in some patients. Despite the fact that RRT has been available since the 1950s, several issues related to its use remain controversial. Although the need for dialysis is clear for several life-threatening indications, there is yet a consensus on when RRT should be initiated in less severe circumstances. The proper use of RRT is further shrouded by such topics as means of clearance (diffusion versus convection) and type of delivery (CRRT versus IHD). It is in many ways shocking that RRT has advanced so far technologically yet we have so many fundamental clinical questions regarding its use.

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Management of Surgical Site Infections

12

R. Mario Vera

History

Infection has been a substantial hindrance to both patients and surgeons throughout the history of surgery. The earliest known operations were trepanations, performed by humans of the proto-neolithic era. Holes were drilled into the skull to expose the dura mater often to relieve pressure likely secondary to trauma or malignancy [1]. Ancient cultures in the Americas similarly practiced trepanation and some evidence suggests survival rates as high as 50 %. It is believed that the greatest contributor to mortality after these early operations was infection. Despite the limitations of pain, bleeding, and infection, these operations continued to be performed into the classical era.

Due to the high rate of complication, the practice of surgery continued to be relegated to a therapy of last resort until the European renaissance of the sixteenth century. Andreas Vesalius contributed knowledge of anatomy through direct dissection. Ambrose Pare was a French military surgeon who was the first to suggest the cauterization of wounds and direct ligation of bleeding vessels in traumatic amputation. Their works initiated an era of surgical advancement that eventually led to two major milestones: the development of anesthesia allowing for more complex operations and antisepsis which reduced the largest contributor to post-operative mortality [2].

In 1847 Hungarian obstetrician Ignaz Semmelweis noted that medical students caring for laboring women had a higher incidence of maternal death from puerperal fever or child-bed fever as compared to the midwives who did not participate in the dissection laboratory. He concluded that the vector for fever was related to the un-washed hands of the students and instituted compulsory hand-washing resulting in a decrease in mortality of over 70 %. Despite this groundbreaking observation, he was ultimately ridiculed by the medical establishment and died at the age of 47, shortly after being committed to an asylum [3].

Joseph Lister acting on the discoveries of Louis Pasteur, who had shown that in the spoilage of food could occur under anaerobic conditions if there were microorganisms present, championed the use of surgical antisepsis by spraying carbolic acid on his instruments. In 1867 he published *Antiseptic Principle of the Practice of Surgery* and thus ushered in the era of antiseptic surgery. His later contributions include the use of surgical gloves and the introduction of the steam sterilizer [4].

Epidemiology

According to the Centers for Disease Control (CDC), there were 16 million operative procedures performed in the USA in 2010 [5]. The following year there were over 157,000 surgical site infections (SSI) associated with inpatient surgeries alone [6]. The overall rate of SSI has been found to be about 2 % though it has been difficult to quantify directly. Many agencies have taken a keen interest in reducing the rate of SSI given that they lead to increased health care costs, morbidity, mortality, and length of hospitalization. Despite efforts to institute protocols that are aimed at reducing SSIs, adherence to such protocols remains inconsistent. The rate of SSI mortality is thought to be about 3 % [7]. In addition, patients who suffer from SSI are twice as likely to require intensive care unit (ICU) admission and five times as likely to need hospital re-admission [8]. In real terms, SSIs constitute a significant public health problem with substantial detriment to the patient, hospital systems, and the health care system as a whole.

Health Care Costs

The nation has increasingly turned more attention toward controlling what is perceived as a health care system wrought with unreasonable cost. Health care in the USA costs nearly

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_12

Table 12.1 Surgical site infection definitions

Superficial incisional SSI	Infection occurs within 30 days after any operative procedure and involves only the skin and subcutaneous tissue of the incision *and* at least one of the following: a. purulent drainage from the superficial incision b. organisms identified from an aseptically obtained specimen from the superficial incision or subcutaneous tissue by a culture or non-culture based microbiologic testing method which is performed for purposes of clinical diagnosis or treatment (e.g., not Active Surveillance Culture/Testing [ASC/AST]) c. superficial incision that is deliberately opened by a surgeon, attending physician or other designee and culture or non-culture based testing is not performed *and* at least one of the following signs or symptoms: pain or tenderness; localized swelling; erythema; or heat d. diagnosis of a superficial incisional SSI by the surgeon or attending physician or other designee
Deep incisional SSI	Infection occurs within 30 or 90 days (for a sub-group of procedures) after the operative procedure and involves deep soft tissues of the incision (e.g., fascial and muscle layers) *and* at least one of the following: a. purulent drainage from the deep incision b. a deep incision that spontaneously dehisces, or is deliberately opened or aspirated by a surgeon, attending physician or other designee and organism is identified by a culture or non-culture based microbiologic testing method which is performed for purposes of clinical diagnosis or treatment (e.g., not Active Surveillance Culture/Testing (ASC/AST) or culture or non-culture based microbiologic testing method is not performed *and* the patient has at least one of the following signs or symptoms: fever (>38 °C); localized pain or tenderness c. an abscess or other evidence of infection involving the deep incision that is detected on gross anatomical or histopathologic exam, or imaging test
Organ/space SSI	Infection occurs within 30 or 90 days (for a sub-group of procedures) after the operative procedure and involves any part of the body deeper than the fascial/muscle layers, that is opened or manipulated during the operative procedure *and* the patient has at least one of the following: a. purulent drainage from a drain that is placed into the organ/space (e.g., closed suction drainage system, open drain, T-tube drain, computed tomography [CT]-guided drainage) b. organisms are identified from an aseptically obtained fluid or tissue in the organ/space by a culture or non-culture based microbiologic testing method which is performed for purposes of clinical diagnosis or treatment c. an abscess or other evidence of infection involving the organ/space that is detected on gross anatomical or histopathologic exam, or imaging test

twice as much per person as compared to the rest of the developed world [9]. One substantial component of increased costs in the USA as compared to the rest of the world is an increased reliance upon technology and a greater availability of surgical care. Though it has been difficult to quantify the direct cost of SSIs, some work has been done in specific areas of surgery. In one prospective study of elective orthopedic operations health care costs were found to be increased by up to 300 % in patients who developed an SSI [10]. On a national scale, it is believed that SSIs account for an addition one million inpatient days and approximately $1.6 billion in additional health care costs [11]. As both law makers and tax payers continue to focus on reducing health care costs, it is clear that one area that could have a profound impact is reducing the rate and severity of SSIs.

Definition of Surgical Site Infections

The CDC began defining SSIs separately in the 1990s to differentiate them from wounds secondary to traumatic injury. Categorized according to depth, the CDC has specific definitions for superficial incisional SSI, deep superficial SSI, and organ space SSI (Table 12.1). Superficial incisional SSIs involve only the skin and subcutaneous tissue. Deep incisional SSIs involve the soft tissue to the fascial and muscle layers. Organ/space infections involve deep structures including the space and organs involved in the operation. Significant changes from prior versions include a list of excluded infections including cellulitis alone, a stitch abscess, and circumcisions in newborns that become infected. Additionally, they defined a sub-group of procedures that are under surveillance for 90 days under the deep incisional and organ/space categories. These procedures include breast surgery, peripheral vascular bypasses, and cardiac surgery among others.

Prevention

Benjamin Franklin declared that “an ounce of prevention is worth a pound of cure” and that is no less true today than it was when Franklin spoke those words to colonial Philadelphians when arguing to establish the city’s first firefighting organization. While it seems shocking to us that it is better to prevent the spread of fire rather than rebuild a city burnt to the ground, future surgeons may similarly fault the infection control practices of today. Prevention of SSIs must

be a multifactorial approach involving not only the surgeon and patient but also the anesthesiologist and operating room staff.

Non-surgeon Driven Factors

There is no question that patients undergoing surgery have improved outcomes with optimized communication between the surgeon and the anesthesiologist. Intraoperative hypothermia has long been thought to cause significant complications including coagulopathy and cardiac events. The data regarding surgical site infections is less clear. A recent review of 1400 patients undergoing prolonged gastrointestinal operations found that only those who suffered from severe hypothermia or late-nadir hypothermia had an increased rate of SSI [12]. Similarly, others have found no association between inadvertent hypothermia and SSI [13]. It is likely that several confounders factor into the mixed data. There is a lack of consensus on the definition of hypothermia and many studies are limited to single institution reviews with small sample sizes. Similarly, a recent Cochrane review found limited support for strict glycemic control as compared to conventional (maintenance of glucose <200 mg/dl) glycemic control to prevent SSI [14]. Transfusion of blood products during an operation has more robust evidence supporting its association with SSI. The immunological effects of blood and blood product transfusion are increasingly being found to be detrimental. Several studies including some multi-institutional collaborations have found perioperative transfusion to be an independent risk factor for SSI [15]. Despite the lack of clear evidence to support both strict glycemic control and maintenance of perioperative normothermia, many influential institutions including the World Health Organization (WHO) have adopted these measures as part of a larger goal of standardizing surgical care worldwide [16].

Surgeon Driven Factors

The use of bowel preparation before elective gastrointestinal surgery has long been both vilified and exalted in the surgical literature. Mechanical bowel preparation alone was the rule until the tradition of preoperative hospitalization began to lose favor. Several large reviews around that time resulted in no perceived benefit to mechanical bowel preparation alone for elective colon surgery [17]. Critics of bowel preparation alone argue that reduction of colonic flora prior to operation requires the addition of a poorly absorbed oral antibiotic as well as the routine perioperative systemic antibiotic. Recently, large meta-analysis yielded evidence to support that claim. One meta-analysis that included seven randomized controlled trials found that the addition of oral antibiotics resulted in an SSI rate of 7 % compared to 16 % among those who did not receive them [18]. Mechanical bowel preparation in conjunction with oral antibiotics and preoperative systemic antibiotics has become the standard of care with this literature. Areas that could benefit from additional study include selection of the optimal oral and preoperative systemic antibiotics.

The use of parenteral systemic antibiotics prior to surgery is an essential part of the prevention of SSI. Prophylactic antibiotics have been established in the surgical literature since the late 1960s [19]. While the use of preoperative antibiotics has been nearly universally accepted, the exact choice of regimen as well as the timing of administration remains less well supported. It remains good principle to select the appropriate antibiotic based on the organisms likely to come in contact with the wound. Specific regimens, however, have not been well studied. Additionally, the nationally sponsored Surgical Care Improvement Project (SCIP) requires administration of prophylaxis 1 hour prior to incision while recent data suggest that timing is less of a factor in preventing SSI than previously thought. A recent study of the Veterans Administration (VA) database found that antibiotic timing was not significantly associated with the risk of SSI [20]. While the exact timing and correct regimen may remain in question, the use of preoperative antibiotic prophylaxis overall does not. Until more data becomes available, it remains the surgeon's responsibility to think critically about the antibiotic being selected and that it is administered prior to incision.

Despite many advances in surgical preparation and surgeon antisepsis since the era of Joseph Lister, the principles remain the same. Effective cleaning of the patient's skin and meticulous attention to sterile technique are the hallmark of lowering bacterial contamination of the surgical wound. With regard to surgeon antisepsis, iodine based scrub has been replaced by chlorhexidine based solutions due to lower colony counts on skin following their use. In addition, they appear to enjoy improved compliance compared to the older technique [21]. Large analysis comparing iodine scrub versus chlorhexidine for skin preparation also results in lower rates of SSI for the latter [22]. Of note, this effect was observed in superficial and deep incisional SSIs but not in organ/space SSIs suggesting that different factors are at work with the latter type of infection. Careful adherence to meticulous surgical technique cannot be overstated in any discussion of prevention of SSIs. Factors that lead to the creation of a rich nidus of infection include skin, soft tissue hematomas, and the presence of a dead space. In addition, the overuse of permanent suture should be avoided when possible.

Recent innovations in the use of negative pressure wound therapy (NPWT) suggest that it may have a role in the prevention of SSIs. Once only used on open wounds, newer devices have been developed for the use on closed wounds with positive results. One systematic review and meta-analysis

compared closed incision NPWT to conventional dressings using data from ten studies. They found lower rates of SSIs and seroma formation in the NPWT group, though they also found that the groups were too heterogeneous to draw a generalizable conclusion [23]. Nonetheless, their results optimistically point to another factor that may help prevent SSIs.

Diagnosis of Surgical Site Infections

History and physical exam is the cornerstone of diagnosis of surgical site infections. A thorough review of the chart is important for the type and site of operation. Careful attention to the time course of the patient's clinical status will often yield worsening of symptoms on the third to fifth post-operative day. In both superficial and deep incisional SSIs, pain will be most pronounced at the incision site which may not exhibit more than mild erythema or swelling at first, but in most cases will proceed to express purulence. Infections that reveal themselves earlier should be considered for their potential to harbor beta-hemolytic streptococci or *Clostridium* spp. and thus potentially a serious necrotizing infection that carries a mortality as high as 50 % [24]. Surgical site infections should also be considered in wounds that fail to properly heal. Organ/space SSIs may have effects related to the site of the operation or a more systemic manifestation. For example, failure to resolve a post-operative ileus following bowel surgery should prompt evaluation for the presence of an intra-abdominal abscess. Pertinent laboratory tests include a complete blood count and chemistries. Once observed, the presence of erythema, swelling, warmth, or pain should lead to opening of a suspected superficial or deep SSI and collection of culture. The importance of collecting a culture cannot be overstated. While infections that appear to have systemic manifestations or produce physiologic derangements may require immediate use of broad spectrum antibiotics, often it is prudent to utilize agents more narrowly appropriate guided by culture. Signs of systemic inflammation such as fever, tachycardia, hypotension, and hyperventilation should prompt rapid assessment of the wound and imaging for the presence of an organ/space SSI. Computed tomography scan and magnetic resonance imaging (MRI) are useful for the identification of organ/space SSI depending on the operative site.

Treatment of Surgical Site Infections

As with any infection, source control is the basic principle of management. In the case of superficial SSIs, in most cases opening the wound and allowing the pus to drain following collection of a culture is sufficient. The routine use of antibiotics for wounds displaying minimal erythema is not indicated (Fig. 12.1). Five cm of erythema that extends beyond the incision has been suggested as a good threshold for the initiation of systemic antibiotics. The most common organism

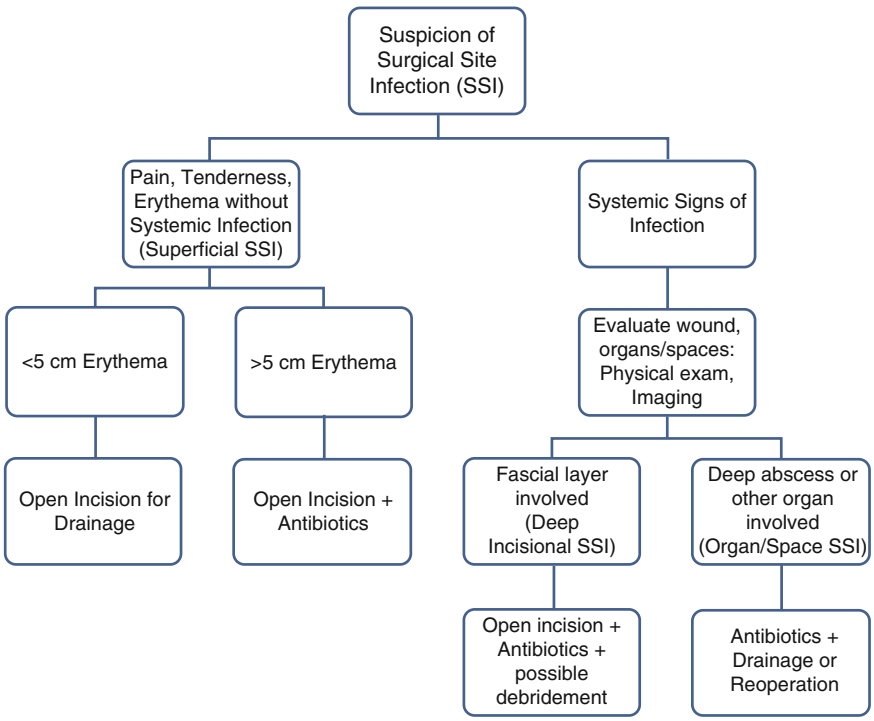

Fig. 12.1 SSI treatment algorithm

isolated from superficial SSIs is S. aureus along with other gram-positive bacteria, thus antibiotic coverage should focus on gram-positive coverage. As always, if the patient is displaying systemic signs of infection, broad spectrum coverage is likely indicated.

Deep SSIs often present a much more significant problem. Often showing signs of systemic inflammation, broad spectrum antibiotics should be initiated immediately upon recognition of a deep SSI. In many cases, simply opening the wound and allowing purulence to drain will only yield partial source control. If the wound cannot be visualized due to discomfort or pain, the patient should be taken to the operating room for a thorough examination of the deep soft tissues, fascia, and muscle that may be involved. Operative debridement is essential to remove any necrotic appearing tissue that will otherwise continue to be a nidus of infection. The wound left after operative debridement following a deep SSI continues to be a clinical quandary. There is some evidence that NPWT increases angiogenesis and fibroblast growth factors thus leading to improved wound healing [25]. However, there still remains limited clinical data to support these basic science findings. A recent Cochrane review that was only able to include two studies showed no difference between NPWT and conventional dressings in healing by secondary intention [26]. Further study is clearly needed. One potential benefit of NPWT is the less frequent dressing change as compared to traditional moist dressings.

Finally, organ/space SSIs are found at the intra-cavitary site of operation. Presentation is distinctly related to the cavity that is affected. They range from intra-cranial, intra-pleural or mediastinal, or intra-abdominal abscesses to osteomyelitis in the case of orthopedic procedures. Rapid assessment with a history and physical examination should be supplemented by imaging to help elucidate the extent and location of the infection. Source control will be guided by findings on imaging in most cases. As the field of Interventional Radiology has grown, many once operative re-explorations have yielded to a less invasive approach using image-guided drains. Cultures should be taken from any specimen collected, but broad spectrum antibiotics should be initiated immediately, especially in the setting of systemic signs of inflammation. Though increasingly less common, if Interventional Radiology is unable to access the source, operative re-exploration is warranted.

Conclusion

Though the practice of surgery has made vast advances in the mortality due to infection, we have not entirely eradicated the problem. Surgical site infections continue to be a substantial cost to society, and more importantly the patient. Complications of SSIs include disfigurement, increased rate of hernia, failed prosthesis, functional deficit, prolonged hospitalization, and of course death. The principles of prevention remain the same as proposed by Lister, effective antisepsis measures for both the surgeon and the patient, complemented by meticulous surgical technique. The increasing incidence of resistance to current antibiotic therapy additionally solidifies the need not only for prevention of SSIs but also for further inquiry as to how to optimize both prevention and treatment.

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Hemorrhage and Transfusions in the Surgical Patient

13

Holly Whitt and Bryan A. Cotton

Hemorrhage remains the leading cause of intra-operative deaths and those in the first 24 h. Many cardiovascular and hepatobiliary procedures result in massive hemorrhage and postpartum hemorrhage events in labor and delivery place the patient at a high risk for mortality. Both upper and lower gastrointestinal bleeding (e.g., diverticulosis, esophageal and gastric varices, and peptic ulcer disease) can also result in significant blood loss requiring massive transfusion and resuscitation from hemorrhagic shock. Therefore, safe, timely, and effective transfusion of blood products is critical. The aim of this chapter is to provide clinicians with a discussion of the current literature on the various blood component products, their indications, and unique hemostatic conditions in the surgical patient. While the majority of data concerning optimal management of acquired coagulopathy and hemorrhagic shock resuscitation is based on trauma patients, many of the principles can and should be applied to the surgical patient (or likely any patient) with profound hemorrhage.

The Lethal Triad of Acute Resuscitation

The concept of the lethal triad—hypothermia, acidosis and coagulation—was first promoted in the trauma population in those undergoing emergency surgery. In an effort to prevent its development (or at least attenuate its progression), investigators began advocating for Damage Control Surgery [1–3]. Central to this concept is aggressively and rapidly addressing all three pathologies simultaneously, as each greatly affects the other.

Hypothermia, defined as a core body temperature of 34–36 °C, in the trauma patient primarily results from reflexive peripheral vasoconstriction in the hypovolemic patient. This phenomenon is further exacerbated by rapid infusion of unwarmed crystalloid fluid during initial resuscitation. This condition impairs coagulation factor activity and platelet function, such as their ability to produce thromboxane, and must be rapidly reversed [4]. Dilutional coagulopathy follows large crystalloid and colloid fluid resuscitation, further promoting ongoing bleeding. Early plasma therapy and platelets have been associated with a reduction in hemorrhage-related mortality [5, 6].

Acidosis has been hypothesized to result from hypoperfusion and excess administration of ionic chloride in normal saline administration. The acidosis disturbs platelet function and morphology, reduces coagulation factor complex activity, and degrades fibrinogen. Approximately 25 % of trauma patients present with abnormal coagulation parameters, and these have been associated with poorer outcomes in these patients. The three conditions above contribute to poor clot formation and aggravated coagulopathy [4].

Evidence exists supporting increased survival upon rapid treatment of initial coagulopathy [5, 7]. Pre-emptive strategies have been shown to actually reduce coagulopathy and the number of overall transfusions required to treat the patient [8, 9]. However, challenges to implementation include time limitations of laboratory-guided component therapy since the results of the tests are not immediate. Another difficulty is that once it has been determined that the patient should receive plasma, an additional 30–45 min is required to thaw and deliver the products [5]. As such, hospitals should have in place a thawed plasma program, keeping adequate numbers of "universal" and type-specific thawed plasma available for immediate release. Plasma thawing protocols exist to avoid this issue and will be discussed in later sections. In acutely bleeding patients, massive transfusion protocols should be activated in order to efficaciously restore blood volume and hemostasis and thawed plasma is critical to their success [5, 10]. Blood products can always be sent back should the clinical setting change, but you can't speed up delivery and preparation of products when you need them.

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_13

Massive Transfusion Protocols

A massive transfusion (MT) is defined as more than ten units of red blood cells (RBC) in 24 h [5]. A massive transfusion protocol (MTP) is the standardization of the delivery and transfusion of RBC, plasma, and platelets in predetermined and predefined ratios as facilitated by a surgical or medical team. In the patient requiring immediate resuscitation, a typical MTP will call for 6–10 units of RBC, with a ratio of RBC to plasma and platelets in 1:1:1–1:1:2 fashion. This protocol and release of products will continue based on ongoing bleeding (Fig. 13.1). These assessments are generally implemented "blind," with subsequent releases guided by routine coagulation laboratory studies as well as thromboelastography (TEG) [11].

Even before the transfusions take place, MTPs call for the rapid mobilization of blood components by having AB (or low-titer A) plasma and group O RBC [12]. Plasma should be available in either thawed form (5 day shelf-life once thawed) or liquid form (never frozen, absolute shelf-life of 21–26 days). A type and screen should be drawn as soon as possible to allow for the transition from universal products to type-specific ones. The efficacy of an MTP also lies in its early implementation as well as identification of patients who would benefit from such an intervention. Criteria for activation include laboratory values, anatomic injuries, and mechanism of injury. Although individual laboratory values (hemoglobin, INR, hematocrit, and pH) have been shown to correlate with massive transfusion requirements, MTP activation should never be delayed on the basis of lab results, which can take up to 45 min to return. The urgency in treating severely injured patients requires early and immediate initiation of MTP based on clinical assessment for rapid delivery of blood products to the bedside. Several scoring systems have been developed to facilitate rapid identification of patients requiring MTP activation based on physical and laboratory results (Table 13.1). Several authors have demonstrated that the transfusion of uncross-matched RBCs is an independent predictor of substantial hemorrhage and the transfusion of multiple units of RBC, plasma, and platelets [12, 13]. As such, when one is requesting uncross-matched product for transfusion, the institution's MTP should be activated.

Prior to the advent of MTPs, resuscitation protocols for severely injured patients began with large volumes of crystalloid followed by RBC transfusions. Later on, plasma, platelets, and cryoprecipitate were administered if the patient had survived the operating theater and then only based on laboratory values and the opinion of anesthesiologists and transfusion specialists. These guidelines recommended transfusions at prothrombin time ratio of >1.5, platelet counts of $<50 \times 10^9$/L, fibrinogen level <1.5–2.0 g/L or after a predetermined volume loss. This approach relied on a reactive

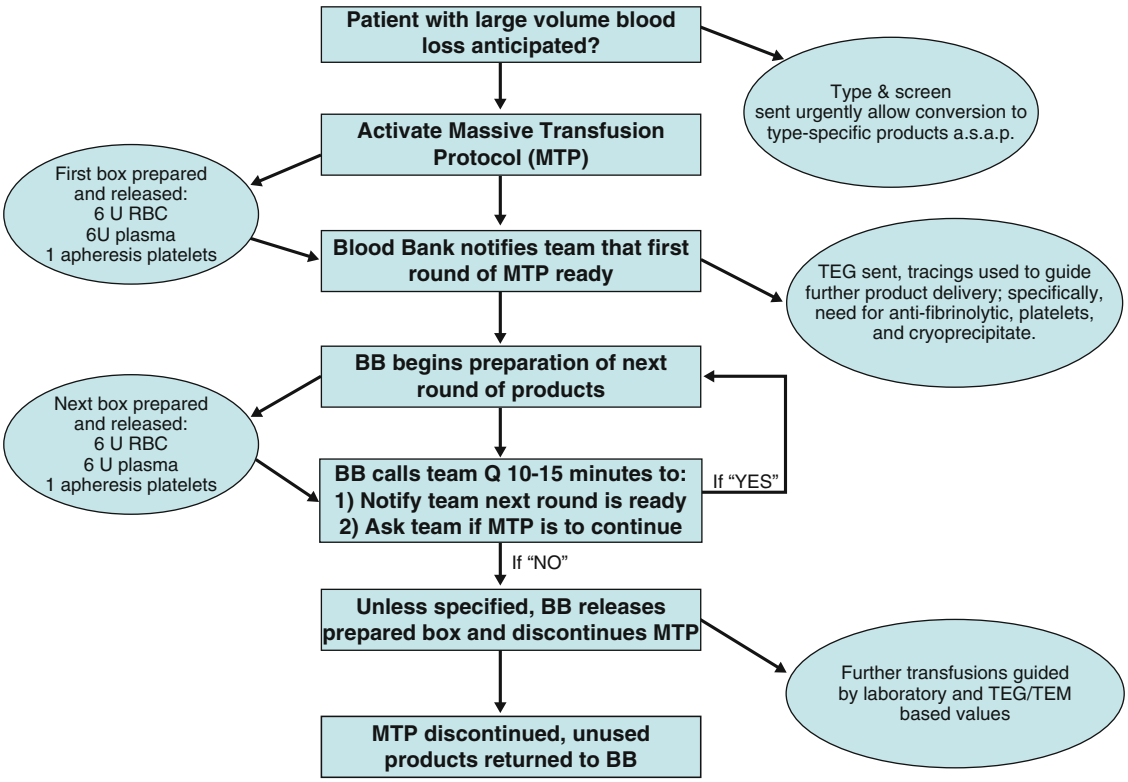

Fig. 13.1 An example of a massive transfusion protocol. (Adapted from Young PP, Cotton BA, Goodnough LT. Massive transfusion protocols for patients with substantial hemorrhage. Transfus Med Rev 2011, with permission.)

Table 13.1 Scoring systems and variables used to predict MTP requirements

	ABC	TASH	ETS	McLaughlin
Tachycardia	X	X		
Hypotension	X	X	X	
+FAST	X	X		
Penetrating injury	X			
pH				X
Base deficit		X		
Pelvic fracture		X		
Hemoglobin/hematocrit		X	X	X
Age			X	

ABC Assessment of Blood Consumption Score; Nunez TC, Dutton WD, May AK, Holcomb JB, Young PP, Cotton BA. Emergency department blood transfusion predicts early massive transfusion and early blood component requirement. Transfusion. 2010;50:1914–20
TASH Trauma Associated Severe Hemorrhage Score; Yücel N, Lefering R, Maegele M, Vorweg M, Tjardes T, Ruchholtz S, Neugebauer EA, Wappler F, Bouillon B, Rixen D, Polytrauma Study Group of the German Trauma Society. Trauma Associated Severe Hemorrhage (TASH)-Score: probability of mass transfusion as surrogate for life threatening hemorrhage after multiple trauma. J Trauma. 2006;60(6):1228–36
ETS Emergency Transfusion Score; Kuhne CA, Zettl RP, Fischbacher M, Lefering R, Ruchholtz S. Emergency Transfusion Score (ETS): a useful instrument for prediction of blood transfusion requirement in severely injured patients. World J Surg. 2008;32(6):1183–8
From McLaughlin—McLaughlin DF, Niles SE, Salinas J et al. A predictive model for massive transfusion in combat casualty patients. J Trauma. 2008;64 Suppl 2:S57–63, with permission

strategy where the clinician was constantly "catching up" with values representing an earlier hemodynamic state of the patient [14].

While this standard resuscitation method is adequate for patients who are not in shock or not bleeding, studies have demonstrated that it does not suffice for the subset of patients who have sustained serious injuries, are coagulopathic or in shock [5]. One reason is that the coagulopathy is addressed after a time lapse since the original laboratory values were obtained. Other reasons for the suboptimal results of this method are due to the ratios of each blood component product infused. Specifically, evidence exists that demonstrates that large volume of crystalloid fluids is associated with increased hemorrhage and lower survival rates [15]. It has been hypothesized that this effect is due to insufficient replenishing of hemostasis factors, and the complex coagulopathy of dilution, consumption of factors, and fibrinolysis is not adequately addressed. MTPs also offer the advantage of reducing intraoperative crystalloid use and hence, reducing opportunities for hemodilution.

Damage control resuscitation (DCR) expands on the MTP process and calls for low-volume resuscitation, sparing the patient of resuscitation with fluids such as crystalloids and colloids that are low in hemostasis factors [15]. Instead, DCR adheres to transfusion of blood products in a ratio of plasma and platelets to red blood cells consistent with that which is being lost to hemorrhage. It also involves more permissive hypertension, and acting preemptively on the hypovolemic, hemorrhaging patient. DCR is also supported by findings from the military, which demonstrated improvement in outcomes in severely bleeding patients who were transfused in ratios of products similar to whole blood. A large amount of retrospective civilian trauma data has demonstrated that an RBC to plasma ratio between 3:2 and 1:1 is associated with increased survival [5]. Fox et al. found that patients undergoing vascular surgery with DCR had improved revascularization and graft patency. Their results demonstrated that recombinant VIIa, whole blood, FFP, platelets, cryoprecipitate and minimal crystalloid prevented early graft failures [16].

A recent randomized, multicenter trial further supports higher ratios in bleeding patients [6]. Investigators at 12 centers in North America randomized 680 trauma patients to receive a ratio of either 1:1:1 or 1:1:2. The trial showed a significant reduction in hemorrhage-related 30-day mortality (15 % vs. 9 %, $p=0.03$), all-cause 3-h mortality (11 % vs. 5.8 %, $p=0.02$), and a strong trend towards reduction in 24-h all-cause mortality (17 % vs. 12.7 %, $p=0.12$) when a 1:1:1 plasma: platelets: RBC ratio was used, compared to 1:1:2. The study did not show a difference in non-hemorrhage deaths or overall mortality.

While there is a wealth of data in the trauma population, less data is available regarding coagulopathy in the severely bleeding patient in other surgical specialties. It is, however, important to consider the underlying pathology responsible for exsanguination, such as in obstetric patients, as well as related comorbidities, such as uremia, pharmacologic anticoagulation, in assessing for need of blood products [5]. For instance, Kılıç et al.'s review of resuscitation in patients with gastrointestinal bleeding found that 1:1:1 ratios of RBCs, FFPs, and platelets reduced dilutional coagulopathy, similarly to trauma patients. Patients undergoing open thoracoabdominal aortic aneurysm repair are also vulnerable to coagulopathy due to systemic heparinization, hypothermia, and left-heart bypass with a centrifugal pump [17]. As well, several authors have noted its benefit in the vascular population [16, 18, 19]. Mell evaluated 168 patients with ruptured abdominal aortic aneurysm who had massive hemorrhage in the perioperative period. Their findings showed reduced 30-day mortality in patients who were transfused 1:1 RBC to plasma ratios. These patients also experienced lower rates of colonic ischemia. The value of this study is that the average age of patients was 73 years, much older than the average trauma patient, demonstrating applicability of MTPs in different patient age populations [19].

Lastly, evidence on MTPs has focused on the acutely bleeding surgical patient, and less is known about patients in other surgical settings. Due to the less emergent nature of such settings, it is likely that MTPs are activated more reactively, and it

may have a different effect on patient outcome [5]. However, some groups have shown that those patients receiving less than massive transfusion levels may still benefit from higher plasma to red blood cell ratios [20]. Wafaisade and colleagues demonstrated decreased mortality rates in such patients. To date, unfortunately, no randomized studies exist in the bleeding, non-trauma patient.

Blood Component Products

Red Blood Cells

Red blood cells are the component of choice used to restore hemoglobin levels in resuscitation. Over 30 % of ICU patients receive RBC transfusions and over 40 % are transfused during hospitalization [21]. The Cardiovascular Health Study found that anemia is associated with increased mortality in elderly patients, emphasizing the importance of treatment [22]. However, correction of anemia in the non-bleeding surgical patient has not been well studied, and its benefits remain controversial.

While most would agree that actively bleeding patients should be maintained at a hemoglobin between 8 and 10 g/dL, agreement is lacking as to what degree of anemia exceeds benefit:harm ratio in the non-bleeding population (Fig. 13.2). The majority of literature currently supports more conservative trigger points in the non-bleeding population, between 7 and 8 g/dL. Englesbe and colleagues reviewed the literature in surgical patients and found that survival was not improved when postoperative patients were transfused to correct a hematocrit of 25 % [23]. The authors recommended making the decision to transfuse using a host of physiological measures and evaluation of the patient's compensatory ability, not only the hemoglobin or hematocrit. They have used a hematocrit of 16 % for initiating transfusion in cases where the patient has excellent compensatory ability, and 21 % when they lacked such capabilities. The 21 % trigger should

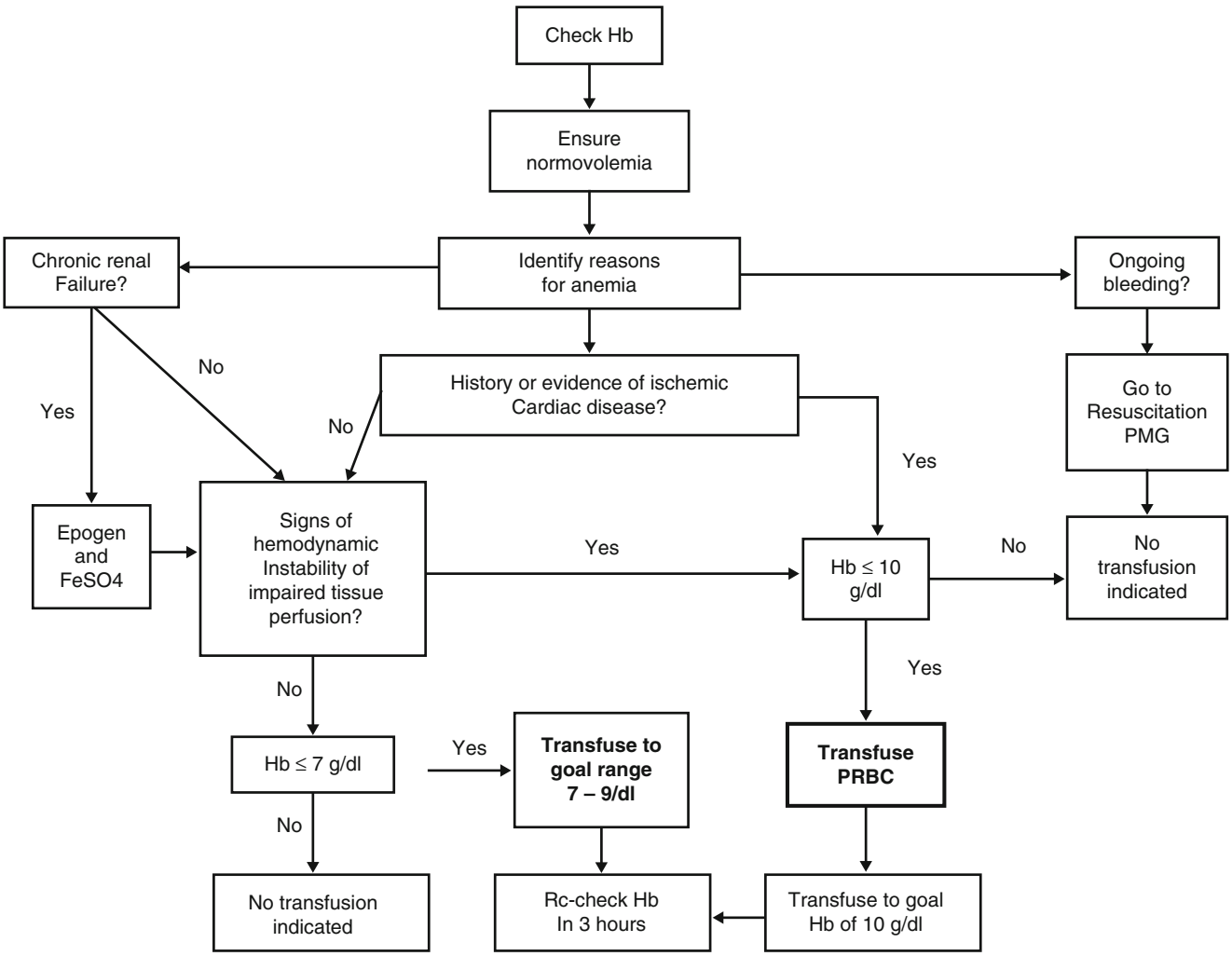

Fig. 13.2 Example of a practice management guideline for managing anemia in the ICU patient

also be employed in stable elderly patients without hypotension, tachycardia, or hypoxia. Investigations have not yet shown benefits in stratification of surgical patients by specialty or procedures [24].

Among critically ill patients, high quality evidence supports conservative triggers for RBC transfusion in critically ill patients [25]. A multicenter randomized, controlled, clinical trial of 838 critically ill patients compared the outcomes of patients who were transfused at hemoglobin levels of less than 7.0 g/dL and those who were transfused at hemoglobin levels below 10.0 g/dL [25]. Their study ultimately found that the more restrictive trigger of 7.0 g/dL was superior to the liberal one and patients experienced improved 30-day survival rates. Of note, of the various patient populations studied, this improvement was not found to be significant in patients with acute myocardial infarction and unstable angina. Based on this, many would argue that in patients with acute cardiac events, data does not robustly support either strategy over the other.

It is important to be mindful of false triggers for transfusion, such as anemia due to hemodilution, commonly seen in patients receiving fluids during prolonged hospital stays. A peripheral hematocrit is not enough to determine the patient's red blood cell levels, and calculations of total blood volume, red blood cell volumes, and normalized hematocrit are necessary [26]. Van et al. report that relying on peripheral hematocrit alone resulted in over-diagnosis of anemia in 23.8 % of analyses, and this finding can lead to unnecessary transfusions. Blood Volume Analyzers are one option that has been shown to separate anemia due to hemodilution compared to other sources such as surgical bleeding [26].

In patients with prolonged hospital stays and critically ill patients, it is important to keep in mind anemia due to phlebotomy for various laboratory testing and other needs [21]. Between 40 and 240 mL of blood per day is collected from ICU patients, with surgical patients generally on the higher end. Hence, the conservation of blood and reducing unnecessary blood draws is key to preventing a need for RBC transfusions. So one must weigh the use of "serial hematocrits" in following patients with solid organ injury or gastrointestinal bleeding against the associated "serial phlebotomies."

Erythropoietin

A randomized, double-blind, placebo-controlled trial investigated the role of epoetin alfa, a recombinant erythropoietin, in reducing the RBC transfusion requirement of long-term acute care patients, thereby reducing risks associated with transfusions [27]. Investigators found that treatment with epoetin alfa significantly increased hemoglobin concentration and reduced the likelihood of receiving an RBC transfusion by greater than 70 %. Another randomized, double-blind, placebo-controlled study demonstrated that a once weekly dose of epoetin alfa augmented the erythropoietin response [28]. As for its effects on mortality, Corwin et al. conducted a prospective, randomized, placebo-controlled trial of 1460 medical, surgical, or trauma patients [29]. Weekly injections of epoetin alfa were shown to decrease mortality at day 29 and day 140, especially in trauma patients compared to placebo. However, epoetin alfa was associated with an increase in thrombotic events, and did not affect the number of patients who received a transfusion of RBCs.

Iron Supplementation

Iron sucrose has also been investigated as a possible adjunct to RBC transfusions in order to reduce transfusion requirements. To answer this question in colorectal cancer surgery patients, Edwards et al. conducted a randomized prospective blinded placebo-controlled trial of 60 patients [30]. Patient outcomes, which were assessed using change in hemoglobin levels, serum iron markers, transfusion rate, length of hospital stay and perioperative events, were unaffected by the addition of 600 mg of iron sucrose.

Plasma

Plasma is an acellular blood product consisting of clotting factors involved in coagulation and fibrinolysis, as well as proteins involved in immune reactions and maintenance of the oncotic balance of blood. Plasma can be obtained from separation of whole blood or unique plasma donations from a donor using plasmapheresis. Common indications for plasma are reversal of warfarin-induced anticoagulation, massive transfusion in trauma and surgery, procedures with limited bleeding or risk thereof, liver disease with coagulation factor deficiencies, single coagulation factor deficiency, and thrombotic thrombocytopenic purpura (TTP) [31].

Historically, plasma transfusions have been associated with various side effects including transfusion-related acute lung injury (TRALI) [32]. However, these complications have been dramatically reduced with blood donation centers transitioning to male only and or nulliparous female donors [33]. Recent estimates place the risk of TRALI at 4.2 cases per 1,000,000 units transfused [34]. These current low risks need to be weighed against its numerous benefits. Each unit contains >400 mg of fibrinogen, helping to address the losses during hemorrhage. Plasma also acts as a tremendous buffer (due to high citrate content) in shock patients with severe acidosis. In fact, plasma has a buffering capacity 50 times that of standard crystalloid products [35]. In hypovolemic patients, plasma is as an excellent volume expander with high oncotic pressures. Compared to other resuscitation fluids, plasma is more effective in maintaining vascular endothelium integrity and clot stability [36].

Norda et al. studied two types of plasma—thawed plasma and liquid plasma (never frozen). Liquid plasma is an AABB approved product and may be stored at 2–6 °C for up to 26 days. Both of these types of plasma have been considered clinically equivalent. As for their individual components, liquid plasma has been shown to contain levels of Factor V and von Willebrand factor at levels 70 % or greater [37]. Murad et al.'s meta-analysis of 37 studies on adults transfused with plasma (compared with non-transfused controls) demonstrated that in the setting of massive transfusions in trauma patients, transfusion was associated with increased survival and a decrease in multiorgan failure [31]. However, the meta-analysis also demonstrated increased risk of mortality in patients who received plasma not part of a massive transfusion protocol. Their findings highlight the need of assessing each individual patient's indication for plasma transfusions. Of note, none of these studies involved the use of plasma in patients with hemorrhagic shock. In this population of patients, the incidence of multiorgan failure has been shown to be lower than comparison cohorts (most likely as a result of less overall transfusions in the higher plasma group) [10, 15].

Alternative Plasma Protocols

Because of the nature of frozen plasma, transfusion delays of 45 min occur as units are thawed and prepared. Young and colleagues surveyed members of the University Health System Consortium, consisting of 107 academic medical centers and 232 affiliated hospitals and found that only 60 % of participating hospitals had thawed plasma sufficient for the first cycle of their MTP [5]. This problem delays the critical availability of plasma in the initial phase of resuscitation. Reviews of plasma, cryoprecipitate, and platelet transfusions alongside massive blood transfusion protocols have demonstrated that earlier use of plasma and platelets in trauma patients have decreased the incidence of coagulopathy [38]. Unfortunately, by the time one or more blood volumes have been lost, plasma may still be unavailable in the absence for a thawed or liquid plasma program. Hence, protocols have been established to reduce wastage of products and use them for patients in an efficacious manner [39].

Thawed plasma is prepared by thawing FFP or FP24, after which it may be used for an additional 96 h beyond the standard 24-h post-thaw shelf life. Extending the lifespan of plasma allows transfusion of units that would otherwise expire untransfused, postponing the need to dispense more FFP. Implementation of a thawed plasma protocol, under which a blood bank technologist identifies and re-labels eligible FFP and FP24 as "thawed plasma" at the start of each shift, was shown to reduce the number of units wasted by 80 %. [39].

Thawed plasma may be used in all cases where FFP is indicated, with two exceptions: neonates and certain patients requiring the higher levels of factor V and VIII present in FFP. Radwan and colleagues demonstrated that the implementation of a protocol with thawed plasma readily available in the emergency department, rather than stored in the blood bank, results in a significant reduction in time-to-transfusion of plasma [40]. This study also found that this earlier administration of plasma was associated with markedly reduced blood product use within the first 24 h of hospitalization and a 60 % odds reduction in 30-day mortality.

Maintaining a consistent and rapidly available inventory of thawed plasma requires attentive management and rotation of product that are near expiration to avoid wastage of expired units. A study by Novak et al. that evaluated plasma usage by the 12 institutions in the Pragmatic, Randomized Optimal Platelets and Plasma Ratios (PROPPR) trial found that keeping an inventory of thawed plasma for immediate use resulted in an increase in the number of units discarded at the end of the 5 day shelf life at several medical centers [41]. The institutions that reported no appreciable increase in waste were those that consistently recycled untransfused, unexpired units back into the general blood product inventory to be made available for use in other departments. Development of such protocols may mitigate the number of discarded units while maintaining adequate supply in for early use in the ED.

As previously noted, however, thawed plasma only has a five shelf-life and, more importantly, only 4–5 % of the population are blood type AB. Therefore, it is not surprising that many blood banks are unable to provide adequate stores of thawed AB plasma. As such, many centers have begun using liquid plasma and or low-titer A plasma as an alternative. Liquid plasma is never frozen and is kept refrigerated, with storage life of 21–26 days. Recent data suggests that liquid plasma may maintain superior coagulation profiles during storage (compared to thawed plasma) [42, 43]. Approximately 40 % of the US population is blood type A, offering a tremendous increase in plasma donor pool. Low-titer A plasma has the potential to serve as an alternative to AB plasma in these universal donor settings. Similar to that with liquid plasma, several centers (including ours) have recently adopted low-titer A plasma for emergency use [44].

Platelets

The purpose of platelet transfusions is to avoid spontaneous hemorrhage, which can occur at very low platelet levels, especially in patients who are already hemorrhaging or have various platelet deficiencies and abnormalities of function. Along with plasma and fibrinogen, platelets are key in

achieving hemostasis in the obstetric patient with postpartum hemorrhage [45]. Approximately 50,000 cells/L of platelets are necessary in order to achieve adequate hemostasis. In addition to the total number of platelets, their quality is also important to overall hemostatic function. A patient's platelets must be efficacious, that is, remaining in circulation and completing its physiological role in clot formation [46]. This efficacy can be assessed by various modalities, from the traditional laboratory coagulation studies to viscoelastic testing such as thromboelastography (TEG).

Cryoprecipitate

Cryoprecipitate consists of von Willebrand factor/VIII complex, factor XIII and fibrinogen. It is used to supplement plasma transfusions with fibrinogen, especially in patients with fibrinogen levels of less than 100 mg/dL, the level at which hypofibrinogenemia results in bleeding [5]. It is named cryoprecipitate because single units of plasma are rapidly frozen to −30 °C and are slowly thawed overnight to 4 °C, causing many clotting factors such as fibrinogen to precipitate out of the solution [32]. Indications for cryoprecipitate include factor VII deficiency, congenital or acquired hypofibrinogenemia, disseminated intravascular coagulation, and massive transfusion.

Unlike plasma, virus-inactivated cryoprecipitate is not yet available, and studies on the efficacy of SD FFP and MB FFP have not shown a benefit [32]. The complications of cryoprecipitate are similar to those of plasma, with a slightly lower occurrence of complications associated with higher volumes of plasma, such as TRALI and hemolysis [32].

Whole Blood

The practice of using whole blood is largely uncommon due to the separation of blood components for targeting specific deficiencies currently supported by evidence-based medicine. Decision-making for each transfusion requires laboratory testing, and each product must carefully be stored and transported to the site of need. When this is not possible, such as in acute settings with limited resources, whole blood transfusions can adequately resuscitate certain patients. Grosso et al. recount a case of collecting whole blood from hospital personnel donors in a US field surgical hospital in Kosovo. This whole blood was used to treat exsanguinating coagulopathy in an acutely bleeding patient. The advantage of whole blood is its ability to increase hemoglobin levels, similarly to red blood cells, and its ability to restore blood volumes, similarly to crystalloids [47]. Because of its physiological ratios of each blood component, it may hold an advantage over individual blood component transfusions, but more work is necessary to substantiate this idea.

Recombinant Activated Factor VII

Recombinant activated factor VII (rFVIIa), originally developed for use in hemophilia A and B patients, has recently been explored in various off-label uses, such as stemming acute bleeding alongside standard replacement therapy. Mayo et al. demonstrate the use of a coagulopathy score that they found to be statistically correlated to rFVIIa response and survival in thirteen trauma patients in Israel [48]. This finding was turning point in the understanding of rFVIIa indications due to its previous contraindication in coagulopathy. Other uses for rFVIIa are factor VII deficiency, thrombocytopenia, functional platelet disorders, von Willebrand disease, intracranial bleeding, and reversal of warfarin overdose, liver disease, and transplantation. However, little evidence is currently available to support these uses [48].

Transfusion-Related Complications

Before entering the discussion on complications related to transfusions, the difficulty of study design to answer such questions must be appreciated. There are ethical obstacles to randomizing patients to transfusion and non-transfusion arms. Hence, many trials show patients who received more blood component transfusions fared worse than patients who did not, but this may be entirely because of the condition of the patients that necessitated the transfusions [23]. Khorana et al.'s retrospective cohort study of 504,208 patients hospitalized with cancer demonstrated that RBC and platelet transfusions were associated with increased mortality, as well as venous and arterial thrombotic events. However, it is unclear if this is a causal relationship [49].

As with large-scale introduction of exogenous elements to the body, immune reactions can develop sequelae that are well known with blood product transfusions. The most feared of these immune reactions are hemolytic reactions. To prevent these events, it is critical to crossmatch patients and donor blood whenever possible. The most common cause of hemolytic reactions due to transfusion of an incorrect match is clerical error. Hemolytic reactions in blood transfusions occur because each individual carries antibodies against the blood group (A or B) that it does not express endogenously. Hence, when products containing anti-A or anti-B antibodies in plasma, such as plasma, are transfused to patients of A, B or both blood groups, the donor antibodies stage an attack on the patient's red blood cells. Allergic reactions are another common immune-mediated complication of transfusions. Severely anaphylactic reactions are more common after plasma compared to RBC transfusion [32]. Patients present with wheeze, hypotension, tachycardia, laryngeal edema, and urticarial rash.

TRALI is defined as acute lung injury occurring within 6 h of transfusion with a blood product, with most commonly reported cases occurring due to FFP [50]. TRALI is the most

common cause of death due to transfusion [32]. TRALI is characterized by respiratory insufficiency, not limited to but including tachypnea, cyanosis, dyspnea, and acute hypoxemia [50]. In patients with gastrointestinal bleeding, TRALI is further exacerbated by the presence of end-stage liver disease. Proposed mechanisms for this phenomenon have included antibody-mediated reactions, but these findings are not definitive and many are subject to selection bias due to no screening in the asymptomatic population [50]. Autopsies and animal models have suggested hyperactive PMN involvement, since mass infiltration was noted [50]. A two-event model has also been proposed, with the first event dictated by the clinical health of the patient and the second event by the quality (affected by storage, donor immunologic components) of the blood product [50]. The treatment of TRALI is aggressive respiratory support and ventilation in more severe cases, such as in critically ill patients [50]. Practices to reduce the risk of TRALI include prestorage leukoreduction as well as avoiding the use of old blood products, defined as older than 14 days for RBCs and older than 2 days for platelet concentrates. Another prevention strategy is using only male donors or donors who have never been pregnant due to look back studies showing fewer TRALI events in blood donations from those populations [51]. Eder et al. demonstrated that preferential distribution of plasma from male donors reduced the reported number of TRALI cases. However lethal these rare events are, it is critical to understand the risk–benefit ratio in such cases. As noted earlier, current rates of TRALI are estimated at just over 4 cases per 1,000,000 units transfused [52].

Transfusion-associated immunomodulation refers to the immunosuppression resulting from the introduction of foreign antigens via blood products to the host [23]. The exact mechanism of this effect has not yet been elucidated, but plasma components, WBCs, metabolic products from storage processes are thought to play a role. This effect may be responsible for the immunosuppressive effects of transfusions on severely ill patients. Transfusions can cause sensitization to HLA antigens, creating a unique problem in potential kidney transplant patients. Studies have demonstrated increased sensitization of patients on a kidney transplant waiting list after transfusion, rendering them unsuitable candidates for living donation. Their only remaining alternative once this has occurred is to wait for a cadaveric graft, which takes up to 4 times longer, and may never receive a transplant. Hence, non-life-sustaining transfusions should be avoided in potential kidney transplant recipients [23].

Red blood cell transfusion is also an independent predictor of SIRS, ICU admission, mortality, length of hospital stay, and the development of multiple organ failure (MOF) [53]. In particular, the age of the blood plays an important role, with increased age of RBCs resulting in increased instances of MOF. RBCs are not alone in this adverse event. A multicenter prospective cohort study demonstrated that plasma was independently associated with increased risk of MOF and ARDS of 2.1 % and 2.5 % [54]. The same study found, however, decreased risk of MOF per unit of cryoprecipitate, and platelets were not found to be associated with MOF or ARDS [54].

In addition to MOF, blood transfusions are associated with transmission of infectious diseases. In their review of the current literature, Englesbe et al. found that patients who received transfusions experienced a significant increase in nosocomial infection rates compared to those who did not receive transfusions, and that the occurrence of nosocomial infections increased with each additional unit of RBCs transfused [23]. *Staphylococcus aureus* is the most commonly transmitted bacterial pathogen [51]. Bacterial pathogens in blood products arise mainly from donor skin, and platelets are especially prone to these contaminants [32]. However, bacterial infections are less common than viral infections in blood transfusions.

Despite increased screening and testing, each RBC transfusion is associated with a risk for viral infections such as hepatitis [27]. Virus risks in the UK in plasma have been estimated at 1 in 8 million for HIV, 1 in 30 million for HCV, and 1 in 900,000 for HBV [32]. Since up to 50 % of adult donors are CMV carriers, there is a risk of transmission of this virus to patients, especially the immunosuppressed, transplant patients and neonates [32]. Compared to viral causes, bacterial, endotoxin and prion contamination rates are more rare [32]. In order to avoid this deleterious complication, virus-inactivated preparations of plasma exist, such as methylene blue and solvent-detergent treated products. While these options may offer increased viral protection, they have been associated with loss of clotting factors [32]. The most stringent testing protocols and sensitive tests may not ever eradicate the risk of infectious agent transmission as new pathogens of unknown methods of spread are constantly emerging and may not actively be screened for in its early emergence. In addition, long incubation period of pathogens before seroconversion of blood make it even harder to prevent [27]. Prion diseases transmitted by transfusion has been a concern in the UK, following the BSE epidemic. Unfortunately, no screening test for this condition has been established, and the occurrence of prion diseases in blood products in the UK is largely unknown. In order to avoid transfusions with prion disease, plasma has been imported from the USA since 2002 for pediatric transfusions [32].

Another concerning complication is the loss of efficacy in stored blood, and the adverse effects it causes. These consequences of the storage process are known as a storage lesion. With current technology, the shelf life of red blood cells cannot be extended further than its physiological shelf life of 120 days, and 35 and 42 days is the limit of viability in whole blood and adenine-saline preservation, respectively [27]. Even this length of shelf-life results in counterproductive

transfusions. Specifically, RBC products older than 2 weeks have been shown to not improve oxygen uptake in septic patients. In fact, RBCs of that age have been associated with higher mortality, increased adverse events, extended hospital stay, and electrolyte imbalances. This reduction in efficacy may be due to decreased ability of the older RBCs to unload oxygen [27]. Another proposed mechanism is that since stored RBCs have depleted nitric oxide, this may have a vasoconstrictive effect, leading to thrombosis and the observed increases in venous and arterial thrombotic events in patients with increased RBC and platelet transfusions [49]. The question is how realistic it is to maintain strict storage age in a finite and scarce resource such as blood. A double-blind, prospective randomized pilot study demonstrated that controlling the storage age of RBCs in transfusion compared to the current standard of care is feasible and results in decreased exposure to older blood [55]. More evidence is needed to determine precisely the cut-off age of RBCs in their efficacy and availability. In stored platelets, it has been estimated that the recovery rate of 5-day-old platelets is about 50 %, with many nonviable platelets being sequestered into the spleen [38]. For these reasons, there is some concern that platelet counts performed immediately after transfusion do not provide an accurate picture of platelet function [38].

Given the complications listed above, a discussion of known preventative measures is warranted. Transfusion with RBCs that have not been leukoreduced has been associated with increased risk of multiple organ failure and degenerating leukocytes may cause RBC toxicity. Furthermore, nationwide leukoreduction protocols in Canada were shown to lower mortality rates [27]. Currently, in the USA, leukoreduction is not a standard practice despite evidence of benefit, and additional work is required to determine effects on outcome in various patient populations, such as ICU patients [27].

Hospitalized patients receiving transfusions are already in a vulnerable state of health, and when transfusion-related adverse events occur, it is most regrettable. With institutional triage protocols and transfusion guidelines, such unnecessary harm can be avoided, and cost reduction of a limited and precious resource can be achieved [56]. Protocols and scoring systems, such as the Emergency Transfusion Score (ETS), have been successfully shown to triage patients in need of transfusions and those for whom it would be unnecessary [57].

Special Populations

The Anticoagulated Patient and the Patient Receiving Platelet Inhibitors

There are many considerations to address in the management of an anticoagulated surgical patient, such as reversing anticoagulation fully before operation, in order to avoid bleeding complications. In the non-elective setting, such as life-threatening hemorrhage or emergent surgical indications, this process must be sped up, using prothrombin complex concentrate (PCC) [58]. Available in 4 factor (II, VII, IX, X) and 3 factor (lacking VII) forms, PCC can be used to improve hemostasis and reverse anticoagulation quicker in patients taking warfarin [56]. In addition, patients on warfarin should receive vitamin K (10 mg) along with concurrent PCC administration.

Major disadvantages of these newer oral factor Xa and thrombin inhibitors are the lack of a specific antidote to rapidly reverse anticoagulation in the case of life-threatening hemorrhage and an inability to follow their "efficacy." There are currently no tests available to follow their degree of anticoagulation in a clinical setting. Four-factor PCCs have been used off-label (with some success) with the newer oral anticoagulants such as rivaroxaban and apixaban. However, PCCs are ineffective at reversing the anticoagulant effect of dabigatran. Administration of the anti-dabigatran antibody (idarucizumab) or removal of the drug via hemodialysis may be warranted [59, 60]. Additionally, oral activated charcoal is effective at reducing the absorption of oral anticoagulants if given within 3 h of ingestion.

Unlike plasma, PCC can be administered without the need for crossmatching or thawing, has more predictable concentrations of clotting factors, and has been shown to reverse warfarin-related coagulopathy. The clotting factors are also in high concentrations, approximately 25 times that of plasma, decreasing the volume of PCC needed. In addition, the INR is rapidly corrected, taking about 15 min [58]. Four-factor PCC is administered as a single dose of 35 units per kg, or 50 units per kg if the patient is on warfarin with an INR $\geq$ 6. Repeat doses have been associated with increased risk for thromboembolic events and have not been shown to improve efficacy.

Anticoagulated patients and patients using antiplatelet agents are especially vulnerable to coagulopathies, which may develop during resuscitation. Kılıç et al.'s findings recommend using individualized treatment, providing the deficient blood component as per laboratory value deficiency. In addition, patients who are overly anticoagulated with warfarin may also be treated with PCC containing vitamin K dependent factors [51].

In the surgical patient, it is important to discontinue aspirin and reversible platelet inhibitors such as clopigrel 10 and 7 days, respectively, before an operation to avoid bleeding complications [58]. However, risks of thrombotic events in discontinuation of these agents in cardiovascular surgeries have been noted [58]. Because of these risks with anticoagulated patients and patients receiving antiplatelet agents, it is important to weigh the benefits of the surgery against these risks, among others.

Obstetrical and Gynecological Patients

Obstetric patients are one subpopulation of actively bleeding surgical patients that can easily confuse the provider. Their generally young age may lead one to dismiss some vital sign changes or lab values, while alterations of their physiology in response to pregnancy often result in the misinterpretation of critical findings. During pregnancy, blood becomes less viscous in order to increase oxygen carrying capacity while minimizing increased cardiac load as much as possible. Intravascular volume, and more specifically, plasma volume increases proportionately more than red cell volume, creating a "physiologic anemia of pregnancy" [61]. Fibrinogen, von Willebrand factor, and factors VII, VIII, IX, X, XII are synthesized more frequently while levels of factors XI and XIII and platelets decrease [45]. Levels of factor II decrease, yet interestingly, prothrombin time (PT), and partial thromboplastin time (PTT) remain unaffected [61]. Mechanical obstruction of the uterus on the inferior vena cava and other vessels encourages stasis and the formation of thrombi. The summation of these effects results in a net hypercoagulable state [61].

The utero-placental circulation has increased activity of both coagulation and fibrinolysis, contributing to increased levels of fibrin degradation products such as D-dimer, especially in the third trimester [45]. This effect may contribute to the hemostatic challenges in obstetric patients. Antifibrinolytics such as tranexamic acid and aminocaproic acid can be used to treat hyperfibrinolysis. In fact, tranexamic acid has been shown to reduce blood loss after elective cesarean section and vaginal delivery [45]. Plasma and cryoprecipitate contain fibrinogen and may be used to replenish fibrinogen in states of hypofibrinogenemia (<180 mg/dL).

Postpartum hemorrhage (PPH) is a major cause of obstetric mortality that may require peripartum hysterectomy and is the most common cause of maternal mortality worldwide. PPH, in general, is not associated with underlying coagulation disorders but rather acute events related to placenta abnormalities, trauma from large births or instrumentation, or uterine atony [45]. In addition to rapid surgical intervention, hematologic management of PPH includes rapid volume replacement and blood transfusions. These patients are likely to benefit from management strategies similar to that for acutely injured patients who are in shock from hemorrhage.

In obstetrical patients, rFVIIa has also been found to control and decrease hemorrhage. Segal et al.'s observation of three patients with PPH, hypovolemic shock, and DIC who received massive transfusions suggests that rFVIIa may be beneficial adjunctive therapy after the completion of hysterectomy. The therapeutic effect of rFVIIa may be due to its binding of tissue factor at the site of vessel injury and forming a complex, activating platelets and facilitating fibrin clot formation [62]. However, these findings have not been consistent in the current literature, and especially because of the expense of rFVIIa, the decision to administer this to the patient must involve a thorough consideration of the benefits, if any [45].

The Non-Hemorrhaging Surgical Patient

Intensive care unit (ICU) patients are another patient population that frequently receives blood transfusions in order to correct their anemia, which has been shown by a large body of work to indicate worse prognosis [27]. These patients are anemic due to sepsis, occult blood loss, hemorrhage, decreased production, and functional iron deficiency. ICU patients with low hemoglobin levels are more likely to suffer from complications such as sepsis, and they are more likely to experience delayed weaning from ventilator support. The decision to transfuse such patients should weigh the benefits and the risks of blood transfusions, especially given the patients' increased susceptibility to infections, iatrogenic events, and increased metabolic demands [28]. Vincent et al.'s multicenter prospective observational study of 1136 patients demonstrated that ICU patients frequently received transfusions, with a transfusion rate of 37 % during their stay. The patients who received transfusions also experienced a higher mortality rate, prolonged hospital stay, and decreased organ function [28]. There is also evidence suggestive of increased transfusions in patients with hemoglobin levels higher than the generally accepted trigger value of 8 g/dL. Specifically, Vincent et al. [28] found that under 30 % of cases, patients with hemoglobin levels greater than 9 g/dL received blood transfusions. Hence, future work is needed to recommend strict hemoglobin cutoffs for transfusion.

TEG and TEG-Guided Therapy

In the acute trauma setting, conventional coagulation testing (CCT), which consists of prothrombin time, international normalized ratio (INR), partial thromboplastin time, and platelet count, is used to assess coagulation status. This approach, however, is limited by slow results, incomplete characterization of the coagulation abnormality, and poor prediction of patient outcome. Furthermore, CCTs, which are riddled with delays from time to arrival in the laboratory and duration of testing, end up reflecting the coagulation state of the patient after 30–45 min of interventions and resuscitation [63]. Since CCT only examines plasma factors, the integral role of platelets and their function is ignored. In addition, the CCT assesses only the extrinsic pathway, intrinsic pathway, and platelet count, painting an incomplete picture of the pathologies of clotting in the severely exsanguinating patient. These deficiencies are addressed by thrombelastography (TEG), a test that creates a dynamic,

graphical representation of the coagulation characteristics of a blood sample from initial clot formation to fibrinolysis. Since specific coagulation components have specific disturbances on TEG, this test reveals diagnostic as well as therapeutic information [64].

The procedure involves obtaining an uncitrated whole blood sample, activation of the specimen with kaolin, and spinning the sample in a thromboelastograph machine within 4–5 min in order to avoid clotting [64]. If this timeframe cannot be achieved, a "reversal" method can be used, where citrate is used to avoid clotting until the sample has arrived at the laboratory, at which point, the citrate will be "reversed" using calcium chloride as per manufacturer instructions. While this method has been shown to affect TEG results, it has not been shown to be inferior to the standard method and may be used in centers where 4–5 min from sample collection to running the TEG is not realistic [64].

Rapid TEG differs from conventional TEG in its addition of tissue factor to the blood sample and kaolin, accelerating activation of the clotting cascade. This modification makes it well suited for the trauma setting since its results are available much earlier, namely under 20 min, compared to kaolin TEG and CCTs, which can take over 30 min, without sacrificing accuracy [64].

Interpreting the results involves analyzing each of the sequential measurements (Fig. 13.3). Reaction time, or R-time, in TEG is the time until initial clot formation. It is also known as activated clotting time (ACT) in r-TEG in order to denote intentional anticoagulant agents in the sample. Factor deficiency or severe hemodilution can prolong reaction time or ACT. Next, *k*-time represents the time needed to reach 20-mm clot strength, and has a normal range of 1–2 min. The −angle, normally between 66 and 82°, represents the rate of clot formation. In platelet deficiency or hypofibrinogenemia, where one of the two key components of clots is missing, the *k*-time is increased and the −angle is

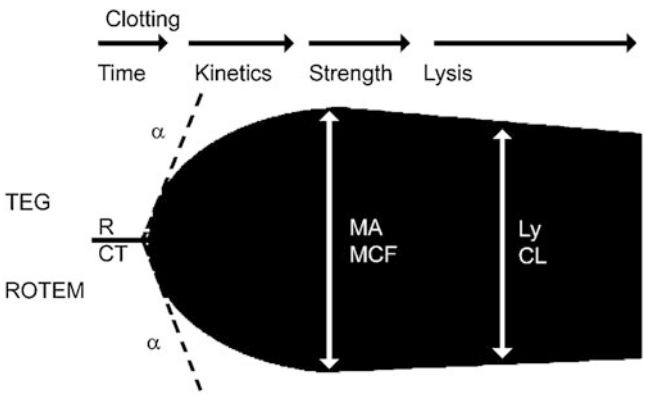

Fig. 13.3 The various sequential measurements of TEG. (Adapted from Johnasson PI, Ostrowski SR, Secher NH. Management of major blood loss. Acta Anaesthesiol Scand. 2010;54:1039–49, with permission.)

decreased. Oshita et al.'s linear regression analysis of 36 samples from healthy individuals reported that MA and *k*-time were linearly related to platelet count [65]. The maximal amplitude (MA) of the tracing represents platelet contribution to clot strength (normal range 54–72 mm). It is decreased in states of platelet dysfunction and hypofibrinogenemia. The *G*-value represents overall clot strength, including platelet function as well as enzymatic, and is decreased in hypocoagulable states (normal 5.3–12 K dynes/cm^2). The LY30 is the percent of amplitude reduction at 30 min after the MA, and is elevated in hyperfibrinolytic states (normal range 0.0–7.5 %) [64].

The use of r-TEG is further facilitated by advanced software that displays the r-TEG tracing as the test is being performed, providing physicians with "real time" results. Cotton et al. report that early r-TEG parameter tracings (ACT, *k*-time and *r*-value) appeared within 5 min while later values (−angle, MA) were seen within 15 min, compared to CCT panels, which were not available until 48 min [64]. Installation of graphical software in the trauma bay, operating room, and shock-trauma intensive care unit computers can further facilitate the rapid access to TEG results [64].

TEG data results compare well to the previous standard, CCTs. Cotton et al. [64] conducted a pilot study of 272 patients to investigate the role of rapid thromboelastography (r-TEG) in (1) assessing speed of results (2) correlation with CCT findings, and (3) predictability of early transfusions of pRBCs, plasma, and platelets. Their findings demonstrated that graphical r-TEG is available within minutes, an improvement compared to CCTs. They also demonstrated that ACT, *r*-value, and *k*-time strongly correlated with PT, INR, and PTT. MA and −angle strongly correlated with platelet count, and ACT, *r*-value, −angle and MA were predictive of pRBC, plasma, and platelet transfusions within the first 2 h of arrival. In fact, an ACT > 128 predicted massive transfusion in the first 6 h and an ACT < 105 predicted patients that did not receive transfusions in the first 24 h [64]. In addition, comparison of TEG and CCT in cardiopulmonary bypass patients found that TEG measures were useful surrogates for CCT values [66]. Because of the speed of their availability and predictive ability, integrating TEG results in MTPs can strengthen decision-making and management of patients and improve patient outcomes (Tables 13.2 and 13.3).

A wide array of evidence exists in surgical patients in support of TEG's ability to predict prognosis, and in some instances, guide therapy that improves it. Table 13.1 is an example of TEG-guided protocol with such an aim. Platelet dysfunction in cardiopulmonary bypass patients has been attributed to microvascular bleeding, and TEG has been used in the setting of cardiac surgery as a predictor of worsening patient outcomes due to this mechanism [17]. Solomon et al. demonstrated that fibrinogen clot elasticity assessed by TEG correlated to fibrinogen concentration in cardiopulmonary

Table 13.2 Thrombelastography treatment algorithm for actively bleeding patients implemented at Rigshospitalet, University of Copenhagen, Denmark

TEG parameter	Treatment
R (11–14 min)	2 × FFP or 10 mL/kg
R > 14 min	4 × FFP or 20 mL/kg
MA (46–50 mm)	1 PC or 10 mL/kg
MA < 46 mm	2 PC or 20 mL/kg
Angle < 52°	2 × FFP or fibrinogen
Ly30 > 8 %	Tranexamic acid

R reaction time, *alpha angle* clot dynamics, *MA* maximal amplitude, *Ly30* lysis in percent 30 min after MA is reached, *FFP* fresh frozen plasma, *PC* platelet concentrate
From Johansson PI, Ostrowski SR, Secher NH. Management of major blood loss: an update. Acta Anaesthesiol Scand. 2010;54:1039–49, with permission

Table 13.3 Rapid thrombelastography (r-TEG) transfusion and treatment guidelines

rTEG value	Treatment
ACT ≥ 128 s	Transfuse plasma
r-value ≥ 1.1 min	Transfuse plasma
k-time ≥ 2.5 min	Transfuse plasma, add cryoprecipitate/ fibrinogen source if angle also abnormal
α-angle ≤ 60°	Transfuse cryoprecipitate/fibrinogen source, add platelets if mA also abnormal
mA ≤ 55 mm	Transfuse platelets, add cryoprecipitate/ fibrinogen source if angle also abnormal
LY-30 ≥ 3 %	Administer tranexamic acid

ACT activated clotting time; time from start of assay to initiation of clot, *r-value* reaction time value; time between beginning of assay and initial clot formation, *k-time* clot kinetics; time needed to reach 20 mm of clot strength, *α-angle* alpha angle; rate or acceleration of clot formation, *mA* maximal amplitude; contribution of functional platelets to clot formation, assessment of platelet–fibrin interactions, *LY-30 %* lysis at 30 min; amplitude reduction of clot 30 min after achieving mA (degree of fibrinolysis)

bypass patients [67]. TEG has been found to predict the risk of postoperative bleeding, and has been used to direct desmopressin therapy and FFP transfusion requirement in cardiopulmonary bypass patients [17].

TEG has been shown to be useful in liver surgery, especially in transplantation. Unlike other surgeries, liver surgery poses the additional problem of increased risk of coagulation factor deficiencies due to hepatic dysfunction and lack of synthesis. TEG-guided transfusion algorithms in this area have been shown to reduce the transfusion requirements in such patients [17]. However, Ogawa et al.'s prospective observational study of 26 patients undergoing cardiac surgery did not find a significant correlation between TEG measures and volume of intraoperative and total transfusions [66]. Despite these findings, Ronald et al.'s literature search and appraisal of 170 studies on the topic found otherwise [68]. They investigated thromboelastography in cardiac surgery patients and found fourteen studies that provided the best evidence. Their synthesis concluded that TEG can guide transfusion therapy algorithms and result in decreased blood component requirements. In orthopedic surgery patients, TEG was used in a prospective study to identify disturbed fibrin polymerization as a pathological mechanism in dilutional coagulopathy, and to rescue this state with fibrinogen administration [69].

To further support the use of viscoelastic testing in the bleeding patient, a recently completed randomized trial from Denver demonstrated that TEG-directed resuscitation and transfusion resulted in significantly lower mortality (20 % vs 36 %, $p = 0.02$) than those resuscitated and transfused according to conventional lab tests (INR, platelet count, fibrinogen). In addition, these outcomes were achieved with transfusion of less plasma ($p = 0.022$) and less platelets ($p = 0.041$) [70].

However, TEG has been found to be less sensitive for certain categories of platelet inhibition. In addition, hemostasis point of care tests such as PFA-100 and TEG are affected by nonopioid analgesic drugs. Scharbert et al.'s crossover, double-blinded, placebo-controlled study demonstrated that in low back pain patients scheduled for invasive pain therapy, cytochalasin D-modified thromboelastometry had a low sensitivity for detecting platelet inhibition by diclofenac [71].

Conclusions

There are hemostatic states unique to the surgical patient as a result of medications such as warfarin, perioperative bleeding especially in high bleeding risk surgeries, and emergent surgical indications such as trauma. Various mechanisms affect coagulation cascades in these patients, and techniques from the standard coagulation tests to TEG are currently available. These have shown mostly success in predicting the course of the patient and guiding therapy. The therapeutic options include various blood product components, ranging from whole blood to concentrations of individual factors. Using physiological ratios of RBCs, plasma, and platelets have improved patient survival in the massively hemorrhaging patient. However, like all powerful therapy, they are associated with adverse effects. Preventative options such as decreasing storage lengths and screening for infectious agents have drastically reduced these risks. Lastly, administering these products in a rapid and directed fashion would not be feasible without in-house triage and massive transfusion protocols. These algorithms include steps that must be taken to smooth out logistics of urgent transfusions, such as anticipating adequate thawing times of fresh frozen plasma and collaborating with blood banks to crosscheck appropriateness of each order.

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Principles of Vascular Access

14

Ramyar Gilani

Background

Vascular access procedures are commonly performed by acute care physicians within a wide myriad of clinically settings such as the operating room (OR), emergency department (ED), or intensive care unit (ICU) for a wide variety of indications. Regardless of location or indication, vascular access procedures are not innocuous and procedural success traditionally has relied on knowledge of anatomy and familiarity of the procedure. In a prospective study by Schummer et al. [1] that included 1794 cases using landmark techniques, there was a 3.3 % complication rate with vascular catheterization. Also, as the number of passes with the entry needle increases so does the rate of mechanical complication whereby three or more needle passes incurs a six-fold increase in complication rate [2]. Furthermore, certain subgroups such as children and obese patients have been further identified as having increased risk with vascular access. Although the reported complication rates are relatively low, considering the number of vascular access procedures performed annually as the denominator, the absolute number of complication occurrences becomes significant. Improved assessment of vascular anatomy and visualization during the procedure in an effort to mitigate complications and improve procedural success form the argument supporting ultrasound (US) guided vascular access.

Anatomy

Two common sites for vascular access are the neck and groin, both of which have conserved identifiable landmarks that are referenced and serve as beacons of guidance for successful access. Landmark techniques are still effectively utilized by experienced operators and should remain in the knowledge depot of all individuals performing vascular access regardless of technique. Prior to assessing for anatomic landmarks, maximum regional exposure of the access site is suggested. In the neck this may include placing a shoulder roll and extending the neck if allowable. Within the groin, the patient is ideally flat with the hair trimmed prior to access. For venous access, vein distention is facilitated by patient tilting to allow for venous pooling.

Within the neck (Fig. 14.1), the key anatomic landmark is the anterior border of the sternocleidomastoid muscle (SCM). After defining this, the pulse for the carotid artery is palpated immediately medial and deep to the SCM. The internal jugular vein (IJV) lies between these two points just deep to the anterior border of the SCM and lateral to the pulse of the carotid artery (Fig. 14.2). The sternal notch, clavicle and ipsilateral nipple are also useful points to locate for directionality. It is important to note the anterior posterior relationship between the carotid artery and the IJV is variable. In addition, it is advisable to maintain needle tip position cephalad to the clavicle to decrease the likelihood of entering the pleural space, although in the setting of lung hyperinflation this space may extend into the supraclavicular fossa.

Groin vascular anatomy is also quite conserved however depending on the size, hemodynamic status, and vascular status of the patient, the anatomy may not be easily identifiable. The key landmark for groin anatomy is the inguinal ligament. This is visualized as a line between the palpated anterior superior iliac spine (ASIS) and the pubic symphysis. Cephalad to the inguinal ligament, the vessels enter the retroperitoneum and access is more prone to inadequate compression during decannulation. Within the groin space the relationship between artery and vein is such that the vein lies medial to the artery and at times somewhat posterior. The common femoral artery (CFA) and common femoral vein (CFV) are not long vessels and bifurcate as they traverse caudally usually in the region of the groin skin crease; however depending on the size of the patient, this is highly variable.

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_14

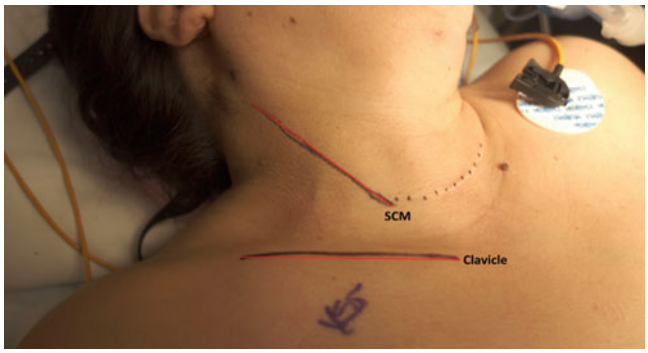

Fig. 14.1 The key anatomic landmark is the anterior border of the sternocleidomastoid muscle (SCM)

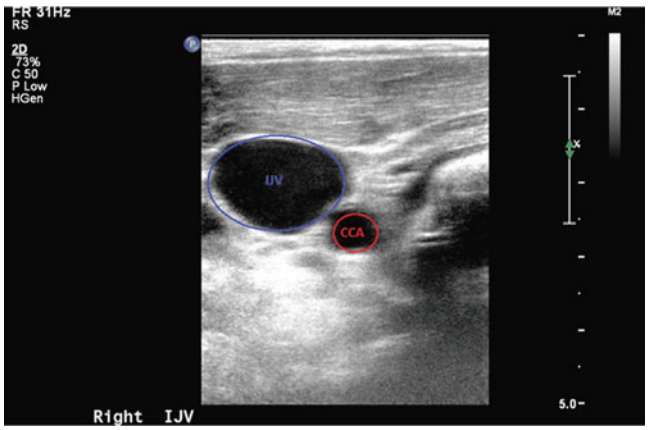

Fig. 14.2 Ultrasound view of the internal jugular vein (IJV)

Access below the common femoral vessels is at risk for thrombotic and decannulation complications. An additional point of reference in the groin is the point of maximum pulsation which corresponds to the position of the CFA over the femoral head which is a location that can be easily controlled with manual pressure during decannulation.

Evidence for Ultrasound

Supporting this argument are numerous studies showing that US reduces complications, improves cannulation rates, and decreases time for cannulation. A 2006 study by Karakitsos et al. prospectively compared internal jugular vein (IJV) catheterization with real-time US versus landmark techniques [3]. Significant differences ($P<0.001$) were found between the two groups in regard to overall success rate (100 % vs. 94 %), inadvertent arterial puncture (1 % vs. 10.6 %), hematoma formation (0.4 % vs. 8.4 %), pneumothorax (0 % vs. 2.4 %), and hemothorax (0 % vs. 1.7 %), all favoring US guided access. Furthermore, 7.6 % of patients were noted to have ipsilateral thrombus and the contralateral IJV was accessed. Also, 25 patients that had unsuccessful attempts using landmark techniques were successfully accessed with US. Reasons for failure were presence of thrombus in 20 patients and aberrant anatomy in five patients. Further supporting the use of US is a meta-analysis published in 2003 consisting of 18 randomized control trials [4]. Once again, the use of US demonstrated significantly improved success, reduced complications, and decreased procedural times.

Access procedures in pediatric patients, especially premature infants, can be a humbling endeavor largely due to small vessel size and variant anatomy. Verghese and colleagues evaluated the use of US for IJV cannulation in infants [5]. US significantly improved procedural success (100 % vs. 77 %) and decreased arterial punctures (0 % vs. 25 %). It was also shown to improve overall procedural times. These findings have been reproduced in similar patients by numerous other investigators [6, 7].

Certain vascular access procedures, such as peripheral intravenous (PIV) access, do not amend well to landmark techniques but rather are performed via palpation and visualization. The utility of US for insertion of PIV access has been documented. Gregg et al. evaluated PIV insertion with US in patients that were otherwise unable to have PIV access placed by standard means [8]. They reported a 99 % overall success rate of which 71 % were placed on the first attempt. As a result of the 147 PIVs placed, 40 central venous catheters (CVC) were discontinued, and 34 were avoided, a much welcomed indirect benefit.

Much like venous access, arterial access can also pose significant complication risks, to include hemorrhage, pseudoaneurysm, thrombosis, dissection, and nerve injury. The secondary effects of arterial access complications can result in significant morbidity and mortality by way of amputation, stroke, need for open surgery, and death [9]. The use of US for arterial access has been validated through prospective randomized trials demonstrating improved success rates, decreased complications, and shorter procedural times [10, 11]. Also compelling is data published within the pediatric population. Once again, US use correlates significantly with increased success (100 % vs. 80 %), decreased number of attempts (1.3 vs. 2.3), and shorter procedural times ($P<0.05$) [12].

As one can see, there is much data supporting the use of US for vascular access. Furthermore, an apparent observation is that the potential for benefit with US guided vascular access increases with incremental increase in difficulty. However, the possibilities for US use remain more expansive than that which has been touched on by the literature. A sampling of challenges to access would include obesity, hypovolemia, coagulopathy, need for anticoagulation, previous access procedures, all of which are routinely encountered by acute care surgeons. Ultrasound-guided vascular access is not a requirement for success; however, the facile physician must be readily prepared to implement its use reliably when traditional access methods appear to be insufficient.

Equipment

Advances in technology have made US nearly ubiquitous within hospitals today. Furthermore, machines are often mobile or portable which makes US available for use nearly anywhere vascular access procedures are performed. Manufacturers offer a wide array of portable and mobile units ranging in capability available with a variety of transducers each designed for specific applications. Linear-array transducers, so called because of the parallel alignment of the contained crystals, in contrast to curved-array transducers are most commonly used for vascular access procedures (Fig. 14.3). Each transducer, regardless of crystal orientation, operates within a frequency range. It is the operating frequency that determines the resolution and depth of penetration which are inversely related. Linear-array transducers with a frequency 10–5 MHz and scan depth of 6 cm are appropriate for peripheral access and IJV cannulation. Curved-array transducers (5–2 MHz and scan depth of 30 cm) may be more appropriate for femoral access in obese patients; however, resolution is diminished. The ideal probe utilized achieves the required depth of penetration at the highest possible frequency thereby providing the best resolution.

Scanning

Vascular ultrasonographic evaluation utilizes three separate imaging modalities while scanning in order to perform a complete exam. These are 2D grey-scale B-mode imaging, color-flow imaging, and pulsed-Doppler spectral waveform analysis. Regardless of the exam performed, adequate skin-transducer interface is required while performing surface US. This is facilitated with the use of ultrasound gel applied on the skin as well as within a probe cover during sterile procedures. Sufficient pressure is applied to the transducer to maintain proper interface while not excessive to compress venous or arterial structures.

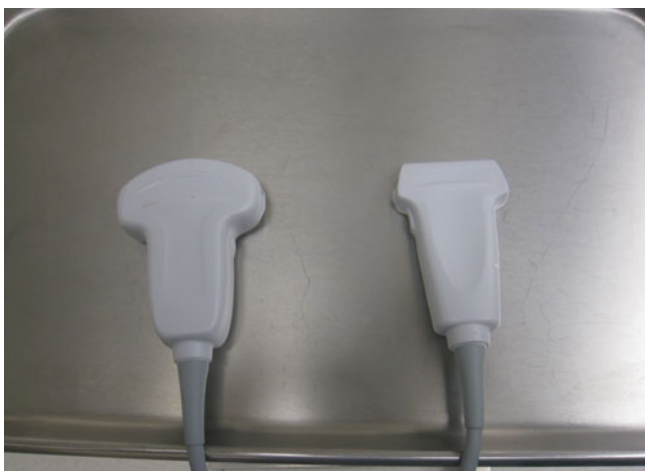

Fig. 14.3 Linear-array transducers are most commonly used for vascular access procedures

Examination begins with 2D grey-scale imaging which is also used while performing access procedures. The monitor should be readily visible throughout the exam and procedure. Appropriate depth of penetration is selected to visualize structures of interest while maximizing resolution and minor adjustments are made to far and near gain knobs to optimize image quality. Grey-scale imaging allows the operator to visualize access site anatomy, visualize the lumen and wall of the access vessel (looking for thrombus or calcification), evaluate for compressibility of veins (the presence of echolucent thrombus may render the vein non-compressible), and assess for arterial pulsation (non-pulsatility may indicate more proximal obstruction). After grey-scale, color-flow is selected within the region of interest. The presence of flow helps to ensure patency of the lumen. Flow may be sluggish and distal compression and Valsalva can be used to modulate venous flow. The exam is completed with Doppler waveform analysis. An area of sampling is selected within the vessel of interest and pulsed analysis is initiated. Veins should display phasic flow and arteries pulsatile phasic flow. Lack of phasic flow may indicate more central obstruction. Using this information, the access site can be confirmed as appropriate or if unsatisfactory another site can be selected for evaluation.

Access Technique with Ultrasound

Access Site Selection

After assessing a patient for vascular access, a point of access must be selected. Generally, PIV sites are evaluated from distal to proximal. Common CVC access sites are IJV, CFV, subclavian vein, and basilic vein for peripherally inserted central catheters (PICC line). Arterial access points are selected where manual pressure can be adequately applied over bony landmarks to ensure hemostasis during decannulation such as the radial artery and common femoral artery. The access site is then evaluated via US prior to initiating the access procedure to confirm adequacy of the access site.

Preparation

The patient is positioned for comfort and adequate exposure of the access site must be ensured. Venous dilation can be enhanced by positioning into a gravity dependent position or through the use of a proximal tourniquet for PIV placement. The access site is then prepped and draped using sterile technique. The ultrasound monitor is placed in direct view of the operator.

The probe is placed into a sterile probe cover containing ultrasound gel. Sterile gel is necessary on the field to ensure proper skin-transducer interface.

Cannulation

Prior to cannulation the access vessel is visualized along the transverse axis (Figs. 14.4 and 14.2). During transverse reference, visualized vessels will appear round. Furthermore, veins can be identified as being compressible and arteries as pulsatile. Center the vessel in the field of view and identify a point on the skin overlying the vessel by gently probing with a 21-ga needle supplied in a micropuncture set (21-ga needle, 0.018″ wire, 4 Fr sheath) attached to a syringe. A micropuncture set is used during difficult access to mitigate complications from inadvertent or unsuccessful cannulation. While maintaining the position of the needle, turn the probe 90° into the long axis (Fig. 14.5). The vessel should now appear rectangular along the length of the screen (Fig. 14.6). Long reference visualization allows for more precise assessment of penetration depth with the tip of the needle helping to avoid accidental back wall penetration. Slowly advance the needle to identify the tip. Once the tip is located, gently advance the needle until the vessel is cannulated under direct vision, visualizing the tip at all times (Fig. 14.7). A 0.018″ guidewire is threaded through the needle and should pass without difficulty. Failure to easily pass the wire indicates a potential problem such as extravascular position, central obstruction or placement within a dissection plane. The probe is returned to the transverse axis and guidewire placement within the lumen is confirmed. The wire will appear as an echogenic dot within the lumen. The needle is exchanged for a 4 Fr sheath that will allow passage of 0.035″ and 0.038″ guidewires that are supplied in most vascular access kits. The guidewire and inner cannula are removed and blood return through the sheath is assessed whether as being venous or arterial. If satisfactory, the procedure is then completed in standard fashion using over-the-wire technique.

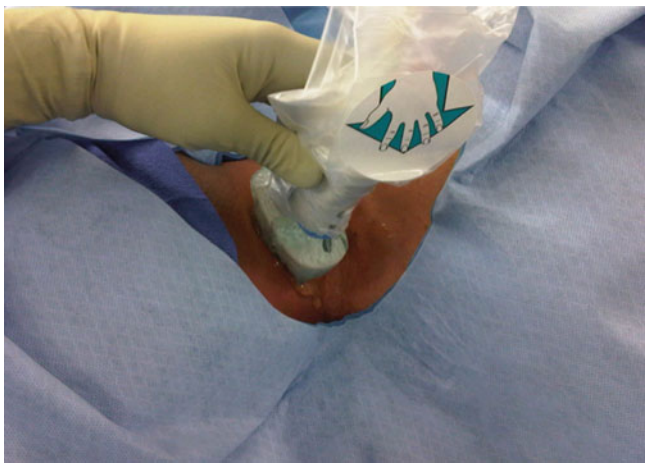

Fig. 14.4 Prior to cannulation the access vessel is visualized along the transverse axis

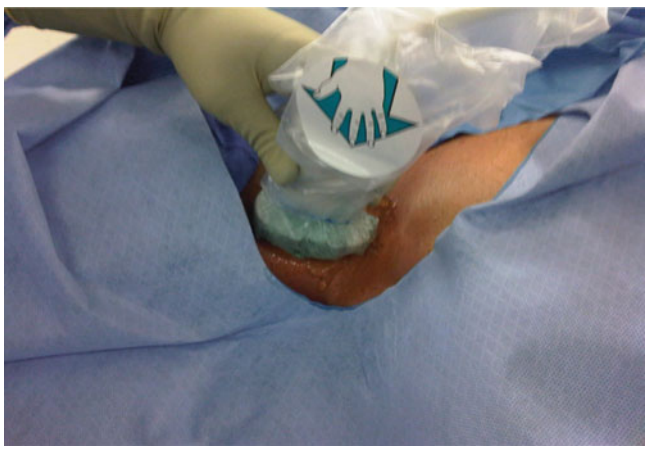

Fig. 14.5 While maintaining the position of the needle, turn the probe 90° into the long axis

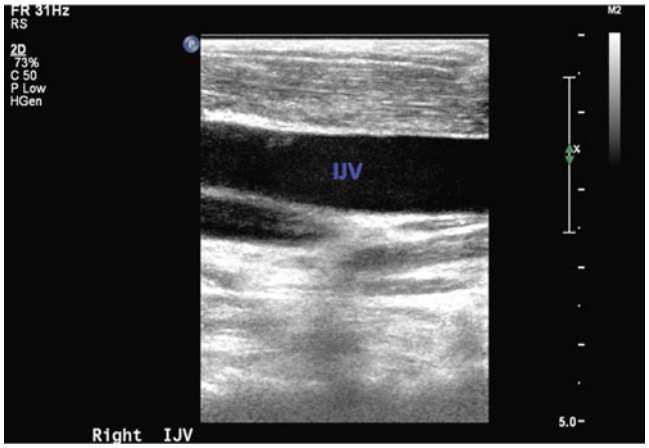

Fig. 14.6 On ultrasound, the vessel should appear rectangular along the length of the screen

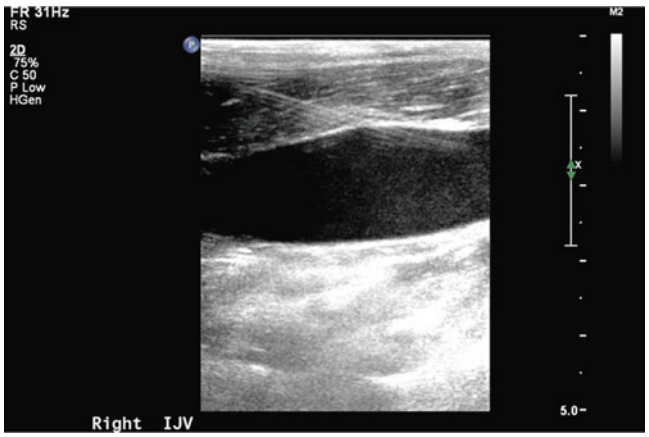

Fig. 14.7 Once the tip is located, gently advance the needle until the vessel is cannulated under direct vision, visualizing the tip at all times

Cannulation Summary

1. Perform ultrasonographic evaluation of access site.
↓
2. Position and prep.
↓
3. Identify overlying skin position in transverse axis.
↓
4. Cannulate vessel in long axis under direct vision.
↓
5. Confirm position of wire in transverse axis.
↓
6. Place 4 Fr sheath and assess blood return.
↓
7. Place standard wire and complete procedure.

Decannulation

Success with decannulation begins with proper cannulation. For venous access the margin for error is quite large for decannulation. Assuring that the access has been placed in the desired compressible location and assuming normal coagulation, venous access can be aborted with relatively little consequence. However, when holding pressure, the amount of pressure applied is significantly less when compared to arterial decannulation to avoid venous thrombosis. Sufficient pressure is such that no external hemorrhage occurs. Time of compression can be determined by evidence of thrombus formation in the blood that has escaped externally during decannulation.

In terms of arterial decannulation, the margin for error is significantly lessened and adherence to proper technique is mandatory. External manual pressure can be successful for decannulation in properly selected sites and normal coagulation for up to 9 Fr devices. Larger devices, non-compressible locations, and coagulopathy should prompt one to consider operative decannulation and repair. As a general rule, direct manual compression is held 3 min for every Fr of the access device. For example, a 5 Fr sheath removed from the common femoral artery will require 15 min of external manual compression. Effective external manual compression can be delivered with two fingers. The second and third fingers are held together straight with the elbow extended. Pressure is held directly over the access site with the tips of the fingers and not the fat pads. The goal is to compress the surrounding tissues between the skin and arteriotomy where hemorrhage would occur and not to completely occlude the artery which can result in thrombosis. Periodically checking for hemostasis before the required amount of time is not recommended.

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Part II

Common Diseases in Acute Care Surgery

Management of Intra-Abdominal Infections

15

Laura J. Moore

Intra-abdominal infections are common problem in the practice of the acute care surgeon. Evidence based guidelines have been developed to aid clinicians in the diagnosis and management of this common and potentially complex clinical problem [1]. The management of patients with intra-abdominal infections consumes considerable hospital resources and spans multiple areas of the hospital including the emergency department, operating room, and intensive care unit. Intra-abdominal infections can be categorized as either uncomplicated or complicated. Uncomplicated intra-abdominal infections involve a single organ and do not spread to the peritoneum. The mainstay of management of uncomplicated intra-abdominal infections is antimicrobial therapy. Complicated intra-abdominal infections extend beyond a single organ and present with focal or diffuse peritonitis necessitating surgical intervention in addition to antimicrobial therapy. Patient outcomes are strongly influenced by the initial clinical decision making, including rapidity of diagnosis, timely operative intervention to obtain source control, and antibiotic selection. This text will provide a concise but comprehensive review of the key diagnostic and management strategies for the management of patients with intra-abdominal infections. Recommendations for surgical intervention for specific disease processes (e.g., appendicitis, diverticulitis) are beyond the scope of this chapter and will be discussed in subsequent areas of the textbook.

Background

Intra-abdominal infections (IAIs) are divided into uncomplicated and complicated types. Uncomplicated IAIs are defined as an infection that involves a single organ and does not spread to the peritoneum. Typically patients with uncomplicated IAIs can be managed with either surgical intervention OR antibiotics. Examples of uncomplicated IAIs include nonperforated appendicitis, acute cholecystitis, and acute diverticulitis. Complicated IAIs occur when the infectious process spreads beyond the single organ, resulting in either localized or diffuse peritonitis. The treatment of patients with complicated IAIs involves BOTH surgery and antibiotic therapy. Patients with IAIs can be further categorized based upon their overall health status into low-risk and high-risk populations. Categorization into low-risk and high-risk categories takes into account the patient's history, the type of infection, and the patient's physiologic status at the time of diagnosis. Low-risk patients present with community acquired IAIs without physiologic derangements. High-risk patients (Table 15.1) typically present with underlying comorbid conditions often in a delayed fashion. This combination of factors increases the complexity of the decision making process for the optimal management of these patients. Finally, it is also important to recognize the difference in potential pathogens associated with community acquired vs. hospital acquired IAIs. The major clinical difference between community acquired and hospital acquired IAIs is that patients with hospital acquired IAIs typically have a higher severity of illness at the time of presentation.

Initial Diagnostic Evaluation

As with all clinical problems, initial evaluation should begin with a complete history and physical. Patients presenting with an intra-abdominal source of infection will often present with acute onset of abdominal pain accompanied by evidence of gastrointestinal dysfunction. Common presenting symptoms include loss of appetite, nausea, vomiting, bloating, and obstipation. These symptoms may be accompanied by systemic signs of infection including fever, tachycardia, tachypnea, and leukocytosis. Focal or diffuse peritonitis may also be present on physical examination. Routine laboratory

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_15

Table 15.1 Characteristics of high-risk patients

Delay in initial intervention (>24 h)
High severity of illness (APACH II score > 15)
Advanced age
Comorbidity and degree of organ dysfunction
Low albumin level
Poor nutritional status
Diffuse peritonitis
Inability to achieve adequate debridement or control of drainage
Presence of malignancy

testing to include a complete blood count should be sent to evaluate for leukocytosis. In those patients presenting with systemic inflammatory response syndrome (SIRS) criteria, a serum lactate level should also be sent to evaluate for the presence of tissue hypoperfusion and severe sepsis [2]. The initial clinical impression of a patient with an intra-abdominal infection should influence the urgency with which additional interventions occur. High-risk patients (Table 15.1) and those patients presenting with severe physiologic derangements (i.e., septic shock) should undergo emergent interventions [3].

In those patients without a reliable physical exam due to either altered mental status or quadriplegia/paraplegia an intra-abdominal source of infection should always be considered in patients with clinical evidence of infection from an unknown origin. It is also important to keep in mind certain high-risk populations that may not manifest a robust inflammatory response, therefore obscuring the classic signs of intra-abdominal infection. This includes elderly patients and immunosuppressed patients. In this patient population, the signs of sepsis may be minimal with a resultant delay in both diagnosis and intervention.

In those patients presenting with peritonitis on physical exam, further diagnostic workup is not indicated and operative intervention with either laparotomy or laparoscopy should be pursued. Hemodynamically unstable patients with septic shock in the setting of an acute abdomen should undergo initial resuscitation followed by damage control laparotomy as discussed below [4, 5]. However, in those patients without an immediate indication for surgical intervention, additional diagnostic imaging is warranted. Computed tomography (CT) of the abdomen and pelvis is generally the preferred imaging modality for intra-abdominal infections. Further management should be dictated by the findings on CT scan.

Initial Resuscitation

Intravascular volume depletion is common in patients with an intra-abdominal infection. This is due to a combination of factors including the presence of fever and concomitant gastrointestinal dysfunction with poor oral intake. In addition, these patients are often tachypneic resulting in additional evaporative fluid loss. The initial resuscitation phase should begin immediately on recognition of an intra-abdominal infection. The goals of the resuscitation phase include restoring intravascular volume, diagnosing the source of infection, initiation of broad-spectrum antimicrobial therapy, and source control. Many institutions have developed order sets that specifically address each of these issues. The major tenets of initial resuscitation can be initiated in any area of the hospital and should not be delayed pending admission to the hospital or intensive care unit.

Establishing IV access is a critical first step, because this allows for the administration of intravenous fluid and antimicrobials. For those patients without evidence of tissue hypoperfusion (i.e., normal serum lactate), a large bore peripheral IV should be sufficient. In the event that peripheral IV access is not attainable, a central venous line should be inserted in a timely fashion. The initial resuscitation fluid of choice remains extremely controversial. There are no prospective, randomized controlled trials evaluating crystalloid versus colloid resuscitation in surgical patients with sepsis. If colloids are given, the initial fluid bolus should be 300–500 mL of colloid over 30 min. If crystalloids are given, the initial fluid challenge should be 1000 mL of crystalloid over 30 min. Additional fluid boluses should be repeated based on the patient's response. Fluid resuscitation should be initiated with the following resuscitation goals in mind: (1) A target central venous pressure (if available) of 8–12 mmHg in non-intubated patients and a target CVP of 12–15 mmHg in mechanically ventilated patients [6], (2) MAP ≥65 mmHg [7], (3) UOP ≥0.5 mL/kg/h, and (4) Central venous ($ScvO_2$) oxygen saturation ≥70 % or mixed venous (SvO_2) oxygen saturation of ≥65 % (if available) [8]. These goals of resuscitation should be achieved within 6 h of the recognition of sepsis. In addition, a baseline serum lactate should be sent on the identification of sepsis. A repeat serum lactate level should be sent 4 h later to monitor the progress of the initial resuscitation.

For those patients presenting with severe sepsis and septic shock, the timely restoration of tissue perfusion is critical. The concept of early, goal-directed therapy in severe sepsis and septic shock was initially developed and validated in the emergency department (ED) setting. The ED is frequently the point of entry for many patients with sepsis secondary to intra-abdominal infections into the hospital. Unfortunately, many of these patients may wait for prolonged periods in the ED. The result is often a delay in the implementation of early sepsis resuscitation. The use of early goal-directed resuscitation has been shown to improve survival in patient presenting with severe sepsis and septic shock [8, 9]. The basic tenets of early goal-directed therapy are to identify tissue hypoperfusion and institute therapies to reverse global tissue hypoxia by optimizing oxygen delivery.

To restore intravascular volume and enhance cardiac output, an initial crystalloid fluid bolus of 30 mL/kg of IBW is recommended. This fluid bolus can be initially administered through existing peripheral IVs; however, placement of a central venous line for monitoring of CVP is recommended. In addition, an arterial line should be placed in those patients presenting with hypotension who do not rapidly respond to volume loading. The use of noninvasive blood pressure monitoring for patients in septic shock often produces inaccurate measurements and should not be used for titrating vasoactive medications. A Foley catheter should also be inserted to allow for close monitoring of UOP, and bladder pressures should be monitored in patients requiring vigorous volume loading. The goals of resuscitation remain the same as those listed earlier: (1) A target CVP (if available) of 8–12 mmHg in nonintubated patients and a target CVP of 12–15 mmHg in mechanically ventilated patients [6], (2) MAP ≥65 mmHg [7], (3) UOP ≥ 0.5 mL/kg/h, and (4) $ScvO_2$ oxygen saturation of ≥ 70 % or SvO_2 saturation of ≥ 65 % [8]. In the event that an $ScvO_2$ of ≥70 % or SvO_2 ≥ 65 % cannot be achieved with restoration of intravascular volume and MAP of 65–90 mmHg, red blood cells should be transfused to achieve a hematocrit of ≥30 %. If the goal CVP, the goal MAP, and the goal hematocrit are all reached but there is still evidence of tissue hypoperfusion, inotropic agents should be initiated to improve cardiac output.

In patients presenting with septic shock, the initial fluid bolus may not restore their MAP to ≥65 mmHg. A repeat fluid bolus of up to 20 mL/kg of IBW can be given to correct hypovolemia. However, transient vasopressors therapy may need to be initiated, even if volume resuscitation is still ongoing. Septic shock is primarily a vasodilatory shock, associated with a high cardiac output and a low systemic vascular resistance. Therefore, initial vasopressors therapy should be targeted at restoring vascular tone. Norepinephrine is now recommended as the first-line agent for treatment of septic shock. This should be administered through a central venous catheter. Norepinephrine is primarily an α-receptor agonist that promotes widespread vasoconstriction and has little effect on heart rate or stroke volume. The updated 2013 guidelines recommend that dopamine only be used in highly selected patients (patients with low risk of tachyarrhythmias and absolute or relative bradycardia). Dopamine has dose-dependent effects on α, β, and dopaminergic receptors. The initial increase in blood pressure seen with dopamine is related to increasing cardiac output. At higher doses (>7.5 μg/kg/min), dopamine does activate α-receptors with resultant vasoconstriction. In those patients with septic shock refractory to first-line vasopressors, the addition of vasopressin may be beneficial. Vasopressin is a stress hormone that has vasoactive effects. Recent work by Landry et al. suggested that in septic shock states there is a relative deficiency of vasopressin. The administration of vasopressin in this patient population improves responsiveness to catecholamines and potentially reduces the dose of catecholamine needed to maintain blood pressure. It is our current practice to initiate a vasopressin drip at a rate 0.04 units/min in those patients requiring norepinephrine infusion at ≥15 μg/min. The dose of vasopressin should not exceed 0.04 units/min because of the possibility for myocardial ischemia and decreased cardiac output at higher doses.

Antimicrobial Management Strategies

A broad range of antimicrobial regimens, both single agent and combination, are available for the management of intra-abdominal infections. As soon as the presence of an intra-abdominal infection is suspected, antimicrobial therapy should be initiated. The goals of antimicrobial therapy are elimination of infecting organisms, decrease rates of recurrent infection, and shorten the time to resolution of clinical signs and symptoms of infection. The timing and initial selection of antimicrobial agent have been strongly linked to patient outcomes. Delay in the administration of antimicrobials and improper antimicrobial selection result in increased failure rates and increased mortality. The time to antimicrobial administration has been identified as a critical determinant of survival in patients presenting with sepsis. Kumar et al. found that each hour in delay of antimicrobials was associated with an average decrease in survival of 7.6 % [10]. With this in mind, initial empiric antimicrobial therapy should be initiated upon suspicion of an intra-abdominal infection. For those patients presenting with severe sepsis or septic shock, antimicrobial therapy should be administered within one hour of clinical recognition.

The choice of empiric antimicrobial regimens is a critical component in the management of intra-abdominal infections. The antimicrobial selection process should begin with determining whether or not the infection is community acquired or hospital acquired in nature. The main pathogens involved in community acquired intra-abdominal infections include Enterobacteriaceae, Streptococcus species, and anaerobes, particularly B. fragilis. In hospital acquired infections the spectrum of potential pathogens becomes much larger. There has been a dramatic increase in the number of drug resistant microorganisms. The increase in the number of drug resistant pathogens is likely due to a combination of factors including escalating levels of antibiotic exposure along with patient factors such as increasing severity of illness, increased age, the presence of organ dysfunction, poor nutritional status, and the presence of malignancy. Commonly identified drug resistant pathogens include methicillin resistant Staph aureus (MRSA), vancomycin resistant Enterococcus species (VRE), extended spectrum beta-lactamase (ESBL) producing Escherichia coli and Klebsiella species,

multi-drug resistant Acinetobacter species, and Candida species [11, 12].

Empiric antimicrobial therapy should take into account the patient's history (including drug allergies and recent antimicrobial exposure), suspected source of infection, and hospital-specific antibiograms. When selecting empiric antimicrobial therapy, a few general rules should be applied. The initial antimicrobial coverage should be broad enough to cover all potential pathogens. By covering for common pathogens based upon the source of infection (upper GI vs. lower GI vs. Biliary) the clinician can provide adequate antimicrobial covering while avoiding the unnecessary use of overly broad antimicrobial coverage. There is substantial evidence that administering inadequate antimicrobial coverage is associated with increased morbidity and mortality [13–16]. Any antimicrobial agent that the patient has recently received should be avoided. Vigilant monitoring of culture data and de-escalation of the antimicrobial regimen based on culture results and sensitivities will reduce the risk of super infection and the emergence of resistant organisms. The improper and excessive use of antimicrobials is a major healthcare problem and has been associated with increasing healthcare costs due to selection of multi-drug resistant bacteria.

The choice of empiric antimicrobial coverage should take into account the source of infection AND the severity of illness. In the upper GI tract and biliary system, gram positive and gram negative aerobes and facultative organisms are frequently isolated. *Candida* sp. are also commonly isolated from upper GI perforations. It is important to remember that *Candida* sp. are usually benign, commensal organisms that do not require treatment in otherwise healthy individuals. The only time fungal coverage should be added is in patients that are either 1) immunocompromised, 2) have recurrent or postoperative infections, and/or 3) have a health care associated infection. In the distal small bowel, gram negative aerobic and facultative organisms (*Bacteroides* sp.) predominate. In the colon, facultative and obligate anaerobes such as *E. coli* are most common.

Table 15.2 outlines the suggested single and combination antimicrobial regimens for patients with extra biliary intra-abdominal infection based upon the severity of illness (mild-moderate vs. high risk/severity). Table 15.3 outlines the suggested regimens for biliary infections [3].

The duration of antimicrobial therapy should be dictated by the patient's clinical condition. As mentioned previously, in order to minimize the risk of antimicrobial resistance it is critical to select an appropriate antimicrobial at the appropriate dose for an appropriate duration of time. For uncomplicated IAIs in which surgical excision of the source of infection has occurred (e.g., nonperforated appendicitis) perioperative antibiotic prophylaxis is sufficient. In patients with complicated IAIs (focal or diffuse peritonitis) both source control with a surgical intervention and antimicrobial therapy are required. In cases of complicated IAIs antimicrobial therapy can prevent both local and hematogenous spread and may reduce the occurrence of late complications [17]. A recent randomized study of 518 patients with complicated

Table 15.2 Suggested antimicrobial regimens—extrabiliary intra-abdominal infections

	Mild to moderate severity: perforated hollow viscus	High risk or severity: severe physiologic disturbance, advanced age, immunocompromised
Single agent regimens	Cefoxitin, ertapenem, Moxifloxacin, tigecycline, and ticarcillin-clavulanic acid	Imipenem-cilastatin, meropenem, doripenem, and piperacillin-tazobactam
Combination agent regimens	Cefazolin, cefuroxime, ceftriaxone, cefotaxime, ciprofloxacin, or levofloxacin, each in combination with metronidazole[a]	Cefepime, ceftazidime, ciprofloxacin, or levofloxacin, each in combination with metronidazole[a]

[a]Due to increasing resistance of *E. coli* to fluoroquinolones, local population susceptibility and isolate susceptibility should be reviewed

Table 15.3 Suggested antimicrobial regimens—biliary infections

Infection	Regimen
Community acquired mild cholecystitis	Cefazolin, cefuroxime, or ceftriaxone
Community acquired cholecystitis, severe physiologic disturbance, advanced age, immunocompromised	Imipenem-cilastatin, meropenem, piperacillin-tazobactam, ciprofloxacin, levofloxacin, or cefepime in combination with metronidazole
Acute cholangitis following bilio-enteric anastomosis (any severity)	Imipenem-cilastatin, meropenem, piperacillin-tazobactam, ciprofloxacin, levofloxacin, or cefepime in combination with metronidazole
Health-care associated biliary infection (any severity)	Imipenem-cilastatin, meropenem, piperacillin-tazobactam, ciprofloxacin, levofloxacin, or cefepime in combination with metronidazole

IAIs and adequate source control by Sawyer and colleagues evaluated the use of a short course (4 days) of antimicrobial therapy as compared to a longer course (average of 8 days) [18]. The study demonstrated that outcomes after fixed duration antimicrobial therapy (4 days) were similar to those with a longer course of antimicrobials. Patients with complicated IAIs that are not improving clinically despite appropriate antimicrobial therapy should undergo an aggressive search for additional infections.

Source Control for Intra-Abdominal Infections

Source control is any procedure that eliminates the focus of infection. As a general principle, all verified sources be controlled as soon as possible. In the case of intra-abdominal infections, these patients frequently require diagnostic imaging to identify the source and an operative procedure for source control. This includes emergent debridement of necrotic tissues, abscess drainage, and exploratory laparotomy. Localized collections in the hemodynamically stable patient can be managed with percutaneous drainage. However, in the setting of septic shock or diffuse peritonitis exploratory laparotomy is required. The performance of an emergent exploratory laparotomy in the setting of hemodynamic instability, while necessary, can present a unique challenge to the surgical team.

The concept of damage control laparotomy (DCL) was first used for the care of critically injured trauma patients [19–21]. *Damage control* is defined as initial control of hemorrhage and contamination followed by intraperitoneal packing, as needed, and rapid, temporary abdominal closure. This concept was used on those patients who presented with severe physiologic derangements such as coagulopathy, acidosis, and hypothermia. Rather than persist for hours performing definitive surgery in the operating room, these patients have their critical surgical issues addressed in an abbreviated fashion so they may be taken to the ICU for further resuscitation. Once their physiologic derangements have been corrected, they are taken back to the operating room for a definitive surgical procedure. The decision to use DCL should not be viewed as a bailout. Instead, it is a deliberate decision to truncate the surgical procedure to minimize the time away from the ICU. The decision to perform DCL is often made before arriving in the operating room and is based on the severity of the patient's physiologic derangements at the time of presentation.

The concept of DCL has now evolved to include critically ill patients with surgical sepsis. Much like the trauma patient with the lethal triad of acidosis, hypothermia, and coagulopathy, many patients with septic shock present in a similar fashion. For those patients presenting with septic shock and a source of infection that requires surgical intervention, the use of DCL can be lifesaving.

The surgeon needs to assess the degree of physiologic derangement early in the operation and whether the severe physiologic derangements exist; then the operative interventions need to be truncated. The primary aim is to control the source of infection (e.g., resect dead bowel, close bowel perforations, and washout the abdomen). Ostomies are not created at this first operation. The abdomen is then temporally closed (via a variety of techniques), and the patient is rapidly returned to the ICU where he or she undergoes postoperative optimization. This includes optimizing volume resuscitation and mechanical ventilation, correction of coagulopathy and hypothermia, and monitoring for abdominal compartment syndrome. Over the next 24–48 h, abnormal physiology is corrected so that the patient can safely return to the operating room for a definitive operation and abdominal closure. Septic shock is a tremendous metabolic insult, and it is very important to provide optimal nutritional support (often requires combine enteral and parenteral nutrition) and early mobilization to prevent the loss of lean body mass, which impairs recovery.

Diagnostic laparoscopy is another valuable method of identifying and managing intra-abdominal infections. Laparoscopic approaches have become standard of care for the management of acute cholecystitis and acute appendicitis. There is ongoing interest in the use of laparoscopy for the management of acute diverticulitis, although this remains a topic of controversy in the current literature. The Laparoscopic Peritoneal Lavage or Resection for Generalized Peritonitis or Perforated Diverticulitis (LADIES) trial is an ongoing randomized controlled trial that will hopefully help further define the role of laparoscopy in the management of diverticulitis [22]. Laparoscopy has proven to be a useful diagnostic study in patients with an unclear source of intra-abdominal pathology on conventional imaging studies [23].

Microbiologic Evaluation in Intra-Abdominal Infections

Culture data can be extremely useful when managing complicated intra-abdominal infections. While blood cultures are not indicated for uncomplicated, community acquired intra-abdominal infections, they may be useful in ICU patients with more complicated intra-abdominal infections. In high-risk patients, empiric antibiotic treatment failure can have severe consequences. Therefore, cultures should routinely be sent in this population. In high-risk patients, initial gram stain may aid clinicians in the detection of gram positive cocci and/or yeast that would lead to additional antimicrobial coverage.

In certain clinical settings, there are significant resistance rates (10–20 %) for organisms commonly isolated in intra-abdominal infections. If this situation exists within an

institution, routine culture and susceptibility data should be used even in uncomplicated, community acquired infections. This helps avoid the potential for treatment failure due to resistant organisms.

Specimens should be collected at the time of operation (or percutaneous drainage) from the source of intra-abdominal infection. At least 1 cc of abscess fluid should be obtained. However, for optimal recovery of aerobic organisms, the maximum possible volume of abscess fluid (up to 10 cc) should be directly inoculated into an aerobic blood culture bottle. When sending anaerobic cultures, at least 0.5 cc of fluid or tissue should be collected and transported in an anaerobic system. An alternate option of anaerobic culture is to inoculate an anaerobic blood culture bottle with up to 10 cc of abscess fluid. The use of swabs should be discouraged since this sampling method is inadequate for the anaerobic organisms that are often found in intra-abdominal infections.

The ongoing emergence of multi-drug resistant infections further emphasizes the importance of obtaining cultures from sites of intra-abdominal infection to insure appropriate antimicrobial regimens are being utilized. Bacterial resistance has been identified as a major risk factor for treatment failure and mortality in patients with complicated IAIs [24]. The main resistance threat in intra-abdominal infections is from ESBL-producing Enterobacteriaceae [12]. In light of this, the antimicrobial regimen should be re-evaluated on a daily basis with adjustment made based upon patient specific culture data.

Conclusion

Intra-abdominal infections are a common, potentially lethal problem that all surgeons will encounter. The principles of management include timely diagnosis, source control, and appropriate selection of antimicrobial therapy.

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Obtaining a Surgical Airway

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Robert Ellis Southard

Encountering a patient in need of an emergent surgical airway is one of the most harrowing situations a surgeon faces. The surgeon is often called as the patient becomes hypoxic after multiple attempts at an airway. In these cases it is necessary to rapidly assess the situation and develop a plan. Therefore, the surgeon must possess an understanding of the indications for an emergent surgical airway, a detailed knowledge of the anatomy of the neck, procedural options available, and the potential complications. With this knowledge the acute care surgeon can be adequately prepared for this rare but challenging scenario.

Indications for a Surgical Airway

Development of guidelines and algorithms related to placement of a surgical airway are complicated by the relative infrequency of these procedures. Also, the emergent nature of the scenarios in which these procedures are performed make it difficult to perform randomized trials or comparative effectiveness studies in actual clinical scenarios. There are many scenarios which may develop requiring the need for a surgical airway including a foreign body or mass in the upper airway; edema of the upper airway to infection, inflammation, or anaphylaxis; trauma and burns to the face or neck; or encountering an anatomically difficult airway during attempted intubation [1]. Signs which should prompt immediate consideration of obtaining a surgical airway include stridor and impending obstruction due to edema of the upper airway, particularly if signs of hypoxia are present. An obvious laryngeal injury particularly with respiratory compromise is also an indication for obtaining a surgical airway. The presence of a traumatic tracheocutaneous fistula may require emergent placement of an airway if there is a significant air leak.

Outside of the setting of direct trauma and obstruction, the need for a surgical airway arises when a difficult airway preventsSurgical airway:indications: endotracheal intubation. The American Society of Anesthesiologists has published Practice Guidelines for Management of the Difficult Airway which contains a useful algorithm for approaching the potentially difficult airway [2]. There are a growing number of tools and modalities which allow rescue ventilation and intubation such as intubating laryngeal masks and video laryngoscopes. These adjuncts have proven useful, but still fail at times. The Practice Guidelines for Management of the Difficult Airway defines the difficult airway as "the clinical situation in which a conventionally trained anesthesiologist experiences difficulty with facemask ventilation of the upper airway, difficulty with tracheal intubation, or both." Factors predictive of a potentially difficult airway are listed in Table 16.1, and should prompt preparation for a difficult airway, including calling for additional personnel and equipment and utilization of the difficult airway algorithm. Acute care surgeons may be called upon to obtain an airway in a variety of circumstances and should be familiar with this algorithm and the rescue devices available for orotracheal or nasotracheal intubation listed in Table 16.2.

There are several scenarios in the difficult airway algorithm which call for the consideration of a surgical airway. If the patient is awake with a patent airway or can be adequately ventilated, an emergent airway is not required. In cases where a patient is undergoing an elective procedure, the procedure may be aborted or other anesthetic options can be considered. However, if a patient cannot be ventilated and rescue attempts at intubation and ventilation using the alternatives to standard direct laryngoscopy then an emergent condition exists, often referred to as the "cannot intubate, cannot oxygenate" scenario. Immediate placement of an invasive airway should be performed at this time.

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_16

Table 16.1 Findings associated with a potentially difficult airway

Findings impairing ability to perform direct laryngoscopy	Factors impairing ability to visualize vocal cords
Long upper incisors	Stiff, indurated, occupied by mass, or non-resilient mandibular space
Prominent overbite	Thyromental distance less than three ordinary finger breadths
Patient cannot bring mandibular incisors anterior to maxillary incisors	Short neck
Less than 3 cm between upper and lower incisors	Thick neck
Mallampati class >2 (i.e., uvula not visible when tongue is protruded)	Inability to extend neck

Table 16.2 Techniques to facilitate the intubation of a difficult airway

Alternative laryngoscope blades
Fiberoptic intubation
Videolaryngoscope
Awake intubation
Intra-tracheal jet stylet
Supraglottic airway
Intubating stylet or tube-changer
Oral and nasopharyngeal airways
Light wand
Blind intubation

Anatomy of the Anterior Neck

A detailed knowledge of the anatomy of the anterior neck is imperative when placing an emergent surgical airway [3]. Many of the conditions which require placement of an emergent airway also result in distortion of the anatomy, such as masses or direct trauma to the neck resulting in tracheal deviation from the midline. The combination of landmarks by visualization and palpation can help reorient the surgeon to the location of structures in cases of distorted anatomy. The borders of the anterior neck include the sternocleidomastoid muscles laterally, the head superiorly and the manubrium inferiorly. The sternal notch of the manubrium and the laryngeal prominence of the thyroid cartilage can help identify the midline and are typically palpable. These landmarks should be identified if possible at the beginning of the procedure and throughout the procedure as needed.

The first layer of the neck deep to skin is the platysma, a muscle which varies in thickness from patient to patient. The anterior jugular veins lie immediately beneath the platysma. These veins run longitudinally and are typically paired within 1–2 cm of the midline. Deep to the platysma and anterior jugular veins are the strap muscles which are made up of the sternohyoid, sternothyroid, thyrohyoid, and omohyoid muscles. These muscles are paired and typically meet in the midline at the median raphe. Deep to the strap muscles, the isthmus of the thyroid gland lies over the upper tracheal rings. The pre-tracheal fascia is the final layer encountered superficial to the trachea.

Regarding the anatomy of the airway itself, the laryngeal prominence of the thyroid cartilage is easily identified by sight or palpation in the vast majority of patients. This structure serves as the most important landmark when placing a surgical airway as it allows identification of the midline as well as the location of the cricothyroid membrane. The laryngeal folds are housed within the thyroid cartilage. The cricoid cartilage is immediately inferior to the thyroid cartilage. These two structures are connected anteriorly by the cricothyroid membrane which is a fibrous ligamentous structure. Extending inferiorly from the cricoid cartilage is the trachea. The trachea is made up anteriorly of series of cartilaginous rings connected by an annulus. Posteriorly the trachea is made of a muscular membrane. Typically only the first few tracheal rings are visible in the anterior neck, and these structures may be completely deep to the manubrium if the neck is flexed due to positioning or kyphosis.

Additional structures in the neck may be in danger of inadvertent injury. The typical anatomy of the neck may be obscured in many of the scenarios leading to the need for a surgical airway. Therefore structures which are typically not at risk during elective tracheotomy should be taken into consideration. The brachiocephalic vein and the innominate artery may rise superiorly out of the chest into the lower neck. If these structures are entered, the ensuing blood loss may be catastrophic. Therefore, careful dissection must be used in the lower portion of the neck to avoid potential injury to these vessels [4].

The esophagus lies immediately posterior to the trachea. The membranous portion of the trachea may be traversed when instrumenting the airway leading to the possibility of a traumatic tracheoesophageal fistula. When trauma or a mass has caused deviation of the trachea, the dissection may be inadvertently carried lateral to the trachea. The recurrent laryngeal nerves typically run in the tracheoesophageal groove, and injury to these structures could impair the ability of the patient to recover a patent airway.

Cricothyroidotomy and Tracheostomy

Because the cricothyroid membrane lies in close proximity to the readily palpable thyroid cartilage and the trachea typically lies somewhat deeper in the neck, most surgeons

recommend using a cricothyroidotomy to obtain access to the airway in emergent situations. If a mass or injury prevents access to the cricothyroid membrane or passage of an airway device through the membrane, then tracheostomy should be performed. Tracheostomy is the procedure of choice in elective placement of a surgical airway during which the patient may be adequately ventilated and some surgeons choose tracheostomy as the procedure of choice for emergent airways as well given their familiarity with the procedure [5]. In children, cricothyroidotomy should be avoided as the cricothyroid membrane is much smaller making inadvertent injury to the larynx more likely while simultaneously impeding placement of an adequately sized tube in the airway for ventilation. The risk of subglottic stenosis may also be higher in children [6]. At the beginning of these procedures, the surgeon should call for help from the most experienced person available. An assistant familiar with the procedure may prove invaluable in establishing an airway.

Cricothyroidotomy is performed by initially locating the pertinent landmarks of the anterior neck including the laryngeal prominence of the thyroid cartilage and the sternal notch. With the non-dominant hand on the thyroid cartilage, the skin is incised. The platysma is often incised along with the skin. Because the anterior jugular veins run longitudinally in the anterior neck near the midline, many surgeons recommend using a linear midline incision through the skin for emergent airway placement rather than a transverse incision which is commonly used for elective tracheostomy. The anterior jugular veins should be avoided if possible as the blood loss may obscure the field of view for deeper dissection. If the veins are divided, they may be ligated if necessary for visualization but may also be ignored until the airway is established. The strap muscles are subsequently encountered and may be divided if necessary, but more typically the median raphe is opened longitudinally allowing access to the deeper structures. At this point, the cricothyroid membrane will be exposed and should be opened transversely. A tracheal hook may be useful to assist with exposure of the cricothyroid membrane. An airway device such as an endotracheal tube or tracheostomy tube may be placed through this defect in the cricothyroid membrane. Typically, the cricothyroid membrane will only allow passage of 6 mm diameter tubes or smaller [7]. Care should be taken to avoid injury to the thyroid cartilage as this may have implications in the ability to restore the airway after the patient has recovered.

If an emergent tracheostomy is necessary, the procedure begins similarly to the cricothyroidotomy down to the level of the strap muscles. Once the strap muscles are separated in the midline, the isthmus of the thyroid gland is divided. Although the thyroid gland is typically quite vascular, it may be divided sharply in the emergent situation. The trachea is exposed after division of the thyroid gland. The second or third tracheal ring is typically used for entrance to the airway. The tracheostomy will allow a larger bore tube than a cricothyroidotomy and an appropriately sized endotracheal tube or tracheostomy tube may be used.

Many surgeons advocate revising the cricothyroidotomy to a tracheostomy once the patient has been stabilized. However, a recent study demonstrated that many survivors of cricothyroidotomy could be safely decannulated with minimal complications [8]. The majority of patients who underwent cricothyroidotomy and were decannulated between 2 and 7 days postoperatively, while only two had the cricothyroidotomy left in place more than 1 week. These two long-term cricothyroidotomy patients did not suffer complications. Mandatory revision of a cricothyroidotomy may be unnecessary. However, data for this practice is limited, particularly if the cricothyroidotomy remains in place for more than 1 week.

Alternatives to the Open Surgical Airway

Multiple devices are now commercially available to assist with placement of an emergent airway [9–11]. These devices have been studied under controlled circumstances using cadavers or animal models with variable results in effectiveness. No recommendation can be made regarding a particular type of device and the use of these devices should be based on the comfort level and experience of the surgeon [12].

Narrow bore cricothyroidotomy involves using a 2 mm or smaller cannula placed over a needle. The cricoid cartilage is identified by palpation and the needle and cannula are inserted through the membrane. High-pressure oxygen is used to attempt ventilation. Self-assembled devices for ventilation have not been adequately validated and should not be used. Furthermore in the setting of complete obstruction of the airway, the high-pressure oxygen delivered to the patient would have no route of egress. Cases of pressure-related complications have been reported with these methods.

Wide bore cannula systems with internal diameter greater than 4 mm are also available which have been studied for use in emergent cricothyroidotomy. These devices are placed in a similar fashion to the narrow bore devices, but require more forceful insertion risking injury to the membranous portion of the trachea. These systems have the advantage of allowing conventional ventilation with standard ventilator equipment.

Other systems are available for cricothyroidotomy using the Seldinger technique. These systems allow placement of larger bore cannulae. The use of a guidewire allows more careful passage of the cannula into the airway. These systems may be more complex for inexperienced users and run the risk of kinking of the guidewire leading to creation of a false passage.

Percutaneous dilational tracheostomy has been described for obtaining an emergent airway with reasonable success and is a viable option for obtaining an emergent surgical airway [13]. Many acute care surgeons routinely utilize this

method for elective tracheostomy placement. Familiarity with this technique and rapid availability of equipment make this technique very attractive. Emergent percutaneous dilational tracheostomy is performed without bronchoscopic assistance. The introducer needle is placed into the trachea superior to the sternal notch based on palpation of external landmarks. Confirmation of access to the trachea is confirmed by aspirating air, and a guidewire is inserted into the trachea. A small skin incision is made and serial dilation is performed and the tracheostomy device is inserted over the wire into the airway [14].

Each of these modalities has benefits and drawbacks. All direct comparisons between these alternative techniques were performed in controlled circumstances using either animal models or cadavers. The results of the comparisons are not consistently reproduced across different studies. It is also unclear whether the alternative procedures are superior to standard open procedures. The surgeon should be familiar with the equipment available and should utilize the most familiar technique which is appropriate for the situation.

Ultrasonography in the Emergency Airway

Frequently, emergency airways need to be secured in less than ideal situations. Obesity is a common problem which may obscure landmarks which are typically readily identifiable. Furthermore, traumatic injuries and masses may lead to distortion of the anatomy of the neck. The growing availability of ultrasonography has led some centers to apply this technology to assist with obtaining a surgical airway with promising results [15]. With experience, ultrasound guidance may prove superior to the use of landmarks, though the two techniques are not mutually exclusive [16]. The best views and methods for ultrasound visualization of the cricothyroid membrane are still being evaluated [17].

Training

The rarity of obtaining an emergent surgical airway means trainees might only encounter this situation a few times during the training period. Furthermore, the most experienced surgeon is usually performing the operation given its need to be performed rapidly. Therefore it is very likely that trainees will complete general surgery training having never performed this procedure [18]. While classic didactic lectures are necessary to understand the procedure, lectures alone are not adequate for training. Animal models historically have been used to provide training for placement of emergent airways, but comparative studies have not shown animal models to be superior to other training devices [19]. "Live" cadaver models which mimic real life conditions may also be useful for training, but are complex to construct [20]. Virtual simulators are being developed which may significantly improve the ability to train residents in this procedure without relying on scarce resources such as animals and cadavers [21]. Multiple modalities have been studied to provide realistic training models, but comparisons between these tools are limited as these studies did not involve evaluation of the trainees in live scenarios.

Austere and Prehospital Environments

Acute care surgeons may find themselves in less than ideal environments as part of military or prehospital response teams. Furthermore, airway difficulties in the hospital are not only encountered in the operating room, emergency room, or intensive care units where equipment is readily available. Austere circumstances will alter the decision-making process and the performance of emergent airway procedures [22].

In an austere environment, advanced airway equipment and assistance is unlikely to be available, making it actually more likely that an emergent surgical airway will be performed. The absence of high-pressure oxygen makes narrow bore and needle cricothyroidotomy less useful. Battlefield injuries requiring emergent airways are also typically more severe than those encountered in civilian populations. An analysis of prehospital success rates found a 90 % rate of successful placement of an airway in the prehospital setting [23] while a study of combat causalities in Iraq and Afghanistan revealed only a 68 % success rate [24].

When performing an emergent surgical airway in the prehospital setting, discerning landmarks may be difficult. Additional methods of locating the cricothyroid membrane which may be helpful include estimating the location of the cricothyroid membrane four fingerbreadths above the sternal notch as well as estimating the location near the prominent neck crease. However, these methods poorly correlate with the location of the cricothyroid membrane and are estimations at best that should be reserved when other methods are not possible [25].

Complications

While the most obvious complication of these procedures is failure to obtain an airway resulting death or severe anoxic brain injury, there are many potential complications of these procedures [26]. Injuries to laryngeal structures such as the cricoid cartilage have been reported [27]. Other structures of the neck and upper chest are also at risk, including the innominate artery and brachiocephalic vein. The membranous portion of the trachea may also be injured when inserting the airway device, placing the esophagus at risk of injury.

Complications may also arise due to the high pressures required to ventilate through narrow tubes which are often required in the setting of cricothyroidotomy and jet ventilation, including tension pneumothorax and pneumomediastinum [28]. While there are numerous complications which may arise during and after the emergent surgical airway, it is important to remember that the most immediately life-threatening complication is failure to obtain the airway.

The need to obtain an emergent airway often arises unexpectedly. Successfully performing any of these procedures requires familiarity with the anatomy of the neck and the equipment available. While tracheostomy and cricothyroidotomy are relatively straightforward under elective circumstances, the emergent scenarios can be much more challenging due to the status of the patient, distortion of anatomy, austere surroundings, and ongoing blood loss in the operative field. Mental planning and simulated training may be the only preparation the surgeon has for these challenging procedures.

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Esophageal Perforation

17

Karen J. Dickinson and Shanda H. Blackmon

Esophageal perforations and leaks can be classified as acute or chronic and contained or uncontained. The management is usually dictated by the anatomical location of the perforation. Mortality and morbidity may be reduced by expedient management but is variably reported as between 3 and 67 % [1]. Factors associated with poorer prognosis include mediastinitis, empyema, and sepsis, which occur more frequently with perforation of the thoracic or abdominal esophagus. Outcomes may also be improved by managing these patients at large volume esophageal surgery centers [2].

Etiology

Nearly 60 % of all cases of esophageal perforation are iatrogenic [3]. A smaller percentage occur due to foreign body ingestion (12 %) or traumatic injury (9 %). Table 17.1 describes the causes and clinical findings associated with esophageal perforations of various etiologies. The majority of iatrogenic perforations are the result of therapeutic endoscopic procedures. Those patients undergoing pneumatic dilation for stricture or achalasia appear to be particularly vulnerable. Despite this, overall rate of perforation associated with endoscopy is less than 0.1 % [4]. Other iatrogenic causes of esophageal perforation or leak include surgery (e.g., Heller's myotomy, or Collis gastroplasty leak) and Sengstaken–Blakemore tubes. To reduce the risk of iatrogenic esophageal perforation when using a Sengstaken–Blakemore or Minnesota tube, the gastric balloon should be inflated under fluoroscopic surveillance and using a manometer.

Spontaneous esophageal perforation (Boerhaave's syndrome) results from abrupt increases in intraesophageal pressure. Originally described by Herman Boerhaave in 1724 on post-mortem examination of Baron de Wassenaer, the Grand Admiral of Holland, Boerhaave's syndrome has historically been associated with violent emesis following massive food consumption. However, the gluttonous Baron suffered a fatal esophageal rupture after self-induced vomiting [5].

Traumatic esophageal perforation is rare, but the cervical and thoracic esophagus are susceptible to injury from penetrating trauma. Gunshot wounds may inflict indirect thermal injury missed at initial examination that can subsequently progress to esophageal perforation. Blunt trauma may also cause esophageal disruption. Ingestion of caustic materials, both acidic and alkaline, can result in esophageal perforation, with alkaline fluid often causing more serious injury. Alkalis cause liquefactive necrosis and have a propensity for transmural progression of the injury. Acid ingestion results in a coagulative necrosis but has less potential for esophageal penetration than alkaline ingestion. Acute inflammation and infection may also lead to esophageal perforation, particularly in the immunocompromised patient. Eosinophilic esophagitis has been associated with spontaneous esophageal perforations [6, 7].

Clinical Presentation

The clinical signs and symptoms of esophageal perforation are largely dependent upon the anatomic location of the defect. Patients with cervical esophageal perforations are less likely to have systemic manifestations. When eliciting a history, these patients may describe neck pain, vocal disturbances that are classically described as "nasal" tonality, they may also complain of dysphagia symptoms and notice oral bleeding. On examination, these patients may have crepitus on neck palpation due to subcutaneous emphysema.

Patients with perforations of the thoracic or abdominal esophagus often present with a history of vomiting, chest and/or back pain, dyspnea and may have antecedent dysphagia symptoms. Clusters of clinical symptoms and signs have been described in relation to esophageal perforations and include Mackler's triad which describes a classic presentation of

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_17

Table 17.1 Etiologies of esophageal perforations

Type	Causes	Features
Pyriform sinus	Singing, yelling, trumpet playing, recent endoscopy	Marked mediastinal and cervical subcutaneous emphysema
Anastomotic/Staple line	Leakage at the site of a surgical anastomosis/staple line	History of surgically created esophageal anastomosis
Boerhaave's	Vomiting, straining, retching, weight lifting, hyperemesis causing a full-thickness tear at the gastroesophageal junction	Characteristic longitudinal tear on the left side of the esophagus, typically in the distal 1/3 segment
		Mucosal defect typically longer than muscular defect
Iatrogenic	Endoscopic: Ablation, dilation, sclerotherapy, instrumentation	Recent history of surgery or endoscopy
	Surgical: Esophageal surgery, foregut cyst decortication, spine surgery	
Traumatic	Penetrating or blunt trauma to neck or torso	Strong association with neck hyperextension
Cancer	Perforation of an esophageal tumor	Gas near or abutting the tumor on imaging
	Erosion of surrounding tumor through esophageal wall	
Paraesophageal hernia	Incarceration with necrosis of the distal esophagus	History and imaging demonstrating paraesophageal hernia
		Left sided pleural effusion or fluid associated with hernia
Foreign body	Ingestion of a foreign body (i.e., chicken bone) that becomes lodged	May be associated with underlying esophageal abnormality, e.g. esophageal web or stricture
Esophagitis	Eosinophilic esophagitis Inflammation and erosion of ulceration	Immunocompromised patient
	Zollinger–Ellison syndrome	
	Barrett's ulcer	
	Infection (candida, herpes simplex, viruses, CMV)	
Ingestion	Ingestion of caustic substance	Tetracycline
		Potassium
		Quinidine
		NSAIDS
		Sustained-release formulations
	Drug ingestion/impaction	

CMV cytomegalovirus, *NSAIDS* nonsteroidal anti-inflammatory drugs

spontaneous esophageal rupture: vomiting, lower chest pain, and subcutaneous emphysema. An alternative is the Anderson triad, which may be more applicable to intra-abdominal esophageal perforation and includes: subcutaneous emphysema, rapid respirations, and abdominal rigidity. Intra-abdominal esophageal leaks and perforations commonly cause abdominal pain with signs and symptoms of peritonitis.

Evaluation

Evaluation of the patient with suspected esophageal perforation begins with a detailed history and physical examination. Particular attention should be given to any recent history of esophageal instrumentation, trauma to the neck or torso, quantitative assessment of recent food and liquid consumption, documented or suspected esophageal malignancy (any recent weight loss or dysphagia), or any symptoms of progressing sepsis. Tachycardia, tachypnea, hypotension, and pyrexia should be noted if present. Hemodynamic instability should be immediately addressed with placement of large-bore intravenous catheters and fluid administration. When esophageal perforation is suspected, antero-posterior and lateral upright chest and abdominal radiographs should be obtained without delay. Radiographic findings suspicious for perforation include subcutaneous emphysema, pleural effusions, pneumomediastinum, hydro/pneumothorax, and pleural thickening. Radiographs are particularly useful in the setting of suspected iatrogenic perforation, as they are diagnostic in up to 80 % of these patients. Plain radiographs may help localize the perforation, a right pleural effusion suggests a mid-esophageal perforation, while a left effusion portends a lower esophageal lesion. Despite these clues, the gold standard for diagnosis of esophageal perforation is an esophagogastroduodenoscopy which may be diagnostic and therapeutic.

Esophageal perforations may be investigated by a contrast swallow. The patient should be oriented obliquely relative to the source and remain in a standing, semi-erect position to facilitate detection of small leaks (Figs. 17.1, 17.2, and 17.3). There is a risk of pneumonitis associated with gastrografin aspiration, and angiography contrast agents may be preferable. Barium can complicate future imaging and cause complications from extraluminal leak, therefore is infrequently used. Although useful in the evaluation of suspected esophageal

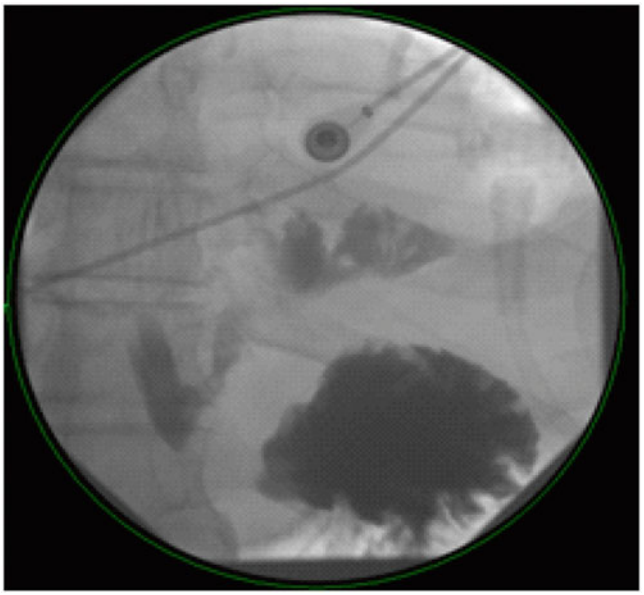

Fig. 17.1 Contrast esophagram of a Boerhaave perforation of the esophagus at the gastroesophageal junction resulting in left pleural contamination

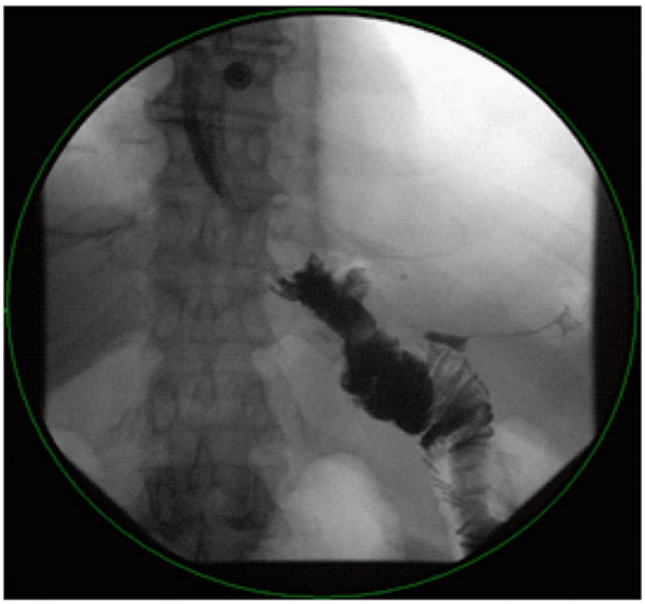

Fig. 17.3 Contrast esophagram of a gastric bypass leak resulting in left pleural and abdominal contamination

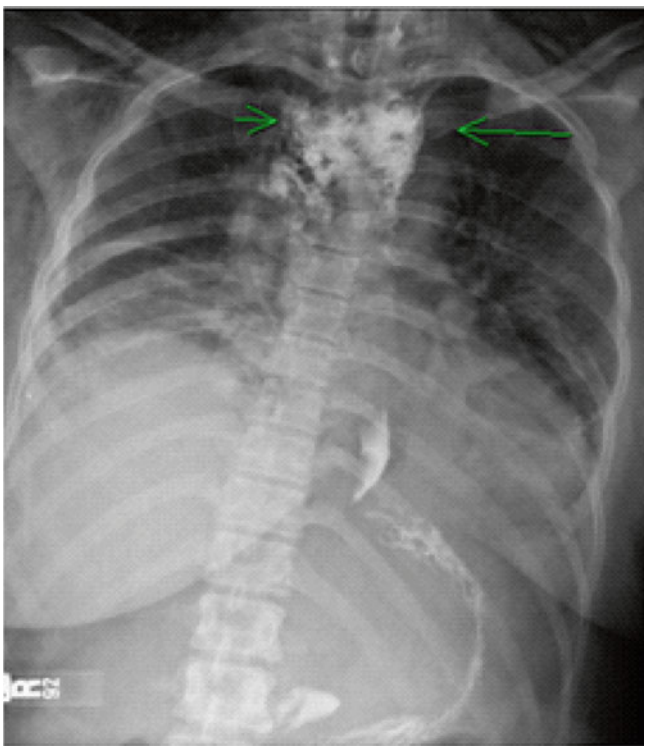

Fig. 17.2 Contrast esophagram of a fish bone perforation of the cervical esophagus resulting in mediastinal contamination

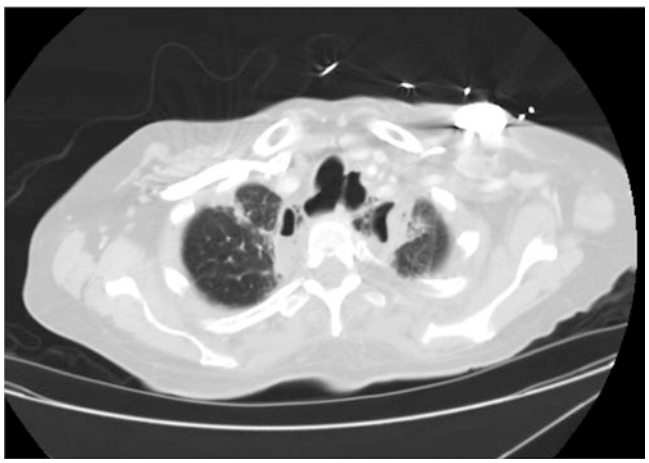

Fig. 17.4 Computed tomography (CT) scan of a tracheo-esophageal fistula after chemotherapy and radiation therapy for esophageal squamous cell carcinoma

perforation, the false negative rate of contrast swallow approaches 30 %. Computed tomography (CT) is useful for cases of suspected perforation with non-diagnostic swallow and gives important additional information regarding empyema or collections (Figs. 17.4 and 17.5). CT is the primary diagnostic modality for intubated patients or those in whom a swallow evaluation is not possible. It is essential to ensure that the endotracheal tube or tracheostomy cuff is inflated prior to contrast administration to prevent aspiration.

Endoscopic assessment of esophageal perforations allows diagnosis, assessment of the mucosa component of the perforation, and can facilitate irrigation and drainage of large perforations prior to intervention. Endoscopic therapy is being increasingly used for definitive management of esophageal perforation in carefully selected patients.

Management

The first successful surgical repair of esophageal perforation was reported in 1944 [8]. Currently surgery is widely considered definitive treatment for esophageal perforations, but the increased use of endoluminal therapy is challenging this perception [9–11]. The goals of any treatment for esophageal perforation are: complete drainage of extraluminal infection, restoration of esophageal integrity to prevent continued contamination, and nutritional support (Fig. 17.6).

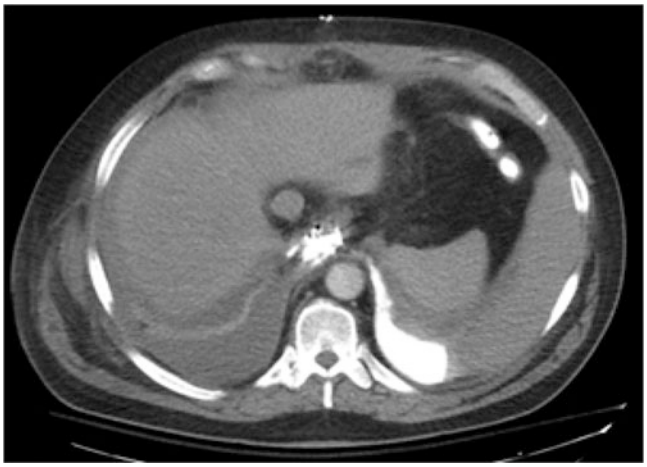

Fig. 17.5 CT scan of an intrathoracic anastomotic leak after esophagectomy resulting in left pleural contamination

Surgical treatment of esophageal perforation should drain all contaminated spaces and preserve the esophagus when this is appropriate. Intra-thoracic contamination and empyema necessitate decortication through either a thoracotomy or video-assisted thoracoscopic surgery (VATS) approach when appropriate [12]. Thorough decortication allowing full expansion of the lung will augment healing. Tube thoracostomies with a minimum caliber tube of 32-French should be placed generously to achieve optimum postoperative drainage. Smaller caliber tubes are vulnerable to obstruction and should be avoided.

Cervical esophageal perforations can be accessed via a left oblique neck incision anterior to sternocleidomastoid (Fig. 17.7, #1). In the upper two-thirds of the thoracic esophagus, a right posterolateral (often muscle-sparing) thoracotomy in the fourth or fifth intercostal space is required (Fig. 17.7, #2). If an intercostal muscle flap is planned to buttress the esophageal repair, it should be harvested when the thoracotomy is performed. A muscle-sparing approach is preferred when performing open thoracotomy to preserve chest wall musculature for later surgeries if required, e.g. muscle flaps. Perforations in the lower third of the esophagus are best accessed through a left posterolateral thoracotomy in the sixth or seventh intercostal space (Fig. 17.7, #3). Intra-abdominal esophageal perforations can be approach through laparotomy or through a laparoscopic approach (Fig. 17.7, #4).

Most uncontained esophageal defects, particularly when detected early, are amenable to primary repair. This is done by closing the esophageal mucosa and muscularis in separate

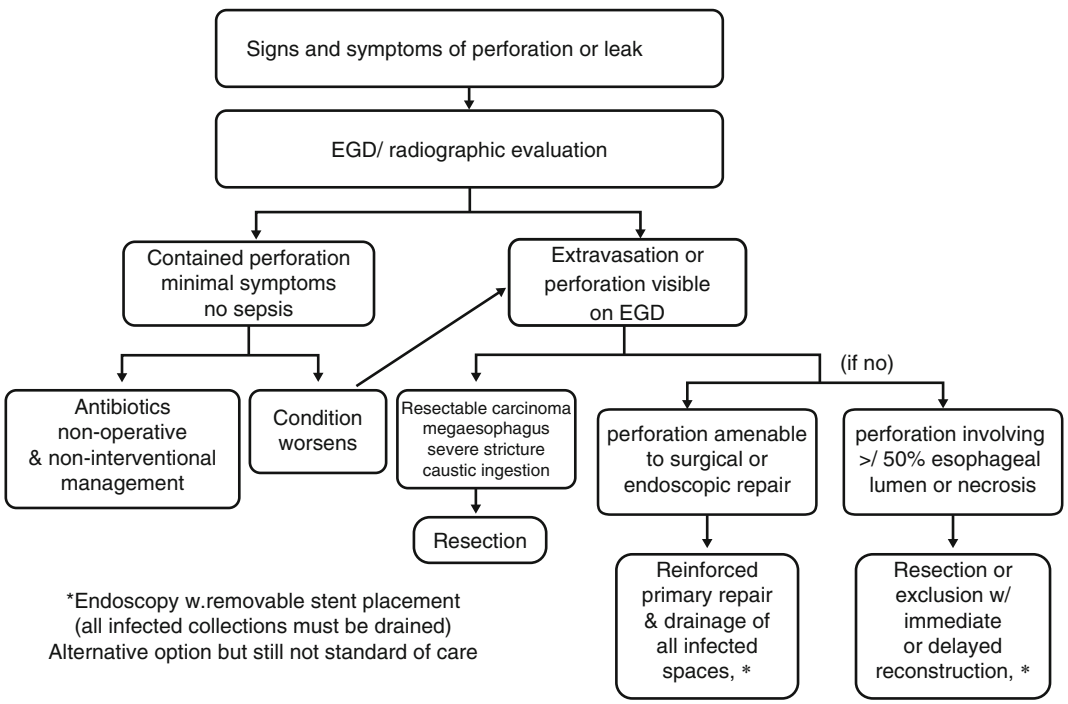

Fig. 17.6 Algorithm for the management of esophageal perforations

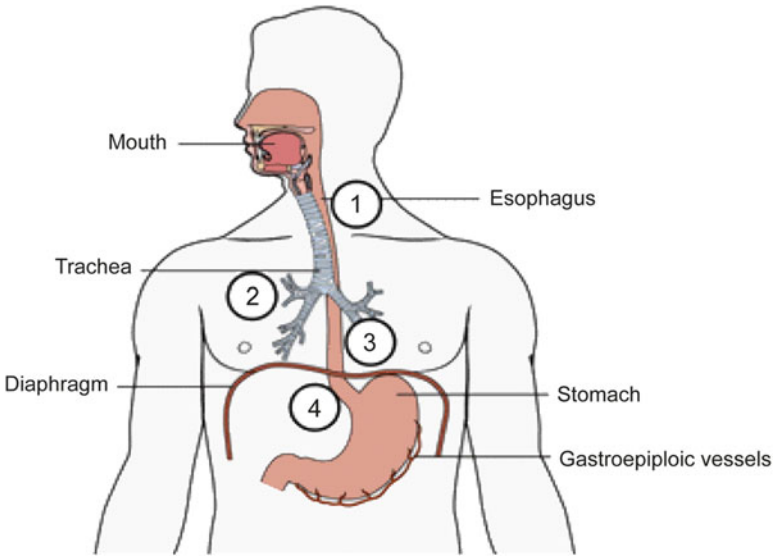

Fig. 17.7 Common locations of esophageal perforation

layers using 3-0 Vicryl or similar absorbable suture. It may be necessary to separate the outer components of the inner circular and outer longitudinal muscle layers in order to gain adequate exposure to the underlying mucosal disruption. The thoracic cavity is then filled with saline and the esophagus insufflated using an endoscope to assess the integrity of the repair, which may be buttressed using a flap. We commonly use a pedicled intercostal muscle flap for this purpose, although the latissimus dorsi, serratus, pericardial fat pad, diaphragm, omentum, or gastric fundus flap are alternate options [13]. The sternocleidomastoid, rhomboid, or pectoralis muscles are available for use in the repair of cervical esophageal perforations; however, these perforations typically heal well with drainage alone. Novel techniques such as fibrin tissue patches can be employed at the time of primary esophageal repair [14].

Defects not suitable for primary repair can be resected or stented. These include perforations involving more than 50 % of the circumference of the esophageal wall, or those longer than 3 cm as they confer an unacceptable risk of stricture formation. Surgical repair may not be suitable for patients with a delayed presentation (>48 h). Alternative management strategies for delayed perforations include hybrid endoscopic and surgical treatment. These include stenting the esophageal perforation in association with surgical placement of a buttressing muscle flap over the perforation, debridement of the contaminated area with wide local drainage. It is important to note that not all patients are suitable for this approach. In this highly selected population the surgeon must monitor to ensure adequate drainage of infected spaces and perforation closure postoperatively. If clinical deterioration occurs with failure of treatment, the surgeon should identify this promptly. In the case of a persistent leak from the esophagus T-tubes can be used to drain perforations deemed irreparable, but they are an unreliable means of ensuring fistula control. Esophagectomy may be performed when the esophagus is unsalvageable and whilst reconstruction may be possible, esophagostomy with a chest wall stoma may be required in some situations. If possible, esophagostomies should be created on the left anterior chest wall just below the clavicle rather than with a neck incision, as this improves the fit and function of the ostomy appliance. High cervical defects with insufficient length for a diverting esophagostomy may require placement of a salivary bypass drainage tube. Placement of a surgical gastrostomy tube should be considered in diverted patients and in those in whom the need for prolonged gastric drainage is anticipated. Care should be taken to considering future reconstruction and the gastrostomy tube placed without injuring the right gastroepiploic artery. A jejunostomy tube offers alternative access for enteral feeding.

Vigilant postoperative monitoring is essential for these patients. Enteral nutritional support is always preferred. These patients should be continued on broad-spectrum antibiotics until they have recovered fully from the current infection. Narrowing the spectrum of antibiotic coverage is recommended once the sensitivities of the offending agent(s) are known. Microbes responsible for infections associated with esophageal perforations include *Staphylococcus*, *Pseudomonas*, *Streptococcus*, and *Bacteroides* and adequate coverage for each of these species should be provided.

Re-perforation following complete healing is rare. Persistence of a leak after what is considered to be otherwise standard therapy should prompt an investigation for the presence of cancer or other impediments to normal wound healing. These include epithelialization, steroids, retained foreign body, poor nutritional status, radiation damage, persistent undrained infection, or distal obstruction. Persistent esophageal

leakage after stent placement may also be due to technical issues with stent placement and these should be actively sought and managed [15]. Patients who develop any symptoms, such as dysphagia, odynophagia, regurgitation, or non-cardiac chest pain following hospital discharge should undergo a contrast swallow evaluation to assess for stricture, which may occur in up to 33 % of patients [16].

Conclusion

Esophageal perforations and leaks are life threatening and the management should be tailored to the individual patient to ensure the best chances of success. The principles of adequate drainage, esophageal repair, nutritional support, and antibiotics remain whether the treatment involves endoscopic therapy, surgery, or a combination thereof.

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Pneumothorax, Hemothorax, and Empyema

18

K. Shad Pharaon and Benjamin L. Davis

Pneumothorax, hemothorax, and empyema are commonly encountered by the acute care surgeon. This chapter discusses the presentation, diagnostic features, and current treatment strategies for these entities.

Pneumothorax

Epidemiology

Trauma and acute care surgeons are often called upon to treat a *traumatic* pneumothorax: a pneumothorax that results after blunt or penetrating trauma, usually as a result of displaced rib fractures. A *spontaneous* pneumothorax is also a common cause of a pneumothorax that is typically seen in smokers or in patients with either a congenital bleb or blebs from chronic obstructive pulmonary disease (COPD). It is seen in 1–18 cases per 100,000 people per year. The risk of spontaneous pneumothorax in the smoking population is reported to be 20 times higher than the nonsmoking population and is dose-dependent [1]. In one large population study, 77 % of patients who developed a spontaneous pneumothorax were male, and 28 % of all patients who developed a spontaneous pneumothorax had a repeat event within 4 years [2]. A spontaneous pneumothorax is often managed by a thoracic surgeon and will not be the focus of this discussion. For the remaining portion of this chapter, the word pneumothorax will be used to represent a traumatic pneumothorax.

Many patients with pneumothoraces present to the emergency department after a motor vehicle crash (MVC). Chest trauma is found in half of patients involved in MVC. A pneumothorax can quickly become life threatening if overlooked, but is a preventable cause of death if identified. The rate of pneumothorax in one study is 20.6 % of major trauma and 81 per 1 million people per year [3]. In this same study, pneumothorax was unilateral in 73.9 % and bilateral in 26.1 %. A common sequela from a penetrating chest wound is a pneumothorax.

Clinical Presentation and Diagnosis

Some patients will present to the emergency department with minimal complaints, have normal oxygen saturation, "normal" breath sounds, and may even have a normal supine chest X-ray, yet still have a pneumothorax that needs treatment. Emergency departments and trauma bays are often too noisy to confidently recognize absent breath sounds on the affected side. Other patients may present with subcutaneous air in the soft tissue, which on physical exam is often referred to as feeling like "Rice Krispies®". In several studies, a supine chest X-ray can miss 30–40 % of pneumothoraces that were subsequently diagnosed on CT scan of the chest [4–7]. If spine precautions are not needed, an upright chest X-ray will often demonstrate the pneumothorax on the apicolateral aspect of the lung. Ultrasound used to diagnose pneumothorax is associated with greater sensitivity than a supine chest X-ray. Ultrasound was 90.9 % sensitive and 98.2 % specific for detection of pneumothorax, while chest X-ray was only 50.5 % sensitive and 99.4 % specific [8]. The test is simple to perform, rapid, accessible, and with no radiation exposure. Many smaller pneumothoraces not seen on chest X-ray but seen on CT are referred to as occult pneumothoraces. A tension pneumothorax occurs when the air trapped in the pleural space is under pressure resulting in

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_18

mass effect on the mediastinal structures and contralateral lung. Patients may develop hypotension due to decreased cardiac filling, and may have shifting of the trachea. A chest X-ray is not needed to confirm the clinical suspicion of a tension pneumothorax.

Management

Some small pneumothoraces can be watched, but patients that are intubated or those that are to undergo surgery (i.e. exposed to positive pressure ventilation) are at increased risk of developing a tension pneumothorax. Many surgeons would agree that placing a chest tube in patients that are going to be put on positive pressure ventilation is safe, although that is being challenged by some [9, 10]. A pneumothorax may be observed for ventilated patients up to a positive end expiratory pressure (PEEP) of 10, however there must be resources to monitor the patient and a way of treating quickly if the patient decompensates. For example, having thoracotomy supplies at the bedside in the ICU or in the operation room for patients with a known pneumothorax that is being managed expectantly. A brightly colored sticker or note attached above the patient's ICU bed or attached to the front of the chart stating "observing a small pneumothorax" is a preferred approach because it keeps everyone caring for the patient reminded of a potential complication. A patient with a small pneumothorax that you elect to watch should get a repeat upright chest X-ray within 12 h, or sooner if there is dyspnea, change in blood pressure, or change in oxygen saturation. The traditional treatment for symptomatic pneumothorax has been placement of a chest tube (32–36 Fr) in the fourth or fifth intercostal space mid-axillary line attached to a drainage collection system such as Atrium Ocean™ (wet suction water seal drain) or Oasis™ (dry suction water seal drain) (Fig. 18.1). Patients with simple, uncomplicated pneumothorax can have a 14-Fr pigtail catheter placed with successful results. These tubes are associated with reduced pain at the site of insertion [11]. These tubes are placed using the Seldinger technique at the second or third intercostal space anteriorly, or in the fourth of fifth intercostal space laterally. The use of prophylactic antibiotics for chest tube insertion has occurred but its recommendation is controversial. While a number of studies show favorable effects in reducing the incidence of empyema, some reports have shown no benefit [12]. Patients with hemodynamic instability, decreased breath sounds, shifting of the trachea, or dilated neck veins have the clinical suspicion of a tension pneumothorax and need immediate treatment. If clinical suspicion is present, the treatment is immediate needle decompression. The time it takes to get additional studies to confirm your suspicion may result in death of the patient. The needle decompression has traditionally occurred at the second intercostal space mid-clavicular line. However, there is an increasing trend toward performing needle decompression in the fourth intercostal space in the anterior axillary line because of the decreased amount of tissue thickness at this location. A chest tube can later be placed. Once the tube is placed and properly working, the needle used for the decompression can be removed. If your diagnosis is correct, the patient will have improved color and hemodynamics.

Once the chest tube is placed, an upright chest X-ray is obtained to confirm that the lung has re-expanded. Failure of the lung to re-expand may indicate that the chest tube is kinked, malpositioned, or worse, not inside the chest. Failure of the lung to re-expand *with* an air leak may indicate a tracheobronchial injury. A second chest tube may be inserted to see if this resolves, but if a second chest tube fails, consider performing bronchoscopy to rule out an injury. Many thoracic surgeons can manage a tracheobronchial injury, and this management is beyond the scope of this text.

Increased use of CT has resulted in increased rates of diagnosis of small pneumothoraces, which would have otherwise gone undiagnosed. This phenomenon is referred to as occult pneumothorax which is a pneumothorax that is seen on CT but not seen on initial chest X-ray. The management of occult pneumothorax is controversial. It is not clear if these patients should be observed or be treated with immediate chest tube placement and be subjected to complications and side effects such as vascular injury, improper positioning of the tube, or infection. Some surgeons prefer to place chest tubes in all pneumothoraces. Some observe occult pneumothoraces, but if positive pressure ventilation (PPV) is needed, then place a chest tube. Others believe occult pneumothoraces, even on PPV, can be observed. The advocates of chest tube for occult pneumothorax generally base their argument upon the risk of progression of the pneumothorax into a tension pneumothorax. Advanced Trauma Life Support (ATLS) recommends chest tube for all patients undergoing PPV. Enderson et al. support placing a chest tube in occult pneumothorax patients on PPV [13]. At least two studies, however, show that patients with an occult pneumothorax on PPV can be observed [9, 14]. Observation may be at least as safe and effective as a chest tube for management of occult pneumothorax. There is, however, inadequate data to draw any definitive conclusion on safety of expectant management in patients with occult pneumothorax that undergo PPV [15].

Small iatrogenic pneumothorax due to attempted subclavian central venous catheter placement can generally be treated by observation or by placement of an apical pigtail catheter with good results since the site of injury is known to be at the apex. Larger iatrogenic pneumothorax can undergo conventional chest tube placement.

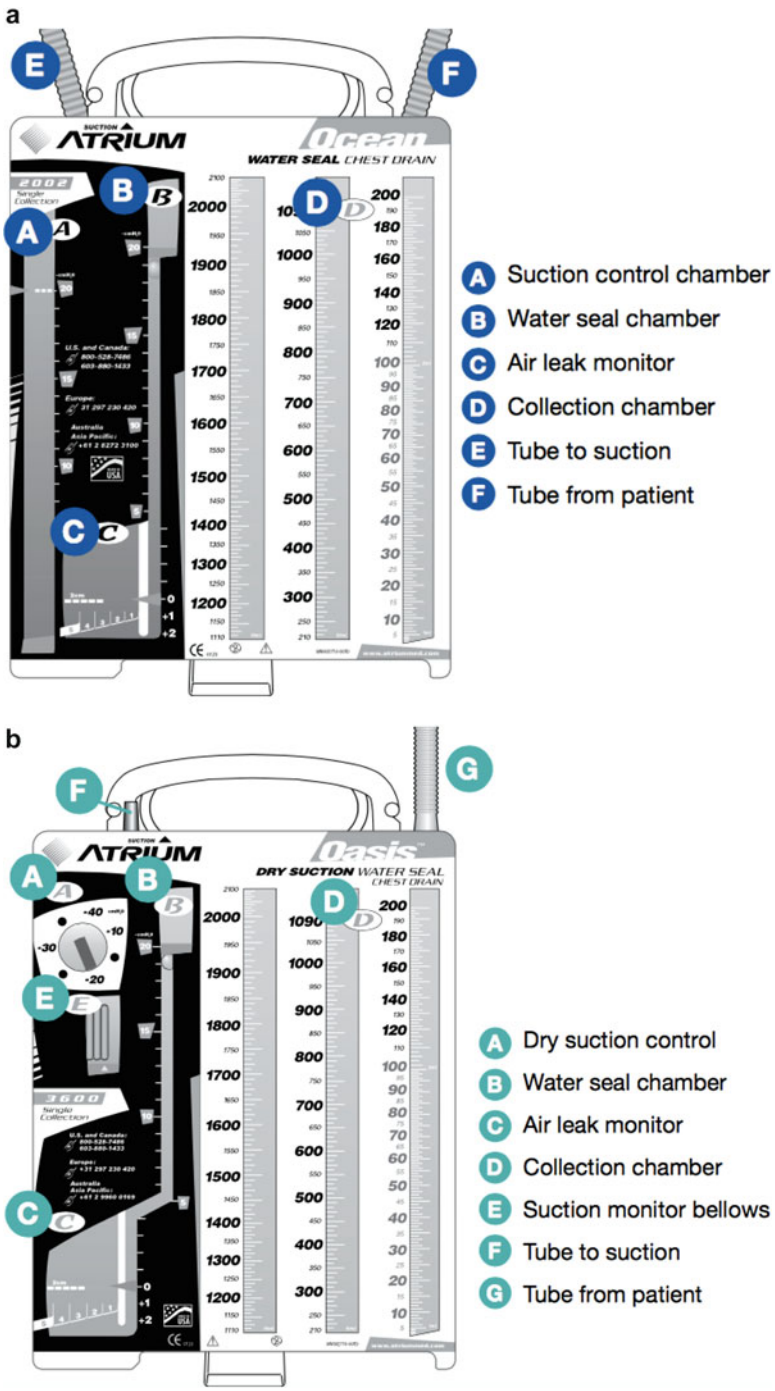

Fig. 18.1 The traditional treatment for symptomatic pneumothorax has been placement of a chest tube (32–36 Fr) in the fourth or fifth intercostal space mid-axillary line attached to a drainage collection system such as (**a**) Atrium Ocean™ (wet suction water seal drain) and (**b**) Oasis™ (dry suction water seal drain). (Courtesy of atriummed.com.)

Once the chest tube is in place and reinflation of the lung has occurred, there is little consensus on the subsequent management of these tubes once placed. General practice is to leave the patient on suction for 24–48 h. This is usually enough time for the lung to reinflate and for sealing of an air leak to occur. The next step in chest tube management is placing the patient on water seal, which is removal of the chest tube from wall suction. Patients should be left on water seal for at least 3 h, but most wait 24 h. The water chamber is monitored for an air leak. Having the patient take deep breaths and coughing are methods used to detect a leak. If no air leak is detected, and the lung remains fully expanded, then the chest tube may be removed. If there is an air leak, the chest tube is placed back on wall suction for another 24 h and the process is repeated. Persistent small air leaks can occur and can be frustrating. If these small leaks fail to seal after a reasonable amount of time on wall suction, then a CT scan of the chest may be ordered to identify uninflated areas of lung that may be contributing to the persistent air leak (Fig. 18.2).

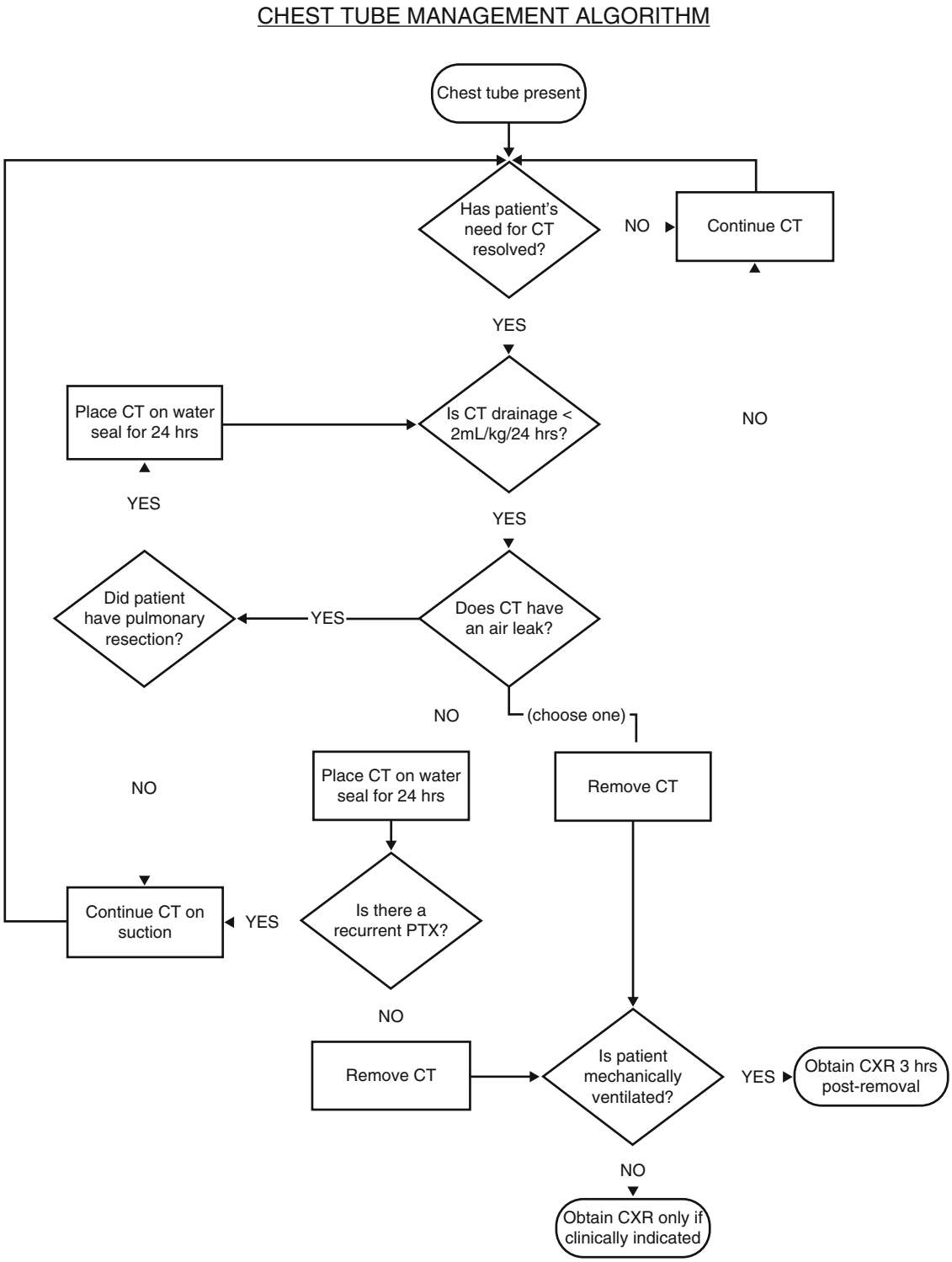

Fig. 18.2 Chest tube management algorithm

One prospective randomized study evaluated if pulling a chest tube was better at end-inspiration or end-expiration. The results showed an 8 % rate of recurrent pneumothorax in the end-inspiration group and 6 % rate in the end-expiration group [16]. Some surgeons will have the patient take a deep breath in and hold it while the tube is removed. If the patient has fully inhaled, then theoretically no further air can rush in. Another method is to have the patient take a deep breath in,

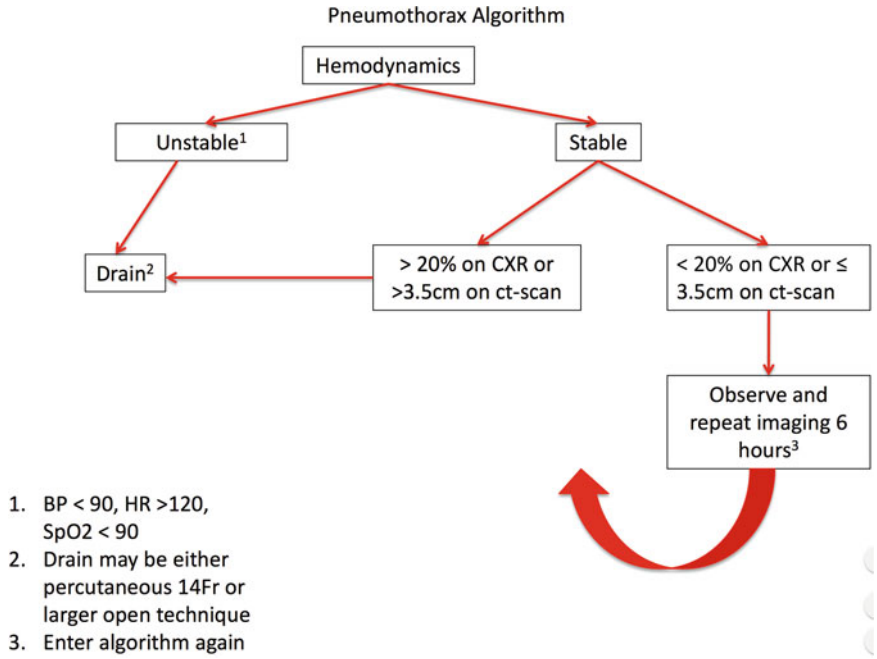

Fig. 18.3 Pneumothorax management. (From Western Trauma Association, http://westerntrauma.org/algorithms/algorithms.html, and courtesy of Dr. Marc DeMoya.)

but blow air out (while having their thumb in their mouth, lips tightly around the thumb, and pretending to blow up a birthday balloon) while the tube is being pulled. This method gets the patient engaged in the act of removal, and while they are concentrating on their thumb, they have been distracted from the chest tube removal itself.

As mentioned before, some surgeons will place the patient on water seal for 24 h after resolution of the pneumothorax and air leak, and proceed to pull the tube from water seal. Others will pull the tube *while still on suction* skipping the water seal step, decreasing their need for more chest X-rays, etc. A randomized prospective study evaluated the practice of removing chest tubes on suction versus removal on water seal. The authors concluded that chest tube removal on suction was safe, and protocols using water seal before removal led to longer hospital length of stay and an increased number of chest X-rays [17]. One study, however, showed that a short trial of water seal might allow occult air leaks to become clinically apparent and reduce the need for having to reinsert a chest tube [18].

Video-assisted thoracoscopic surgery (VATS) for pleurodesis may ultimately be needed. Surgical pleurodesis involves the application of various irritants to the pleural surfaces to cause inflammatory adhesion of the visceral and parietal pleura and thereby seal air leaks (Fig. 18.3).

Complications

Not treating a pneumothorax in a timely matter has the potential to lead to tension pneumothorax, decreased filling of the heart, and potentially death in the patient. Avoiding this complication has been the basis of traditional chest tube insertion for all pneumothoraces. This practice is changing and continues to evolve. As mentioned before, some surgeons are very comfortable watching a stable pneumothorax, some even on PPV. Another complication of a pneumothorax is complications from the treatment itself—chest tube insertion. In one retrospective study of chest tube complications following initial insertion found that over 20 % of patients required an additional intervention related to that tube placement. Most commonly it was the need for chest tube reinsertion for recurrent pneumothorax following chest tube removal either from underlying parenchymal lung damage, or an underappreciated air leak. Chest tube complications have been associated with longer ICU and length of stay [19]. One study found that 31 % of chest tubes placed in the emergency department for trauma were positioned suboptimally and 17 % required repositioning [20]. Major complications such as bleeding from injury to intercostal arteries, insertion on the wrong side, insertion into the lung parenchyma, or insertion through the spleen

and liver have all been described. The reporting of these complications has caused some surgeons to change their practice and manage some patients with a pneumothorax expectantly.

Follow-up

It is customary practice at many institutions to obtain a follow-up chest X-ray after removal of the chest tube and at their first clinic visit. Patients who have been treated conservatively for a small pneumothorax generally receive a follow-up chest X-ray a couple of weeks later in clinic to document full lung expansion. The benefit of this practice is unclear as there is very little evidence to suggest this as the best practice. Our personal preference is to obtain a follow-up chest X-ray about 4 h after chest tube removal whether the patient is being discharged or if the patient continues to be an inpatient. Some surgeons will argue that routine chest X-rays are not needed for those that stay as an inpatient, and should only be obtained if there is a clinical change.

The safety of air travel following a traumatic pneumothorax is controversial. According to Boyle's law, air trapped within a body cavity can expand by up to 30 % during flight. A study showed that patients that waited a full 14 days before flying were able to do so without development of a pneumothorax. It has been accepted that air travel is safe 14 days following radiographic resolution of a traumatic pneumothorax [21]. A recent ongoing unpublished study suggests that patients may be able to shorten their wait time from 14 days to 1 day (personal communication, Zonies).

Hemothorax

Epidemiology

Trauma is widely recognized to be the major cause of hemothorax. The exact incidence of hemothorax is unknown, but estimates in trauma patients range from 4 % [22] to 37% [23]. The actual source of the bleeding varies per mechanism of injury, but bleeding intercostal vessels, rib fractures, pulmonary vessel, and parenchymal injuries can all contribute. Non-traumatic or spontaneous hemothorax is far less common and is usually related to coagulopathy, malignancy, or iatrogenic injury (e.g., subclavian artery or vein injury during indwelling central venous catheter placement).

Though most cases of hemothorax occur immediately after trauma, delayed hemothorax has been described as hemothorax occurring 2 or more days after injury [24, 25], with the majority occurring within 14 days. With an incidence of 5–7 % of all hemothoraces, delayed hemothorax is a rare but real entity. In the two studies noted above, all cases of delayed hemothorax occurred in patients with rib fractures, and incidence appears to be proportional to number of rib fractures.

Clinical Presentation and Diagnosis

Because the most common cause of hemothorax is trauma, most patients will have a history suggesting blunt or penetrating trauma. It bears mentioning that the traumatic causes of hemothorax and pneumothorax are similar and so combined pathology—hemopneumothorax—is not uncommon. Therefore, any patient suspected of having a traumatic pneumothorax should also be suspected of suffering from hemothorax as well.

Patients with hemothorax may or may not be hemodynamically normal. In the hemodynamically normal trauma patient, varying degrees of respiratory distress may be present, depending on the presence of concomitant pneumothorax, baseline pulmonary status, and size of the hemothorax. Hemothorax may be suggested on physical exam by identification of bruising and abrasions or a penetrating wound on the chest wall, palpable rib fractures, crepitus, or ipsilateral absent or distant breath sounds during auscultation. If the hemothorax is small and the trauma bay is noisy, identification of hemothorax in the hemodynamically normal patient might not occur until a chest X-ray is obtained as an adjunct to the primary survey. Since many trauma plain films are performed on supine patients, liquid blood in the thorax often spreads along the posterior thorax. This may appear on chest X-ray as subtle haziness if the hemothorax is small or total "white out" on the affected side if large. If the volume of blood is sufficient to pool posteriorly and laterally to the lung, an absence of lung markings at the lateral chest wall can be mistaken for a pneumothorax. If the chest X-ray is done with the patient sitting or standing, the hemothorax may be manifest as fluid at the costovertebral angle, and will be seen to displace a variable volume of lung tissue. Very small hemothoraces—and slightly larger hemothoraces in patients in which upright films are contraindicated—may not be identified until computed tomography is obtained for another indication. Ultrasonography has been shown to have similar sensitivity and specificity to plain films [26, 27] and some centers have, in fact, begun to extend the traditional FAST exam to the thorax in order to detect hemothorax and pneumothorax earlier in their initial trauma evaluation [28].

In the hemodynamically abnormal trauma patient, history, physical exam, and imaging findings will be similar to those findings noted above. However, as hemodynamic abnormalities with stigmata of thoracic injury will often prompt rapid needle decompression and tube thoracostomy for presumed pneumothorax, hemothorax may be diagnosed at the time of

those procedures. All chest tube output should be collected and measured as the sufficient blood volume lost can indicate operative thoracotomy. Post-procedural plain films are necessary to confirm adequate drainage of hemothorax or—in some cases—identify retained hemothorax.

Delayed hemothorax occurs seemingly exclusively in patients with rib fractures 2 or more days after injury. It can manifest in a variety of ways depending on patient factors and the briskness of the bleed. Symptoms range from mild exercise intolerance and chest discomfort to respiratory distress and hemorrhagic shock.

Management

Both unstable patients and hemodynamically normal patients with clinically evident hemothorax should receive large bore (36 or 40 Fr) tube thoracostomy early [29]. Once the chest tube is in place, initial and ongoing drainage must be monitored closely and a chest X-ray to confirm tube placement and complete drainage of the hemothorax must be obtained. The exact amount of chest tube output which defines a massive hemothorax varies per author and institution, but between 1 and 1.5 L initially or 125–250 cc/h over 4 h are generally accepted to indicate operative thoracotomy. However, there is no substitute for sound surgical judgment and patients who do not strictly meet these requirements may still require thoracotomy in the face of continued hemodynamic instability, sudden deterioration after precipitous drop in chest tube output, or other factors.

In the unstable hemothorax patient or patients in whom a massive hemothorax is suspected, application of an autologous transfusion collection device to the chest tube can be considered as an adjunct to the treatments already described. In a recent retrospective study of 272 trauma patients with hemothorax, the autologous transfusion group had no increase in complications vs. the non-autologous transfusion group (primary endpoint), and had statistically significant reductions in transfusion requirements (secondary endpoint) [30].

In the case of retained hemothorax after initial tube thoracostomy, as many as 15–30 % of patients may develop empyema or fibrothorax necessitating thoracotomy [31, 32]. Therefore, if post-procedural chest X-ray fails to confirm resolution of a hemothorax, some attempt to drain the retained hemothorax should be made. A second chest tube is advocated by some authors [33, 34] in an attempt to avoid surgical intervention. Video-assisted thoracoscopic surgery (VATS) for retained hemothorax as early as 48 h post injury for is being advocated more and more frequently as well [31, 35] though the more traditional practice of VATS in the 3–5 day timeframe is still practiced widely [32]. Regardless, as many as 25 % of patients may require more than one operation to clear the hemothorax [32]. Small studies have found that intrapleural fibrinolysis can be safe, effective, and lead to a reduction in the need for more invasive interventions [36, 37], but no level I evidence exists to support this practice [32] and concerns persist with regard to the use of this therapy in the multiply injured trauma patient, especially those with central nervous system injuries or concern for ongoing bleeding remote from the thorax.

Occult hemothoraces—those found only on computed tomography for another indication—are by definition too small to identify clinically or with plain film and can be safely monitored if the patient is otherwise doing well, no other indications for tube thoracostomy exist, and appropriate monitoring is possible [38].

As with most patients with thoracic injuries pain control, pulmonary toilet, and ambulation when possible are critical to the prevention of pulmonary complications such as atelectasis and pneumonia (Fig. 18.4).

Complications

Complications of hemothorax have been alluded to previously, and may include exsanguination and a tension component in the immediate phase. Retained hemothorax may result in empyema, fibrothorax, and may necessitate thoracotomy. Malpositioned or occluded (from kinking or coagulated blood) chest tubes may mask the true degree of bleeding and if not vigilant for such, a surgeon may make a fatal underestimation for thoracic bleeding.

Follow-up

Once the hemothorax has been shown to be resolved by imaging as well as by a change in character (to mostly serous) and the volume has fallen to an acceptable level, the chest tube may be safely removed provided no air leak is present. What constitutes "an acceptable level" varies greatly, though one prospective, randomized study showed that chest tubes can be removed with output volumes as high as 2 cc/kg without increasing need for secondary drainage procedures, thereby reducing hospitalization time [39]. Removal should be done as soon as it is judged safe as the pain associated with the tube can cause splinting and prevent adequate pulmonary toilet, predisposing to atelectasis and pneumonia. Many surgeons will obtain an upright chest X-ray 8–12 h after removal, though the practice is not universal and there is a paucity of evidence to prove this is necessary. A follow-up chest film 1–2 weeks after discharge may be warranted in some cases if there is reason for concern or if a VATS or thoracotomy was performed.

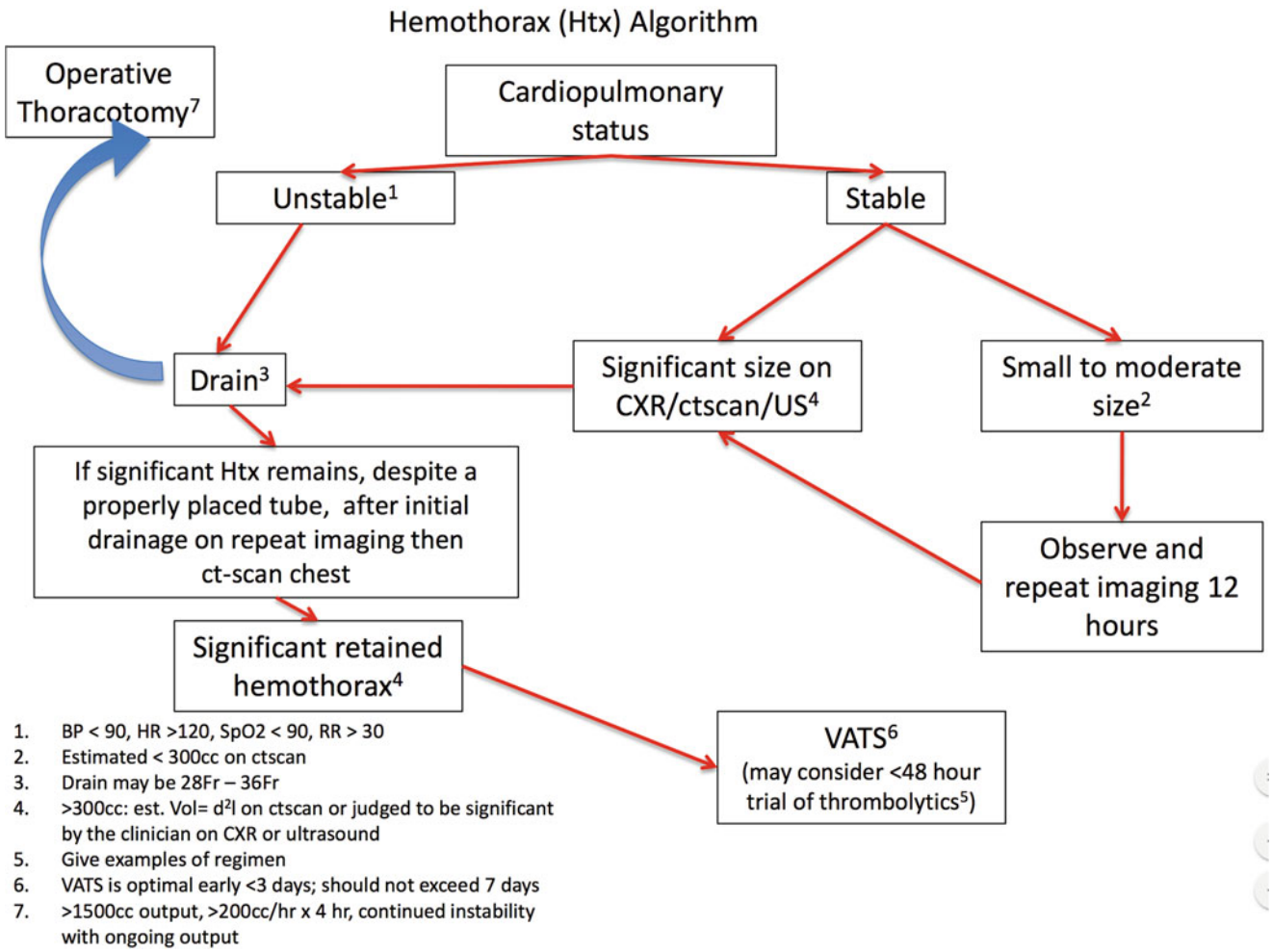

Fig. 18.4 Hemothorax management. (From Western Trauma Association, http://westerntrauma.org/algorithms/algorithms.html, and courtesy of Dr. Marc DeMoya.)

Empyema

Epidemiology

A study of 310 patients with major thoracic trauma to a major medical center showed that approximately 10 % of these patients developed empyema, and the diagnosis of empyema carried a 10 % mortality [40]. Another study [41] showed a 4 % rate of empyema in patients with retained hemothorax. Overall, retained hemothorax with seeding of collected blood through various routes (direct inoculation during tube thoracostomy, hematogenous/lymphatic seeding of bacteria, and a handful of other proposed routes) appears to be the most common cause of empyema in the trauma patient [42]. Other risk factors for post-traumatic empyema are long intensive care unit stays, higher injury severity, concomitant pulmonary contusion, and laparotomy [43].

The primary atraumatic cause of empyema is bacterial pneumonia with contamination of the pleural space (parapneumonic empyema), and risk is heightened with the various causes of infirmity and immunocompromise. Gram-positive organisms—primarily *Staphylococcus* species—are the most commonly isolated pathogens associated with empyema whether parapneumonic or post-traumatic. A significant portion of cases (30 % according to one study) has no identifiable causative organism [44].

Clinical Presentation and Diagnosis

The clinical presentation of empyema can be very subtle. The surgeon caring for patients with major chest trauma—especially hemothorax—must remain vigilant regarding the possibility of empyema, especially in those patients with multiple risk factors. As always, a thorough history and knowledge of the patient's clinical course is critical. The non-intubated patient may have productive cough suggestive of pneumonia or worsening pleurisy suggesting irritation of

the pleura beyond that of simple hemothorax. Vague constitutional signs and symptoms—fatigue, chills, rigors, night sweats, low-grade fever, unexplained mild tachycardia—may or may not be present. Breath sounds may be decreased and the chest may be dull to percussion. If there is still a chest tube in situ, the drainage may appear more purulent.

In an intubated patient, the findings may include some of the signs mentioned above. Other signs of uncontrolled infection—glucose intolerance and leukocytosis, for example—may be present as well. Ventilator weaning may stall or backslide. New or worsening opacities on chest X-rays may suggest empyema, and other clinical entities such as pulmonary contusion may obscure these findings. In a patient with suggestive findings whose clinical trajectory is unsatisfactory, computed tomography of the chest is indicated. This can better delineate pulmonary contusion from simple or infected fluid. In the later, fibrous, phase, a rind may be identified. Additionally, CT is helpful in identifying loculations, which may dictate video-assisted thoracoscopy or thoracotomy. Confirmation of the diagnosis should be made by sampling the fluid via simple thoracentesis or image-guided drainage. Because this procedure may be therapeutic as well as diagnostic, a pre-procedure discussion concerning the surgeon's preferences with regard to chest tubes and catheters is most helpful if an interventional radiologist is to be consulted.

Management

The goals of therapy in an empyema are to drain the infected fluid, obliterate the space in which the infected fluid accumulated via adequate lung inflation and approximation to the thoracic wall, and to treat initially with broad-spectrum antibiotics and narrow antibiotic regimen once culture sensitivities are obtained from this initial fluid sample. How these goals are achieved depends on the pathological stage of the empyema at the time of presentation. Because the less invasive (and less morbid) interventions are possible with earlier pathological stages, rapid source control is critical to arresting the disease in the earliest (and least morbid) phase.

The earliest phase in the natural history of empyema, the exudative phase, is characterized by a collection of sterile fluid, which collects in the pleural space secondary to pleuritic inflammation from whatever cause. In the case of retained hemothorax, undrained blood replace replaces sterile exudate as a culture medium. In either case, failure to adequately drain the fluid collection and treat underlying cause of the exudate may allow progression to the fibropurulent and fibrous stages. Drainage of the simple fluid or blood may abort the process in the early stages and can be achieved through tube thoracostomy and drainage appears to improve the clinical course despite the fluid's sterility. Large bore chest tubes (36 or 40 Fr) should be used in the case of hemothorax, though smaller percutaneous catheters are being used for simple fluid if still early in the process.

If the exudate or retained blood is not identified or adequately drained in a timely manner, it may progress to the fibropurulent stage, characterized by the presence of neutrophils in the exudate (which is thicker and more difficult to drain), possibly loculations, and the initial formation of a fibrous rind around the collection. The fluid or blood is no longer sterile at this stage. Though the lung tissue is still relatively mobile, adequate drainage must be obtained in order to prevent fibrous entrapment of the lung. A large bore chest tube is the initial step in managing an empyema known or suspected to contain thick fluid. Tube output is monitored closely and the patient is followed with chest X-rays as well. As with hemothorax, tissue plasminogen activator (TPA) instilled through the chest tube has shown promise in small, retrospective studies [23]. Intrapleural TPA is a reasonable next step if a well-placed, large bore chest tube fails to return fluid (initially or within the first 12–24 h) or chest X-ray fails to show resolution of the empyema, and there is no clinical improvement [45]. Failure of both thoracostomy and TPA indicates operative intervention, be it VATS or thoracotomy. Further, several groups have advocated early VATS in the treatment of fibropurulent empyema, some going so far as to advocate VATS the first line of treatment citing shorter chest tube time, shorter length of stay, and decreased operative blood loss [46].

The last stage in the evolution of empyema is the chronic or fibrous phase. The effusion has now formed a well-defined rind that may entrap the lung. Additionally, capillary ingrowth into the rind is now occurring in earnest or may even be complete in more advanced cases. Mere thoracostomy is unlikely to be helpful at this stage. VATS at this stage is possible if the surgeon is experienced in the procedure but later intervention appears to correlate with a higher conversion rate to thoracotomy, more chest tube days, and longer hospitalizations.

The question of which patients should receive VATS and which should receive thoracotomy is a matter of debate. Studies have shown equivalent or better outcomes with VATS compared thoracotomy, even in later stages [47]. Therefore the skill and experience of the operating surgeon, the patient's condition, and the known or suspected stage of the empyema should all be taken into account when deciding the best surgical approach. Regardless of the approach, however, the ultimate goals remain the same: drainage of the infected fluid, rupture of loculations, decortication of the rind, and complete release of the lung to allow full expansion and therefore obliteration of the potential space. Mechanical pleurodesis can be helpful as well, though the process of decortication may render this redundant.

Complications

If a pulmonary resection has occurred for any reason in the setting of empyema, the patient is at risk for bronchial stump leak. This is a severe complication that will possibly require specialized maneuvers such as intercostal muscle flaps and should be managed with the assistance of a thoracic surgeon if available. Additionally, critically ill, infirm, malnourished, or debilitated patients may be deemed too ill to undergo open thoracotomy or the one-lung ventilation needed for VATS. In these patients, open drainage of the empyema space to the skin in the form of an Eloesser flap may be indicated. In this procedure, a skin flap is raised in the axilla and an overlying rib is excised at that location. The skin flap is then sewn to the parietal pleura to allow drainage and ideally prevent the entrance of air. Such a procedure can provide drainage at the cost of a chest wound that will require local wound care, possibly indefinitely. Again, consultation with a thoracic surgeon is advisable in such a case.

Follow-up

Chest tube removal protocols in the treatment of empyema should mirror those in hemothorax. As mentioned in the previous section, chest tube output should be of acceptable volume and character before removal and absence of air leak should be documented before the chest tube is removed. One additional consideration in the case of empyema is that follow-up computed tomography may be helpful to rule out any undrained or recurrent loculations. Once the decision is made to remove the chest tube, this should be executed as soon as possible.

The duration of antibiotic therapy is an area seemingly ripe for investigation. One common practice among internists and medical subspecialists involved in the treatment of empyema appears to be several weeks of antibiotic therapy, including home intravenous antibiotics. Surgeons involved in the care of these patients often advocate ceasing antibiotics either at the time the last chest tube is removed or soon thereafter if there is reason to believe that no re-accumulation of fluid has occurred and the patient is clinically well (improving symptoms, afebrile, normal or normalizing white blood cell count).

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Acute Paraesophageal Hernia

19

David C. Gochnour

There are many types of diaphragmatic hernias. Diaphragmatic hernias are divided into those that are due to defects in the diaphragmatic musculature, and those that occur through the esophageal hiatus. Defects through the musculature include congenital hernias such as the Bochdalek and Morgagni hernias, defects due to blunt or penetrating trauma, and iatrogenic hernias after invasive procedures.

Hiatal hernias are classified into four categories based on the position of the gastroesophageal junction (GEJ) and the stomach or other viscera. A type I hiatal hernia, or sliding hiatal hernia, is the most common; comprising 85–95 % of all hiatal hernias. It is defined as the gastroesophageal junction and gastric cardia moving above the diaphragm into the posterior mediastinum. Type II, III, and IV hiatal hernias are collectively referred to as paraesophageal hernias (PEH). A type II hiatal hernia is defined as the displacement of the gastric funds through the hiatal defect alongside a normally positioned gastroesophageal junction. A type III hernia is similar, except that the gastroesophageal junction is displaced along with the gastric fundus. Type IV hernias are those with a large majority of the stomach, or other viscera, such as the transverse colon or spleen, are displaced into the thorax. Other terms are often used to describe large hiatal hernias. When more than 1/3 of the stomach is displaced into the thorax, it is often referred to as a "giant paraesophageal hernia." "Intrathoracic stomach" is a term used when 75 % or more of the stomach is in the chest (Fig. 19.1).

This chapter will focus primarily on paraesophageal hernias (types II–IV), since these are the hernias that present acutely. Many of these hernias could also be described as "giant paraesophageal hernias" or "intrathoracic stomach." The acute paraesophageal hernia is relatively rare, but can lead to significant morbidity and mortality if not managed appropriately. This is complicated by the fact that most patients with this condition are elderly with other medical comorbidities that increase their perioperative risk. Because of this, it is imperative that the acute care surgeon be familiar with the presentation, diagnosis, and management of acute paraesophageal hernia.

Epidemiology

Given that the vast majority of patients with hiatal hernia are asymptomatic, the true incidence of hiatal hernia is difficult to elucidate. There is wide variation in the reporting of the incidence of hiatal hernia, with incidences ranging from 10–70 % depending on age. Asymptomatic patients are generally diagnosed only after an incidental finding on routine imaging for other complaints, making a true incidence almost impossible to determine. Generally, it is believed that 85–95 % of hiatal hernias are Type I, sliding hiatal hernias, with the remaining 5–15 % encompassing all other types (Type II–IV) [1–4]. They are usually found in middle-aged to elderly patients, who often suffer from other medical comorbidities.

The rate at which patients with paraesophageal hernia progress to an acute presentation remains unclear. Hill et al. published a series claiming up to 30.4 % of paraesophageal hernias eventually result in acute presentation with obstruction, strangulation, volvulus, and/or perforation. In this report, the authors are specifically addressing "true" paraesophageal hernias (type II), where the GEJ remains fixed within the abdomen [3]. However, the incidence of acute presentations for all hiatal hernias is difficult to determine, mostly due to varying definitions of the type of paraesophageal hernia and discrepancies in how the position of the gastroesophageal junction is determined. In contrast to Hill's published series, Maziak and Pearson published their experience and claim that most acute presentations are actually mixed, Type III hernias. They base these claims on their observations of significant preoperative reflux symptoms in their population as

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_19

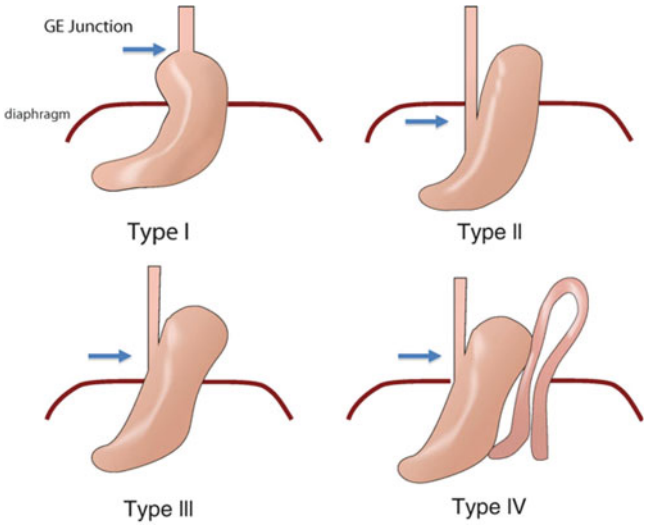

Fig. 19.1 Paraesophageal hernia types. A type I hernia is characterized by an upward dislocation of the gastroesophageal (GE) junction and the cardia of the stomach through the attenuated phrenoesophageal ligament into the posterior mediastinum. A type II hernia occurs when the fundus herniates through the hiatus alongside a normally located GE junction. In a type III hernia, the GE junction, cardia, and fundus of the stomach are all intrathoracic. In a type IV hernia, other organs such as the colon, small bowel, or spleen herniate into the chest along with the GE junction and stomach

well as their belief that endoscopy more accurately localizes the position of the GEJ [4, 5]. What can be concluded is that acute presentations are relatively rare, and usually involve type II and type III hiatal hernias.

Hiatal hernias develop primarily due to weakening of the phrenoesophageal ligament and increases in intraabdominal pressure. The primary risk factors for paraesophageal hernia are age and obesity. Obesity increases hiatal hernia risk due to increases in intraabdominal pressure, which progressively increases with a patient's body mass. In a recent meta-analysis, the odds ratio for patients with a body mass index (BMI) >25 for hiatal hernia was 1.93 (95 % confidence interval 1.10–3.39). In the same meta-analysis, the prevalence of hiatal hernia doubled in patients over the age of 50 [6]. This is likely due to fibromuscular degeneration of the phrenoesophageal ligament and the loss of elastic properties of the structures surrounding the hiatus. Other risk factors include kyphosis, scoliosis, and pectus excavatum; all of which can increase intraabdominal pressure and distort diaphragmatic anatomy. Previous gastroesophageal surgery is also a risk factor due to the disruption of the phrenoesophageal ligament and its relationship to crural structures [7].

Though it is difficult to determine the exact incidence of acute paraesophageal hernia, there does seem to be some consistency to the risk factors for its occurrence. Most studies show a preponderance for type II paraesophageal hernia, where the GEJ remains anchored in the peritoneal cavity, or large mixed type (type III) hernias where the fundus moves superior to the sliding gastroesophageal junction. This anatomic situation leads to incarceration of the gastric funds and/or volvulus, both of which have the potential to lead to obstruction, the formation of Cameron's ulcers (erosions or ulcerations of the mucosal folds lining the stomach where it is constricted by the thoracic diaphragm) with subsequent hemorrhage, or ischemia [2, 3, 8].

Pathophysiology

Attenuation of the phrenoesophageal ligament leads to formation of paraesophageal hernias. However, the exact etiology leading to attenuation is unknown. There are familial occurrences that suggest an autosomal pattern of inheritance, however most hiatal hernias are diagnosed in the elderly; making degeneration of the ligament a likely cause, especially when augmented by conditions that cause increases in intraabdominal pressure.

The phrenoesophageal ligament is a continuation of the transversalis and endothoracic fascia and contains ascending and descending leaflets. It is composed of elastic and collagen fibers that insert onto the esophagus just above the gastroesophageal junction. In normal subjects, the ligament bridges the space between the esophagus and the hiatal margin and inserts above and below the diaphragm with multiple additional anchoring fibers between the endothoracic and transversalis leaflets.

Attenuation of the phrenoesophageal ligament can lead to formation of a hernia sac in which intraperitoneal contents are able to migrate into the posterior mediastinum. It is believed that degeneration is due to loss of elastin and collagen fibers. Curci et al. conducted a histological study comparing tissue samples from patients with gastroesophageal reflux disease (GERD) alone and those with GERD and hiatal hernia. They found that those patients with hiatal hernia had >50 % reduction in collagen and elastin fibers [9].

In acute presentations of PEH, the widening of the hiatus along with the attenuation of the phrenoesophageal ligament allows the gastric fundus to herniate into the mediastinum. The esophagus is anchored posteriorly in the hiatus, and attenuation is most pronounced lateral and anterior to the esophagus. Regardless of whether the hernia is a pure, type II PEH, or a large, mixed, type III PEH, if the gastric fundus is able to displace superior to the GEJ, then incarceration, obstruction, or volvulus is more likely to occur. In cases of incarcerated type II hernias, the fundus can become distended and protrude out of the mediastinum, and back into the abdominal cavity, causing obstruction at the duodenal, mid-gastric, and esophageal levels [8].

In large type III hernias, Marziak et al. noted that 50 % of the patients had organoaxial volvulus at the time of operation. They describe this process as being a result of displacement of the funds superior to the GEJ. When distended, volvulus is likely to occur, causing obstruction.

Incarceration can potentially lead to other life threatening complications such as UGI hemorrhage and perforation. Cameron's ulcers are linear erosions found on the mucosal folds along the diaphragmatic impression in those with hiatal hernia [10]. They are prevalent in approximately 5 % of patients with hiatal hernia discovered during endoscopy. There is some debate whether this pathology is caused by mechanical trauma and ischemia, as initially proffered by Cameron, or whether the insult is due to acid related injury. It is likely that both etiologies contribute to the formation of the lesions since studies have shown both ischemia in the lesions and improvement with the use of acid suppression therapy [11, 12]. Cameron's ulcers have the propensity to lead to chronic anemia, as well as significant UGI hemorrhage, requiring acute surgical management. Perhaps the most worrisome complication is gastric perforation. Vascular congestion due to incarceration, as well as frank ischemia, has the potential to lead to acute perforation. Cameron's ulcers may become full thickness, leading to perforation as well.

Clinical Presentation

As stated previously, most hiatal hernia patients are asymptomatic. Non-acute, symptomatic patients most commonly present with vague complaints of postprandial fullness, pain, or heartburn. Typical patients are elderly; most commonly older than 50 years of age. Larger hernias may elicit complaints of progressive intolerance to solids or liquids, nausea, vomiting, or regurgitation. More subtle or atypical findings include chronic anemia due to ulceration, or symptoms of dyspnea related to restrictive lung disease. Chronic reflux or regurgitation may lead to chronic cough, frequent pulmonary infections, laryngitis, or pharyngitis.

Patients with acute paraesophageal hernia present with symptoms of obstruction, UGI hemorrhage, or sepsis. Obstructive symptoms predominate and are summarized with Borchardt's triad of (1) severe epigastric pain (2) intractable retching without emesis (3) inability to pass a gastric tube. While one or all of these criteria may be different or not present at all, it is a good description of the obstructive process. Pain is almost universally present. The classic description of retching without emesis is predicated on a complete obstruction that does not allow reflux into the incarcerated fundus. Many patients will have intractable nausea with emesis (usually non-bilious) and still require urgent diagnosis and management. These symptoms are also found in acute patients that present with volvulus since both volvulus and incarceration lead to obstructive physiology.

In addition to obstructive symptomatology, patients may present with UGI hemorrhage or perforation. These presentations may or may not be accompanied by obstructive symptoms and may also include life threatening conditions such as hemorrhagic shock and sepsis. Whatever the chief complaint may be, many of these patients present acutely ill, and may manifest signs and symptoms of shock or profound dehydration to include overt sepsis and acid base disturbances.

Diagnosis

The diagnostic workup for paraesophageal hernia is dependent upon the acuity of presentation. Those patients with symptomatic, non-acute paraesophageal hernia are generally evaluated in a similar fashion as reflux patients. This workup includes a number of studies, each with their own diagnostic utility. They are as follows:

Upright chest X-ray: classically will demonstrate an air fluid level above the diaphragm and behind the cardiac silhouette.

Upper gastrointestinal series: Dynamic radiographic study that utilizes barium or water-soluble contrast to examine the oropharynx, esophagus, stomach, and proximal small bowel. It provides valuable information about oropharyngeal function, the morphology of the esophagus, the character of the GEJ and the presence of reflux, gastric function, and emptying into the duodenum.

Upper Endoscopy: Allows the surgeon to directly view the upper gastrointestinal tract and can provide information on esophageal pathology such as Barrett's esophagus, strictures, or achalasia. Upper endoscopy provides for the visualization of the gastric and duodenal mucosa so that other pathologies such as neoplasm, ulceration, or ischemia can be excluded. Most importantly, it allows the surgeon to observe the gastroesophageal junction in real time and see firsthand the status of the hiatus and the position of the GEJ relative to the diaphragm.

Esophageal manometry: A study that places pressure monitors within the esophagus to measure the pressure profiles of peristalsis, as well as the lower esophageal sphincter (LES). A resting LES pressure of <5 mmHg has been highly associated with gastroesophageal reflux. It also identifies patients whose symptoms are due to esophageal dysmotility rather than acid reflux.

pH studies: There are two methods available to measure intraesophageal pH. The intraluminal pH probe or wireless Bravo pH probe (Medtronic, Minneapolis, MN). Either study provides the surgeon with data on esophageal acid exposure. Patients are able to log symptoms, providing

correlation between acid exposure due to reflux and the symptoms they are experiencing.

Patients who present acutely are usually diagnosed with CT scan. This is likely due to the common presenting complaint of severe epigastric pain. Many of these patients are critically ill and require rapid diagnosis and concomitant resuscitation of vital functions, while definitive diagnosis is achieved. CT of the abdomen can provide valuable information in addition to the presence of hiatal hernia. It gives the surgeon an idea of the volume of stomach in the posterior mediastinum, and is usually able to detect the presence of volvulus. It can provide some evidence as to the significance of incarceration or ischemia by demonstrating gastric wall thickening and evidence of perforation demonstrated by free air and/or perigastric fluid [13]. If CT of the abdomen demonstrates an acute paraesophageal hernia, no further imaging or functional studies are needed prior to management.

Laboratory analysis is primarily helpful for resuscitation. A leukocytosis may be a harbinger of ischemia or perforation, but is not specific. A baseline hemoglobin may be used for monitoring resuscitation measures, especially in cases presenting with upper gastrointestinal hemorrhage. A basic chemistry panel can alert the surgeon to the sequela of organ failure or acid base disturbances and is also used for monitoring resuscitation.

Management

As should be the case with all acutely ill patients, the initial priorities are stabilization and support of vital functions. A patent airway should be confirmed or established and adequate oxygenation and ventilation ensured by means of a ventilator if needed. The hemodynamic status of the patient should be promptly assessed and managed with volume resuscitation using isotonic crystalloids, blood products as needed, and vasopressor support if necessary. These vital functions should be managed before and during the diagnostic workup.

Patients that present with acute paraesophageal hernia can be divided into those who are acutely incarcerated or obstructed and those who are simply symptomatic. Those who are simply symptomatic can generally be reassured and managed as an outpatient after an appropriate workup has been completed. Those who are acutely incarcerated or obstructed are further subdivided by the ability to pass an endogastric tube and decompress the stomach. This distinction is important because up to 50 % mortality has been reported with emergent repair. Acutely incarcerated hernias are usually complicated by bleeding, strangulation, and/or perforation [1, 4, 14–17]. A recent analytical model published by Stylopoulos et al. questions the historically high mortality with a calculated mortality risk of emergency surgery of 5.4 % (CI 4.9–5.8 %) [18]. Despite the possibility of a decreased mortality risk, it remains prudent to avoid emergency surgery unless indicated. The operative decision making process guides the surgeon as to when and how to intervene.

The first determination to be made is whether the patient is acutely incarcerated or volvulized. Those who are not acutely obstructed or volvulized can be managed electively after a complete evaluation of their hernia and optimization of their comorbidities. Those patients that are found to be acutely incarcerated or obstructed require more urgent intervention. As described previously, they should initially be resuscitated and attempts at gastric decompression should be made (Fig. 19.2). If the patient is able to be decompressed, then repair can be delayed until the patient has been completely resuscitated and all medical comorbidities optimized. Usually, definitive surgical repair is offered during the index admission, or soon thereafter. For those who cannot be decompressed, urgent surgical management is warranted depending on the clinical situation [19]. The patient's vital functions should be resuscitated prior to operation, but there may not be enough time available to completely optimize other comorbidities.

Classically, hiatal hernias were repaired through a thoracotomy or laparotomy. More recently, laparoscopic repair has emerged as a safe and efficacious approach that allows for rapid recovery, decreased morbidity, and shorter length of hospital stay [19–23]. The robotic platform has also proven to be a reliable approach with similar benefits of laparoscopy, with the added benefit of improved articulation with wristed instruments and a stable camera platform. There are a number of questions that remain regarding optimal repair and prevention of recurrence. Despite these questions, the basic tenets of repair are as follows:

1. *Appropriate placement of trocars*: If a minimally invasive approach is utilized, most cases will require five ports: three working ports, a camera port, and usually a fifth port location for liver retraction. The ports are placed to triangulate the working area, and vary in configuration. It is important to remember that the diaphragm and hiatus will move cephalad after insufflation, and one must take care not to place the ports too low. The patient should be placed in a reverse Trendelenburg position to facilitate access to the foregut.
2. *Complete reduction of the stomach and hernia sac*: The stomach should be gently pulled out from the hiatus into an intraabdominal position. Often, due to scarring, this is difficult to achieve. In this instance, it is prudent to approach this problem by completely reducing the hernia sac. The hernia contents will reduce from the hernia cavity with the sac. If possible, begin by using an energy

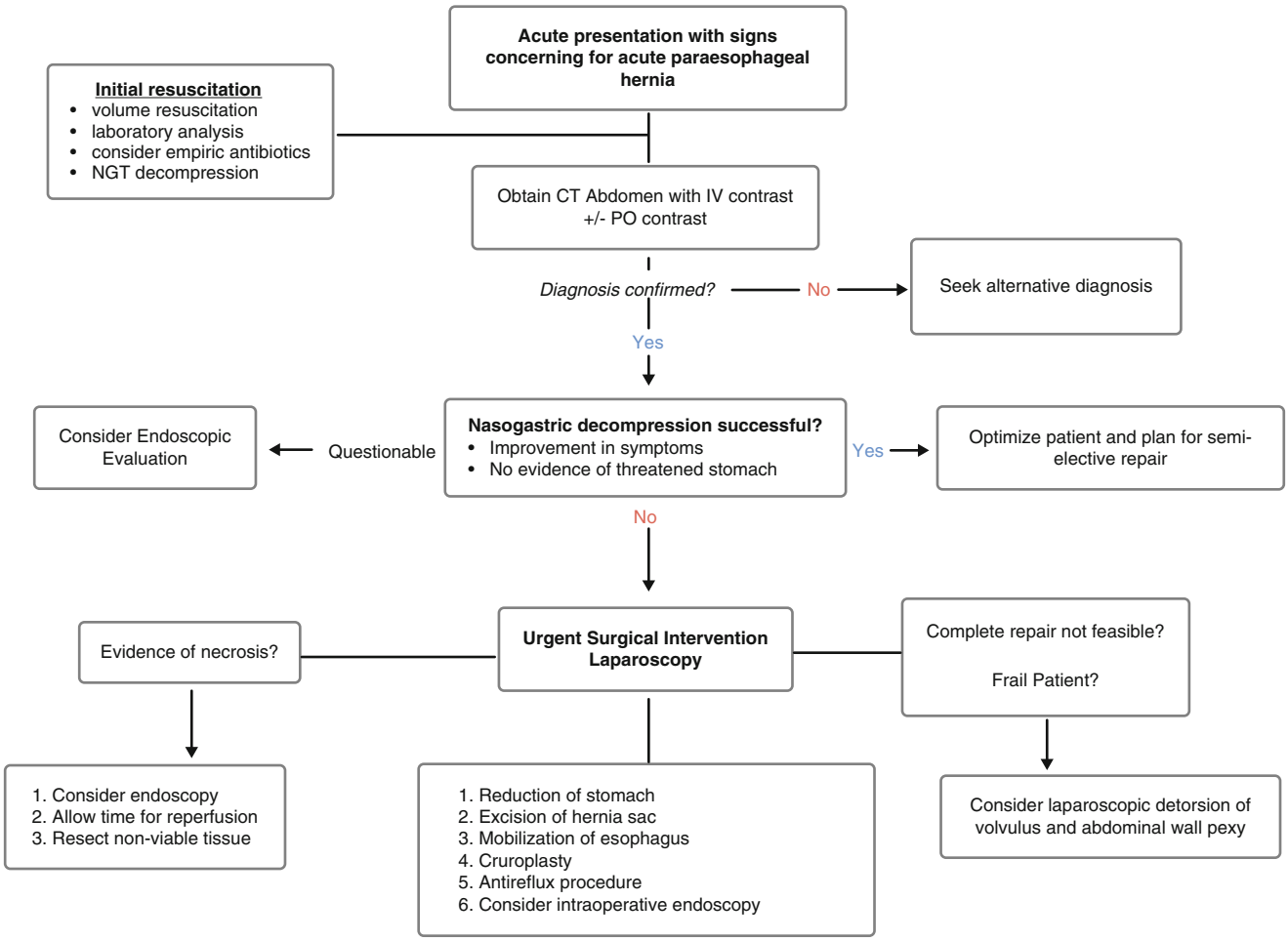

Fig. 19.2 Algorithm for acute paraesophageal hernia

device to divide the short gastrics, beginning at the inferior pole of the spleen. The dissection is carried toward the hiatus, until the left crus is encountered. The hernia sac is separated from the muscular crus and divided. The sac can then be retracted into the abdominal cavity and dissected in the avascular plane between the sac and the hernia cavity within the posterior mediastinum. This dissection is accomplished using blunt dissection and sparing use of an energy device. The dissection is then carried toward the anterior aspect of the hiatus. The right crus is approached by bluntly dividing the pars flaccida. The hernia sac is divided from the right crus in a similar fashion as was the left crus. This dissection is carried through the anterior aspect of the hiatus, where it joins with the previous dissection. The dissection is then carried posteriorly, dividing all attachments between the hernia sac and the aorta. This can be facilitated by encircling the distal esophagus with a Penrose drain to assist with retraction. The dissection is complete when the entire hernia sac and its contents are reduced into the abdominal cavity and the hiatus is cleared circumferentially, to include clear exposure of the decussation of crural fibers posteriorly.

3. *Evaluation of incarcerated stomach*: Incarcerated stomach is at risk for ischemia and possible perforation. While the stomach has a robust blood supply, the potential for irreversible ischemia is present. The stomach should be examined closely using the laparoscope and intraoperative endoscopy. Partial gastrectomy of non-viable stomach should be performed if ischemia persists after and adequate amount of time is provided to allow for reperfusion.
4. *Mobilization of the esophagus*: The esophagus should be mobilized free from the mediastinum using blunt dissection and the energy device to divide the adhesions between it and the hernia cavity. It is prudent to have a bougie or 34–36 F orogastric tube to help in identification of the esophagus. 2–3 cm of distal esophagus should lie within the abdominal cavity without the aid of retraction. Care should be taken to avoid injury to the vagus nerves or the esophagus. This can be challenging in patients with a chronically incarcerated stomach.

5. *Tension free approximation of the crura*: Using interrupted sutures, approximate the crura with non-absorbable suture. These sutures should be placed every 5 mm–1 cm until the crura are brought together around the distal esophagus. Another option is to use figure of eight sutures in the place of simple interrupted sutures. Anterior sutures are placed selectively to avoid acute angulation of the distal esophagus. It is important to incorporate robust tissue, preferably with remaining peritoneum, to avoid the sutures tearing through tissue that is often attenuated. Some surgeons prefer to use pledgeted sutures to avoid this scenario. Others perform mesh cruroplasty to reinforce the repair and further alleviate tension.
6. *Antireflux procedure*: With the exception of pure type II hernias, patients will require an antireflux procedure. This is accomplished by performing a 360° Nissen fundoplication or a 270° Toupet fundoplication. It is important to include bites of the esophagus with either procedure to avoid herniation of the stomach through the wrap.
7. *Intraoperative endsocopy*: Endoscopy is used to confirm patency of the distal esophagus after the performance of an antireflux procedure. It is also useful early in the operation, when there is concern for ischemic stomach, to examine the mucosa and evaluate for the presence of Cameron's ulcers.

In addition to the basic tenets of successful paraesophageal hernia repair, there are a number of adjuncts that have been the subject of controversy. These include esophageal lengthening procedures, mesh cruroplasty, relaxing incisions, and the use of anterior abdominal pexying or gastrostomy tube placement.

The use of an esophageal lengthening procedure should be considered when less than 3 cm of intraabdominal length can be obtained in order to reduce axial tension on the hiatal repair [24]. In current practice, this can usually be achieved laparoscopically using a wedge fundectomy technique with a laparoscopic linear stapling device [25]. A point is marked 3 cm below the angle of his along the lesser curvature of the stomach. It is imperative to have a bougie or calibration tube in place when performing this procedure. The fundectomy is begun by dividing the fundus with an articulated stapler aiming toward the angle of his. The staple line is then continued toward the mark made 3 cm below the angle of His. At this point, the staple line is carried through the angle of His, along the bougie, completing the fundectomy. The neo-fundus is then used to perform the fundoplication.

Mesh cruroplasty has been shown to reduce intrathoracic recurrence in a number of trials [26, 27]. However, these improvements have been questioned with longer term follow-up [28, 29]. While many surgeons perform mesh cruroplasty routinely, others only use this adjunct selectively in those cases where the crura are obviously under tension. Most studies advocate the use of absorbable mesh due to concern over mesh related complications such as dysphagia and esophageal erosions. There are some that continue to use prosthetic mesh with minimal complications, but prospective studies are lacking. Mesh cruroplasty performed by bridging crural gaps should not be performed. The complications associated with prosthetic mesh in this manner are prohibitive and recurrence is almost assured with absorbable mesh.

Often, in very large hiatal hernias, the crura are unable to be reapproximated. In this situation, a crural relaxing incision can be made to allow for tension free approximation of the crura. The simplest relaxing incision is made between the vena cava and the right crus. A full thickness incision is made through the diaphragm, allowing for a cuff of tissue medial to the vena cava for suturing of mesh. This is generally carried vertically between the decussation of crural fibers and the anterior crural vein for approximately 1.5 cm. This defect is then repaired using PTFE graft. It is rare for this relaxing incision to be insufficient for crural closure. However, in that case, a left relaxing incision is made. This is also a full thickness incision that follows the inferior aspect of the 7th rib and carried laterally. This allows significant medialization of the diaphragm, and is also repaired using PTFE graft [30].

There are a number of case reports concerning the use of anterior abdominal wall gastropexy or use of a gastrostomy tube to anchor the fundus to the anterior abdominal wall in an attempt to prevent recurrence. There are various methods described to achieve fixation. When using suture gastropexy, most advocate anchoring the funds to the abdominal wall, with an additional gastropexy performed at the left crus. Most would agree that a full hiatal hernia repair operation should be completed if possible. These case reports usually involve patients who are elderly and believed to be unable to tolerate a full paraesophageal hernia repair due to their extensive comorbidities or clinical condition. The results seem to be acceptable, but there is little follow-up and no comparative studies. However, it is reasonable to assume that most patients who are able to tolerate pneumoperitoneum, reduction, and gastropexy will likely also be able to tolerate a complete repair. There does seem to be utility in this approach when volvulus occurs outside the presence of a hiatal hernia and is due solely to laxity of the gatrosplenic and gastrohepatic ligaments. There are benefits to selectively using a gastrostomy as part of a complete hiatal hernia repair. In many patients with an intrathoracic stomach, the function

of the stomach is compromised with delayed gastric emptying when returned to an intraabdominal position. Placement of a gastrostomy tube allows for periodic venting of the stomach when patients have severe distention. It also serves as a potential feeding conduit in extreme cases.

Postoperative Management and Complications

Postoperatively, patients should be admitted to an appropriate surgical ward or intensive care unit as their clinical condition dictates. There is no need for routine use of nasogastric decompression, although many will maintain decompression for 2–3 days if an esophageal lengthening procedure or partial gastrectomy has been peformed, in order to prevent tension on the staple line. Most patients are able to be started on a clear liquid diet postoperative day 1 or 2. There are numerous protocols for advancement of diet, with most involving a gradual advancement from full liquids to a regular diet over 4–6 weeks. It is important to allow sufficient time for edema and swelling to subside within the wrap before challenging the repair with solid food. Continuing a liquid diet helps to avoid dysphagia and distention that can lead to retching and vomiting and compromise the repair. The use of routine postoperative upper gastrointestinal imaging is not mandated and is obtained according to surgeon preference. It is likely prudent to obtain these studies prior to initiating diet for complex cases with extensive esophageal dissection or if the stomach required division for esophageal lengthening or resection of ischemia.

Patients should be ambulated early in their postoperative course and appropriate deep venous thrombosis prophylaxis initiated. Continued management of preoperative comorbidities such as diabetes, hypertension, and COPD should be initiated as soon as clinically feasible. Oral medications can be used, however, it is recommended to crush pills if able, and transition to elixir regimens when possible. Discharge is considered when the patient is tolerating a full liquid diet without significant distention or dysphagia, their pain is well controlled with oral analgesia, and they are able to ambulate and perform their activities of daily living with available assistance.

Conclusion

In conclusion, the management of acute paraesophageal hernia is complex and challenging and is usually needed in a patient population that is difficult to manage at baseline. There is little quality data published on this topic, and experience seems to be the primary driver for management guidance. The keys to successful management include accurate diagnosis, identification of those patients who require immediate surgical intervention, and optimization of those patients who can be decompressed and operated on later in their course. While there are a number of contentious topics concerning optimal repair, the primary tenants include (1) reduction of incarcerated stomach and complete excision of the hernia sac (2) evaluation of incarcerated contents with resection as needed (3) adequate esophageal mobilization with or without an esophageal lengthening procedure (4) tension free approximation of the crura and (5) performance of an antireflux procedure. There are many surgical approaches to achieve these ends, however, transabdominal minimally invasive approaches have emerged as the gold standard with decreased morbidity and more rapid recovery.

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Peptic Ulcer Disease for the Acute Care Surgeon

20

Sherry L. Sixta and Millard Andrew Davis

Peptic ulcer disease (PUD) was not well elucidated as a significant contributor to patient morbidity and mortality until the early 1900s. From that time up until the late twentieth century, PUD was felt to be caused by stress and dietary factors, with treatments focusing on dietary modification, bed rest, and later on, acid suppression and neutralization [1–3]. With the discovery of *Helicobacter pylori* in the 1980s and the subsequent development of improved medical regimens to treat the organism and suppress acid production, the incidence of PUD has decreased dramatically over the past 30 years [4]. Furthermore, data gathered from multiple countries within the same time period reveals a 40–50 % global decline in incidence [5–7]. In accordance with the trend of successful medical management, surgeons have seen a steady decline in the rate of elective surgery for PUD over the past three decades. Procedures that were once common have become a rarity for today's surgical residents to encounter. However, though the rate of elective interventions has declined dramatically (80–97 %), the rate of emergency surgery related to PUD has remained constant or increased [6, 8]. Wang et al. reported a 44 % increase in emergent operative interventions related to PUD from 1993 to 2006, and in 2006, there were nearly 25,000 operations performed in the USA alone for perforated or bleeding peptic ulcers. With the evolution of therapeutic modalities for the treatment of PUD, including pharmaceutical advancements and endoscopic therapies, surgical interventions have become more salvage in nature. The majority of surgical indications for PUD are now limited to complications from hemorrhage or perforation that have failed medical and minimally invasive interventions. Less frequently, surgical interventions are sought for rare causes of PUD such as gastrinoma or Zollinger–Ellison syndrome (ZES), antral G-cell hyperplasia, trauma, or burns. Elective operative gastric procedures, though rare, are primarily for lesions suspicious for malignancy or refractory PUD due to failed medical therapy, patient intolerance, or noncompliance [9]. Undoubtedly, the next generation of acute care surgeons will be called upon to manage the urgent and emergent complications of PUD, on a much more complicated population of patients, with significantly less experience than generations prior. The goal of this chapter is to provide a brief overview of the pathophysiology, epidemiology, and presentation of PUD with a more in-depth description of the management and operative techniques as they relate to the acute care surgeon in urgent and emergent situations.

Epidemiology

It is estimated that 1 in 10 Americans are plagued with symptoms related to PUD, with an overall 2 % prevalence in the USA. The majority of patients who endure complications secondary to PUD are 70 years of age or older, and the rate of complications is estimated to be from 2 to 10 % [10–12]. The prevalence of disease is 1.5 times greater in men than women. Yet in regard to the rate of perforation, data from the USA reveals a rise in the female population and an overall decline in the male population [7, 13]. This is thought to be secondary to nonsteroidal anti-inflammatory drug (NSAID) use and smoking patterns [14]. Duodenal ulcers are more common than gastric ulcers, and are more likely to be the source of PUD in younger patients. However, there has also been an association established implicating increased risk of duodenal ulceration with chronic lung, liver, and pancreatic disease processes [13, 15]. Gastric ulcers account for only 5 % of all PUD, yet more operative interventions are needed for gastric ulcers than for duodenal ulcers. Additionally, gastric ulcers are more frequently associated with the elderly, and are therefore associated with a higher mortality rate [16, 17].

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_20

Despite the overall decline in PUD over the past 30 years, the rate of emergent operative intervention for bleeding, obstruction, or perforation has remained relatively unchanged in the USA. Moreover, there is data out of European countries that may reveal an actual increase in need for emergent operative interventions. There is an overall decrease in the prevalence of PUD in developed countries due to advances in pharmaceutical technology and sanitation that have significantly reduced the *H. pylori* infection rate [5, 6]. However, when considering the increased overall usage of NSAIDS in an increasingly older population, the explanation for the relative lack of improvement in the frequency of operative intervention becomes evident.

Anatomic Considerations

Peptic ulcers have characteristic anatomical occurrence patterns. Ninety-five percent of all duodenal ulcerations are located within 2 cm of the pylorus in the first portion, or the bulb, of the duodenum. These lesions are almost always non-malignant disease processes. There are five different classifications of gastric ulcers according to the most commonly used classification system, the Modified Johnson classification system. Type I ulcers occur along the lesser curvature of the stomach near the incisura angularis, and 60 % of these are located within 6 cm of the pylorus [15]. Type II ulcers are pre-pyloric gastric ulcers. They occur in association with duodenal ulcers and are often referred to as "kissing ulcers." Type III gastric ulcers are located in the antrum or pre-pyloric region. Type IV ulcers are located near the gastroesophageal junction, on the proximal lesser curvature. Type V ulcers are the newest category: lesions that are secondary to NSAID or aspirin usage. They can be located anywhere throughout the stomach. Ninety-five percent of gastric ulcers are also benign in nature. Even giant ulcers, lesions greater than 2 cm, which were once thought to be malignant, are now known to be benign processes in 90 % of patients. Ulcers located in the fundus of the stomach are very rare; however, these lesions should elicit concern as most are malignant [18].

Pathophysiology

Although there may be numerous factors that contribute to the development of gastroduodenal mucosal breakdown, we now recognize that the majority of gastroduodenal ulcerations are caused by *Helicobacter pylori* (*H. pylori*) infestation, NSAID use, or a combination of the two. 75 % of patients with gastric ulcers and 90 % of those with duodenal ulcers are infected with *H. pylori,* yet only 15–20 % of people colonized with the bacteria will develop PUD in their lifetime [14]. Greater than half of patients with PUD report recent NSAID use [18, 19]. Additionally, several studies have demonstrated a cumulative effect of cigarette smoking with H. pylori that leads to an increased risk of complicated PUD [20, 21]. The overall mechanism of ulcerogenesis results from the inability of the mucosal barrier to protect the gastroduodenal mucosa from acidic gastric secretions [22]. There are multiple factors that have been associated with mucosal injury and excessive acid secretion including smoking, psychological stress, alcohol, drugs (including aspirin and cocaine), and various environmental associations [2].

The treatment philosophy for PUD was historically "no acid no ulcer." It remains a viable statement since acid suppression is the key management strategy to the promotion of healing. Prior to our understanding of the role of *H. pylori* and NSAIDs in ulcerogenesis, therapy was long-standing and consisted of avoidance of known ulcerogenic stimuli such as caffeine, smoking, and alcohol along with pharmaceutical management to relieve symptoms. Surgical intervention, such as antrectomy and vagotomy for acid suppression, was then used if relief was not obtained from conservative measures. Pharmaceutical therapy consisted of antacids, H2 blockers (introduced in the late 1960s), and various oral cytoprotective agents. Proton pump inhibitors (PPIs) were not introduced until the late 1980s. In 1984, Marshall and Warren published their discovery of "an unidentified curved bacillus in the stomach of patients with gastritis and peptic ulcerations," eventually known as *Helicobacter pylori* [23]. Multiple trials over the following several years established the etiology of *H. pylori* in PUD. Subsequently, evidence demonstrated that a short treatment course with antibiotics and antisecretory agents resulted in a cure for the majority of ulcers without recurrence [24–27]. In 1994, the National Institute of Health Consensus Conference officially recommended the medical eradication of *H. pylori* as the primary therapy for PUD [28].

It is now understood that *H. pylori* infection results in the alteration of gastric acid secretion that is observed in PUD. If the infection is localized primarily in the antrum, an impairment and alteration in the negative feedback loop results in increased acid productivity. The ultimate outcome is an increased prevalence of pre-pyloric and duodenal ulcers. Patients that have a global infection of the gastric mucosa consistently have decreased acid secretion in response to the chronic inflammation within the gastric body. This leads to impaired protective function of the gastric mucosa resulting in ulcer formation [2].

In regard to NSAIDs, as well as aspirin, the mechanism of insult is related to the inhibition of prostaglandins by both of these classes of drugs. Prostaglandins act to increase mucous secretion and bicarbonate production as well as to modulate the blood flow to the mucosal tissue [29]. The inhibition of the mucosal defense mechanisms along with decreased blood flow and impaired healing leads to the direct correlation of both

NSAIDs and aspirin with ulcer formation. In concordance, there is an additional synergistic effect that occurs in patients with underlying *H. pylori* infection that also take anti-inflammatory medications. The protective function of the mucosa is further weakened leading to increased ulcerogenesis [30]. The majority of gastric and duodenal ulcers are attributable to one or both of these two pathogens in combination. Taking this into account, it would be prudent to say that the majority of ulcerogenesis can be contributed to treatable or avoidable causes that can be managed medically [31]. Therefore, the current surgical approach in elective and emergent management of PUD has become reflective of this treatment philosophy.

Medical Management of Peptic Ulcer Disease

If PUD is in the differential diagnosis for a patient in accordance with symptoms or the chief complaint, a complete history and physical should focus on the cause or confounding factors associated with the disease process. Medical management can then focus on addressing these factors with the patient. Patients should be tested for *H. pylori* so that a treatment regimen can be initiated. An esophagogastroduodenoscopy (EGD) is not mandatory for diagnosis. Serology is the test of choice if endoscopy is not required. The urea breath test is also an option, but it is used more frequently as a test of cure after a treatment regimen has been completed. An EGD should be considered for all patients with symptomatology consistent with PUD for evaluation and diagnosis. Biopsies can be taken for *H. pylori* histology or culture, or a rapid urease assay can be performed. In addition, visualizing the location and overall presentation of the ulcerative disease helps to address the causative factors, especially if the patient uses NSAIDs chronically. Most physicians will presumptively treat for PUD with a H2 blocker or PPI in order to improve symptoms prior to attaining an EGD to verify the diagnosis. If symptoms persist and noninvasive testing is pending or inconclusive for *H. pylori*, an empiric therapeutic regimen is also a reasonable option. Although there are multiple ways to test or screen for *H. pylori*, the most accurate test is with a tissue sample for histology or culture.

All NSAIDs and aspirin should be discontinued if the patient has an upper GI bleed, a diagnosed ulceration, or if PUD is strongly suspected based upon the clinical presentation. For those who are on aspirin therapy for recent cardiac stent placement or other co-morbidities, there should be an expedited workup and thorough multidisciplinary evaluation of the risks and benefits associated with continued salicylate use. In addition, all practices that may be ulcerogenic such as smoking, caffeine intake, alcohol consumption, and cocaine abuse should be addressed and abandoned if PUD is suspected. It is essential that patients understand the importance of lifestyle modification on the progression and resolution of PUD.

Table 20.1 Treatment regimens for *Helicobacter pylori*

Medications/dose/frequency	Duration (days)
PPI + Clarithromycin 500 mg bid + Amoxicillin 1000 mg bid	10–14
PPI + Clarithromycin 500 mg bid + Metronidazole 500 mg bid	10–14
PPI + Amoxicillin 1000 mg bid then:	5
PPI + Clarithromycin 500 mg bid + Tinidazole 500 mg bid	5
Salvage regimens	
Bismuth subsalicylate 525 mg qid + Metronidazole 250 mg qid + Tetracycline 500 mg qid + PPI	10–14
PPI + Amoxicillin 1000 mg bid + levofloxacin 500 mg daily	10

PPI proton pump inhibitor
Data from [32]

Acute presentations of PUD, such as pain, bleeding, or perforation, should be treated with continuous infusion of an intravenous PPI. Upon discharge, these patients should remain on an oral PPI or a H2 blocker for at least 3 months. A follow-up endoscopy should then be scheduled to monitor healing, especially if there is a chronic component to the presentation. Depending upon the initial pathology and the source of the lesion, healing has usually peaked by 4 weeks. Patients who are hospitalized for complications due to PUD, those with a repetitive history of PUD, and patients that require aspirin or NSAID therapy for other co-morbidities should be considered for lifelong maintenance with PPI or H2 receptor blocker therapy. Additionally, patients who are noncompliant with smoking cessation or alcohol abuse should remain on maintenance therapy as well if these behaviors were felt to be contributory to their PUD. Misoprostol and sucralfate are useful as adjuncts to antisecretory therapy. However, these drugs should be used only as preventative maintenance therapy, or in conjunction with H2 blockers or PPIs. They should not be used as sole therapy in patients who are acutely symptomatic. As previously mentioned, the majority of PUD can be attributed to an association with *H. pylori* infection. If *H. pylori* has been diagnosed via biopsy or serology, the patient should complete a treatment regimen for eradication [3, 18]. There are multiple acceptable regimens [32] (see Table 20.1).

Clinical Presentation of Peptic Ulcer Disease

The majority of patients who are diagnosed with PUD complain of pain in the epigastric region. The pain is often described as a localized burning, aching, or "gnawing" pain. Other symptoms include nausea, vomiting, bloating, anemia, and anorexia or weight loss due to decreased oral intake secondary to symptoms. An extensive and thorough history should be elicited from the patient. In particular, the questioning should

focus on previous episodes or symptoms consistent with PUD, correlation with oral intake, and the patient's association with known ulcerogenic risk factors. An aggressive medication history should also be attained with a specific focus on NSAIDs, aspirin, antisecretory medications, consumption and correlation of antacid use, and a complete social history including alcohol, tobacco, and substance abuse as well as recent psychological stressors.

Duodenal ulcers characteristically have a cyclic type of associated pain. Patients often awake from sleep at night with epigastric pain; however, it is usually resolved by the time they awake. Throughout the day, pain recurs 1–2 h after eating a meal and then temporarily dissipates with oral intake or antacids. Symptoms worsen and become more constant if the ulceration erodes posteriorly into the pancreas. Back pain may then also ensue. Pain with palpation during physical exam is an inconsistent and unreliable finding.

Gastric ulcers usually present with epigastric pain that is coupled with oral intake. Patients often complain of pain within 30 min of eating, and at times, symptoms can be aggravated by oral intake. In spite of this, many patients claim to have at least temporary relief of symptoms with oral intake or antacids. Symptoms from gastric ulcers can also be reliably vague and nonspecific in nature leading to a circuitous and extensive differential diagnosis and workup. PUD should be a differential diagnosis for any patient with abdominal symptomatology.

The most common indications for acute surgical intervention for PUD are bleeding and perforation [3]. Anemia may be the presenting symptom with chronic PUD; however, chronic bleeding is rarely managed surgically as most lesions will respond to medical management with compliance. Other reasons for surgical intervention due to PUD include intractable pain, refractory PUD, gastric outlet obstruction, known malignancy, and sequelae secondary to gastrinomas (ZES). Since the majority of emergent procedures for PUD involve perforation or bleeding, the remainder of the chapter addresses surgical management for this population of patients as it pertains to the acute care surgeon.

Bleeding Peptic Ulcer Disease

Sixty percent of all upper GI bleeds are secondary to PUD [33]. Of all deaths that are felt to be attributable to PUD, bleeding is the most common cause of mortality. This patient population is usually older than 65 years of age with concurrent chronic co-morbidities [15]. Although 80 % of UGI bleeds are self-limited, there is an overall mortality of 8–10 % in those that continue to bleed or have recurrent bleeds. Recurrent bleeds occur in 20–30 % of patients and the mortality after a re-bleed ranges from 10 to 40 %. Not surprisingly, the onset of a GI bleed during an unrelated hospital stay is associated with a higher mortality rate (33 %) than an initial bleed outside of the hospital or before admission (7 %) [14, 34]. The American Society of Gastrointestinal Endoscopy (ASGE) investigated the correlation of eight different disease co-morbidities with outcomes in patients with upper GI bleeding. These included central nervous system, cardiac, gastrointestinal, hepatic, pulmonary, neoplastic, renal, and psychological stress. The mortality rate for an upper GI bleed with no concurrent diagnoses was 2.5 %. However, if the patient had three coexisting diagnoses, the mortality rate rose to 14.6 %, and then to 66.7 % with six diagnoses [35].

Due to the significant amount of blood supply to the stomach, 35–40 % of gastric ulcers will bleed, but significant hemorrhage is more associated with type II and type III gastric ulcers [14]. Gastric ulcers are more commonly found in older patients. This explains the correlation with increased morbidity and mortality in patients with bleeding gastric ulcers in comparison with bleeding duodenal ulcers. The duodenum, however, also has a generous blood supply from the gastroduodenal artery (GDA), which lies just posterior to the duodenum. When a duodenal ulceration progressively erodes through the duodenal wall and into a branch of the GDA, or the artery itself, the resultant bleeding can be substantial. Fortunately, the majority of duodenal ulcers are superficial in nature, and most bleeds are self-limited or amenable to endoscopic interventions [34]. In reality, the majority of duodenal ulcers will present as minor bleeds with guaiac-positive stools or melena. However, approximately 25 % of all upper GI bleeds that present for urgent treatment are due to duodenal ulcerations [14].

Acute upper gastrointestinal bleeding due to PUD presents as hematemesis, melena, or occasionally hematochezia with massive hemorrhage. Not uncommonly, patients will present after actively bleeding or possibly with syncope to the emergency department with a history of having been "found down" at home for some unknown amount of time. These patients are frequently hemodynamically unstable due to hemorrhagic shock. Aggressive resuscitation and transfusion may be required to stabilize the patient enough to even tolerate endoscopy for diagnostic or therapeutic measures.

As with any critically ill patient that is hemodynamically unstable, the standard airway, breathing, circulation (ABC) algorithm should be followed by verifying a patent or secure airway, ensuring adequate oxygenation and ventilation, and then focusing on the patient's circulation and hemodynamics. Two large-bore IVs should be attained for volume resuscitation with crystalloid or blood products if significant hemorrhage is suspected or known to have occurred. If peripheral access is not available, a central venous catheter, such as a large-diameter cordis catheter, should be placed to better facilitate resuscitation and transfusion. Blood products should be available and transfused as necessary, and coagulopathies should be addressed and corrected. A Foley catheter is usually

placed so that accurate urine output can be monitored to reflect kidney perfusion. Central venous lines and arterial lines are often placed in order to accurately monitor hemodynamic parameters, volume status, and resuscitation efforts.

The increased use of antithrombotic and antiplatelet therapies in a growing elderly population merits discussion with regard to correction of coagulopathy in the setting of an acute bleed. When major gastrointestinal bleeding is associated with supratherapeutic doses of warfarin, intravenous Vitamin K can reverse the coagulopathy but won't reach its full effect for 24 h. Fresh frozen plasma will also help with reversal but adds extra volume to patients who may not be able to tolerate fluid overload, such as those with cardiac or renal dysfunction. Prothrombin complex concentrate (PCC) rapidly reverses coagulopathy and is the preferred modality to quickly reverse warfarin-induced coagulopathy. Furthermore, PCC has also been used to reverse the effects of newer factor XA inhibitor anticoagulants such as dabigatran and rivaroxaban [36].

If the source of bleeding is unclear, an upper GI source versus a lower GI source, a nasogastric tube should be inserted and a gastric lavage should be performed looking for clots or bloody aspirate. Some would advocate irrigation with ice water or cold saline solution until the nasogastric tube irrigation is clear as the iced irrigation will usually stop or slow the bleeding. Although there is no evidence basis behind the practice, most practitioners will immediately start intravenous PPIs or H2 blockers while resuscitating. Once the patient is resuscitated and hemodynamically stable, the upper endoscopy can be facilitated. These patients are critically ill with the potential for instability, regardless of the endoscopy findings. The majority of these patients, and in particular the elderly, frail, or those patients with multiple co-morbidities, should be monitored in an ICU setting with serial hemoglobin monitoring for a minimum of 24–48 h after the initial event.

Endoscopy is first-line treatment for all upper GI bleeds, especially and including variceal bleeds. Many facilities will consult a gastroenterology service; however, many general surgeons also have privileges to perform interventional endoscopic procedures. A surgical endoscopist would also have the advantage of visualizing the anatomy and location of the bleed. This would be optimal should endoscopic measures be unsuccessful and operative intervention become necessary. Either way, the surgical team should be present to visualize the source of bleeding and the interventions attempted for hemorrhage control in order to formulate an operative plan. In the hands of a skilled endoscopist, surgical intervention is only required in 5–10 % of bleeding ulcers, and many upper GI bleeds will actually stop spontaneously [31]. There are several different scoring systems that have been developed to predict the need for intervention for control of bleeding. The use of these prognostic scoring systems to identify patients at greater risk is one of the recommendations from the international consensus of recommendations for management of non-variceal upper GI bleeding that was published in 2010 in the *Annals of Internal Medicine* [37]. Gastroenterologists as well as surgeons should be comfortable and familiar with these scoring systems. Blatchford published a scoring system in *Lancet* in 2000 that is likely the most referenced. The system uses both clinical and laboratory data to help predict the likelihood of need for intervention to attain hemostasis. Patients with a score of less than or equal to 3 have a 6 % chance of requiring intervention for hemostasis, whereas those with a score of 6 or higher have a greater than 50 % chance of needing endoscopic or surgical intervention for control of hemorrhage [38] (see Table 20.2 and Fig. 20.1).

Table 20.2 Blatchford admission risk markers for peptic ulcer bleeding

Admission risk marker	Score component value
Blood urea (mg/dl)	
6.5–8.0	2
8.0–10.0	3
10.0–25.0	4
>25.0	6
Hemoglobin (g/dl) for men	
12.0–13.0	1
10.0–12.0	2
<10.0	6
Hemoglobin (g/dl) for women	
10.0–12.0	1
<10.0	6
Systolic blood pressure (mmHg)	
100–109	1
90–99	2
<90	3
Other markers	
Pulse > 100 bpm	1
Presentation with melena	1
Presentation with syncope	2
Hepatic disease	2
Cardiac failure	2

Scores ≥6 have a greater than 50 % chance of requiring intervention
Adapted from Blatchford O, Murray WR, Blatchford M. A risk score to predict need for treatment for upper-gastrointestinal haemorrhage. Lancet. 2000;356(9238):1318–21, with permission

The first goal of endoscopy is to locate and visualize the source of bleeding, and there are many endoscopic techniques used for control of upper GI hemorrhage. There is often excessive clot over the lesion, and irrigation is necessary to visualize the mucosa below the clots. This is done with caution as not to disturb the clot directly over the lesion and the hemostasis that may have already been achieved. Indications for endoscopic therapeutic intervention include active bleeding or oozing at an identified site, stigmata of a recent bleed such as a large blood clot, or the presence of a visible vessel at the base of the ulceration. If the lesion is no longer bleeding, or if it is merely oozing, epinephrine is

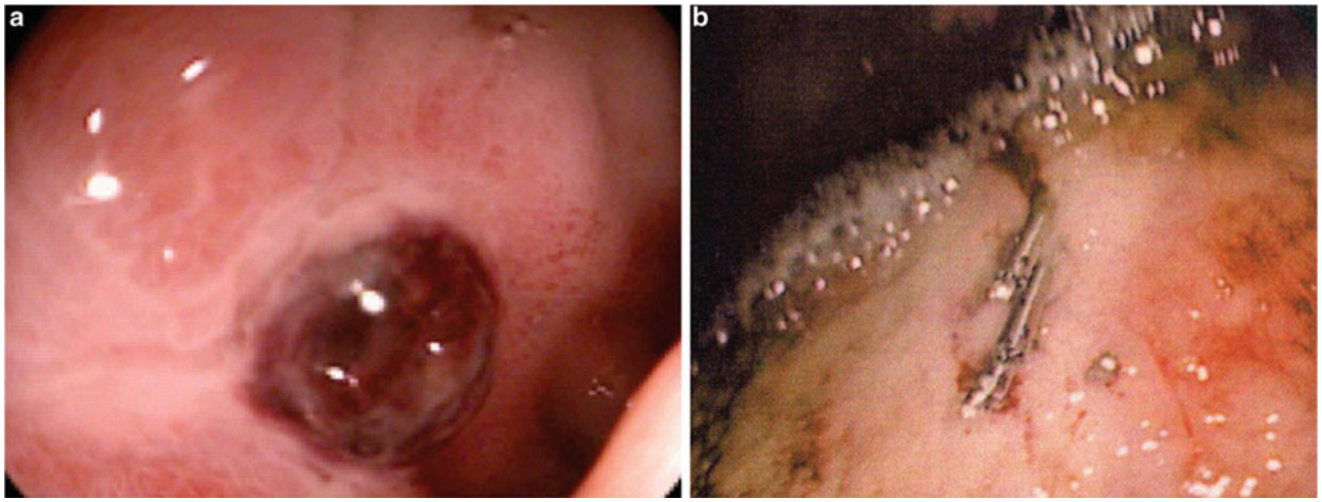

Fig. 20.1 (**a**) Ulcer in the bulb of the duodenum with overlying clot. (**b**) Endoscopic clips used to control hemorrhage from a gastric ulcer

often injected in or around the lesion and the surrounding mucosa in order to employ its vasoconstrictive properties for assistance with clot formation. Beyond injection, there are several other methods of direct vessel control depending upon the source and location of the bleed. Cautery may be used to provide hemostasis, or sclerosing agents may be directly injected into the bleeding vessel. Clips can be placed directly on a visualized vessel or circumferentially to address the rich vascularity of the region. Banding is more frequently used on variceal bleeds, but can also be successful depending upon the source. Most endoscopists will use epinephrine in association with another method of intervention such as clips or cautery. Dual intervention has been shown to improve the success of initial endoscopic hemorrhage control and also to decrease the incidence of recurrent bleeding [39, 40].

The majority of upper GI bleeds can be initially controlled via endoscopic interventions; however, 8–15 % of patients will not have their bleeding initially controlled by endoscopy, and of those that are controlled, 15–20 % of patients will experience recurrence of bleeding from the site of ulceration [36, 41]. It is the surgical team's responsibility to evaluate the patient and his or her co-morbidities, the cause of bleeding, and any other extenuating factors to decide if and when operative intervention is necessary. Historically, many surgeons have used a threshold of six transfused units of packed red blood cells as the deciding point to proceed with operative intervention. The number six certainly defines the need for excessive transfusion, but several other factors need to be considered along with the patient's transfusion requirements. The location of the ulcer should be influential in the decision of whether or not to intervene early. In particular, lesions in areas with grossly exposed vasculature, those with abundant blood supply such as posterior duodenal ulcers, or ulcers on the lesser gastric curvature with extensive inflow from the left gastric artery may benefit from early operative intervention.

Many endoscopists routinely perform a second-look procedure at 24 h after the initial endoscopic intervention. There is also frequently a trend to repeat therapies such as cautery or injection of epinephrine in order to prophylactically treat continued oozing or to reinforce previous interventions. If a patient has a significant re-bleeding episode after having undergone an initial endoscopy, many practitioners will proceed with repeat endoscopic therapeutic interventions. However, if the source was visualized on previous endoscopy, operative intervention may be the more prudent decision. In a prospectively randomized study performed at a high-volume center, Lau and colleagues demonstrated a 75 % success rate in control of re-bleeds via repeat endoscopic intervention. They also found similar mortality rates and decreased complication rates when compared to a similar group of patients who underwent surgical intervention. Additionally, their data recognized two factors that independently predicted failure of repeat endoscopic interventions for re-bleeding: hypotension and ulcers greater than 2 cm [42]. Elemunzer et al. did a meta-analysis of ten prospective studies to assess re-bleeding after endoscopic therapy for hemorrhage due to PUD. They found the rate of re-bleeding to be 16.4 %. The following factors were found to be independently predictive of re-bleeding after endoscopic interventions: pre-endoscopic hemodynamic instability, comorbid illness, active bleeding at endoscopy, large ulcer size (>2 cm), posterior duodenal ulcerations, and ulcerations on the lesser gastric curvature [43]. Every patient must be individually evaluated and the transfusion requirements, hemodynamic status, and co-morbidities taken into consideration. However, it seems reasonable to proceed with early surgical intervention after the first endoscopy if the ulcer is greater than 2 cm, there is hemodynamic instability, there was extensive hemorrhage, the location of the ulcer is concerning (the posterior duodenum or the lesser gastric curvature), or the patient is greater than 60 years of age and/or has multiple co-morbidities (Fig. 20.2).

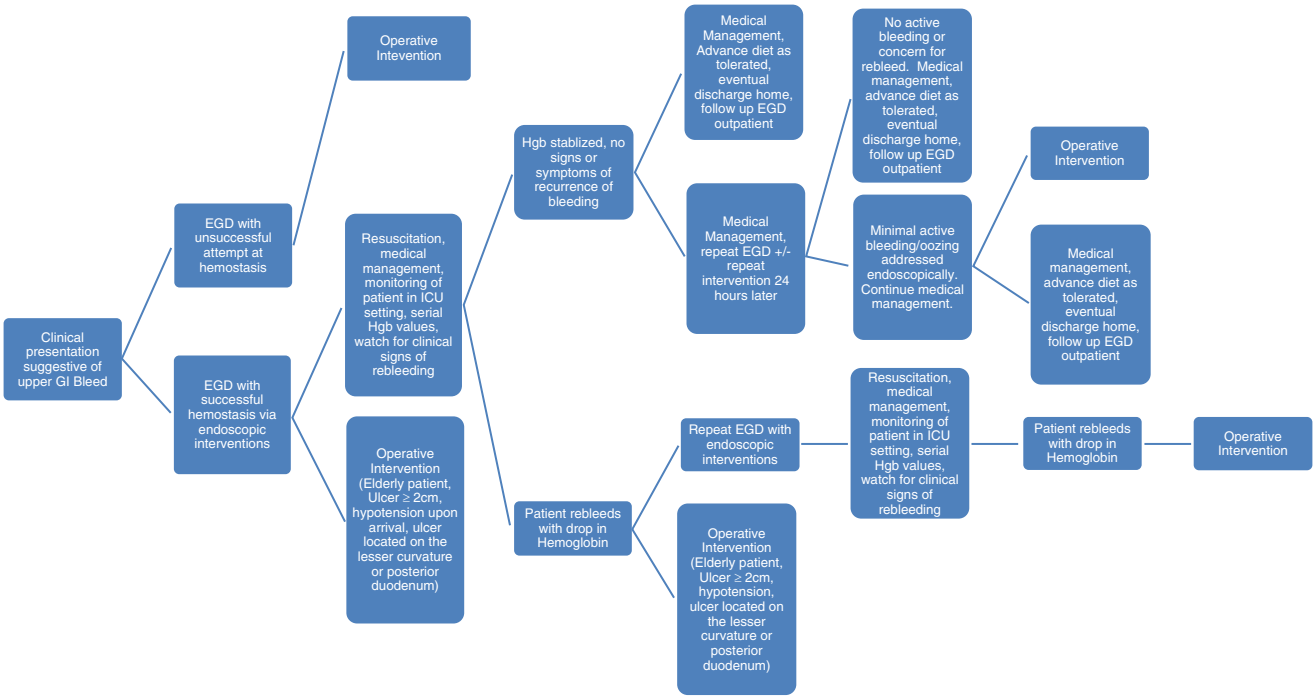

Fig. 20.2 Algorithm for contemporary management of upper GI bleed due to peptic ulcer disease

In complicated patients with intricate surgical or medical histories, localizing the source of the hemorrhage and identifying the best method to attain hemostasis may be challenging. A technetium-99 m tagged red blood cell scan is a nuclear study that can identify bleeding at 0.1 ml/min and therefore may be beneficial in identifying a slow GI bleed. The study may be difficult to facilitate as availability may be institution dependent, and although it may be somewhat sensitive, it lacks specificity in localization of hemorrhage [44]. However, this information can be instrumental at times in helping to guide the next stage of clinical intervention. Computed tomography angiograms (CTA) have recently been used more frequently with lower GI bleeding for source localization. Depending upon the patient and the clinical scenario, a CTA may be helpful in localizing bleeding in the upper GI tract as well. Modern-day multi-detector CT scans can detect bleeding at a rate between 0.35 and 0.40 ml/min, which is improved in sensitivity in comparison to angiography. CT scans may be useful for identification of an upper GI bleed; however rarely is there a practical need for the expense or the radiation exposure incurred without any means of truly effecting prognosis or outcomes.

A resource that has become increasingly more utilized in critically ill and complicated patients (those with re-bleeding, uncertain endoscopic findings, or those who are at high risk for general anesthesia) is angiography and interventional arterial embolization. Angiography can identify bleeding at a rate of 0.5 ml/min and is less sensitive than a tagged RBC scan. However, angiography can be used in conjunction with fluoroscopy to localize the region of bleeding and to then embolize the primary blood supply to that region. The most common vessel to be embolized in interventional procedures for bleeding PUD is the GDA followed by the left gastric artery. On average, active bleeding is demonstrated about 50 % of the time leaving 50 % of the interventions categorized as empiric therapy. Selective embolization is performed primarily using either coils or a gel foam material. Although the stomach and duodenum have a rich vascular supply, there is an associated risk of ischemia with any embolization procedure to not only the stomach and the duodenum but also the pancreas [45–47]. Therefore, interventional radiologic procedures should never be introduced as first-line therapy. To date, no prospective randomized trials have compared angiographic embolization with surgery as salvage therapy in patients who have bleeding or re-bleeding peptic ulcers. Several retrospective series have shown that angiography and embolization can reduce the need for surgery and overall complications without increasing overall mortality [48]. Furthermore, studies are being conducted to assess the role of pre-emptive embolization after initial endoscopic hemostasis is achieved as a means to potentially avoid re-bleeding in high-risk patients [36]. All risks and benefits of embolization should be thoroughly evaluated in relation to the patient and the clinical scenario. Post-procedurally, all patients should be monitored closely for any clinical signs of re-bleeding or ischemia with telemetry, serial abdominal exams, and serial laboratory values including base deficits, lactate levels, and complete blood counts to monitor for continued bleeding and leukocytosis.

Regardless of the decision to operate, to repeat endoscopy, to consult interventional radiology, or to observe closely with medical management, the surgical team should remain intimately involved in the care of this population of patients until they are hemodynamically stable and are tolerating oral intake without signs of continued bleeding.

Operative Intervention for Bleeding Peptic Ulcers

Once the decision has been made to operate on a patient with an upper GI bleed, a thorough evaluation of the intraoperative findings and the clinical scenario will help to guide which operation is most appropriate for the patient. With the advancements in endoscopic control of enteric bleeds, the patients that fail endoscopic management tend to be those with the highest risk factors for surgical intervention. Given the shift in the population now requiring these procedures, the historically indicated procedures for stable elective patients may not always be the safest and most appropriate intervention. The type of operation performed should initially be based on the patient's overall clinical picture and hemodynamic status. In unstable patients, the procedure should provide hemostasis within the least amount of time under general anesthesia. Additional procedures can be done at a later time, if necessary, once the patient has stabilized. Other factors that should be considered are the possibility of malignancy, coinciding perforation or obstruction, and the location of the ulcer.

The generalized surgical principles for the treatment of an acute bleed secondary to PUD are relatively straightforward. The most important goal is obviously hemostasis. The option of an antisecretory procedure with respective drainage as indicated may then be considered. Oversewing of the ulcer is the most common intervention for bleeding duodenal ulcers. Bleeding gastric ulcers, although rare, can also be oversewn, but they must additionally be biopsied to rule out malignancy. Dependent upon the patient's clinical presentation, the surgeon's experience, and the patient's history of PUD, medical compliance, and co-morbidities, a highly selective vagotomy (HSV) or a truncal vagotomy with drainage procedure may additionally be performed. The third category of treatment options includes resection or excision of the ulcer which may also involve a vagotomy and a drainage procedure dependent upon the location and indication.

Traditionally the decision of whether or not to do an antisecretory procedure was dependent upon the location of the ulcer. Type II and type III ulcers have classically been categorized as lesions that evolve secondary to acid hypersecretion. The historical recommendation has always been to perform a truncal vagotomy with a gastric emptying procedure. If the pylorus is not resected or bypassed, a pyloroplasty would be the necessary alternative. Some would advocate the use of a HSV to allow gastric emptying and avert the need for pyloroplasty or antrectomy. However, given the relative rarity of HSV in modern-day general surgery, the majority of younger surgeons do not have the exposure or experience to perform the procedure with dependably successful outcomes. In considering our advances regarding *H. pylori* treatment, the pathogenesis of ulcer formation, and the use of PPIs for acid suppression, the necessity for antisecretory procedures is ambiguous. Truncal vagotomies are associated with some level of dumping syndrome, whether it is clinically significant or not. HSV may be associated with lesser detrimental effects; however, the procedure is less common and certainly more time consuming. The patient's overall state of health, his or her hemodynamic status, and the location of the bleed must all be taken into consideration when the operative plan is established.

Most modern-day damage control surgery for acutely bleeding PUD involves either resection or oversewing of the ulceration. Patients are then treated postoperatively for assumed *H. pylori* with an appropriate regimen including PPIs or H2 blockers. In the era of the damage control laparotomy, resection alone also can be performed, leaving the patient in discontinuity with a properly placed nasogastric tube for decompression. A second-look laparotomy can then be utilized, after the patient is adequately resuscitated, for reconstruction or performance of definitive antisecretory and drainage procedures if they are indicated. Regardless of the choice of intervention, it should be understood that the majority of patients requiring surgical intervention for bleeding PUD in the current era have very little physiologic reserve. Operative interventions should focus on expediently addressing the source of the bleeding in order to return the patient back to the ICU for resuscitation and hemodynamic support.

Operative Approach for the Bleeding Gastric Ulcer

Gastric Resection

The procedure of choice for bleeding types I, II, and III ulcers (Fig. 20.3) is a distal gastric resection inclusive of the bleeding ulcer. A Billroth I or Billroth II reconstruction can then be performed depending upon the mobility of the duodenum. As always, the patient's hemodynamic status is the deciding factor as to whether or not it is appropriate to proceed forward with a definitive anastomotic procedure. If the patient is hypotensive, it would be prudent to do a wedge resection, an oversew procedure, or a damage control partial gastrectomy with nasogastric decompression and an eventual second laparotomy to establish continuity. A wedge resection can easily be performed if the ulcer is on the greater

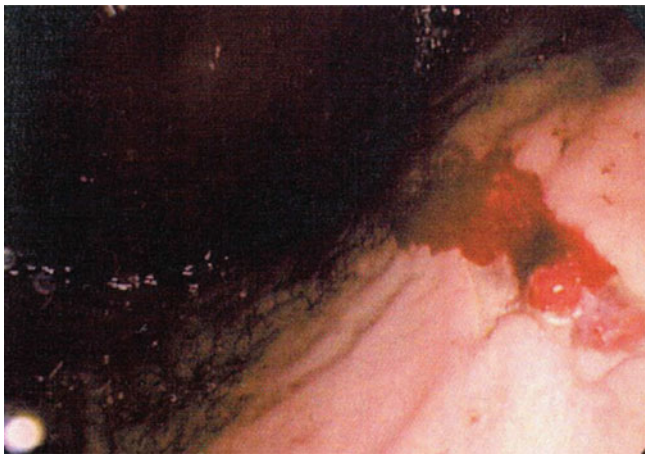

Fig. 20.3 Active arterial bleeding from a gastric ulcer on the lesser curvature of the stomach

curvature, the antrum, or within the body of the stomach. However, resection may be difficult or inappropriate for type IV ulcerations, lesions on the lesser curvature, or those more proximal to the gastroesophageal junction. Multiple bleeding erosions may require total gastrectomy with eventual creation of a Roux-en-Y esophagojejunostomy or esophagogastrojejunostomy, depending upon the extent of gastric resection that is required to gain hemostasis.

Gastric resections, as well as ulcer excisions, are usually performed with a gastrointestinal anastomosis (GIA) stapler after the stomach is sufficiently mobilized and cleared of surrounding attachments. A Kocher maneuver is performed in order to mobilize the duodenum for the gastroduodenal anastomosis of a Billroth I procedure. The anastomosis is created by removing, or avoiding initial placement of, the staple line on the inferior portion of the gastrectomy. The anastomosis can then either be hand sewn in a two-layer fashion using absorbable sutures or stapled with a GIA stapler placed through a gastrostomy.

If the duodenum is scarred or will not reach the distal stomach remnant, a Billroth II will need to be performed. There are several complications associated with this procedure including duodenal stump leaks and afferent or efferent limb syndromes. The Billroth I primary anastomosis has less incidence of complications, but if there is any tension on the anastomosis, a Billroth II is the procedure of choice. The proximal duodenum should be transected using either a TA stapler or a GIA stapler. Attention should be given to the anatomy in regard to the common bile duct, as it lies just posterior to this region. Additionally, the thickness and induration of the duodenal stump should be evaluated. It may be necessary to handsew the stump closed to avoid a stump leak. Many experienced surgeons would suggest placing an omental patch over the stump as well. In the case of a friable or extremely indurated stump, a lateral duodenostomy tube can be placed in a Stamm fashion to the lateral abdominal wall in order to decompress the duodenum, although this is recommended only in extreme conditions. There are several ways to perform the anastomosis for a Billroth II gastrojejunostomy. The jejunal afferent limb should reach the gastric remnant without any tension, but with no more than 20 cm of length from the ligament of Treitz. Placing the jejunum through a retrocolic window will decrease tension on the mesentery, but antecolic placement is functionally equivalent. There are several methods of constructing the gastrojejunostomy using staplers, 2′0 absorbable sutures, or a combination of both. If the anastomosis is hand sewn, it should be a two-layered anastomosis with an outer layer of Lembert sutures and an inner layer of full-thickness absorbable sutures.

The Oversew Technique

Oversewing of a bleeding gastric ulcer is not the ideal procedure, but it may be the most appropriate procedure for a high-risk patient. Remember that all gastric ulcers must be biopsied if resection is not possible, and therefore, if the ulcer is oversewn, a biopsy must be procured. If the location of the ulcer is known, a gastrotomy is made to localize the lesion. The ulcer is then biopsied and oversewn with absorbable sutures to attain hemostasis. The gastrotomy should be closed in a two-layer fashion or via a TA stapler. In type IV ulcers, those lesions located near the gastroesophageal junction, oversewing the ulcer is the procedure of choice as this region is not readily amenable to wedge resection. The area also has a vast blood supply secondary to inflow from the left gastric artery. The appropriate procedure for a type IV lesion then includes oversewing the bleeding ulcer, ligation of the left gastric artery to prevent re-bleeding, and a vagotomy and drainage procedure (pyloroplasty) if the patient is hemodynamically stable.

Truncal Vagotomy and Pyloroplasty

In a stable patient, with straightforward anatomy, a truncal vagotomy should be considered for acid suppression as long as the procedure does not extensively prolong time spent in the operating room. In order to perform a vagotomy, the left lateral section of the liver as well as the triangular ligament must be mobilized. The esophagogastric junction must be retracted inferiorly using gentle tension in order to localize the proximal nerves. Once the nerves are localized, they are isolated using Penrose drains. Clips are placed proximally and distally on each nerve, and a 2 cm long portion of each proximal nerve is excised and sent off to pathology for verification. Exposure and extensive mobilization are often required for this procedure, and therefore should only be pursued in hemodynamically stable patients. If a truncal

vagotomy is performed, the vagal intervention to the pylorus and distal stomach is disrupted. If a bypass procedure is not performed, pyloroplasty is necessary to allow for drainage of the gastric contents. The most commonly performed method of pyloroplasty is the Heineke–Mikulicz pyloroplasty. The pylorus is localized and Bovie cautery is then used to create a longitudinal full-thickness pyloromyotomy extending from 1 cm proximal to 1–2 cm distal to the pylorus. Traction sutures are then placed superiorly and inferiorly and tension is applied superiorly and inferiorly to convert the longitudinal incision into a transverse incision. The defect is then closed transversely in a double-layer fashion with full-thickness bites using non-absorbable suture. A Kocher maneuver and adequate duodenal mobilization may be necessary in order to close the incision without tension.

Operative Approach for Bleeding Duodenal Ulcer

As with the management of bleeding ulcers, the same principles of management apply in regard to an acutely bleeding duodenal ulcer. The ulcer can either be oversewn or resected in order to achieve hemostasis. The option to perform a vagotomy and drainage procedure then also needs to be contemplated. The most commonly used approach is the creation of the pyloromyotomy as previously described. The longitudinal duodenotomy incision is extended another 1 cm as needed in order to visualize the duodenal ulcer. As nearly all duodenal ulcerations are located on the posterior portion of the first part of the duodenum, this incision should give ample exposure. A Kocher maneuver can be performed if necessary for exposure and so that the left hand can be used to manually control bleeding. The source of bleeding is usually the gastroduodenal artery. Figure of eight sutures with a heavy suture material, such as 3′0 silk, should be placed superiorly and inferiorly at the base of the posterior duodenal ulcer for ligation of the vessel. Several sutures may need to be placed before hemostasis is attained. A U-stitch should also be placed at the base of the ulcer in order to control any possible hemorrhage from the transverse pancreatic arterial branches that enter the gastroduodenal artery from the posterior aspect. Once the bleeding has ceased, the ulcer should be manipulated in order to verify the stability of the arterial ligation. If true hemostasis has been achieved, the longitudinal incision can then be closed transversely in two layers as a Heineke–Mikulicz pyloroplasty. A Finney pyloroplasty can also be utilized if transverse re-approximation is not attainable. If the patient is stable, a truncal vagotomy would be the classic next step in management. However, the majority of surgeons, as evident by surveys performed in both the United Kingdom and the USA, no longer perform vagotomies on these patients [7, 49]. Although there is no level 1 evidence to support the change in practice patterns, the transition has come about since the availability of medical acid suppression with PPIs.

The other option for management of a bleeding duodenal ulcer is resection. An antrectomy is performed that extends distally to the first portion of the duodenum in order to encompass the bleeding ulcer. The surgeon must be acutely cognizant of the location of the common bile duct when performing the resection as it can easily be mistaken for thickened tissue within the stapler device. A vagotomy and accompanying reconstructive procedure will then also need to be performed. A Billroth II is usually the type of reconstruction used given the shortened length of the duodenal stump. However, if it can be attained without tension on the anastomosis, a Billroth I would be the procedure of choice. The GIA stapler is usually employed for the gastroduodenectomy procedure. The duodenal stump should be approached in the same fashion as previously described including the use of an omental patch. Complications from the procedure are similar to those previously described for gastric resection including duodenal stump leak, dumping syndrome, and anastomotic breakdown of the gastrojejunostomy. It is also imperative to insure that all of the antrum is resected as retained antrum can result in recurrent ulcerative disease.

As previously mentioned, the majority of surgeons opt to perform the less invasive of the two procedures, the duodenotomy and pyloroplasty. There is data from the early 1990s that supports similar mortality outcomes with either method. In 1991, Poxon published data comparing acid suppression with histamine blockers in combination with oversewing to vagotomy and pyloroplasty or antrectomy and found similar mortality rates [50]. However, the study was stopped early due to several re-bleeding episodes in the conservative group. In 1993, Millat published a randomized controlled study comparing vagotomy and pyloroplasty to excision of the ulcer that revealed increased incidence of re-bleeding (17 % vs. 3 %) with the less invasive procedure, though mortality outcomes were similar [51]. In analyzing these studies, it would seem that although the mortality outcomes are similar there is an increased incidence in re-bleeding with the less invasive method. The problem with all of these studies is that they are outdated, as all of these results were collected prior to the introduction of PPIs. Certainly we know that this class of drugs has completely changed the management of PUD. The majority of surgeons extrapolate the success of the PPIs in acid suppression to their choice in operative management. Many will perform the least invasive procedure with the caveat that these patients will remain on acid-suppressing medications. In saying that, there is no known literature to date that has analyzed either procedure in combination with PPIs. The literature in regard to reoperation for bleeding on patients after having received a pyloroplasty and vagotomy also comes from the early 1990s prior to the introduction of

PPIs when the rate of re-bleed was somewhere between 6 and 17 % [50, 51]. If a patient re-bleeds, endoscopic intervention is usually not an option, especially if the patient is in the acute postoperative period. Reoperation carries a much higher risk of morbidity and mortality. However, if resection was not performed during the initial operation, this would be an option to achieve hemostasis. It has become increasingly more common to employ the expertise of interventional radiology for postoperative hemorrhage control with transarterial embolization under fluoroscopy. There are no studies to date that directly compare operative intervention with transarterial embolization; however, there is data from two large studies that indicate a 75 % success rate in controlling recurrent bleeding after duodenostomy and oversewing of a bleeding ulcer [52, 53].

Perforated Peptic Ulcer Disease

Perforation is the second most common complication related to PUD. The majority of these ulcers tend to occur in the region of the pyloric channel or the first portion of the duodenum. Perforation is most common in the duodenal bulb (62 %), followed by the pylorus (20 %), and then the gastric body (18 %) [54]. Duodenal ulcer perforations are classically located anteriorly or laterally. Although they can occasionally be associated with a concurrent UGI bleed, that is usually not the case. Most patients who present with perforated PUD do not have a history of PUD. The two strongest risk factors associated with perforation are a history of PUD and the use of NSAIDs [55].

Patients with perforated PUD present with an acute onset of pain. They may have been previously experiencing upper GI complaints consistent with PUD. Nonetheless, most patients can recall the exact time of perforation due to the acuteness of the symptoms. Peritonitis usually ensues over the next 2–12 h after perforation. At approximately 12 h, patients will start mounting a systemic inflammatory response syndrome (SIRS) response with fever, abdominal distension, and changes in vital signs such as tachycardia and mild hypotension [31]. As with all surgical disease processes, elderly patients often have more complicated presentations. They may present with confusion, lethargy, falls, abdominal distension, or vague abdominal complaints. Elderly patients and those with concurrent co-morbidities often present in septic shock and may require aggressive resuscitation for stabilization before the workup for diagnosis can even be initiated.

In patients that are cooperative, the diagnosis of perforation can often be attained from a good history and physical exam with a correlative upright chest X-ray (CXR) revealing free air. Upright films will reveal pneumoperitoneum underneath the diaphragm in 80–90 % of perforated patients [3]. If CXR is not confirmatory, a CT of the abdomen, preferentially with oral contrast, is diagnostic. Absolute intraoperative findings of duodenal perforation are not localized in 10–20 % of patients, likely secondary to posterior and retroperitoneal perforations [56]. It is critical to expediently diagnose perforations given the extensive enteric spillage and resultant peritonitis that can occur. A delay in therapeutic intervention beyond 12 h following perforation is associated with an increase in mortality and morbidity, and the prognosis is improved if addressed operatively within 6 h of perforation [57, 58]. All patients should be appropriately resuscitated and relatively stable prior to proceeding forward with operative intervention. In patients with multiple co-morbidities, medical optimization is preferential; however, often sepsis is the driving force behind the organ dysfunction and source control must be obtained prior to resolution. Patients should receive intravenous PPIs and broad-spectrum antibiotics and antifungals for coverage of gram-negative rods, anaerobes, oral flora, and fungus during the preoperative resuscitation, and all ulcerogenic agents should be discontinued [59, 60].

Surgical intervention is nearly always the management option of choice for perforation secondary to PUD. However, emergency surgery for the perforation is associated with a 6–30 % risk of mortality [58]. The variables that have been associated with an increased mortality include age, American Society of Anesthesiologists (ASA) class, shock at the time of admission, hypoalbuminemia, elevated serum creatinine, and a preoperative metabolic acidosis [61]. Infrequently, non-operative management can be used on a patient who is without hemodynamic compromise or peritonitis with CT findings of a contained perforation [62]. However, this encompasses no more than 5 % of the disease population, and the decision to treat medically should be done cautiously with a dedicated plan for serial exams and hemodynamic monitoring. If the patient does not improve within the first 12–24 h of hospitalization, or if the patient exhibits any signs of clinical deterioration, operative intervention should be sought. In 1989, a randomized control study was published by Crofts et al. that randomized a total of 83 patients to either operative or non-operative management for perforated PUD. Patients that did not improve within the first 12 h with non-operative management went to the OR for surgical intervention. Morbidity and mortality rates were similar between both groups; however, the length of stay for the conservative management group was longer, and failure of non-operative management was more frequent in patients older than 70 [63]. Again, this study was performed prior to the introduction of PPIs, but the overall message is that older patients have worse outcomes. Considering that the majority of patients presenting with perforated ulcer disease are either elderly or have multiple co-morbidities, the decision to abstain from operative intervention will seldom be an option.

Operative Approach for Perforated Gastric Ulcers

Perforated gastric ulcers are much less common than duodenal perforations, but the mortality rates associated with the diagnosis are much greater. The difference is likely due to these patients being older with more chronic co-morbidities and typically larger ulcers. This population also tends to have delays in seeking medical attention which also leads to increased mortality [3].

Classically, the management options for a perforated gastric ulcer include resection, either via a wedge resection with vagotomy and pyloroplasty or by a partial gastrectomy. For types II and III gastric ulcers, an antrectomy and truncal vagotomy are performed with reconstruction by means of a Billroth I or Billroth II. The least invasive method of repair is via an omental patch. This may also then be paired with a vagotomy and pyloroplasty. Patch repair is a viable option for gastric perforations as long as the ulcer is appropriately biopsied. Considering that an antrectomy with vagotomy and reconstruction carries an associated 20 % incidence of a post-gastrectomy or post-vagotomy syndrome, this may be the better option depending upon the overall clinical presentation of the patient [18]. All gastric ulcers must be biopsied, if not resected, as the rate of malignancy has been reported to be between 4 and 14 % in gastric perforations [64]. Data from the late 1980s revealed a higher short-term complication rate (20 % vs. 5 %) and a higher recurrence rate (25 % vs. 10 %) in patch closure in comparison with distal gastrectomy [65]. This data was again published prior to our knowledge of the impact of *H. pylori* on ulcer formation as well as prior to the introduction of PPIs. It may be that the success of the gastrectomy was in part due to the control of *H. pylori* with the antrectomy procedure. Now that we can usually eradicate the bacteria quite easily, the resultant outcome is that vagotomies are being performed with increasingly less frequency.

As discussed previously with bleeding gastric ulcers, wedge resections are more feasible anatomically if the lesion is located in the antrum, the body, or along the greater curvature. The ulceration can easily be excised and the gastrotomy closed with a GIA or TA stapler. Depending upon the skill of the surgeon and the clinical presentation of the patient, these procedures can also be done laparoscopically with similar expected outcomes. However, the patient's clinical presentation should be used as a determining factor as patients in shock upon admission have poor tolerance for pneumoperitoneum. Wedge resections along the lesser curvature of the stomach are technically difficult due to the abundant arterial inflow from branches off of the left gastric artery. If the lesion is not amenable to closure via an omental patch, a distal gastrectomy will likely need to be performed. Proximal perforated gastric ulcers, similarly to proximal bleeding gastric ulcers, may definitively require subtotal gastrectomy or a Roux-en-Y esophagogastrojejunostomy. Please refer back to the section on approach to bleeding ulcers for further specifics regarding operative techniques.

Operative Approach for Perforated Duodenal Ulcers

The most commonly performed procedure for duodenal perforated PUD is an omental patch procedure (Graham Patch Repair). This repair has historically been performed with a truncal vagotomy and pyloroplasty or a HSV. The classic antrectomy and truncal vagotomy are usually reserved for those patients with some elicited history of chronic PUD, previous failed management, or need for chronic NSAID maintenance. Most recommend simple patch repair alone without vagotomy if the patient is in shock, has exudative peritonitis with greater than 24 h since perforation, or multiple medical co-morbidities.

Data published in the 1980s supports omental patching with a HSV as the procedure with the lowest risk of recurrence (4 %). Truncal vagotomy was found to have a slightly greater risk (12 %), and simple patch closure was shown to have the highest rate of recurrence at up to 63 % [66]. Other literature from the same time era also validated the duodenal patch with accompanying HSV as the procedure with the least incidence of recurrence [67]. However, none of these studies included high-risk patients with hemodynamic instability, prolonged perforation, or at high risk due to advanced age or co-morbidities. Boey and colleagues demonstrated the mortality rate for perforated duodenal ulcer to be 100, 45, 10, or 0 % based upon whether the patient has three, two, one, or zero of those respective risk factors [68]. Furthermore, this data was collected prior to the discovery of *H. pylori*'s influence on ulcerogenesis and the outcomes associated with eradication. Additionally, PPIs were not yet available. In 2000, Ng and colleagues published a randomized control trial of 99 patients who had an omental patch repair of a perforated duodenal ulcer. Successful treatment of *H. pylori* postoperatively decreased the recurrence rate from 38 % to 5 % [69]. It therefore seems reasonable that in the majority of patients that present with the need for emergent surgical intervention secondary to a perforated duodenal ulcer, a simple omental patch repair with copious peritoneal irrigation is sufficient treatment. The patient should also be treated empirically for *H. pylori* unless colonization is otherwise ruled out by negative serology, histology, or culture. Alternatively, if the patient is stable and there is a concern for recurrent PUD or postoperative noncompliance with completing the *H. pylori* regimen, a definitive operation is warranted. The type of operation should depend not only on the patient's presentation but also on the experience of the surgeon. Failure of HSV in novice hands can lead to a high

incidence of recurrence, so the operative surgeon should be comfortable with the proposed interventions [70]. The complications involved in definitive procedures are similar to those discussed earlier and include duodenal stump leak, anastomotic breakdown, and post-gastrectomy and vagotomy syndromes.

Omental Patch (Graham Patch) for Duodenal Perforation

Upon entering the peritoneal cavity, the perforation site must first be localized. The majority of ulcerations are located in the pyloric channel or in the first portion of the duodenum (Fig. 20.4). However, if the perforation is not visualized or accessible, the duodenum should be fully mobilized via a Kocher maneuver. Once the site of perforation is localized, the edges of the ulceration should be debrided back to healthy tissue. A modified Graham Patch is performed by placing several, usually 3 or 4, interrupted sutures with 2′0 absorbable suture. The tails of the tied sutures are then used to secure a pedicle of viable vascularized omentum over the now re-approximated edges of the defect. The sutures are then secure over the omentum with just enough tension to bolster the pedicle in place without compromising vascular flow. A true Graham Patch is used when the edges of the ulcer cannot be re-approximated either due to induration or because the narrowing would result in compromise of the duodenal lumen. A piece of omental pedicle is then used to plug the defect in a similar fashion without complete re-approximation of the duodenal tissue.

The advent of laparoscopy has changed the way surgeons in the modern era can perform operations that previously had only been done via an "open" approach. In particular, the omental patch repair for a perforated duodenal ulcer can be approached laparoscopically under certain conditions. Boey's classification system mentioned previously (shock on admission, prolonged duration of symptoms/perforation, and American Society of Anesthesiologists (ASA) grade III-V) has proved to be useful in helping to stratify which patients may be candidates for a minimally invasive approach. A point is assigned for each risk factor; the maximum score of 3 indicates a high surgical risk, and those patients with a score of 0 or 1 might be suitable for laparoscopic repair of a perforated duodenal ulcer. Those patients presenting in shock and/or with a high Boey score are best suited for an open repair. Interestingly, if laparoscopic repair is undertaken, no standardized operative technique has yet been developed, with variability present in such aspects as surgeon positioning, camera positioning, trocar number and usage, and even how the perforation is ultimately closed [54]. Comparing laparoscopic versus open repair of perforated peptic ulcers, a retrospective review of National Surgical Quality Improvement Program (NSQIP) data pertaining to perforated gastric and duodenal ulcers by Byrge and colleagues revealed that the outcomes of mortality, wound complications, organ space infections, mechanical ventilation >48 h, sepsis, and a return to the OR were all lower with a laparoscopic approach, but none reached statistical significance. Only length of hospitalization was significantly lower in the laparoscopic group [71]. As with other laparoscopic procedures, other studies have shown shorter lengths of stay, less postoperative pain and need for analgesia, and faster recovery times [72–74]. To date, three randomized controlled trials have been published regarding laparoscopic versus open repair of perforated peptic ulcers. All three showed significant reduction in postoperative pain in the laparoscopic group, with many of the other postoperative complications and outcomes being clinically similar to those associated with an open approach. Siu and colleagues showed significantly shorter operative times via a laparoscopic approach, while those of Bertleff and Lau demonstrated significantly longer operating times [54, 71, 72]. If laparoscopic repair is undertaken, the most reliable factor associated with conversion to an open procedure included a size of the perforation greater than or equal to 9 mm. A duration of perforation greater than 12.5 h was also indicative of the need for conversion. [75].

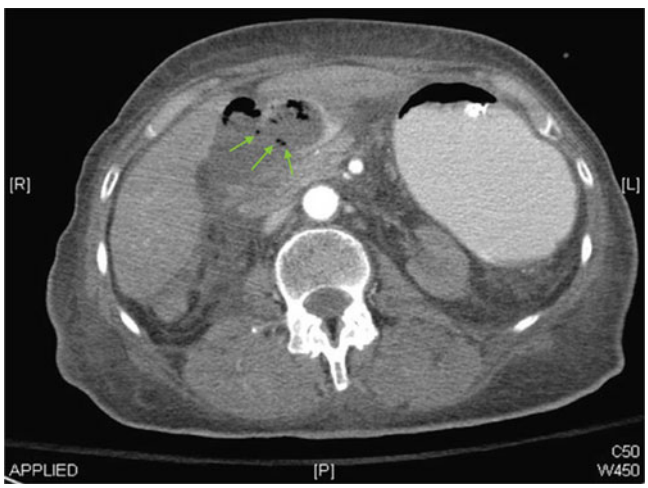

Fig. 20.4 Perforated giant duodenal ulcer on the lateral wall of the second portion of the duodenum. *Arrows* denote the perforation site

Giant Peptic Ulcers

Giant peptic ulcers are defined as having a diameter greater than 2 cm. These lesions have a higher risk of bleeding and perforation. In gastric lesions, although the risk of malignancy is less than historically predicted, the incidence is still around 10 % [76, 77]. Classically, a giant peptic ulcer was an

indication for surgical resection. However, the majority of these ulcers, greater than 80 %, are now successfully treated conservatively with medical management for 6–8 weeks with follow-up endoscopy to evaluate the progression of healing [3]. There are no specific surgical treatment recommendations since the site of perforation and resultant effects on the surrounding anatomy must direct the necessary interventions. These patients are also frequently in septic shock upon presentation given the peritoneal spillage involved. This factor alone should significantly influence the choice of operative intervention. Giant gastric ulcers are most commonly located on the lesser curvature and will often require an antrectomy and reconstruction. For perforated giant duodenal ulcers, the defect is often much too large to secure patent re-approximation. Leak rates of up to 12 % have been reported from attempted closure with an omental patch procedure [78]. The proximity of the defect and its relation to the common bile duct and ampulla of Vater must also be thoroughly investigated. Intraoperative cholangiogram may even be necessary to verify patent anatomy. There are several different procedures that have been described for duodenal defects such as a jejunal serosal patch, tube duodenostomy, and several variations of omental plugs and patches. Of course, an antrectomy with diversion is the classic and most commonly described intervention.

Given the relative rarity of exposure to bleeding and/or perforated giant peptic ulcers, the operating surgeon should do the safest procedure in accordance with the level of experience. Affected patients are often in extremis at the time of presentation, and therefore a damage control procedure will likely be the safest and most appropriate operation for the patient. An antrectomy, with resection of the duodenal defect for duodenal ulcers, will allow for control of spillage. Depending upon the location of the duodenal defect, closure and diversion via antrectomy may be the safest method for damage control. The proximal gastric remnant should be decompressed with a nasogastric tube that was placed and verified intraoperatively. Anastomoses should be avoided in the setting of hypotension or hemodynamic instability, especially if the patient is requiring vasopressors. After copious abdominal irrigation, a temporary abdominal closure device can be placed. The patient can then be resuscitated appropriately in the ICU. The surgeon can return to the OR for re-exploration, restoration of continuity, possible vagotomy, and closure of the abdomen once the patient is hemodynamically stable.

Postoperative Management and Follow-up

Since we now understand that the pathology behind the majority of PUD is infectious in nature, it is important that *H. pylori* is diagnosed either via biopsy or serology. A treatment regimen must then be prescribed and taken to completion. The patient should be tested for cure as the recurrence rate of ulceration with *H. pylori* eradication is 5 % as compared to 38–70 % without [13, 79]. Serology can be attained; however, repeat endoscopy with biopsy for histology or culture is the most accurate method [18]. The urea breath test is another common test of cure, but it should not be attained until 4 weeks after treatment is completed. Patients should also be counseled and encouraged to avoid all ulcerogenic behaviors and medications. If the patient is unwilling to address long-standing behaviors such as smoking or alcohol intake, lifelong PPI therapy should be considered. Patients with medical conditions that require chronic NSAID use should also be started on maintenance PPI therapy. Those patients on antiplatelet and antithrombotic medications should be discussed within a multidisciplinary format as to the appropriate timing for when those therapies should be resumed. For those patients on aspirin alone, while more re-bleeding occurred with its continuation, substantially more deaths occurred at 8 weeks due to the withholding of aspirin. Those patients on dual antiplatelet therapy (aspirin and clopidogrel) had a high risk of coronary stent thrombosis if both drugs were stopped. Patients at low risk of recurrent peptic ulcer bleeding would likely benefit from continuation of dual therapy, whereas patients at moderate-to-high risk of recurrent bleeding should likely remain on at least one antiplatelet medication. For patients on warfarin, as with any other bleeding complication, thrombotic risks must be weighed against the risk of re-bleeding, with consideration given to bridging therapy with intravenous heparin in those patients at high thrombotic risk (e.g., mechanical heart valves or recent thrombotic events) [36]. As with all surgical procedures, patients should have scheduled follow-up with the operating surgeon. Mandatory follow-up endoscopy is probably unnecessary, unless the patient is symptomatic or there were extenuating circumstances that need to be monitored or reevaluated. Additionally, patients with truncal vagotomies or antrectomies should be monitored for post-gastrectomy and post-vagotomy syndromes. Recurrent symptoms after surgical intervention and appropriate *H. pylori* eradication should prompt a workup for less common causes of hyperacidity or hypergastrinemia such as ZES (gastrinoma), retained antrum, or incomplete vagotomy.

Conclusion

The discovery of *H. pylori* and its impact on our understanding and treatment of the PUD, pharmaceutical advances in acid suppression, and new and improved endoscopic and interventional therapies have dramatically changed our management of PUD over the past 30 years. The decision of how to proceed with the acute surgical management of PUD is no

longer as straightforward as the classic surgical algorithms would suggest. The majority of PUD can be sufficiently and appropriately treated medically. This selects out a much more complicated and critically ill group of patients that require our surgical expertise. As described, there are a myriad of options and variations for the surgical treatment of perforated or bleeding PUD. It is important that the current generation of surgeons is familiar with not only the classic surgical interventions but also the interventions that will allow us to stabilize the patient. It is paramount that we understand the risks and potential benefits of each procedure and intervention as it translates historically as well as in collaboration with the use of modern medicinal regimens including PPIs and those that eradicate *H. pylori.* Evidence-based literature regarding acid-reducing surgical procedures in comparison with PPIs in relation to long-term outcomes are desperately needed. However, given that PPIs have become the standard of care, randomized controlled studies are difficult to perform, especially in such a critically ill population. We must use the data that we have to extrapolate those findings to our current patient population. Each specific patient and clinical scenario must be thoroughly evaluated before a definitive decision for management is implemented. The safest and likely the most prudent decision for the majority of these patients will be to control the source of bleeding or sepsis as expediently and safely as possible. Once the patient has been resuscitated and has stabilized postoperatively, further operative interventions can be performed to safely and definitively treat inciting event.

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Gastric Outlet Obstruction

21

Shinil K. Shah and Peter A. Walker

Prior to the introduction of effective anti-ulcer and anti-acid therapies, surgeons commonly dealt with gastric outlet obstruction (GOO) secondary to peptic ulcer disease (PUD). With advances in medical therapy, the number of operations being performed in the USA annually for ulcer related obstruction has decreased to several thousand cases. GOO, however, is still an issue treated by acute care surgeons. Most often, these cases are secondary to malignant etiologies. Surgeons must understand the etiology, diagnostic workup, and surgical management of these patients [1, 2].

Benign Etiologies

Peptic Ulcer Disease

In adults, the most common cause of benign GOO is still related to complications of PUD [3]. About 5–10 % of patients who are admitted for issues related to PUD present secondary to GOO related issues [2]. Although the majority of gastric and duodenal ulcers are related to *H. pylori*, patients with PUD who develop GOO have been variably shown to be infected with *H. pylori*. Studies have reported between 33 and 91 % of patients with PUD related outlet obstruction to have evidence of *H. pylori* infection. Other factors may contribute to obstruction, including the use of nonsteroidal anti inflammatory medications [4]. In patients with PUD related obstruction with documented *H. pylori* infection, treatment of this should be the first step in treatment [4].

Generally, there are five classic types of gastric ulcers, including type 1 (gastric body), type 2 (antral and duodenal), type 3 (pre pyloric), type 4 (gastric cardia), and type 5 (diffuse, typically associated with NSAID use). Type 2 and 3 ulcers are typically associated with acid hyper secretion and are the types most commonly responsible for PUD related GOO [5]. It is rare for isolated gastric ulcers outside the pyloric channel to cause significant GOO (less than 5 % of reported cases) [6].

The clinical presentation of patients with GOO is similar whether it is secondary to a benign or malignant cause and may include nausea, emesis (often of undigested food many hours after eating), abdominal (epigastric) pain and distention, weight loss, reflux symptoms, aspiration, and earlier satiety. Pain and significant weight loss are more commonly associated with malignant causes of GOO. Duration of symptoms is variable and dependent on the etiology. Significant clinical signs of dehydration may be noted. Physical exam (auscultation) may reveal a succussion splash [6, 7]. Laboratory workup classically reveals a hypokalemic, hypochloremic metabolic alkalosis especially if significant emesis is present. Initial plain radiographs may demonstrate a distended, dilated stomach. High resolution computed tomography (CT) imaging with contrast often demonstrates retained contrast in the stomach as well as clues to the potential etiology. Extreme care needs to be taken with administration of oral contrast in patients with suspected GOO due to the risks of aspiration [7].

Historically, a saline load test has been described for the evaluation of GOO. After decompression of the stomach via nasogastric tube, 750 ml of normal saline is infused into the stomach over 3–5 min. The stomach is decompressed 30 min later. Evacuation of 400 ml or more of fluid is suggestive of GOO. [7]

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_21

Patients with PUD related GOO should initially be resuscitated to manage electrolyte abnormalities. Significant bleeding and/or perforation should be ruled out. Initial management consists of nasogastric decompression, fluid resuscitation, evaluation and treatment for *H. pylori* (if present), cessation of nonsteroidal anti inflammatory medications and smoking, and anti-acid therapy [8–10]. In patients with suspected GOO, a meticulous workup for etiology must be undertaken with the realization that the majority of patients will have an underlying malignant cause [1, 11]. History and high resolution imaging is often key to suggest potential malignant etiologies. Particular attention should be paid on imaging to evaluate for potentially enlarged lymph nodes, significant thickening of the stomach, and pancreatic or hepatobiliary abnormalities [10]. Endoscopy plays a key role in diagnosis and often the initial treatment of patients with GOO. In patients at high risk for malignancy (GOO in a setting of no history of PUD or patients older than 55 years), repeat endoscopy should be performed if initial biopsies are negative. Endoscopic ultrasound may be a useful adjunct [12].

The success of pure medical management has been reported by some small series, and is often associated with benign etiology, a clear inciting factor, and lack of significant long-term or repeated episodes [13]. In hospitals with therapeutic endoscopists, pure medical management without endoscopic therapy is rare. However, in patients with a proven benign etiology, lack of repeated episodes, and no evidence of complications, a short period of intensive medical management may be indicated [9]. Generally, if pure medical therapy will be successful, signs of improvement will be seen in 48–72 h [10].

Endoscopy for Benign Gastric Outlet Obstruction

Increasingly, endoscopy is utilized for the initial treatment of benign GOO via endoscopic balloon dilation [3, 10] (Fig. 21.1). Prior to any endoscopy, gastric decompression should be performed. Over the wire balloons are typically utilized with fluoroscopic assistance, especially when treating tight/long strictures. Repeat dilation over several weeks is often performed until a lumen of about 15 mm is achieved [10].

There are a large number of studies evaluating endoscopic balloon dilation for PUD related GOO. However, there are few that are large, prospective, randomized and/or offer long-term outcomes data. Cherian et al. published a series of 23 patients who underwent endoscopic therapy for PUD related GOO and reported success of endoscopic therapy over a median follow-up of 43 months. It is important to note that in this study, which offers some of the longest follow-up, a concerted effort was made to identify and treat the underling causes of PUD. A significant number of treated patients will require long-term anti-acid therapy [14]. Another study of 72 patients with benign GOO demonstrated a long-term success rate of about 70 % of patients during a mean follow-up period of 98 months. Complications noted were perforation (2 cases) and arterial hemorrhage (1 case). Although frequently multiple dilations are often necessary, endoscopic therapy may offer acceptable long-term symptom relief [15].

Factors that have been shown in various studies to predict need for more aggressive surgical intervention includes >1 year of treatment, use of nonsteroidal anti inflammatory medications, younger age, long strictures, and >2–3 dilations [3, 10, 16]. There is some suggestion that patients with GOO

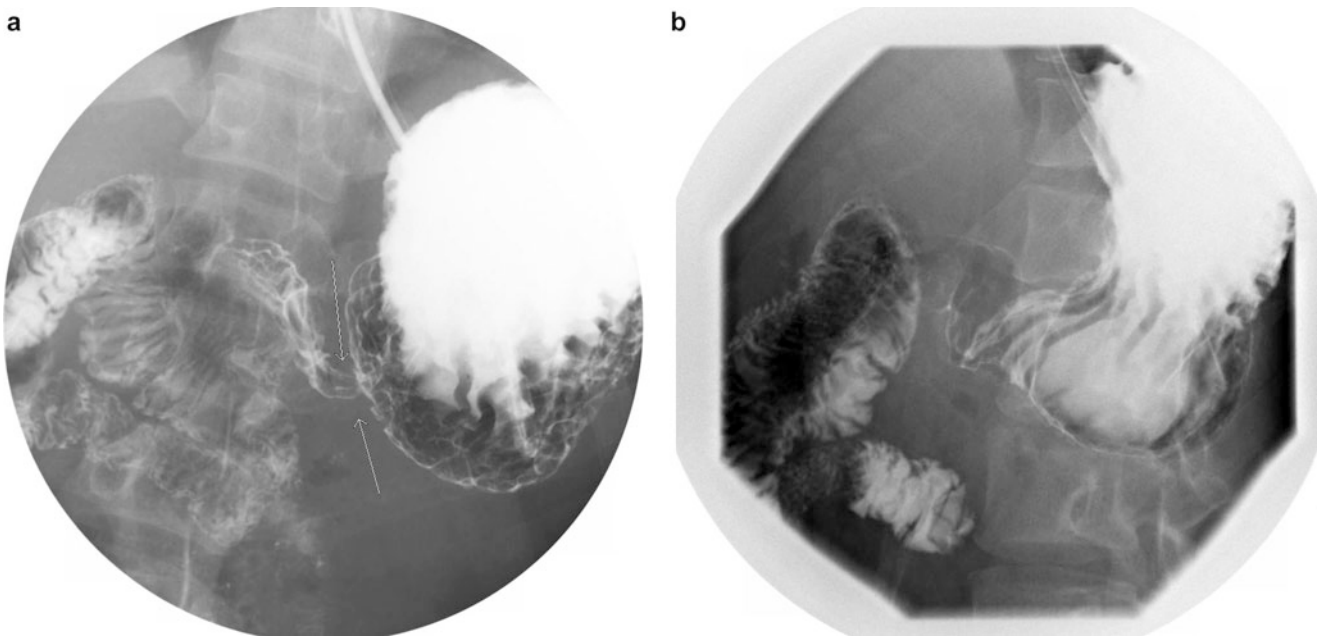


Fig. 21.1 (**a**, **b**) Demonstrated are pre (**a**, *arrows*) and post (**b**) endoscopic balloon dilation contrast images in a patient with a pre pyloric stricture

who are *H. pylori* negative do not respond as favorably to endoscopic dilation [2]. Generally, patients with nonulcer related causes of benign GOO also do not respond favorably to a pure endoscopic approach [6].

Surgery for Benign Gastric Outlet Obstruction

Today, surgery for PUD related GOO is utilized mainly in patients who have failed medical and endoscopic therapy or those who have complications of endoscopic therapy. Surgical options consist of subtotal gastrectomy (rare, depends on location of ulcer), antrectomy with vagotomy followed by Billroth 1, Billroth 2, or roux-en-Y reconstruction, vagotomy with pyloroplasty (or other drainage procedure), or vagotomy with gastrojejunostomy [8]. It is important to note that as the number of patients who present with benign GOO continues to decrease as well as the continued increased in endoscopic options, the number of these procedures being performed continues to decrease in frequency. Consideration to perform one of these procedures should be done in concert with a surgeon experienced in gastric/foregut surgery. Increasingly, these procedures can be performed through minimally invasive means.

Vagotomy

Vagotomy has a sometimes questionable role in modern treatment of PUD related GOO. It was first described for the treatment of PUD in 1922 by Andre Latarget. Significant delayed gastric emptying prevented widespread use of this procedure as an anti-ulcer operation until acceptable results were shown with vagotomy combined with antrectomy or a drainage procedure. Vagotomy can be performed in a selective, highly selective or truncal fashion.

Truncal vagotomy (Fig. 21.2) involves division of the vagus nerves at the hiatus. It is generally combined with a drainage procedure, such as pyloroplasty. Truncal vagotomy is safe, can be done with minimally invasive techniques, and is generally easy to teach and perform, especially in surgeons who have experience with hiatal/paraesophageal hernia repairs. It is important to clip the nerve proximally and distally and to excise a segment of the nerve. It should be sent for pathological examination to confirm vagotomy. Vagotomy with antrectomy generally offers a lower recurrence rate but higher risk of side effects, mortality, and risks of dumping syndrome.

Selective vagotomy (Fig. 21.2) has been described (preserving hepatic and celiac branches) and thought to offer advantages of less dumping symptoms and diarrhea. However, it is technically difficult with unclear clinical benefits and is generally not performed.

Highly selective vagotomy (Fig. 21.2) involves division of the anterior and posterior vagal branches supplying the gastric parietal cells. It is typically accomplished by ligating the anterior and posterior branches of the vagus nerve close to the lesser curvature of the stomach from the GE junction to the incisura. The posterior criminal nerve of Grassi (branch of the right vagus nerve) is divided. The celiac and hepatic branches of the vagus nerve are preserved. Additionally, innervation of the antrum and pylorus (Crow's foot) is preserved. This procedure can be done open or laparoscopically. It is associated with a low rate of complications, as well as lower risks of dumping syndrome and/or diarrhea. It is associated with a high recurrence rate (up to 30 %), which may be related to surgeon experience. This procedure is rarely done in isolated fashion for symptoms of GOO. If it is done for a patient with GOO related obstruction, a drainage procedure generally needs to be performed. In general, the role of vagotomy for the treatment of PUD related GOO generally is in patients with a high risk of recurrence in combination with antrectomy or as a part of pyloroplasty or other drainage procedure [17].

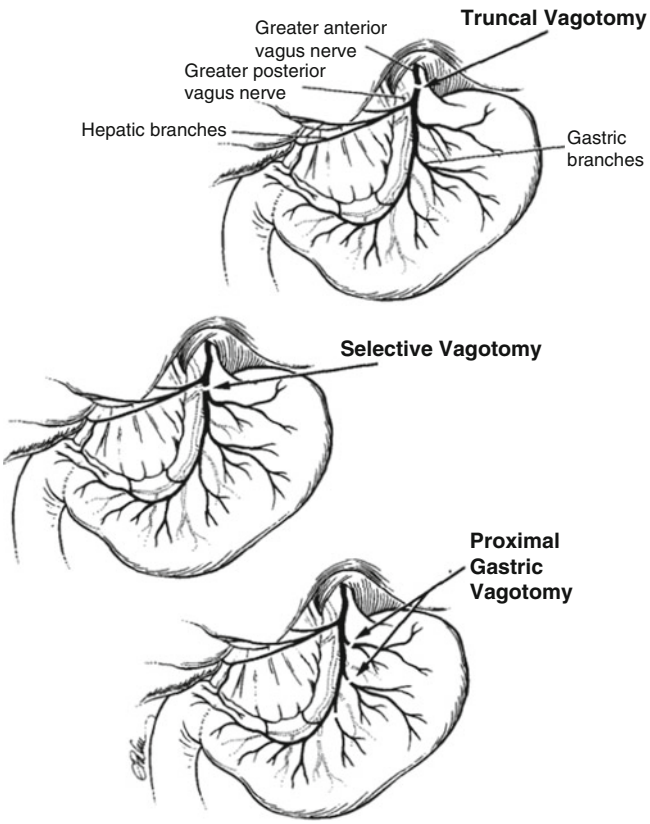


Fig. 21.2 Illustrated in this figure are the three most commonly described types of vagotomy, truncal, selective, and highly selective vagotomy. Truncal vagotomy involves division of the anterior and posterior vagus nerves at the hiatus and denervates the liver, gallbladder, duodenum, small intestine, pancreas, and stomach. Selective vagotomy preserves the hepatic and celiac branches. Highly selective vagotomy involves division of the anterior/posterior vagal branches supplying the gastric parietal cells and involves ligating the anterior and posterior branches of the vagus nerve close to the lesser curvature of the stomach from the GE junction to the incisura as well as the posterior criminal nerve of Grassi. Celiac and hepatic branches of the vagus nerve are preserved as is innervation to the antrum and pylorus (Crow's foot). (From Casas AT, Gadacz TR. *Laparoscopic management of peptic ulcer disease.* Surg Clin North Am, 1996; **76**(2): p 515–22, with permission.)

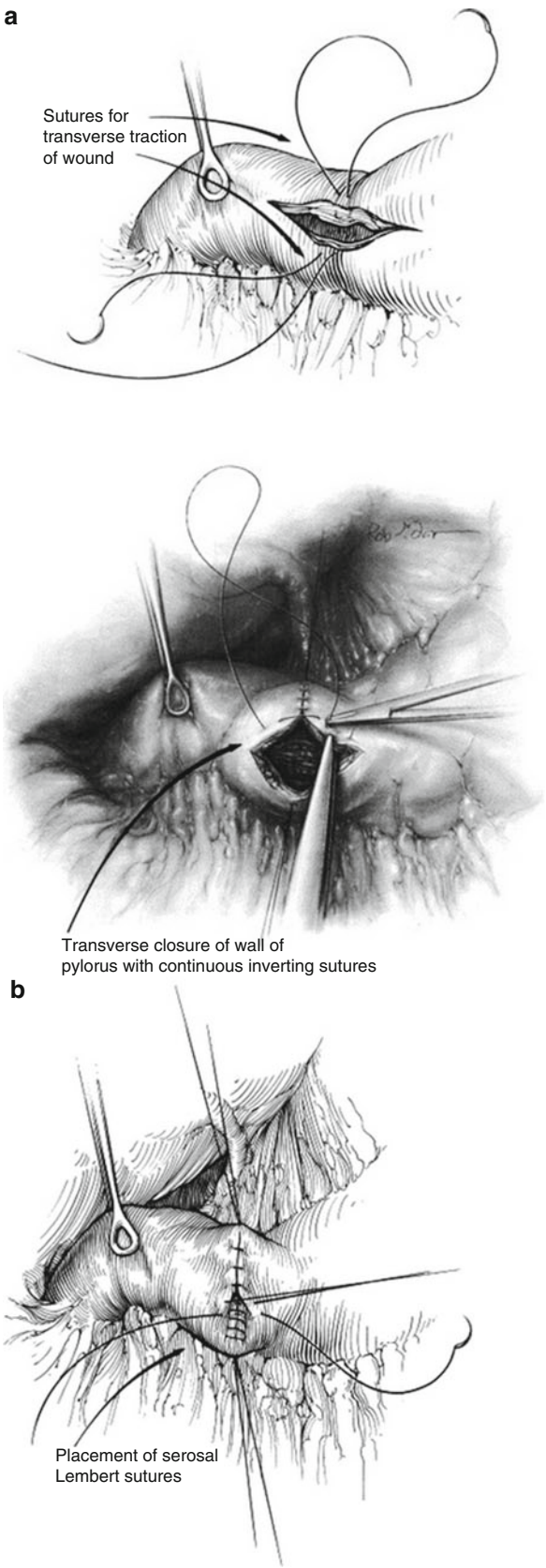
Surgical-Drainage Procedures-Pyloroplasty and Gastrojejunostomy

There are a lack of randomized studies evaluating the best surgical option for PUD related GOO. If antrectomy is not performed, and a drainage procedure with vagotomy is the treatment chosen for a patient with PUD related GOO, there are several points to consider. Although the classically described drainage procedure is pyloroplasty, other options include gastrojejunostomy, duodenoplasty, or surgical dilation. We will focus on gastrojejunostomy and pyloroplasty.

Vagotomy (often truncal) with gastrojejunostomy has been described as an effective treatment for PUD related GOO. In one of the only randomized studies published on surgical treatment of PUD related GOO, Csendes and colleagues compared highly selective vagotomy with gastrojejunostomy, highly selective vagotomy with Jaboulay pyloroplasty, or selective vagotomy with antrectomy. With mean follow-up of 98 months, more patients who underwent highly selective vagotomy with gastrojejunostomy or selective vagotomy with antrectomy had Visick scores of 1 as compared to patients who underwent pyloroplasty [18]. It is important to note the small nature of this study (90 patients total) and the fact that most surgeons do not perform selective vagotomy. Kennedy et al. also published a randomized trial comparing selective vagotomy with Finney pyloroplasty (50 patients) versus with gastrojejunostomy (50 patients) for patients with chronic duodenal ulcer with results favoring selective vagotomy with gastrojejunostomy. However, it is important to note that this was not done specifically for patients with GOO [19].

Vagotomy with gastrojejunostomy can often be performed laparoscopically using intra or extracorporeal anastomosis techniques. It minimizes the complications associated with antrectomy. It may offer an advantage over pyloroplasty when there is severe scarring or inflammation of the duodenum. [20] Gastrojejunostomy is typically performed in an antecolic manner [21].

There are multiple techniques to perform pyloroplasty (Heineke-Mikulicz, Finney, and Jaboulay) and acute care surgeons should be familiar with the different techniques. Heineke-Mikulicz pyloroplasty, which involves a longitudinal incision through the pylorus extending onto the gastric and duodenal side followed by transverse closure in a single or double layer, is probably the most well-known technique. [22, 23] (Fig. 21.3). A Jaboulay pyloroplasty is in essence a side to side anastomosis between the antrum and proximal duodenum in which the incisions do not divide the pylorus (Fig. 21.4). A Finney pyloroplasty may be advantageous



(shown) fashion followed by imbrication of the suture line with serosa to serosa Lembert sutures (C). A single layer closure can also be performed. (From Martin, R. F. *Surgical management of ulcer disease.* Surg Clin North Am, 2005; **85**(5): p. 9–29, with permission.)

Fig. 21.3 Demonstrated is the Heineke-Mikulicz pyloroplasty technique. An incision is made through the pylorus extending onto the gastric and duodenal side after placement of traction sutures (A), followed by transverse closure of the enterotomy in interrupted or continuous

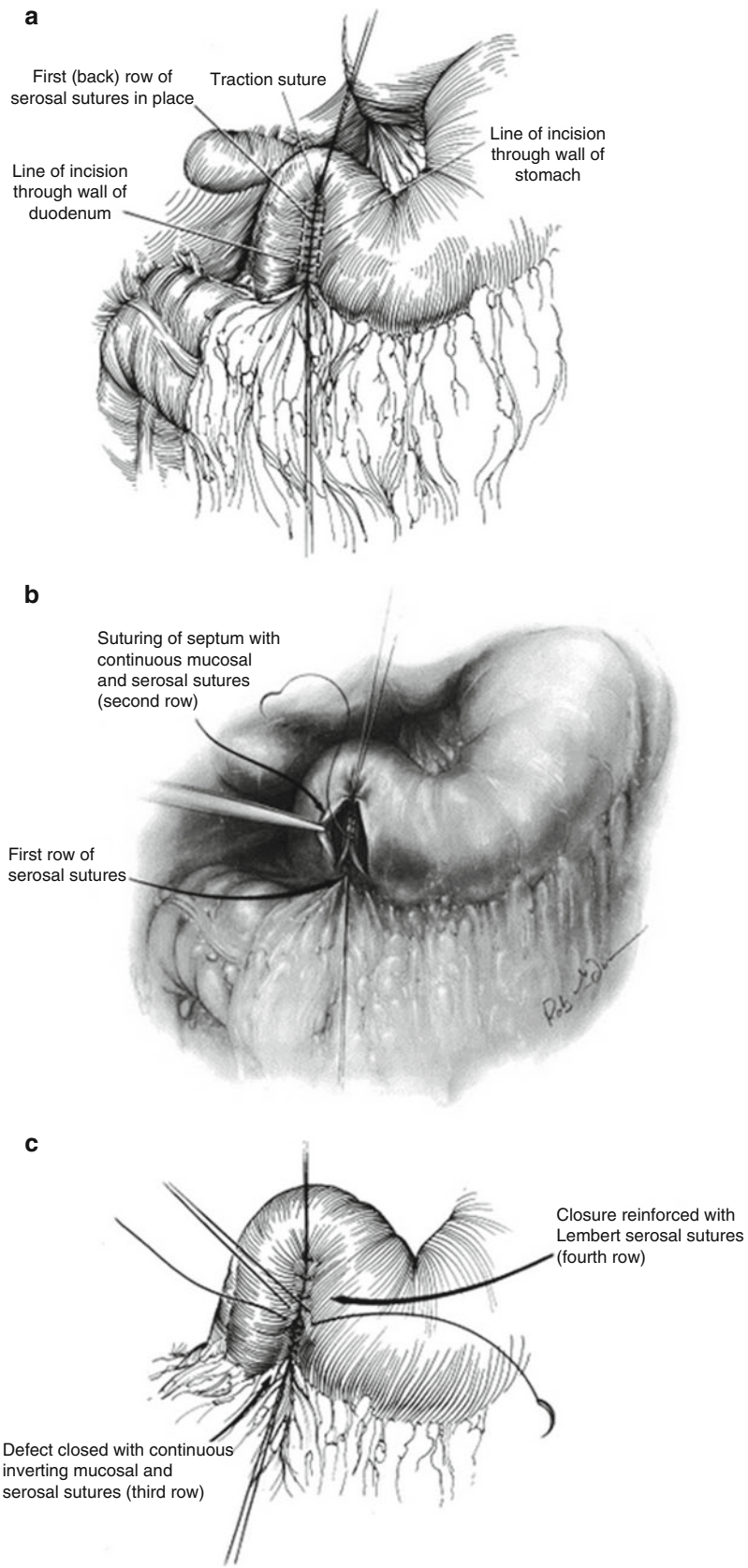


Fig. 21.4 Demonstrated is the Jaboulay pyloroplasty technique. This is essentially a bypass of the pylorus by creating an anastomosis between the stomach and first part of the duodenum. A back row of Lembert sutures is placed (**a**), followed by incision of the duodenum and stomach. The pylorus is not incised as done with a Finney pyloroplasty. A two layered anastomosis is then completed (**b**, **c**). (From Martin, R. F. *Surgical management of ulcer disease.* Surg Clin North Am, 2005; **85**(5): p. 9–29, with permission.)

with a J-shaped stomach. A standard pyloroplasty incision is made through the pylorus and extending along the first portion of the duodenum and proximally along the pre pyloric stomach (horseshoe incision) followed by closure by creating an anastomosis between the antrum and proximal duodenum [24]. It is similar to the Jaboulay pyloroplasty except with the Finney pyloroplasty, the pylorus is divided.

Potential adverse effects after surgery include bile reflux (if antrectomy is performed, sometimes requires conversion to a roux-en-Y reconstruction), recurrence of ulcer, dumping syndrome, diarrhea, and complications related to the surgical procedure including leaks [22].

Adult Idiopathic Hypertrophic Pyloric Stenosis

Hypertrophic pyloric stenosis is often seen in about 0.25–0.5 % of infants and typically presents in the first several weeks of life. Adult idiopathic hypertrophic pyloric stenosis can be seen in adults and typically seen in men. This should be thought of largely as a diagnosis of exclusion as there are less than 200 reported cases [25]. The pylorus is noted to be bulbous or fusiform. It is noted to be thickest at the junction of the pylorus and duodenum. Imaging features include gastric dilatation with a lengthened pyloric channel. A string sign may be seen (thin barium seen going through an elongated pyloric channel). There are other radiological signs (Kirklin's and Twining's sign) described in various publications [25, 26]. During endoscopy, it may not be possible to pass the pylorus. A non-mobile, narrow pylorus with smooth borders that does not completely close may also be seen on endoscopy. Biopsies are mandatory to rule out malignancy. Given the relatively small number of patients, various surgical options have been attempted including endoscopic dilation, pyloroplasty, pyloromyotomy, and distal gastrectomy. Distal gastrectomy with reconstruction appears to have the best long-term outcomes [26].

Superior Mesenteric Artery Syndrome

First reported in 1842, superior mesenteric artery (SMA) syndrome (Wilkie Syndrome) is a rare and sometimes controversial cause of GOO. Compression of the duodenum between the superior mesenteric artery and aorta leads to symptoms of GOO [27]. Significant weight loss is thought to be potentially contributive and/or related to SMA syndrome. CT of the abdomen with contrast is often suggestive and/or diagnostic. Foregut obstruction with a transition seen around the third portion of the duodenum suggests the diagnosis. Close examination of CT imaging should be focused on the angle between the aorta and the superior mesenteric artery as well as the distance between the aorta and the superior mesenteric artery where the duodenum lies between these two structures. Angle is best observed on sagittal reconstructions and distance between the two vessels best on axial images. Normally, the angle is between 38 and 60° and the distance is between 10 and 28 mm [27–29]. An angle less than 22–25° and a distance less than 8 mm is highly suggestive of SMA syndrome [27, 28, 30, 31]. In patients with suspected symptoms, conservative management should be attempted first, including cessation of oral intake, parenteral or enteral nutrition, and nasogastric decompression. Duodenojejunostomy (either open or laparoscopic) is the generally accepted surgical treatment, although gastrojejunostomy as well as takedown of the ligament of Trietz has been described. Takedown of the ligament of Trietz with mobilization of the duodenum (Strong's procedure) has also been described [31]. It is vital that a complete workup be done to exclude other, particularly malignant, gastric, duodenal, or pancreatic etiologies for GOO in patients suspected of having SMA syndrome.

Gastric Polyps

Polyps are found with relative frequency during upper endoscopy (6 %) with most being benign, incidental, and asymptomatic. Rarely, pedunculated, large polyps have been noted to cause intermittent gastric outlet obstruction. This etiology may be suggested with computed tomography (CT) and is confirmed with endoscopy [32]. Endoscopy is generally diagnostic and therapeutic. Malignancy must be ruled out [33].

Caustic Strictures

GOO related to ingestion of caustic substances is relatively uncommon in developed countries. The majority of recommendations for treatment arise out of international experiences. Typically the esophagus (with or without the stomach) is most often affected and isolated GOO is rare. It is most often related to ingestion of acid. The majority of patients who have GOO have short segment strictures near the pylorus [34, 35]. Nutritional optimization (feeding jejunostomy) may be necessary prior to definitive therapy, which traditionally consists of partial or total gastrectomy (depending on the location of the stricture) or bypass with gastrojejunostomy [34]. Patients with isolated gastric involvement appear to have better outcomes [34, 35]. There is limited experience with endoscopic dilation for caustic related GOO; in small studies, it appears to have favorable outcomes. Patients may require serial dilations. If endoscopic expertise is available, consideration should be given to this modality for treatment [36, 37]. Some studies report success with intra-lesional steroid injections at the time of dilation [10].

Gallstone Related Obstruction

Gallstones are a rare cause of GOO (Bouveret syndrome) (Fig. 21.5). This is typically seen with an impacted duodenal gallstone secondary to an associated cholecystoduodenal fistula. It is most often seen in older women and is characterized by pneumobilia, obstruction, and gallstones seen outside the gallbladder (Rigler's triad). Diagnosis is made with computed tomography (CT) or magnetic resonance imaging (MRI) of the abdomen. With appropriate expertise, upper endoscopy with adjuncts (including lithotripsy) may be effective. If there is lack of endoscopic expertise or in patients who fail endoscopic therapy, surgery is necessary and usually involves removal of the gallstone via a gastrotomy or duodenotomy. Generally, if no large stones are noted in the gallbladder, cholecystectomy (often difficult in this setting) is not required [38].

Pancreatic Pseudocysts

Surgeons who treat acute pancreatitis will at some point deal with the management of pancreatic pseudocysts. It is important to differentiate peri pancreatic fluid collections as well as cystic neoplasms of the pancreas from true pancreatic pseudocysts. History is often extremely suggestive of the diagnosis [39, 40]. Pseudocysts are associated with alcohol induced pancreatitis in over 50 % of cases. Although the presentation is varied, symptoms of nausea, emesis, inability to tolerate oral or enteral (gastric) intake may indicate GOO [39]. For non-resolving, symptomatic large pseudocysts either endoscopic or laparoscopic/open internal drainage may offer significant relief. In very high-risk patients, percutaneous drainage is an option. Surgery for drainage of large, symptomatic pancreatic pseudocysts allows for biopsy of the pseudocyst wall [41].

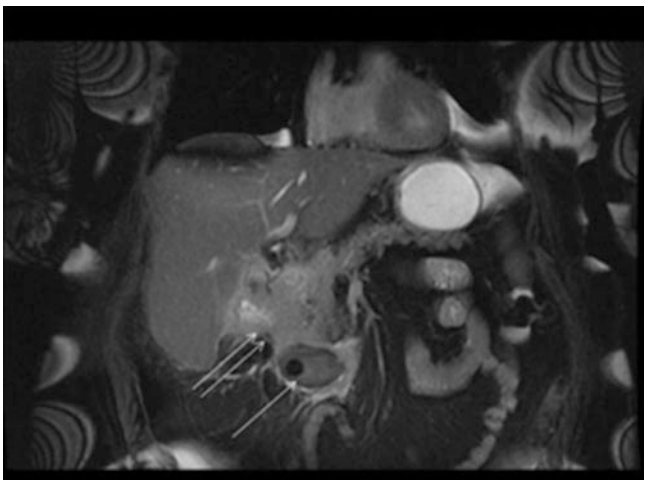


Fig. 21.5 Demonstrated is an MRI of a patient with an impacted duodenal gallstone (*single arrow*) leading to gastric outlet obstruction (Bouveret's syndrome) secondary to cholecystoduodenal fistula (*double arrow*). (From Shah, S.K., et al., *Bouveret syndrome.* J Gastrointest Surg, 2013. **17**(9): p. 1720–1, with permission.)

Bezoars

While rare (found in less than 0.5 % of upper endoscopies), bezoars are a rare cause of GOO. They are most commonly seen in the stomach and most often consist of plant materials (phytobezoars). They may also be formed from ingested hair (trichobezoars), medications (pharmacobezoars), milk proteins (lactobezoars), synthetic products (plastic, metal, toilet paper), or parasites (Ascaris). Patients who are diagnosed with bezoars should be evaluated for an underlying predisposing condition, such as previous gastric surgery, malignancy, PUD, inflammatory diseases (Crohn's disease), or gastroparesis. Patients may be asymptomatic or present with varied symptoms, including pain or discomfort, gastrointestinal bleeding, anemia, dysphagia, nausea and vomiting, and decreased appetite. Diagnosis is often suggested by contrast imaging (CT) [42, 43]. Definitive diagnosis is made via endoscopy and treatment may be medical, endoscopic, or surgical. Given the lack of large numbers of patients with bezoars, there are not standard treatment protocols. Certain investigators have reported success with gastric lavage with Coca-Cola® [42, 44]. Enzymatic degradation with papain and cellulase has been used with some success; the latter is no longer available widely for medical use. Endoscopy, while diagnostic, can often be therapeutic. The bezoar can be fragmented using a variety of tools (forceps, snares, argon plasma coagulation, lithotripsy, or needle knives; certain types of bezoars (e.g., trichobezoars) may difficult to address with endoscopic therapies. Surgery, either laparotomy or laparoscopy, is used for cases not responding to medical or endoscopic therapy [42].

Post Weight Loss Surgery

GOO is seen rarely as a complication of weight loss surgery. A recent review of complications of bariatric surgery presenting to an academic acute care surgery service over a 6-year period demonstrated 2/30 cases as being secondary to GOO [45]. Stricture at the gastrojejunostomy is one of the most common complications seen after roux-en-Y gastric bypass (approximately 7 % reported incidence in large studies) and may be related to postoperative issues or as a result from recurrent or untreated marginal ulcers (Fig. 21.6). Typically patients will present with nausea, emesis, and/or difficulty swallowing. Classically, the diagnosis of an early gastrojejunal stricture is made when patients report difficulty

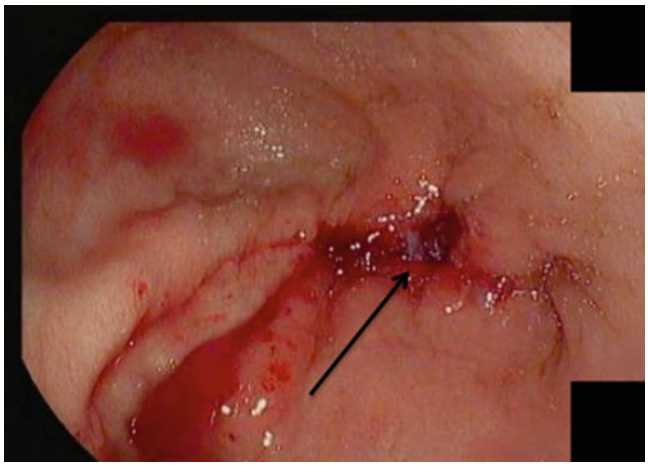


Fig. 21.6 Endoscopic appearance of an early stricture (*arrow*) status post roux-en-Y gastric bypass. These strictures typically respond well to endoscopic dilation

(nausea, vomiting, and/or dysphagia) advancing from a liquid to a solid diet. Diagnosis may be suggested by an upper gastrointestinal contrast series or CT and is confirmed by endoscopy. Endoscopic dilation is generally considered the initial treatment of choice with treatment of any predisposing conditions [46].

GOO may also be seen secondary to strictures or band erosion in patients who have undergone weight loss procedures that are not routinely done in modern practices. This can include vertical banded gastroplasty and fixed gastric bands (e.g., Molina bands) [47]. Symptoms of gastric outlet obstruction can also be seen with severely slipped laparoscopic adjustable gastric bands or patients who have undergone sleeve gastrectomy and have anatomical reasons for obstructive symptoms (such as narrowing at the angularis incisura) (discussed in a different chapter in this textbook). Typically, these present with chronic symptoms and the management of these patients should be in concert with surgeons experienced with complications of weight loss surgery.

Gastric Volvulus

A rare cause of GOO is from a large paraesophageal hernia with gastric volvulus. Acute gastric volvulus is classically characterized by Borchardt's triad of symptoms (retching, epigastric abdominal pain/distention, and inability to place an nasogastric tube). Upper gastrointestinal contrast study will usually demonstrate volvulus [48]. Acute volvulus is a surgical emergency given concern for ischemic complications.

Volvulus is typically described as organo-axial, mesentero-axial, or combined organo-axial and mesentero-axial depending on the pattern of rotation. The most common pattern is when the stomach rotates along an axis created by a line from the pylorus to the cardia (organo-axial) (Fig. 21.7).

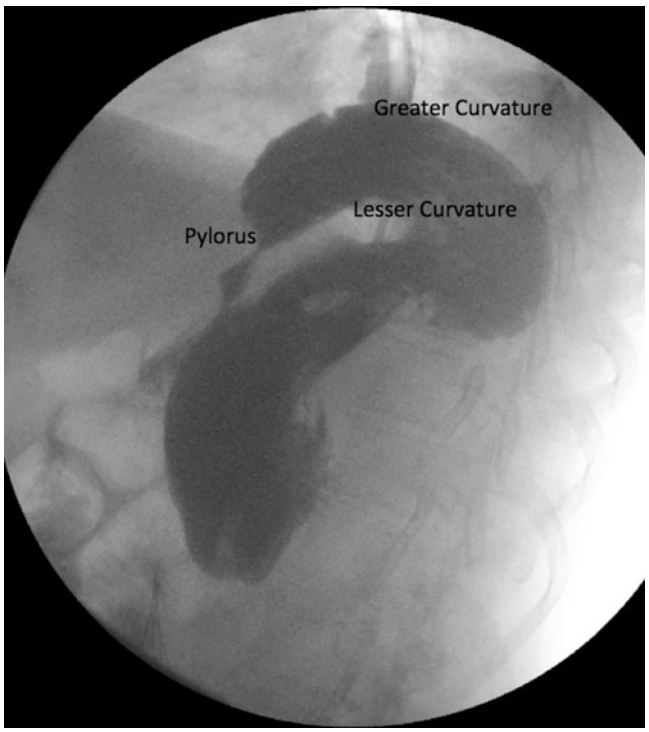


Fig. 21.7 UGI of a patient with a large paraesophageal hernia with organo-axial volvulus. This typically results in the appearance of an upside down stomach with flipped orientation of the greater and lesser curvature

This form tends to be associated with ischemia. Mesentero-axial volvulus is when the stomach rotates around an axis created by a line from the lesser to greater curvature. It tends to be associated with more chronic symptoms.

Early diagnosis and intervention in patients with acute volvulus is key and management should be undertaken with a surgeon experienced with the surgical management of paraesophageal hernias [49, 50]. In stable patients, general principles of repair include reduction of the volvulized stomach, assessment of viability with resection if necessary, resection of the hernia sac and esophageal mobilization, closure of the diaphragmatic defect, gastropexy of the anterior stomach (either suture or with a gastrostomy tube), and possible anti-reflux procedure (fundoplication). This should be performed laparoscopically if expertise is available [51, 52]. Simple reduction of the stomach, detorsion, and gastropexy can be considered depending on the patient's clinical state [53]. Whenever possible, surgeons with experience with paraesopahgeal hernia repairs should assist in the surgical management of these patients.

Other Benign Etiologies

Other common benign causes of GOO include duodenal hematomas. These are typically seen in pediatric patients and after blunt abdominal trauma but have been reported as a

consequence of endoscopy or in patients with therapeutic anticoagulation. They typically resolve with conservative management with bowel rest, nasogastric decompression, and nutrition. Classically, surgical drainage is reserved for patients who do not respond to conservative management. Some report treatment with endoscopic drainage and/or image guided drainage [54, 55].

Crohn's disease, post surgical strictures, gastroduodenal tuberculosis, cytomegalovirus, Kaposi's sarcoma with gastrointestinal involvement, and other infections have all been rarely reported to cause gastric outlet obstruction [56–60].

Gastroparesis (either secondary or idiopathic) can be a cause of functional GOO. The most common etiologies are diabetes, post surgical (typically from compromise of the vagus nerve), or idiopathic. It is typically diagnosed with symptoms as well as gastric emptying studies. Initial treatment involves dietary modification, control of precipitating medical conditions, and pro-kinetic agents. Surgical treatment is limited to refractory cases and options may include gastric pacemaker, pyloroplasty, decompressive gastrostomy/feeding jejunostomy tubes, or subtotal gastrectomy with roux-en-Y reconstruction. There is newer data suggesting that laparoscopic pyloroplasty may be an effective, minimally invasive option with good symptomatic results [61].

Malignant Etiologies of Gastric Outlet Obstruction

Worldwide, the most common reason for GOO is malignancy. Pancreatic malignancy is the most common noted cause of malignant GOO (15–20 % of patients) [6]. Other potential etiologies include gastric malignancy, lymphoma, ampullary and/or duodenal cancer (Fig. 21.8), bile duct malignancy including cholangiocarcinoma, and metastatic disease [62]. Every patient who presents with GOO should be evaluated for a malignant etiology. Unfortunately, advanced presentation often leads to consideration for symptom palliation, but the mainstay of initial evaluation focuses of resectability and/or definitive treatment.

Options for palliation of patients with malignant GOO include gastrojejunostomy for bypass, endoscopic treatment including stenting, medical management to control upper gastrointestinal secretions, and palliative gastrostomy tubes for decompression/venting. Patients who present with malignant gastric outlet obstruction often present with similar symptoms as those with benign GOO, including nausea, emesis, abdominal pain, and distention as well as sequelae from malignancy including significant malnutrition. Average life expectancy tends to be short (3–4 months) [62].

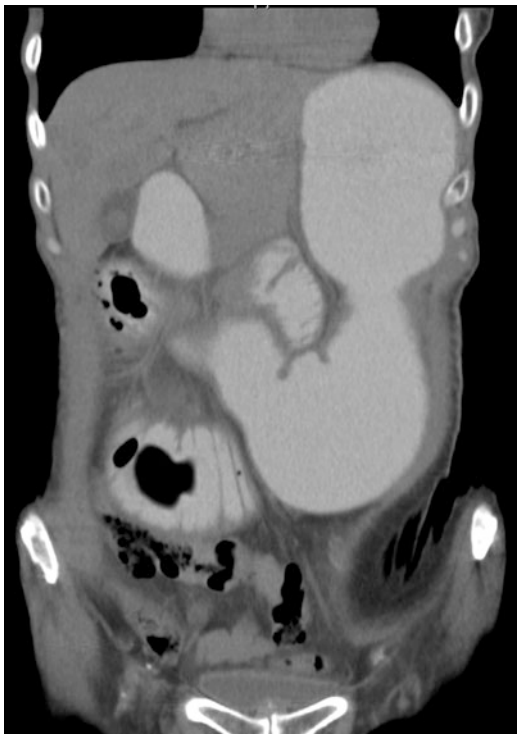


Fig. 21.8 CT scan of a patient with gastric outlet and proximal duodenal obstruction secondary to metastatic duodenal adenocarcinoma. Involvement of an adjacent loop of jejunum created a closed loop proximal jejunal obstruction in addition to gastric outlet and proximal duodenal obstruction. Resection of the 3rd/4th portion of the duodenum and proximal jejunum followed by duodenojejunostomy afforded significant palliation of obstructive symptoms in this patient

Endoscopic Palliation of Malignant Gastric Outlet Obstruction

For palliation of malignant GOO, major options include endoscopic stenting versus surgical gastrojejunostomy. Endoscopic options are usually the initial treatment of choice if feasible. They are associated with less hospital length of stay, quicker time to resumption of oral diet, lower cost, and less major medical complications when compared with open gastrojejunostomy. There are three major randomized studies comparing endoscopic stenting to gastrojejunostomy [62, 63]. Mehta et al. published a randomized study of laparoscopic gastrojejunostomy as compared to duodenal stenting in 27 patients with malignant GOO. Patients who underwent duodenal stenting demonstrated less pain, shorter hospital length of stay, and improvement in physical health (Short-Form 36 questionnaire) [64]. Fiori et al. published similar results in a randomized trial of 18 patients comparing endoscopic stenting versus open gastrojejunosotmy with endoscopic stenting associated with less operative time, quicker resumption of oral intake, and median hospital length of stay [65].

Jeurnink et al. conducted a multicenter randomized trial involving 21 centers in the Netherlands and comparing gastrojejunostomy versus endoscopic stent placement for malignant GOO. Similar to the other randomized trials, it was small study comparing 18 and 21 patients randomized to gastrojejunostomy (performed open or laparoscopic) and stent placement, respectively. Similar to other studies, patients undergoing stent placement had quicker resumption of oral intake, shorter hospital length of stay and less cost. However, with long-term follow-up (beyond 2 months) and not surprisingly, gastrojejunostomy was associated with less recurrent obstruction, re-intervention, and better oral intake. It is interesting to note that 50 % of patients eligible to participate in this trial refused to participate in favor of endoscopic stenting. The authors concluded that gastrojejunostomy should be considered in patients expected to live at least 2 or more months [66].

Recurrence of symptoms can be seen after endoscopic stenting, but treatment of such typically involves a repeat endoscopic procedure [67]. Common adverse effects of stent placement include obstruction, migration, perforation, bleeding, fistula formation, and stent fracture. Additional reported adverse effects include aspiration as well as other sedation/anesthesia related complications. Technical complications of stent placement, such as migration or obstruction can often be treated with endoscopic means. Both covered and uncovered stents have been used; there may be less risk of reobstruction with covered stents but with a higher rate of stent migration [63, 68, 69].

Limitations that may prevent successful stent placement include inability to pass a guidewire through the structure or technical difficulties with endoscopy such as a large dilated stomach that leads to significant loop formation. The stent should overlap the stenosis by at least 3–4 cm. When stenting across the ampulla, especially with a covered stent, consideration should be made for biliary stent placement. Technical success rates for stent placement are usually in excess of 90 % for experienced endoscopists and in the absence of a complete obstruction. Reported clinical success rates of relieving obstructive symptoms by stent placement range from about 80–90 % [63].

Surgical Palliation of Malignant Gastric Outlet Obstruction

With the increasing use of endoscopic therapies, the role of surgical gastrojejunostomy is often in patients who are unable to get endoscopic stenting for anatomic reasons, lack of availability of endoscopic expertise, failure of endoscopic stenting, complications of endoscopic stenting not able to be addressed with endoscopy, or complete obstruction. Technical success rate of gastrojejunostomy is high but is associated with a significant risk of complications, often related to patient related conditions including advanced malignancy and profound malnutrition. Laparoscopic gastrojejunostomy should be considered the procedure of choice, although it too is associated with a significant risk of complications. This is not necessarily related to the procedure itself, but generally related to comorbid conditions and effects of malignancy. It is often easiest and quickest to perform as a loop gastrojejunostomy in antecolic fashion. There are well-described techniques of laparoscopic gastrojejunostomy and typically involve creation of an antecolic side to side anastomosis of the stomach to a loop of jejunum 40–60 cm from the ligament of Trietz. Generally, the anastomosis is created by creating enterotomies on the stomach and jejunum followed by a single fire of a gastrointestinal stapler to create a wide anastomosis. The resultant single enterotomy is then generally closed with absorbable sutures [70].

Palliation of Malignant Gastric Outlet Obstruction: Summary

In certain selected patients unable to undergo stenting or gastrojejunostomy, palliative gastrostomy tube placement placed via endoscopy, interventional radiology, or rarely surgery can offer palliative proximal decompression and allow for minimal oral liquid intake [71]. Anti secretory drugs, including octreotide and proton pump inhibitors may also be of value for symptom palliation [72].

In general, the management of patients with malignant GOO should rely on the following principles. Patients should be evaluated for curative resection/therapy. For those that are unable to be cured, palliation should be considered. For the majority of patients with favorable anatomy, endoscopic stenting represents the primary palliative therapy, especially in those with short life expectancy. Consideration for gastrojejunostomy should be given to patients who are unable to undergo endoscopic stenting or those with complete gastric outlet obstruction or who are not palliated with endoscopic stenting. It should be done laparoscopically if technical expertise is available. For patient with extremely poor functional status or perioperative risk with advanced malignancy, considerations should be given to decompression with gastrostomy tube placement if feasible and medical therapy.

Conclusions

GOO from benign and malignant etiologies is still a problem cared for by acute care surgeons. It is imperative to understand the causes as well as treatment algorithms for this issue. GOO should be considered as secondary to a malignant process until proven otherwise. Although endoscopic therapies are rapidly becoming the initial treatment of choice for treatment of both benign and malignant etiologies, there is still a distinct role for surgical intervention.

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Upper Gastrointestinal Bleeding

22

Jon D. Dorfman and Heena P. Santry

Although operative intervention is infrequently required, upper gastrointestinal bleeding (UGIB) is a common reason for general surgery consultation. Patients typically present with coffee ground emesis or frank hematemesis; however, patients with bright red blood per rectum may also be hemorrhaging from an upper gastrointestinal location, which is defined as proximal to the ligament of Treitz. Significant acute hemorrhage may cause hemodynamic instability. The surgical service may provide their expertise in the resuscitation of the unstable patient whether or not an operative intervention is ultimately necessary.

The number of hospital admissions for UGIB in the USA has decreased over the past decade [1]. However, peptic ulcer disease remains the most common cause of UGIB nationally. Mortality rates have remained constant, ranging from 3 to 14% [1, 2]. Other causes of UGIB, listed in order of frequency, include gastroesophageal varices, neoplasms, Mallory Weiss tears, Dieulafoy's lesions and less commonly hemobilia, aortoduodenal fistulas, and stress gastritis (Table 22.1).

Management

The initial management depends on the presentation and condition of the patient. A complete history and physical should be performed in hemodynamically stable patients. In obtaining a medical history, risk factors for UGIB should be obtained including vomiting, prior episodes of hemorrhage, alcohol use, and medications such as nonsteroidal anti-inflammatory agents, steroids, anti-coagulants, or antiplatelet agents. Prior surgical history should be obtained including gastric bypass or aortic bypass surgery which both create potential for otherwise unique causes of UGIB, namely marginal ulcers and aortoenteric fistulas, respectively. The physical examination is frequently unremarkable; however, the stigmata of cirrhosis such as caput medusa, hepatomegaly, ascites, or jaundice should be noted.

If the patient presents with massive hemorrhage and is critically ill, the focus should be on protecting the airway and correcting hypotension and coagulopathy. Endotracheal intubation should be considered for individuals at risk for aspiration or those who present with altered mentation. Hypotension should be corrected with the transfusion of packed red blood cells (PRBCs) and coagulopathy corrected with thawed plasma, and/or platelets. Emergent reversal with 3- or 4-factor prothrombin complex concentrate and vitamin K should be considered for patients on warfarin with an elevated International Normalized Ratio (INR) and life threatening hemorrhage who cannot tolerate the volume or time required for plasma transfusion [3]. For UGIB associated with antiplatelet agents, holding the medication, platelet transfusion, and the administration of de-amino d-argin vasopressin (DDAVP) should be considered but data supporting reversal of antiplatelet agents in UGIB is limited [4]. For the oral factor Xa and direct thrombin inhibitors, only dabigatran has a specific reversal agent [5]. Cryoprecipitate may be considered depending upon the clinical situation. Centers with thromboelastography may use these results to guide resuscitation strategy and reversal of coagulopathy [6].

The correct ratio of packed red blood cells to fresh frozen plasma to be administered for patients in hemorrhagic shock due to brisk UGIB is uncertain. Studies of traumatically injured patients [7, 8] have been extrapolated to the exsanguinating non-trauma patient to suggest a 1:1:1 ratio of PRBCs, thawed plasma, and platelets for patients who appear as if they will ultimately require >10 units of PRBCs. Randomized controlled trials are needed to validate this treatment strategy. Villanueva et al. found that a hemoglobin target of 7 g/dl versus 9 g/dl improved outcomes in acute upper gastrointestinal hemorrhage with the greatest benefits for patients with bleeding

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_22

Table 22.1 Differential diagnosis

Peptic ulcer
Esophageal and gastric varices
Mallory Weiss tear
Dieulafoy lesion
Hemobilia
Neoplasm
Gastritis
Aortoduodenal fistulas

peptic ulcer or Child Pugh A and B cirrhosis. However low Clinical Rockall score and massively hemorrhaging patients were excluded from this study [9].

Hypothermia and acidosis should be avoided in the exsanguinating patient as the enzymes of the coagulation cascade function poorly outside of homeostatic normal [10]. Blood and blood products should be infused via a warmer set at approximately 38 °C. Room temperature should be increased to 28 °C. Active external rewarming with conduction or convection blankets at 42 °C should be undertaken if passive external rewarming does not maintain a body temperature at 35 °C. Lavage of body cavities and dialysis are rarely needed. Calcium is a cofactor in the clotting cascade and should be monitored as it is bound by citrate, a preservative in PRBCs.

A type and cross should be the first serum blood test drawn. A complete blood count provides a baseline hemoglobin and platelet count. The hemoglobin may not be reflective of ongoing hemorrhage and can take up to 24 h to equilibrate; therefore, lactic acidosis and base deficit may be monitored as they are early markers of hypoperfusion in the face of ongoing hemorrhage. An INR and liver function tests should also be considered for determining baseline coagulopathy and to help determine the presence and extent of cirrhosis.

Intravenous access should be appropriate for large volume resuscitation. Large bore and short catheters reduce resistance and have high flow rates. Peripherally inserted central catheters (PICC) lines are never adequate. 16 and 18 gauge peripheral intravenous lines provide higher flow rates than the same gauge ports on triple lumen central lines. Intraosseous access is also an option with the humerus site allowing higher flow rates than the pretibial site. Introducer sheaths have the highest flow rates, which can exceed 30 liters an hour depending upon the catheter size.

Identification of Bleeding Source

Nasogastric Tube/Lavage

Nasogastric tube placement had previously been advocated for suspected UGIB where the type of fluid aspirated may assist with diagnosis, predict the findings and efficacy of upper endoscopy and even predict prognosis [11, 12]. Frank blood or coffee ground aspirate was thought to confirm the diagnosis, nonbilious nonbloody aspirate was considered indeterminate, and bilious nonbloody aspirate suggested a lower gastrointestinal source. More recently, bloody lavage has been correlated with significant endoscopic findings such as visible vessel and active bleeding vessels [13]. Other perceived benefits included clearing hemorrhage from the stomach to improve endoscopic visualization and reduced risk of aspiration. Huang et al. in a propensity matched retrospective analysis, however, found no improvement in patient length of stay, rate of operative intervention or mortality with lavage, even though it was associated with a reduction in time to endoscopy [13]. Other studies have confirmed a lack of clinical benefit from gastric lavage and no improvement over clinical risk scoring [14]. That being said, it is still considered a useful early adjunct.

Upper Endoscopy

Upper endoscopy is the gold standard for diagnosis and intervention in UGIB. Performing endoscopy within 24 h of patient presentation has been shown to improve clinical outcomes [15]. Blood transfusion and hospital lengths of stays have been reduced with early intervention. In a retrospective review of elderly patients (>66 years old) with UGIB due to peptic ulcer disease, the need for surgery was reduced by early endoscopy [16]. Multiple clinical prediction models have been developed and validated to determine which patients require admission. (Table 22.2) The Glasgow Blatchford score showed better discrimination between low and high risk patients who require admission and intervention [17]. This scoring system includes admission blood urea, hemoglobin, systolic blood pressure, heart rate >100 beats/min, as well as clinical factors such as melena, syncope, liver disease, and cardiac disease [18].

Endoscopic interventions for ulcers include epinephrine injection, clipping of vessels, thermal coagulation, and injection of sclerosing agents. Epinephrine alone is considered ineffective and data support using it only as an adjunct to these other interventions [15]. Epinephrine dual therapy has been shown to reduce the need for surgical treatment [15]. The risk of perforation is slightly higher in patients who undergo injection and thermal dual treatments [19]. For variceal bleeding, banding and sclerotherapy are recommended treatments [20]. After endoscopy, the Rockall Score (Table 22.2) can be used to determine the risk of rebleeding and risk of mortality [20]. This system incorporates hemodynamic parameters (heart rate >100, systolic blood pressure <100), comorbidities (cardiac, renal, and liver disease), endoscopic diagnosis, and signs of hemorrhage (clot, visible vessel, active bleeding) [21].

Table 22.2 Risk assessment scoring systems

Glasgow Blatchford	Rockall score	Baylor Bleeding score
Hemoglobin	Age	Age
BUN	Shock (HR/BP)	Number of comorbidities
Systolic blood pressure	Comorbidities	Severity of illness
Heart rate	Congestive heart failure	Location of hemorrhage
Gender	Ischemic heart disease	Posterior bulb
Melena	Renal disease	Endoscopic findings
Syncope	Liver disease	Clot
Heart failure	Metastatic cancer	Visible vessel
Hepatic disease	Endoscopic findings	Active bleeding
	Hemorrhage	
	Clot	
	Bleeding vessel	

Scoring system references: Blatchford O et al. A risk score to predict need for treatment for upper-gastrointestinal haemorrhage. Lancet. 2000, 356: 1318–1321; Rockall TA et al. Risk assessment after upper gastrointestinal haemorrhage. Gut. 1996, 38: 316–321; and Saeed ZA et al. Prospective validation of the Baylor bleeding score for predicting the likelihood of rebleeding after endoscopic hemostasis of peptic ulcers. Gastrointest Endosc. 1995, 41: 561–565

Angiography

Angiography may be considered if no bleeding source can be localized on endoscopy. This modality can be both diagnostic and therapeutic. Embolization of selective vessels and their branches can be performed with microcatheters although nonselective embolization can also be done. Gelfoam, a temporary thrombotic agent, polyvinyl alcohol and microcoils, which are permanent, can be deployed in targeted vessels [22].

To be successful in localization, bleeding must be ongoing. Factors that may be predictive of successful diagnosis of an UGIB source on angiogram include: hypotension (systolic blood pressure <100 mmHg), tachycardia (heart rate >100 beats/min), and four or more units of packed red blood cells transfused in the prior 24 h. The minimum rate of bleeding for identification of the source is 0.5 ml/min although there is evidence that digital subtraction angiography can detect as little as 0.1 ml/min [22]. Clinical success of intravascular angioembolization as defined by hemorrhage control is reported to be 60–70 % [23, 24]. Clinical failure to control hemorrhage has been associated with coagulopathy, increased transfusion requirements, and multiple patient comorbidities [24].

Angiography is not without risks. First, angiography requires an arterial puncture. Vascular injury can occur leading to vessel thrombosis and limb ischemia. If the puncture is inadvertently through-and-through the vessel wall, significant bleeding and hematoma can occur. If the arterial site does not close, a pseudoaneurysm can result. In a patient with significant iliac and aortic disease, the intravascular wires can cause embolization of plaque. Potential renal dysfunction due to the significant dye load required for angiography is another risk to consider.

Computed Tomography Scan

The role of computed tomography (CT) scans in upper gastrointestinal hemorrhage is not well defined; however, limited data shows the feasibility [25, 26]. CT angiography can detect hemorrhage if the rate is greater than 0.5 ml/min [25]. The ubiquitous availability of CT scanners and the noninvasiveness of this modality are its advantages. The imaging also allows excellent anatomical localization. When aortoenteric fistula is in the differential diagnosis, CT angiography may be most helpful. CT angiography should include three phases with a nonenhanced phase to detect pre-existing hyperattenuating material such as pills, followed by arterial and portal venous phases [27].

Radionucleotide-Tagged Red Blood Cell Scans

Radionucleotide imaging is the most sensitive test and can detect gastrointestinal bleeding rates as low as 0.1 ml/min. Of the two types, technetium-99m sulfur colloid and technetium-99m pertechnetate labeled autologous red blood cells, the later allows repeat imaging for up to 24 h if no bleeding is noted on the first study. The major drawbacks to this imaging modality is its inability to accurately determine the location of bleeding [25], identify the type of lesion, and perform a therapeutic intervention.

Etiologies and Treatment

Peptic and Gastric Ulcer

Ulcer hemorrhage is a leading cause of acute UGIB worldwide and has a mortality rate of 5–10 % [28]. The etiology of gastric and duodenal ulcers may be related to *Helicobacter pylori*, nonsteroidal anti-inflammatory agents, stress, and increased acid secretion. These causes of ulceration are not mutually exclusive and frequently occur together. In a study in the United Kingdom, *H. pylori* alone, NSAIDs alone, or both were found as risk factors in 85 % of patients with bleeding peptic ulcers [29]. While 50 % of the world's population is infected with *H. pylori*, less than 10 % will develop ulcer disease. Host factors and response, including location of gastritis (antral predominant) and duodenal metaplasia, offer an explanation for this disparity. *H. pylori* urease reduces the local pH with production of ammonia and subsequently interferes with the negative feedback loop for gastric acid production leading to a lowered gastric pH. *Helicobacter pylori* type and virulence factors, specifically cytotoxins vacuolating cytoxin and cytotoxin associated gene A, also play a role in mucosal injury [30].

Nonsteroidal anti-inflammatory agents interfere with cyclooxygenase activity. Cyclooxygenase is part of the prostaglandin production pathway and plays an important role in gastric mucosal defense against gastric acid. Reduction of prostaglandins subsequently reduce epithelial mucus and epithelial bicarbonate production [31]. Patients with *H. pylori* experience a 1.8 times increased ulcer risk while those using nonsteroidal anti-inflammatory agents experience a 4.9 times increased risk. Those with both risk factors experience a 6 times higher risk of peptic ulcer [30].

Advances in nonsurgical management have changed the treatment of ulcers as well as the surgical procedures performed. Proton pump inhibitors (PPI) have not been shown to reduce mortality; however, patients receiving PPIs have reduced rates of active bleeding at endoscopy [32]. A meta-analysis of intermittent bolus PPI therapy versus continuous infusion found no clinical differences in transfusion, mortality, and intervention rates [33]. Treatment of *H. pylori* has also played an important role, particularly in preventing recurrent ulcers and reducing the overall incidence of UGIB.

Upper endoscopy has been proven to provide effective hemorrhage control, reduce the need for operative intervention, and reduce mortality for peptic ulcer disease [34]. Endoscopic findings are also important for defining the risk of rebleeding. The Forrest classification system divides ulcers based on the endoscopic findings and correlate with the risk of rebleeding: active bleeding (highest), visible vessel/overlaying clot/flat pigmented spot (intermediate) (Fig. 22.1), ulcer with clean base (lowest) (Fig. 22.2) [35].

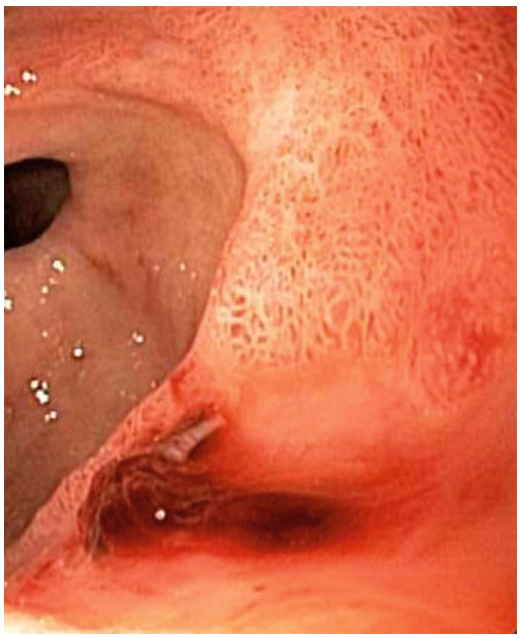

Fig. 22.1 Ulcer with adherent clot. (Courtesy of Isabel A. Zacharias, MD Department of Medicine, Division of Gastroenterology, UMass Memorial, Worcester, MA.)

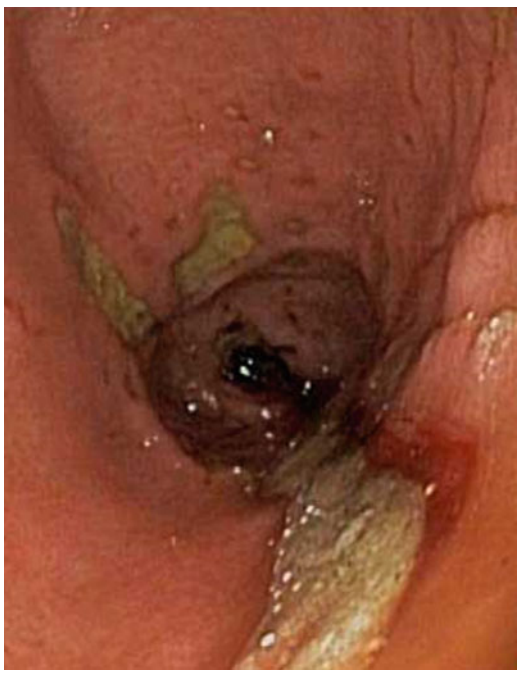

Fig. 22.2 Ulcer with clean base. (Courtesy of Isabel A. Zacharias, MD Department of Medicine, Division of Gastroenterology, UMass Memorial, Worcester, MA.)

If recurrent bleeding occurs, repeat endoscopy is recommended given its lower complication rates [32]. In a randomized prospective study, 48 of 100 patients had repeat endoscopy which was successful in 73 %. Twenty seven

percent failed repeat endoscopy and went to the operating room; 46 % of the patients operated on experienced a complication as compared 14 % of the patients who required two endoscopies. The group who were randomized to the operating room initially had a 36 % complication rate and 93 % success rate in attaining control of the bleeding [31]. Overall, the surgical intervention rate has declined while endoscopy utilization has increased [31].

Meanwhile, the availability of angiographic embolization, in particular in high-risk surgical patients, has also emerged as an alternative to operation. Two retrospective studies have compared surgical intervention with angiographic embolization for UGIB. Wong et al. compared 32 embolization patients with 56 surgical patients and found no difference in the measured clinical outcomes of length of stay, transfusion requirement, and 30-day mortality. Complication rates were, however, higher in the surgical patients (40 % vs. 68 %). Both groups were comparable in terms of age, comorbidities, and presentation of UGIB. Rebleeding rates were higher with embolization [36]. A second study found no difference in rebleeding rate, or mortality despite significantly older age and higher comorbidities in the embolization group [37].

While operative intervention is typically a last resort after failed endoscopy and/or angiographic embolization, ulcer location suggests the etiology and management strategy. Ulcer location has traditionally been divided into five types (Fig. 22.3): Type I occur at the less curvature; Type II also occur along the lesser curvature but with an associated duodenal ulcer; Type III are prepyloric ulcers; Type IV ulcers are near the gastroesophageal junction; Type V are a diffuse ulceration. Types II and III may be related to elevated acid secretion.

Bleeding duodenal ulcers are usually posterior and may have eroded into the gastroduodenal artery. After making a laparotomy, a longitudinal duodenotomy is made. The gastroduodenal artery is ligated proximally and distally. The GDA also has a branch, the transverse pancreatic artery, which should also be ligated. This is the classic "three stitch" technique for bleeding duodenal ulcers. The duodenotomy is closed transversely to prevent stricture and obstruction; furthermore, if the incision extends proximally across the pylorus , it may serve as the pyloroplasty if vagotomy is performed. Traditionally, an acid reducing procedure (truncal vagotomy and pyloroplasty, or highly selective vagotomy) was also performed. An alternative but morbid procedure, distal gastrectomy could also be performed. However, in the modern era, with PPI therapy and treatment for *H. pylori* in the post-operative period, acid reduction procedures may not be necessary [38].

If truncal vagotomy is needed, one begins by exposing the gastroesophageal (GE) junction by retracting the left lobe of the liver medially and the stomach caudally. The peritoneum overlaying the GE junction is opened sharply and the esophagus bluntly freed and a Penrose wrapped around the esophagus in order to retract. Once the anterior and posterior vagi are located, a 2 cm portion is resected. The specimen should be sent to pathology for confirmation that the structure removed is neural tissue. The distal esophagus should be examined for accessory vagal branches, including the criminal nerve of grassi, a branch of the posterior vagus nerve. Pyloroplasty should also be performed [38].

An alternative procedure, the highly selective vagotomy spares the main vagal trunks and the innervation to the antrum. Gastric emptying is not impaired and no pyloroplasty is needed. The vagal nerve branches to the pylorus and

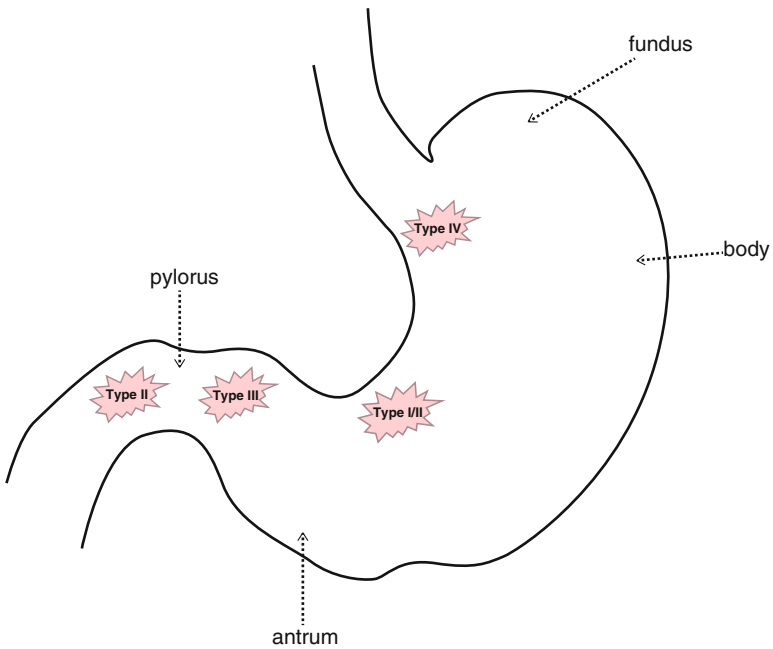

Fig. 22.3 Types of peptic ulcers based on location. Type II ulcers are a type I ulcer with associated duodenal ulcer. Type V ulcers (not shown) are diffuse ulceration

the branches 6 cm proximal are not divided. Once the nerves of laterjet, which are described as a "crow's foot" along the lesser curvature, are identified the vagal branches are divided proximally toward the GE junction. Both the anterior and posterior branches are divided [38].

Distal gastrectomy could also be performed. This procedure removes the antrum and its gastrin secreting cells. Depending upon the extent of gastrectomy, it may be better characterized as a subtotal gastrectomy. Along the greater curvature, the gastroepiploic vessels are divided; the gastrohepatic ligament along the lesser curvature is opened and the right gastric artery divided. The stomach is divided proximally and then distally beyond the pylorus. Reconstruction can be a Bilroth I (gastroduodenostomy), Bilroth II (gastrojejunostomy), or a Roux-en-Y gastrojejunostomy (Fig. 22.4). The latter two procedures leave a duodenal stump with a risk of leak and there is also a risk of hypergastrinemia if antrum is retained [38].

Gastric ulcer treatment depends upon the ulcer location. One key tenet is that a gastric ulcer must always be biopsied at surgery to rule out malignancy. The ulcer could then be oversewn for hemorrhage control with the addition of one of the previously mentioned acid reduction procedures. Excision of the ulcer is the alternative to oversewing. Wedge resection with an acid reduction procedure or a distal gastrectomy can be performed for Type I ulcers. Type II and III ulcers are prepyloric with and without a duodenal ulcer and are managed similar to duodenal ulcers. Type IV ulcers, due to their proximity to the GE junction require a different approach. A Csendes procedure, an esophagogastrojejunostomy with Roux-en-Y reconstruction [39] or a Pauchet procedure, distal gastrectomy with gastroduodenostomy are options [38].

Variceal Hemorrhage

Variceal hemorrhage occurs from portal hypertension and the most common cause of portal hypertension is cirrhosis. However, in cirrhotic patients, variceal hemorrhage is the etiology of UGIB only 50 % of the time [2]. Medical management is the primary treatment of variceal hemorrhage and includes splanchnic vasoconstriction with terlipressin, somatostatin, or octreotide [40]. A short course of antibiotic prophylaxis with ceftriaxone or norfloxacin is recommended to reduce the high rate of bacterial infections in this patient population [41] Endoscopic therapy with injection sclerotherapy and banding have significantly improved outcomes. The mortality rate however remains high, and is related to the patient's Child-Pugh score. Child A cirrhotics have a less than 5 % mortality rate and Child C cirrhotics up to 30 % mortality rate [41] In the exsanguinating patient, balloon tamponade with a Sengstaken Blakemore tube may be considered for a short time period [42] (Fig. 22.5).

Portal caval shunt creation with reduction in portal venous pressure reduces upper gastrointestinal hemorrhage. Surgical shunts include mesocaval shunts and selective shunts. In a Cochrane Review, no type of shunt conferred a mortality benefit over another [43]. Single institution series have shown benefit of surgical shunts but these results have not been replicated. Orloff et al. compared surgical shunt for UGIB with endoscopic therapy but not transjugular intrahepatic portosystemic shunt (TIPS) [44]. Transjugular intrahepatic portosystemic shunts have largely replaced surgical shunts and devascularization procedures such as the Sugiura procedure due to the minimally invasive nature of the former procedure.

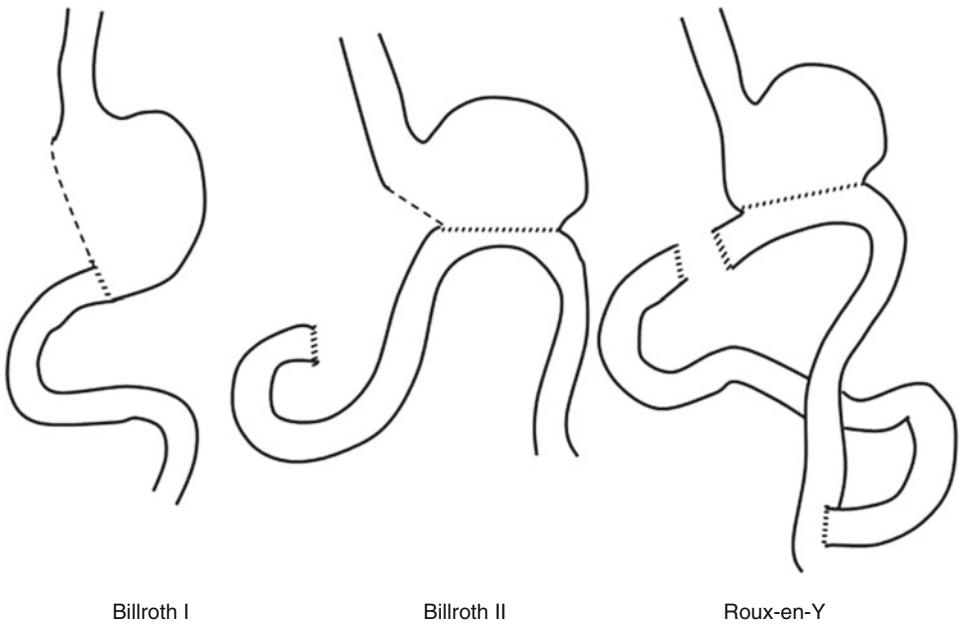

Fig. 22.4 Reconstruction options for distal gastrectomy

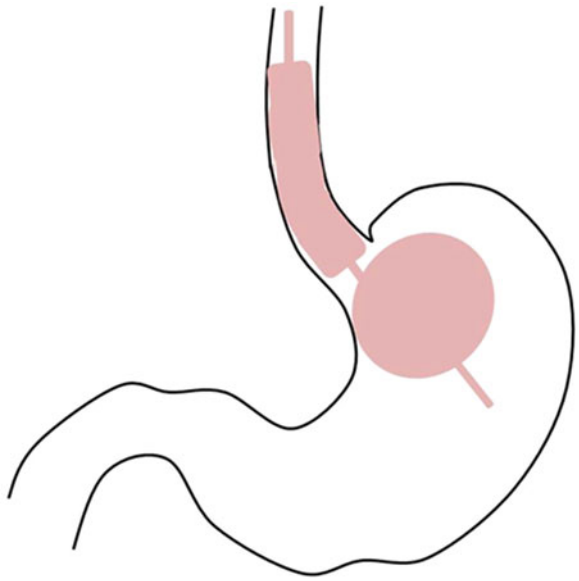

Fig. 22.5 Balloon placement in Sengstaken Blakemore tube for variceal hemorrhage

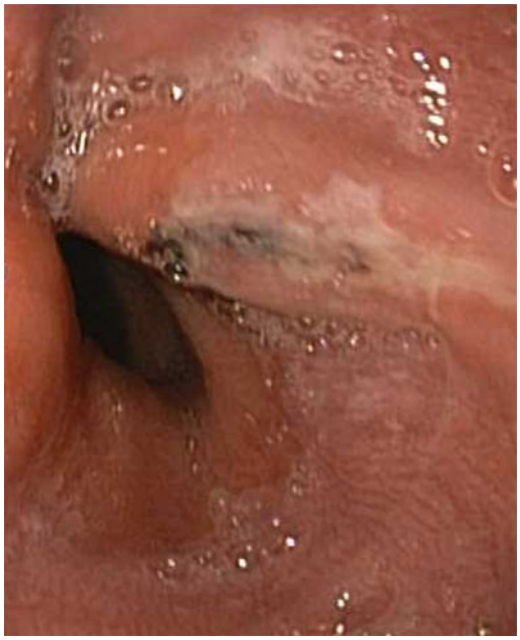

Fig. 22.6 Mallory Weiss tear. (Courtesy of Isabel A. Zacharias, MD Department of Medicine, Division of Gastroenterology, UMass Memorial, Worcester, MA.)

Devascularization procedures divide the venous inflow into the esophageal and gastric veins. The original Sugiura procedure was performed in stages, requiring a thoracotomy and then a laparotomy. The success of Sugiura's series has been difficult to replicate. For selected patients, Child Pugh A or Child Pugh B without ascites, highly specialized centers have performed a modified Sugiura. Via a laparotomy, the distal 6-10 cm of esophagus, upper two thirds of the lesser and greater curvature of the stomach (preserving the left gastric) are devascularized, followed by transection and re-anastomosis of the distal esophagus with an EEA stapler. A splenectomy is also performed [45].

Surgery for variceal bleeding is indicated in rare circumstances. In patients with gastroesophageal varices from isolated splenic vein thrombosis, splenectomy should be performed. The pathophysiology of isolated splenic vein thrombosis is pancreatitis, pancreatic cancer, lymphoma, and prior gastric surgery [46].

Mallory Weiss Tears

First described by Mallory and Weiss in 1929 [47], these longitudinal tears are classically caused by severe retching. Any increase in abdominal pressure may lead to a tear. There is typically only a single tear, but multiple tears may occur at the gastroesophageal junction, the esophagus or the stomach (Fig. 22.6). The preferred management is endoscopy with mechanical hemostasis in patients with active bleeding defined as spurting vessel or oozing [48]. High risk patients for rebleeding or mortality are those who present with hypotension, coagulopathy, have portal hypertension or have active bleeding seen on upper endoscopy [49]. Surgical intervention is uncommonly required. If bleeding cannot be controlled with endoscopic intervention, gastrotomy and oversewing of the bleeding should be attempted.

Dieulafoy's Lesion

Dieulafoy's lesions are congenital abnormally large diameter submucosal arterioles which do not decrease in size as they approach the mucosa. They remain 1–3 mm in size which is nearly 10 fold larger than adjacent vessels [50]. The usual gastric location is along the lesser curvature. A majority of Dieulafoy's lesions are within several centimeters of the gastroesophageal junction where the vascular supply is from both the left and right gastric arteries [51]. Although the stomach is the most common location (nearly 75 %), these lesions have been described throughout the gastrointestinal tract. The pathophysiology of the hemorrhage is not entirely certain but is unrelated to ulceration. Histopathologically the submucosal vessel's wall shows local abnormalities in elastic and circular fibers. Proposed theories include shear stress from peristalsis as the vessel maybe abnormally tethered in the muscularis mucosa [50].

Clinical factors associated with Dieulafoy's lesions include male gender and age. Other noted associations include comorbidities such as cardiovascular disease, renal insufficiency, and diabetes mellitus. Dieulafoy's lesion is a

relatively uncommon etiology for UGIB and accounts for up to 3 % in published series [50]. The bleeding can be profuse. At presentation, hematemesis is reported in over 75 % of patients. Transfusion requirements can be significant and range from 3 to 8 units of packed red blood cells.

Given the low occurrence of Dieulafoy's lesion, published series are small. Endoscopic diagnosis and treatment is successful in 90 % of cases [51]. Combination endoscopic treatment has a higher success rate than monotherapy. Epinephrine injection alone has the highest rates of clinical rebleeding, up to 32 % [52]. Surgery is infrequently required. When multiple endoscopic attempts have failed at controlling the bleeding, laparotomy or laparoscopy with either gastrotomy and oversewing the vessel or wedge resection has been described. Intraoperative endoscopy may be needed to help localized the lesion [53].

Aortoenteric Fistula

Aortoenteric fistulas (AEF) are uncommon and infrequently present with triad of pulsatile mass, hemorrhage, and abdominal pain [54]. A sentinel bleed is not infrequent. The most common location of AEF is the third or fourth portion of the duodenum (75 %) although jejunal and ileal (25 %) [55] involvement has been described. Aortoenteric fistulas are classified as primary, from erosion of the aneurysm into the adjacent bowel, infection, neoplasm, or radiation therapy [54], or secondary where the patient has had a previous endovascular stent or graft aneurysm repair [56]. Computed tomography imaging and endoscopy may aid in the diagnosis. Repairs have been performed via an endovascular approach as the definitive treatment [56] or temporizing until the patient is stabilized for graft removal and extra-anatomic bypass. However open surgery is associated with high morbidity (77 %) and in-hospital mortality (35 %) [55].

Hemobilia

The classic triad of hemobilia is gastrointestinal hemorrhage, jaundice, and right upper quadrant pain (infrequently seen all together). The bleeding may be intermittent and profuse. Diagnostic endoscopy, if not performed fortuitously at a time of hemorrhage thus showing blood emanating from the sphincter of oddi, will be unremarkable. The patient's medical history is an important factor to determine the pretest probability and the diagnostic yield of CT angiography or formal angiogram. A history of trauma, in particular penetrating trauma to the liver, is commonly associated with a vascular biliary fistula [57]. These fistulas may not become clinically apparent until months after the traumatic event. Other causes of hemobilia described in the literature include liver biopsy [58], biliary instrumentation, hepatocellular carcinoma, and cholangiocarcinoma [59], and post-cholecystectomy [59, 60]. The first line therapy is angiogram and embolization. If this treatment fails, liver resection or arterial ligation can be considered depending upon the etiology [59]. Upper endoscopy is also frequently required to sweep the biliary ductal system of blood clots.

Neoplasm

Neoplasms such as gastrointestinal stromal tumors (GIST) and adenocarcinomas rarely cause UGIB. If significant bleeding does occur from a GIST tumor, resection with negative margins can be considered [61]. Adenocarcinoma rarely presents with massive hemorrhage and frequently can be managed with endoscopic therapy [62]. Radiation therapy is an alternative. Tumors which present with hemorrhage are often late stage. Surgical resection would likely be palliative only and should be carefully considered along with goals of care [63].

Conclusion

Upper gastrointestinal hemorrhage management infrequently requires surgical intervention. Management should be multidisciplinary and includes gastroenterology, interventional radiology as well as the acute care surgeon. Proton pump inhibitors, *H. pylori* treatment and endoscopic therapy successfully treat a majority of hemorrhaging patients. Another alternative is transcatheter embolization by interventional radiology. Patients who fail medical management, endoscopic therapy, and/or transcatheter embolization will ultimately require operative care. The acute care surgeon still requires the knowledge in these instances to balance the risks, benefits and determine the correct procedure to perform.

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Acute Biliary Disease

23

Ning Lu and Walter L. Biffl

Gallstone disease is prevalent in western society, with 10–15 % of adults having gallstones [1]. In the USA, 500,000–750,000 cholecystectomies are performed annually. Given the prevalence of biliary disease, it is important to understand the spectrum of gallstone-related pathologies and how to treat them. The major problems caused by gallstones are symptomatic cholelithiasis; acute cholecystitis; choledocholithiasis; cholangitis; and biliary pancreatitis. In addition, the surgeon may encounter a patient with acute acalculous cholecystitis or gallstone ileus. This chapter offers an overview of each of these clinical entities and outlines a diagnostic and treatment strategy for each.

Asymptomatic Cholelithiasis

The incidental finding of gallstones in an asymptomatic patient is not generally considered an indication for cholecystectomy. Although gallstones are common, only 20 % of patients become symptomatic, with 1–4 % of patients with gallstones becoming symptomatic each year [2]. Further, while cholecystectomy is a commonly performed operation with minimal operative mortality (0.14–0.5 %) [3], there can be severe complications. Major and minor complications occur in 2.1 % and 5.9 % of patients, respectively [4]. Given the potential risks of surgery compared to the low incidence of developing symptomatic gallstones over time and the demonstration of the safety of a strategy of observation [2, 5] the accepted management of asymptomatic gallstones is expectant, i.e., watchful waiting.

There are, however, populations of patients with asymptomatic gallstones who are at higher risks of developing gallstones and potentially complicated gallstone disease. This may be related to conditions that alter the cholesterol:bile salt ratio, impaired gallbladder motility with resultant bile stasis, or the accessibility of the gallbladder for future operative interventions [6, 7]. Obese patients have a higher than average incidence of gallstones, and this rises to nearly 6-fold higher than the general population during the first 2 years after gastric bypass. Rapid weight loss, decreased fat absorption, and decreased cholecystokinin secretion due to duodenal bypass can all contribute to gallstone formation. That said, the data do not demonstrate an increase in gallstone-related complications after bariatric surgery. Furthermore, the performance of laparoscopic cholecystectomy may actually be easier after weight loss and ursodeoxycholic acid is effective in avoiding gallstone complications. Thus, prophylactic cholecystectomy is not recommended after bariatric surgery except, possibly, after biliopancreatic diversion [6, 8]. Small bowel resection that alters the enterohepatic circulation is associated with a 30–40 % incidence of cystolithiasis. Thus, increased risk of stone formation is seen after extensive small bowel resection resulting in short gut or prolonged use of total parenteral nutrition, or resection of the terminal ileum [9]. In these cases prophylactic cholecystectomy may be considered [7]. Somatostatin treatment promotes lithogenesis by decreasing cholecystokinin secretion, and so prophylactic cholecystectomy should be considered if this is anticipated, for example, following intestinal carcinoid resection [10]. The gallbladder should be removed when D3 nodal dissection is performed during gastrectomy for cancer; however, this extent of nodal dissection is not generally recommended [7]. A D2 nodal dissection—which dissects along celiac trunk branches—and a "D 1.5" dissection—a D2 dissection without splenectomy— are associated with increased lithogenesis but there are insufficient data to support routine cholecystectomy [7, 11]. Prophylactic

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_23

cholecystectomy should be considered in the presence of gallstones in heart transplant patients, as outcomes of complicated gallstone disease are worse [12, 13]. In patients with hereditary spherocytosis and other chronic hemolytic anemias who have gallstones at the time of splenectomy, prophylactic cholecystectomy is recommended [7].

Symptomatic Cholelithiasis

The symptoms of gallstones are generally referred to as biliary colic. Biliary colic is the combination of right upper quadrant or epigastric postprandial abdominal pain that is episodic, steady, severe, sometimes radiating to the back or right shoulder, and lasting more than 30 min that can be accompanied by nausea and emesis and also have a nocturnal onset [23]. The symptoms are caused by impaction of a gallstone at the neck of the gallbladder or cystic duct, often following fatty meals. The diagnosis of "symptomatic cholelithiasis" requires a combination of the above characteristic symptoms and radiographic evidence of gallstones. Transabdominal ultrasound is the initial diagnostic imaging procedure of choice when evaluating for cholelithiasis. It is noninvasive, portable, and able to confirm gallbladder pathology with 96 % accuracy [14, 15]. Abdominal plain films may be helpful in diagnosing other causes of abdominal pain (bowel obstruction, constipation, perforated viscus), but only 15 % of gallstones contain enough calcium to be visible on plain films. While computed tomography can be helpful in diagnosing the complications of cholelithiasis, it has lower accuracy with respect to diagnosis of cholelithiasis [14, 16]. Magnetic resonance imaging has a high diagnostic accuracy for cholelithiasis, but it has a higher cost and requires a longer examination time [17]. In patients with atypical presentations, CT and MRI may be helpful in diagnosing other etiologies of abdominal pain.

Symptomatic cholelithiasis is a well-accepted indication for cholecystectomy. However, given that cholecystectomy does not relieve pain in 10–33 % of patients with documented gallstones, it becomes critical to differentiate biliary pain from symptoms of other gastrointestinal disease such as irritable bowel syndrome (IBS) and gastroesophageal reflux disease (GERD) [18, 19]. Although safe observation of symptomatic cholelithiasis has been demonstrated, the treatment of choice is laparoscopic cholecystectomy [20–22]. Recurrent episodes of biliary colic can result in chronic cholecystitis.

Once the diagnosis of symptomatic cholelithiasis is made, a good-risk patient may be scheduled for surgery without additional workup. In the absence of a history of jaundice or biliary pancreatitis, and a common bile duct size less than 7 mm, additional laboratory tests are unnecessary as their predictive value for choledocholithiasis is poor [23]. On the other hand, the incidence of unsuspected choledocholithiasis is as high as 7 %, so intraoperative evaluation with ultrasound may be employed for detection of stones (see below) [24].

Acute Cholecystitis

Diagnosis

The 2013 Tokyo Guidelines diagnostic criteria (Table 23.1) indicates that when local signs of inflammation, systemic signs of inflammation, and imaging findings of acute cholecystitis are present, acute cholecystitis can be diagnosed with 91 % sensitivity and 97 % specificity [25, 26]. Ultrasound can demonstrate gallbladder distension, wall thickening, gallstones, debris, pericholecystic fluid, gas formation, and pericholecystic inflammation. CT can demonstrate pericholecystic fluid, subserosal edema, mucosal enhancement, and transient enhancement of the liver adjacent to the gallbladder in acute cholecystitis, as well as emphysematous changes and abscess formation. Technetium-labeled hepatobiliary iminodiacetic acid (HIDA) scintigraphy is time-consuming, but has a sensitivity of 80–90 %, with higher specificity and accuracy in acute cholecystitis when compared with ultrasound [27, 28]. A HIDA scan may be employed in cases of diagnostic uncertainty, particularly when cholecystectomy is considered relatively high risk and the health care team is interested in ruling out the diagnosis of cholecystitis. Routine liver function tests are not cost effective, they do not alter management beyond that dictated by history, physical examination, and ultrasound. A CRP >3 mg/dl in combination with ultrasound findings results in a 95 % positive predictive value for acute cholecystitis [29]. Again, however, it is questionable value in light of evolving approaches to symptomatic and complicated gallbladder disease. A patient presenting with acute or acutely exacerbated symptoms benefits from

Table 23.1 TG13 diagnostic criteria for acute cholecystitis

A. Local signs of inflammation, etc.
(1) Murphy's sign, (2) RUQ mass/pain/tenderness
B. Systemic signs of inflammation, etc.
(1) Fever, (2) elevated CRP, (3) elevated WBC count
C. Imaging findings
Imaging findings characteristic of acute cholecystitis
Suspected diagnosis: One item in A + one item in B
Definite diagnosis: One item in A + one item in B + C

Acute hepatitis, other acute abdominal diseases, and chronic cholecystitis should be excluded

RUQ right upper abdominal quadrant, *CRP* C-reactive protein, *WBC* white blood cell

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early cholecystectomy, so specifically differentiating acute cholecystitis from a "bad case of symptomatic cholelithiasis" is irrelevant [30].

Treatment

Laparoscopic cholecystectomy is the procedure of choice in acute cholecystitis, having been shown to be safe with faster recovery and shorter hospital stay compared to open cholecystectomy [31–35]. Conversion to open cholecystectomy due to complications or unfavorable anatomy occurs at a rate of 10–30 % [36]. Complicated cholecystitis may include gangrenous or perforated cholecystitis with hepatic abscess. Complicated cholecystitis may require a longer course of intravenous antibiotics in addition to cholecystectomy. Abscesses should be drained either percutaneously or surgically. In the case of a "difficult gallbladder," it is important to remember several basic principles (Table 23.2) [37]. If the structures within the Triangle of Calot cannot be clearly identified, or in cirrhotic patients, subtotal cholecystectomy—either laparoscopic or open—is a safe alternative [38]. It is important to highlight that conversion to open is considered safe, and a measure of good judgment—not a failure or complication.

Timing of Surgery

Optimal timing of laparoscopic cholecystectomy for acute cholecystitis has been debated. The first point of contention is whether to perform laparoscopic cholecystectomy at the index hospitalization or to treat with antibiotics and perform a delayed (6–12 weeks) cholecystectomy after resolution of inflammation (i.e., "cooling down"). A meta-analysis of 15 RCTs including 1625 patients compared early (within 7 days of symptom onset) with delayed (>1 week after symptoms resolved) laparoscopic cholecystectomy [39]. Early cholecystectomy was associated with a longer duration of operation, but benefitted the patient in terms of lower hospital costs, fewer work days lost, higher patient satisfaction and quality of life, lower risk of wound infection, shorter hospital length of stay, and similar mortality and morbidity (bile duct injury, bile leakage, conversion to open procedure) [39]. A 2013 Cochrane review defined delayed cholecystectomy as greater than 6 weeks, and had similar conclusions [40]. A national Medicare sample with 29,818 patients >65 years of age with acute cholecystitis included 25 % who did not receive cholecystectomy at initial admission. Among these patients, 38 % had gallstone-related admissions over the next 2 years [41]. A Canadian study of 25,397 adults with acute cholecystitis included 41 % who did not receive cholecystectomy at initial admission. The incidence of gallstone-related events was 29 % at 1 year, with biliary pancreatitis comprising 30 % of these events. Of note, the incidence of recurrent biliary tract disease at 1 year decreased with age, 42 % in those 18–34 years old, 32 % in those 50–64 years old, 27 % in those 65–79 years old, and 24% in those older than 80 years [42, 43]. In addition, a model-based cost-utility analysis from Canada compared early cholecystectomy (within 1 week of presentation), delayed cholecystectomy (8–12 weeks after presentation), and watchful waiting. This study demonstrated early cholecystectomy was the most cost-effective strategy [44]. Thus, laparoscopic cholecystectomy should be performed during the index hospitalization.

The second point of contention is at what point during the index hospitalization cholecystectomy should be performed. A multitude of studies have addressed this issue recently. A National Surgical Quality Improvement Program database study of 5268 patients undergoing emergency cholecystectomy for acute cholecystitis was studied [45]. Cholecystectomy was performed on Day 0 or 1 in 83 % of patients. Those undergoing cholecystectomy Day 2–7 had nearly twice the conversion rate to an open procedure, increased operative time, and increased length of stay [45]. A retrospective review of 95,523 patients from the Nationwide Inpatient Sample who underwent laparoscopic cholecystectomy within 10 days of presentation for acute cholecystitis also demonstrated increasing mortality, postoperative infection, and hospital costs for those who underwent surgery on days 2–10, compared to those who underwent surgery days 0–1 [46]. A Swiss study demonstrated conversion to open surgery increased from 12 to 28 %, postoperative complications increased from 6 to 13 %, and need for re-operation increased from 1 to 3 %, from Day 0 to Day 6, respectively [47]. A randomized prospective study from Germany and Slovenia compared cholecystectomy within 24 h of admission to cholecystectomy on Day 7–45. 1680 patients were randomized, and morbidity was 12 % in the early group, increasing to 34 % in the late group. There was no difference

Table 23.2 Principles for safe cholecystectomy

• Use a 30- or 45-degree high-definition laparoscope
• Apply cephalad traction to the dome of the gallbladder
• Apply lateral traction to the infundibulum
• Find the gallbladder wall and stay on it
• Dissect from above down to the neck
• Widely opening the hepatocystic triangle
• Move the infundibulum back and forth, repeatedly looking at both sides of the gallbladder
• Get the critical view of safety
• Divide the cystic duct as close to the gallbladder as possible
• Never dividing the cystic duct with any cauterizing instrument

From Peitzman AB, Watson GA, Marsh JW. Acute cholecystitis: When to operate and how to do it safely. J Trauma Acute Care Surg 2015; 78:1–12, with permission

in conversion rate, but hospital length of stay was increased in the delayed group [48]. Finally, Schwartz and colleagues [49] queried the Nationwide Inpatient Sample for patients undergoing laparoscopic cholecystectomy for acute cholecystitis between 2003 and 2011, and found over 190,000 records. After controlling for patient- and hospital-related factors, they found that for laparoscopic cholecystectomy performed on each day after the first day, the costs of care increased by approximately $2000/day. This held for those discharged within 24 h of surgery, suggesting they were simply waiting to have the surgery. Given all of these data, laparoscopic cholecystectomy should be performed within 24 h of patient presentation.

Tube Cholecystostomy

Tube cholecystostomy refers to a drainage catheter placed either transhepatically or transperitoneally. It is an alternative to cholecystectomy, generally reserved for patients who are at very high risk for surgery, including critically ill patients with acalculous cholecystitis [50, 51]. The Tokyo Guidelines for severity grading for acute cholecystitis separate the disease into mild, moderate, and severe categories (Table 23.3). Severe cholecystitis (Grade III) often warrants urgent drainage. This may be performed percutaneously with local anesthesia, or may be done laproscopically if a particularly hostile operative field is encountered or if the patient's condition deteriorates and surgery must be aborted.

The tube cholecystostomy procedure is technically successful in over 90 % of patients, with clinical improvement within 72 h in 85–90 % patients. The procedure-related mortality is 0.4 %, with 6 % risk of procedure-related morbidity [52–54]. The drainage catheter is usually removed within 4–6 weeks, once trans-catheter cholangiography demonstrates resolution of cystic duct obstruction. Further management should include elective cholecystectomy given the high recurrence of biliary disease requiring re-admission, as high as 49 % within a year [55]. On the other hand, it is a sick population as de Mestral et al. [55] found that 18 % had died within a year. If a patient is too ill to undergo surgery, the tube may be removed and cholecystectomy deferred if the cystic duct is patent [51].

Table 23.3 TG13 severity grading for acute cholecystitis

Grade III (Severe) acute cholangitis	
"Grade III" acute cholangitis is defined as acute cholangitis that is associated with the onset of dysfunction at least in any one of the following organs/systems	
1. Cardiovascular dysfunction	Hypotension requiring dopamine ≥5 μg/kg/min, or any dose of norepinephrine
2. Neurological dysfunction	Disturbance of consciousness
3. Respiratory dysfunction	PaO_2/FiO_2 ratio <300
4. Renal dysfunction	Oliguria, serum creatinine >2.0 mg/dl
5. Hepatic dysfunction	PT-INR >1.5
6. Hematological dysfunction	Platelet count <1,00,000/mm^3
Grade II (moderate) acute cholangitis	
"Grade II" acute cholangitis is associated with any two of the following conditions:	
1. Abnormal WBC count (>12,000/mm^3, <4000/mm^3)	
2. High fever (≥39 °C)	
3. Age (≥75 years)	
4. Hyperbilirubinemia (total bilirubin ≥5 mg/dl)	
5. Hypoalbuminemia (<STD × 0.7)	
Grade I (mild) acute cholangitis	
"Grade I" acute cholangitis does not meet the criteria of "Grade III (severe)" or "Grade II (moderate)" acute cholangitis at initial diagnosis	

From Yokoe M, Takada T, Strasberg SM, et al. New diagnostic criteria and severity assessment of acute cholecystitis in revised Tokyo guidelines. J Hepatobiliary Pancreat Sci. 2012;19:578–585, with permission

Complications of Cholecystectomy

Operative mortality for laparoscopic cholecystectomy is 0.1–0.5 % [3]. Major and minor complications have a 2 % and 6 % incidence, respectively [4]. Complications include severe bleeding (0.1–2 %), abscess (0.1–0.3 %), bile leak (0.3–0.9 %), common bile duct injury (0.3–0.6 %), and bowel injury (0.1–0.4 %) [56–58]. Misidentification of structures within the Calot triangle is the most frequent cause of bile duct injury. Obtaining the critical view of safety is recommended for reduction of risk of bile duct injury [37]. Nearly 90 % of hemorrhage is from the liver bed, with right hepatic artery injury representing <12 % of hemorrhages. Coagulopathy or misidentification of the right hepatic artery due to anatomical variations may be responsible for the hemorrhage [59]. Intraperitoneal loss of more than 15 stones or stones larger than 1.5 cm was found in more than 40 % of patients with post-cholecystectomy abscess [60]. Extensive peritoneal lavage and maximal stone retrieval is recommended. Risk factors for complications include lack of surgeon experience, patient comorbidities (obesity, prior abdominal surgery, portal hypertension, portal venous cavernous transformation), severity of the biliary disease, unrecognized choledocholithiasis, and ductal/vascular anatomic variations.

Pregnancy

In the past, non-operative management of symptomatic cholelithiasis in pregnancy was recommended. However, currently, early surgical management with laparoscopic cholecystectomy is the treatment of choice, regardless of trimester. Non-operative management of symptomatic

gallstones in pregnancy results in recurrent symptoms in 50 % of patients, with 23 % of these patients developing acute cholecystitis or gallstone pancreatitis; historically, this has resulted in fetal loss in as many as 60 % of patients. Delayed surgical management results in increased rates of hospitalization, spontaneous abortions, preterm labor, and preterm delivery compared to those undergoing laparoscopic cholecystectomy [61]. Laparoscopic cholecystectomy decreased rates of spontaneous abortion and preterm labor compared to open procedures, and has not been reported to result in fetal demise during the first and second trimesters [62, 63]. There is no specific treatment strategy for choledocholithiasis in pregnancy, and safe management has been demonstrated with either intraoperative common bile duct exploration and laparoscopic cholecystectomy with preoperative or postoperative ERCP [64, 65].

Choledocholithiasis

Choledocholithiasis is present in as many as 10–20 % of patients with symptomatic cholelithiasis [66]. Certain disease processes such as cholangitis and biliary pancreatitis are attributed to ductal obstruction; in these cases, there is presumed choledocholithiasis, so the focus is on ensuring ductal clearance (see below). On the other hand, in patients with symptomatic cholelithiasis or acute cholecystitis it is less frequent, estimated at 5–7 %. The clinical suspicion may be based on ultrasonographic findings of enlarged ducts or a visualized stone; laboratory values such as hyperbilirubinemia or increased alkaline phosphatase; or physical finding of jaundice. Unfortunately, none of these findings is entirely accurate or reliable [67]. Thus, the diagnosis relies on imaging. Ultrasonography can demonstrate dilated intrahepatic or extrahepatic bile ducts, but it is not sensitive. Magnetic resonance cholangiopancreatography (MRCP) and endoscopic ultrasonography (EUS) are considered highly accurate diagnostic tests for choledocholithiasis, although the accuracy of MRCP in particular has recently been called into question [68]. Endoscopic retrograde cholangiopancreatography (ERCP) and intraoperative cholangiography (IOC) are considered the diagnostic criterion standards but are invasive. Recent literature has debated the use of these various modalities to detect common bile duct stones.

Options for treatment of choledocholithiasis include laparoscopic or open common bile duct exploration, or preoperative, intraoperative, or postoperative ERCP. Some patients are not good candidates for endoscopic treatment. It can be challenging, or even impossible, to perform ERCP in patients who have had roux-en-Y reconstructions. For these patients a variety of percutaneous transhepatic or other transenteric instrumentation and ERCP strategies, in addition to open and laparoscopic common bile duct exploration, have been described, but not well studied [69]. Operative duct exploration can be transcystic or via choledochotomy. Transcystic common bile duct exploration results in a postoperative course similar to laparoscopic cholecystectomy alone (without the requirement of a T-tube when compared to exploration via choledochotomy), but may be more challenging with anomalous anatomy, hepatic duct stones, strictures, and large stones (>5 mm) [70, 71]. Whether common bile duct stones are detected preoperatively or intraoperatively, the method of treatment depends on the surgeon's expertise, the availability of a skilled endoscopist, and availability of required equipment.

Based on the 2013 Cochrane Review [72], open common bile duct exploration is more successful in clearing common bile duct stones than ERCP, and there is no significant difference in morbidity and mortality. In published series there is no significant difference in success rate, morbidity, or mortality between laparoscopic cholecystectomy with laparoscopic common bile duct exploration (LC+LCBDE) when compared to preoperative or intraoperative ERCP [72]. The LC+LCBDE appears to be the most cost-effective treatment strategy [73]. Cholecystectomy combined with ERCP leads to increased hospital length of stay, increased total hospital costs, and increased numbers of procedures required for treatment [74]. Recently the cholecystectomy first strategy has been shown to be superior among patients with intermediate risk of common bile duct stones [75]. Based on this body of evidence, if the surgeon has the expertise and available equipment, LC+LCBDE via transcystic (if stones 5 mm or less) or choledochotomy exploration should be attempted first.

To sum up the approach to potential or suspected common bile duct stones, we offer the algorithm in Fig. 23.1.

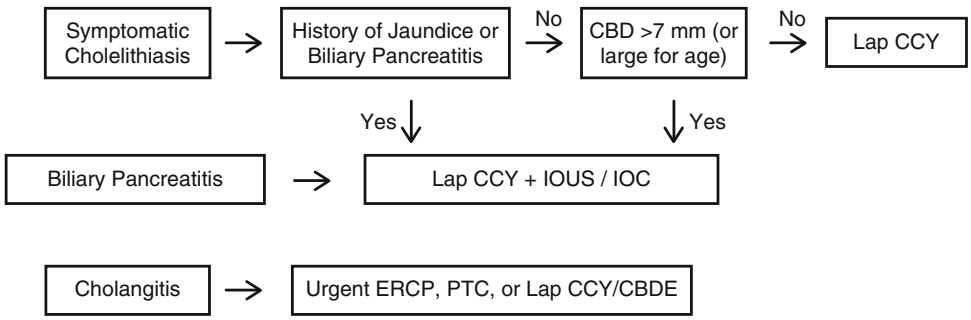

Fig. 23.1 Diagnostic evaluation for common bile duct stones. *CBD* common bile duct, *CCY* cholecystectomy, *IOUS* intraoperative ultrasound, *IOC* intraoperative cholangiography, *ERCP* endoscopic retrograde cholangiopancreatography, *PTC* percutaneous transhepatic cholangiography

In the patient with symptomatic cholelithiasis, history and physical exam focus on prior episodes of jaundice or biliary pancreatitis. If none, and ultrasound does not demonstrate a dilated common bile duct, laparoscopic cholecystectomy is indicated without additional laboratory testing [23]. We favor routine intraoperative ultrasonography to delineate ductal and arterial anatomy, as well to detect unsuspected common bile duct stones. It is noninvasive, quicker, and cheaper than cholangiography and can give more anatomic information [24]. If clinical, ultrasonographic, or laboratory data suggest potential common bile duct stones, ultrasonography or IOC is performed. If the patient is at high risk, the decision to do surgery first versus ERCP first is dependent upon local resources and expertise.

Cholangitis

Cholangitis is a bacterial infection of the biliary ductal system in the setting of biliary obstruction, most commonly due to *E. coli, Klebsiella pneumonia, enterococci,* and *Bacteroides fragilis* [76]. The obstruction may be due to strictures, malignancy, or in the acute setting, choledocholithiasis. Diagnosis is based on clinical signs and symptoms: Charcot's triad (fever, jaundice, right upper quadrant abdominal pain) and Reynolds' pentad (the triad plus mental obtundation and hypotension) are the classic findings. Imaging can help determine the etiology and location of the obstruction. Management includes treating sepsis, administration of broad spectrum parenteral antibiotics, and urgent biliary drainage. Biliary drainage for cholangitis in the setting of choledocholithiasis is best performed via ERCP, followed by laparoscopic cholecystectomy after the patient stabilizes, prior to discharge. In situations where ERCP is not available, percutaneous transhepatic drainage is an alternative drainage method. If neither is available, in a patient with toxic cholangitis, laparoscopic choledochotomy with T-tube placement can be life-saving; although surgical management has higher mortality than endoscopic management [77, 78].

Gallstone Pancreatitis

Gallstone pancreatitis can occur as a result of gallstone obstruction of the ampulla of Vater, resulting in reflux of bile through the pancreatic duct [79]. Elevated levels of serum amylase or lipase are hallmarks of the diagnosis, while Ranson's criteria can aid in assessing disease severity [80]. Ultrasound detection of gallstones can confirm the biliary etiology of pancreatitis. In severe cases, CT scanning is important to elucidate whether there is simply inflammation of the pancreas or if there is also pancreatic necrosis [81]. Acute pancreatitis is classified based on the 2012 revised Atlanta guidelines [82]. In severe cases, treatment is largely supportive with fluid resuscitation, bowel rest, with early enteral nutrition. The role of ERCP has changed over the years, and at present it is reserved for cases of severe pancreatitis with persistent biliary obstruction or demonstrated common bile duct stones [83].

Fortunately, the large majority of patients experience a mild pancreatitis. Due to a 25 % incidence in recurrent biliary complications in the 6-week-period following an episode of gallstone pancreatitis, cholecystectomy should be performed during the same hospitalization [84]. Over the past 15 years, a large body of literature has focused on the timing of surgery, and the detection of choledocholithiasis. In 2000, Chang and colleagues [85] performed a prospective randomized trial that in patients with gallstone pancreatitis. Patients with biliary ductal dilatation on admission, persistent hyperbilirubinemia (>1.7 g/dl) on hospital day 4, or persistent hyperamylasemia on day 4, were randomized to preoperative ERCP, or cholecystectomy with IOC. They found that only 24 % of patients required postoperative ERCP and that was with no attempt to clear the duct laparoscopically. Thus, a selective approach for ERCP is warranted. In fact, it is currently debated whether patients with normal bilirubin levels and normal duct size even require IOC. A large majority of patients undergoing IOC for the diagnosis of gallstone pancreatitis have no common duct stones; and the procedure increases the direct operative costs by 50 % [86]. It is our preference to perform IOUS and forego IOC if duct size is normal and no stones are seen. Regarding the timing of cholecystectomy, the group from Torrance, CA has demonstrated over the course of several prospective trials that it is safe to take a patient with mild pancreatitis to surgery within 48 h of admission, if there has been no clinical worsening since admission [87].

It has been demonstrated that if surgeons admit patients with biliary pancreatitis, the patients are more likely to undergo same-admission cholecystectomy; they also tend to have fewer consultations and tests performed [88]. Thus, the surgeon should manage surgical problems like those of the biliary system.

Intraoperative Cholangiogram (IOC) and Intraoperative Ultrasound (IOUS)

The primary methods for intraoperative assessment of the biliary tree are IOC and IOUS; these modalities are intended to identify common bile duct stones, delineate biliary anatomy, and prevent or identify bile duct injury. Zealous debates over routine versus selective IOC have persisted for years. Proponents of IOC argue that routine use enhances the skill of the surgeon in the performance and the interpretation of the procedure—both critical in achieving the stated goals. They also argue that IOC identifies bile duct injury at the

time it occurs, and may prevent the injury [89]. Opponents point out that IOC adds significant time and cost, carries a risk of complications, and does not prevent bile duct injuries [90, 91]. Although large database studies report an association between routine IOC and fewer bile duct injuries, it is impossible to prove a preventive benefit [92].

Alternatively, IOUS offers accurate assessment of the duct for unsuspected stones, and also allows delineation of arterial anatomy. Arguably, it is better suited than IOC to prevent bile duct injuries: IOUS) and Intraoperative Ultrasound (IOUS) can delineate ductal anatomy before the dissection is performed, whereas IOC requires enough dissection to cannulate the duct [24, 93]. In addition, IOUS is quicker and cheaper than IOC. The learning curve is an issue, but surgeons' increasing familiarity and reliance on ultrasound makes it a natural evolution in care.

Gallstone Ileus

Gallstone ileus refers to intestinal obstruction due to a gallstone. The classic description is of a gallstone impacted in the terminal ileum, but it may occur elsewhere. It accounts for only 1–3 % of cases of small bowel obstruction. A history of symptomatic biliary disease is common, and many patients have concomitant acute cholecystitis. Rigler's triad—small bowel obstruction, a gallstone outside the gallbladder, and pneumobilia—is seen in a minority of cases. The key finding is pneumobilia, and this should be sought in any patient (particularly mature women) with unexplained bowel obstruction [94].

Surgery is indicated to relieve the obstruction. Generally, an enterotomy is made at the terminal ileum to remove the offending stone. Definitive management—i.e., cholecystectomy and closure of the bilio-enteric fistula—is not typically done at the initial operation. This is due to a higher reported mortality rate, along with the fact that recurrence requiring reoperation is actually quite rare (<1 %) [94, 95]. On the other hand, presence of gangrenous cholecystitis warrants cholecystectomy—or at least tube cholecystostomy.

Acute Acalculous Cholecystitis

Acute acalculous cholecystitis has a recognized association with critical illness. The etiology is multifactorial, and most certainly includes some elements of bile stasis and gallbladder ischemia [96]. Ultrasound is diagnostic in most cases. It is critical to make the diagnosis and intervene promptly, as there is a high incidence of gangrene and perforation of the gallbladder (up to 50 % and 10 %, respectively). The associated mortality rate is consequently high, in the 30 % range. The optimal treatment is tube cholecystostomy.

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Management of Complications from Biliary Surgery

24

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Complications of the biliary tree can result from a variety of procedures related to the common bile duct and its branches. Bile duct injuries can occur after gallbladder, pancreatic or proximal small bowel surgery as well as traumatic circumstances. These bile duct injuries can occur in a wide array of clinical scenarios and should be considered among the most challenging complications for surgeons—be they iatrogenic or traumatic in nature. Although a relatively rare occurrence, bile duct injuries portend significant morbidity and mortality for patients. The morbidity of bile duct injuries can be as high as 43% and mortality can be from 1.7 to 9%. Studies have reported clinical outcomes in patients with bile duct injuries to be good; however, quality of life may be poor with associated increased health care costs [1, 2]. Approximately 80–85% of bile duct injuries occur after laparoscopic cholecystectomy with rates of injury ranging from 0.11 to 1.4% in laparoscopic cholecystectomy compared to rates of 0.1–0.3% seen in open cholecystectomy [2]. If a bile duct injury is not recognized promptly, a wide array of complications can occur such as intraabdominal abscesses, peritonitis, biloma, anastomotic stricture, sepsis, and death [3]. Thus, early recognition of bile duct injuries is crucial to the overall long-term outcome of the surgical patient. This chapter provides details on the causes of bile duct injuries, types of bile duct injuries and appropriate management pathways the surgeon can implore when faced with an injury to the bile duct or its tributaries.

Strasberg Classification of Bile Duct Injuries

There are multiple systems that have been used to classify bile duct injuries [4]. The most commonly used is the Strasberg Classification, which describes bile duct injuries using five categories—A through E (Table 24.1). This system is a useful tool to help guide appropriate intervention for each mechanism of injury [4, 5].

Type A describes a bile leak from the cystic duct or an accessory duct from the hepatic bed (i.e., ducts of Luschka) that does not affect the continuity with the common bile duct. Type B and C injuries occur due to occlusion or transection of an aberrant right hepatic duct. If lateral injury to major ducts of the extrahepatic biliary tree occurs, it is deemed a type D injury. For example, a laceration of the common hepatic duct would be considered a type D injury. Type E injuries have multiple subcategories with the commonality of disruption direct communication between the intrahepatic ducts and the duodenum. E_1 injuries occur when there is a stricture or occlusion >2 cm below the biliary bifurcation. If the stricture or occlusion occurs within 2 cm of the biliary bifurcation, it is considered an E_2 injury. E_3 injuries arise when there is damage to the common hepatic duct and biliary confluence with preservation of the back wall. When the injury includes disruption of the back wall resulting in the loss of communication between the left and right hepatic ducts, it is classified as a type E_4 injury. Lastly, type E_5 designates injury to the common hepatic and right hepatic ducts [5] (Table 24.1).

Iatrogenic Bile Duct Injury

Iatrogenesis is the main cause of bile duct injury, representing approximately 96% of injuries. Furthermore, iatrogenic bile duct injury can cause up to 95% of all benign biliary strictures with many of those strictures yielding biliary obstruction [6]. There are two main categories of iatrogenic bile duct injuries—those that occur during biliary procedures and those that occur during operations on other organs such as the stomach, pancreas, small bowel, and liver.

The most common cause of iatrogenic bile duct injury occurs during cholecystectomy with laparoscopic cholecystectomy as the leading cause [7]. The incidence of

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_24

Table 24.1 Strasberg classification of bile duct injury

Type of injury	Description	Examples	Presentation	Treatment	
A	Bile leak from a transected minor duct or cystic duct that does not disturb the continuity with the common bile duct	Transected small duct of Luschka from gallbladder fossa or cystic duct leak	1. Pain 2. Fever 3. Sepsis 4. Mild hyperbilirubinemia 5. Biloma or biliary ascites 6. Possible peritonitis	Clip or ligate if operated upon or endoscopic stenting	Maintains continuity between the central biliary tree and duodenum
B	Ligation of aberrant right posterior sector duct or aberrant segment duct VI or VII	Occlusion of aberrant right hepatic duct using a clip	1. Asymptomatic elevation in AST, ALT, and alkaline phosphatase with normal bilirubin 2. Late presentation as pain or segmental cholangitis in obstructed liver segment 3. Liver atrophy of proximal liver segment or right posterior sector 4. Compensatory hypertrophy of left lobe or right anterior	Observation initially	
C	Bile leak from a duct not in communication with the common bile duct	Transection of an aberrant right posterior sector or segment duct	Same as A injury	Ligation, drainage only, or RY hepaticojejunostomy	
D	Lateral injury to major ducts of the extrahepatic biliary tree	Laceration or tear of the CHD, necrosis of lateral bile duct wall from cautery	Same as A injury	Primary repair, T-tube, or RY hepaticojejunostomy	
E1	CHD stricture or occlusion >2 cm below the biliary bifurcation	Resection/ablation with cautery; stenosis above the cystic duct junction with at least 2 cm of CHD before the bifurcation	Obstructive jaundice if total occlusion and no leak. Signs and symptoms similar to Classes A, C, D if leak present from proximal duct(s)	RY hepaticojejunostomy, bilateral hepaticojejunostomy, or right hemihepatectomy with left hepaticojejunostomy if serious vascular injury to R lobe	Disruption between major biliary tree and duodenum
E2	CHD stricture or occlusion within 2 cm of the biliary bifurcation	Resection/ablation with cautery; stenosis above the cystic duct junction with less than 2 cm of CHD before the bifurcation			
E3	Injury to common hepatic duct and biliary confluence with preservation of the back wall	Resection/ablation with cautery; stenosis at the bifurcation of the right and left hepatic ducts resulting in no CHD			
E4	Injury to the confluence including the back wall resulting in the loss of communication between right and left hepatic ducts	Resection/ablation with cautery of the CHD including the bifurcation			
E5	Common hepatic duct and right duct injury	Resection/ablation with cautery of the hepatic duct along with injury to aberrant right duct			

From Strasberg SM, Hertl M, Soper NJ. An analysis of the problem of biliary injury during laparoscopic cholecystectomy. J Am Coll Surg. 1995;180(1):101–125, with permission

bile duct injury after laparoscopic cholecystectomy ranges from 0.11 to 1.4 %. Though, subsequent reports have found the current incidence of injury trends more towards 0.1 % rather than the higher percentage. Despite a decreased incidence of bile duct injuries since the advent of laparoscopic cholecystectomy, injury continues to have a major impact on healthcare-associated costs and on patient quality of life and outcomes. In 2008, healthcare costs secondary to bile duct injury in the USA were estimated to be as high as $70,000 per patient [7]. Moreover, overall mortality associated with iatrogenic bile duct injury is approximately 3.9 % and about a 3.5 times higher mortality rate in one year in patients who underwent biliary reconstruction as compared to those patients without a bile duct injury [8].

There are many factors that play a role in iatrogenic bile duct injury. Inflammation, both acute and chronic, around the gallbladder and hepatoduodenal ligament make the surgical planes much more difficult to dissect. The "critical view of safety", or the unequivocal observation of the cystic duct and cystic artery entering the gallbladder, can also be skewed due to inflammation and biliary anomalies. Thus, the most common cause of serious biliary injury is misidentification. Only up to 30 % of bile duct injuries are recognized during the index operation [9]. The injuries typically discovered intraoperatively are major duct injuries [10]. If a bile duct injury is suspected intraoperatively, the surgery should be halted and all attempts at identifying the injury at that present moment should be made. Notably, emergency cholecystectomy is associated with a higher rate of bile duct injury (57 %) compared to elective surgeries (31.8 %) [2].

Most bile duct injuries are not recognized at the time of the initial surgery. If the bile duct injury is discovered in the immediate postoperative period, patients typically present acutely ill with elevated liver function tests, specifically with increased total bilirubin and alkaline phosphatase. If no injury is identified during index operation, several signs and symptoms should heighten clinical suspicion for bile duct injury. The early presentation of bile duct injury is typically non-specific with the patient reporting vague abdominal pain, nausea and vomiting, and fever [9]. In contrast, patients who present with a bile duct problem months to years later typically have an insidious onset of symptoms resulting from an underlying bile duct stricture causing biliary obstruction. In the workup of a possible biliary injury in the immediate postoperative period, it is important to distinguish whether the patient has a bile leak secondary to transection or if the patient simply has an obstruction of a major duct due to a retained stone, clip or cautery injury. Imaging is often necessary to diagnose an injury, with abdominal ultrasound or computed tomography (CT) scans with contrast yielding the most useful information. If obstruction is the cause of injury, an ultrasound can show proximal bile duct dilation [9]. If, however, there is a bile leak, an abdominal CT can show intraabdominal collections, biloma, or injuries to the portal structures. The treating physician should consider a cholescintigraphy scan if bile duct injury is suspected with a normal ductal anatomy on ultrasound or CT scan in the presence of a collection. The cholescintigraphy scan can confirm a leakage; however, this modality lacks specificity as to where the specific leakage site is located. Only 1/3 of all bile duct injuries, including cystic duct injuries, can be treated by endoscopic retrograde pancreatography (ERCP) and stenting. In 2/3 of all patients a further surgical biliary reconstruction is necessary [11].

Repair of Bile Duct Injury

Principles and Practices of Bile Duct Injury

The goals of bile duct injury repair include achieving a stable bilioenteric anastomosis that will allow for continued biliary patency and prevent postoperative biliary complications [9, 12]. Various factors must be taken into consideration prior to repair, including location of injury, time at which the injury is recognized, the patient's clinical status and hemodynamic stability, a possible concomitant vascular injury, the skill level and comfort of the surgeon, and the availability of a multidisciplinary team for perioperative management. These factors are important to recognize in order to achieve the optimal timing and method of repair for the best long-term outcomes.

The care of patients with bile duct injuries can be challenging and a multidisciplinary team approach is required. If the primary surgeon is not comfortable with repair of the bile duct injury, a hepatobiliary surgeon should be consulted. Some early data suggests that patients who undergo repair by the primary surgeon may have worse outcomes [13–15]. Prompt recognition and referral are of utmost importance, as a delay in referral may increase the risks associated with the repair [16].

When a bile duct injury is recognized during the index operation, the patient can undergo repair at that time or can be stabilized and transferred to a tertiary care center for further management. Initial definitive repair can only be performed if there is adequate control of the bile leak and the patient is hemodynamically stable. Repair of bile duct injury during the index operation can be done by either primary repair (with or without closure over a T-tube) for injuries involving a small portion of the duct [1, 17], a primary end-to-end ductal repair (with or without T-tube) [1], or a roux-en-Y hepaticojejunostomy [9], depending on the location and size of injury as well as the preference of the surgeon. If the bile duct injury is recognized at the time of the initial operation but repair is not to be completed at that time, drains

should be placed in the right upper quadrant for local control of bile leak until definitive repair is completed [12].

In the majority of cases, biliary injury is not recognized at the time of index operation, and therefore immediate repair is not an option. In such cases, and also in situations where the operating surgeon chooses to defer surgical management, repair can be completed in either the early or late postoperative periods. Early repair can be done in patients who are hemodynamically stable and are without signs of intraabdominal infection or sepsis. However, in cases in which the patient is exhibiting signs of clinical instability or sepsis, definitive repair of ductal injury is deferred for 4–6 weeks until the patient has been medically optimized [12, 18, 19]. In such cases, immediate care should be focused on control of infection and organ dysfunction, as well as control of bile leak which can be obtained via percutaneous and endoscopic methods, as discussed previously. The timing of bile duct repair does not influence overall complications [20, 21]. Initial control of the bile leak and subsequent complications are the most important factors in the long-term outcomes of patients with bile duct injuries. Furthermore, patients may need to undergo extensive preoperative imaging prior to surgical reconstruction to aid in operative planning and improved patient outcomes. Defining biliary anatomy should be done by both invasive (percutaneous transhepatic cholangiography (PTC), ERCP) and noninvasive imaging (magnetic resonance cholangiopancreatography (MRCP), CT +/− angiography) to fully define the extent of ductal injury and possibly identify concomitant arterial injury [22].

Surgical Repair

Definitive surgical repair is the ultimate goal in patients who have sustained major bile duct injuries, which includes primary repair with or without closure over a T-tube, end-to-end ductal anastomosis, and a biliary-enteric anastomosis (hepaticojejunostomy, choledochojejunostomy, and choledochoduodenostomy). The basic principles of a surgical repair include dissecting the bile duct proximally to an area with adequate blood flow so the anastomosis involves healthy tissue thus decreasing the likelihood of postoperative strictures [23, 24]. Other principles of bile duct anastomosis include creating a tension free anastomosis [24], and using interrupted, small monofilament absorbable suture (either maxon or PDS) in a single layer, as permanent suture can cause increased inflammation [24].

Primary repair and closure over a T-tube are appropriate techniques to implore when a small ductal injury, but not transection, has occurred [17]. Although T-tubes are used at times to aid in primary closure of biliary ductal injuries, their use in bile duct repair is controversial. T-tubes are associated with longer hospital stays after biliary repair and longer operating times after common bile duct explorations [17, 25].

A ductal-enteric anastomosis can be performed when the bile duct has been completely transected or when there is an increased risk of stricture formation after primary repair. In cases of complete transection, a ductal-enteric anastomosis is often the preferred technique, as a primary end-to-end ductal repair has been associated with an increased rate of failure [13]. Ductal-enteric anastomoses include a choledochoduodenostomy and hepaticojejunostomy. Choice of anastomosis is primarily dependent on the level of bile duct injury. A choledochoduodenostomy may be appropriate for injuries to the common bile duct, however, a roux-en-Y hepaticojejunostomy should be used for injuries to the common hepatic duct [21]. Many groups, however, feel that a roux-en-Y hepaticojejunostomy is the preferred repair following bile duct injury [9, 18, 20]. In the majority of cases, the roux limb for the hepaticojejunostomy should be retrocolic and approximately 40–60 cm in length [18, 24]. A jejunotomy is made at the site of the anastomosis and should be smaller than the diameter of the duct [26]. Some groups argue for the use of biliary stents to aid in reconstruction and will leave transanastomotic stents in place post-operatively [18, 22], whereas others do not feel stent placement is warranted, as they are associated with an increased risk of complications, including infection of the biliary tree [26]. In patients with percutaneous biliary catheters placed preoperatively, a Silastic stent can be exchanged for the catheter to facilitate creation of the anastomosis, and subsequently be connected to external drainage post-operatively [18]. Biliary-enteric anastomosis should be evaluated via cholangiography prior to the removal of intraoperatively placed stents [18, 20].

Repair Based on Classification of Injury

The specific type of repair performed is dependent on the level and extent of bile duct injury. Special consideration must be taken in cases of proximal ductal injury and in cases of known concomitant arterial injury. In cases where there is a bile leak from the cystic duct remnant, or ducts of Luschka (Strasberg class A), the duct can be ligated with a clip or suture. However, care must be taken to be sure that this is not mistaken for a segmental hepatic biliary duct. Lateral bile duct injuries (Strasberg class D) can be closed primarily or over a T-tube if only a small portion of the duct is involved; however, if a larger portion of the circumference is damaged, then a roux-en-Y choledocojejunostomy or hepaticojejunostomy should be performed to avoid potential stricture formation [4].

Injuries involving segmental right hepatic ducts (Strasberg class B, C and E5), are common in cases in which an aber-

rant right segmental duct drains directly into the right hepatic duct or cystic duct. These injuries are often challenging to diagnose and must be diagnosed via PTC, as ERCP is often read as normal, although incomplete filling of the right ductal system is noted [22]. In cases where both the proximal and distal ends of the duct are ligated (Strasberg class B), no further intervention is warranted as the patient is often asymptomatic [27]. There is some debate as to the best intervention in situations involving transection of small segmental ducts (Strasberg class C and E5). The controversy lies in whether ligation of the duct or a biliary-enteric anastomosis has a better outcome, as there is an increased risk of stricturing with small hepatic ducts [27]. For smaller segmental ducts, conservative management has been shown to be of benefit, and can be managed with either ligation or percutaneous drainage, as the majority of these small segmental ducts will stricture over time [28, 29]. In cases with persistent bile leakage from small ducts or injuries to larger segmental ducts, surgical intervention is often warranted. These injuries can be managed initially with percutaneous transhepatic catheter placement, followed by a roux-en-Y hepaticojejunostomy with the isolated segment. The percutaneous drainage catheter can be advanced through the ductal system to facilitate identification of the transected duct at the time of surgical exploration [22]. Rarely, patients require hepatic resection—either a formal segmentectomy or a right posterior sectionectomy.

Proximal bile duct injuries pose a unique challenge, as the management of these injuries is often complex and requires extensive operative planning. Although many of the aforementioned principles of ductal anastomoses remain the same when comparing biliary-enteric anastomoses of proximal and distal ducts, there are various technical factors that must be taken into consideration with proximal ductal anastomoses [30]. Injuries to the common hepatic duct with an intact ductal bifurcation (Strasberg class E1, E2, and E3) can be repaired with a roux-en-Y hepaticojejunostomy. Injuries to the biliary confluence (Strasberg E4), in which there is complete separation of the right and left hepatic ducts present a unique challenge for which extensive surgical reconstruction is warranted. This can include creation of a neoconfluence (after wedge resection of segments IV and V) and roux-en-Y hepaticojejunostomy; a roux-en-Y portoenterostomy, and a double-barrel biliary-enteric anastomosis [31]. Creation of a neoconfluence between multiple duct segments should be performed whenever possible [26]. The hepaticojejunostomy can be completed through an end-to-side anastomosis or a side-to-side anastomosis. This side-to side anastomosis was originally described by Hepp-Couinaud and some argue is the preferred method in cases of proximal bile duct injuries with excellent long-term outcomes [32, 33].

The risk of concomitant arterial injuries increases with the increased proximity in the biliary tree and this possibility must be taken into consideration at the initial repair and also in cases in which the primary repair fails [34, 35, 36], and although some studies have not demonstrated a link between right hepatic arterial disruption and failed biliary reconstruction, it was associated with other postoperative complications [34].

Occasionally, the surgeon must consider a hepatic resection in the form of a hepatic segmentectomy or lobectomy in cases of extensive ductal or vascular injury. Indications for hepatic resection include ductal injury resulting in persistent bile leak, vascular injury resulting in liver necrosis, strictures or recurrent cholangitis and liver atrophy, and the ability to perform a single biliary-enteric anastomosis [37, 38]. There is an increased risk of need for hepatectomy with proximal ductal injuries and concomitant vascular injuries [37]. In rare cases, patients may develop secondary biliary cirrhosis and end stage liver disease, with liver transplantation providing the best chance for long-term survival [39].

Outcomes

A bile duct injury following cholecystectomy significantly increases the morbidity and mortality of a seemingly benign procedure, with morbidity ranging from 29 to 43 % and mortality from 1.7 to 4 % [1, 20, 40]. However, after definitive surgical intervention, patients undergo an overall successful repair of a bile duct injury more than 90 % of the time. In cases where initial surgical management is unsuccessful, further endoscopic intervention (balloon dilatation) can result in successful outcomes [18]. Additionally, improved outcomes are noted in patients undergoing bile duct repair after injury sustained in a laparoscopic cholecystectomy as compared to after other operations [18].

Complications following repair of bile duct injury include both perioperative complications—wound infection, bile or anastomotic leak, biloma, intraabdominal abscess, biliary peritonitis, cholangitis and sepsis—as well as long-term complications, including strictures, secondary biliary cirrhosis, or malnutrition secondary to external loss of bile salts. Many of these complications can be managed nonoperatively with gastroenterology or interventional radiology performing stent placement or percutaneous drainage, however, there are circumstances that require surgical management.

Patients should have extensive follow-up, especially in the immediate postoperative period and while they have stents and drains in place, which should include both laboratory work and imaging. Multiple studies have looked at quality of life in patients who have had bile duct injuries as compared to patients who have undergone uncomplicated laparoscopic cholecystectomies. Although endoscopic or surgical repair of the bile duct is successful in the majority of cases, some studies report patients who have had a bile

duct injuries score lower on both mental and physical quality of life scales [41, 42], whereas other studies showed patients only scored lower on psychological measures of wellbeing [19, 43]. Ejaz and colleagues recently noted that there was an improvement in psychological wellbeing, but not perceptions of physical health, after bile duct repair as compared to patients' perceptions before the definitive repair [44].

Complications Due to ERCP

Endoscopic interventions for pancreaticobiliary diseases are commonly performed procedures that have the benefit of being both diagnostic and therapeutic and are often used in the diagnosis and management of bile duct injuries. However, endoscopic retrograde cholangiopancreatography (ERCP) and its therapeutic interventions, including sphincterotomy, are technically demanding endoscopic procedures that are not without complication. Complication rates following ERCP range from 4 to 16 % [45–47] and include post-procedure pancreatitis, perforation, bleeding, and infection, as well as cardiopulmonary complications [47]. Rates of complication are higher in patients undergoing ERCP with sphincterotomy as compared to ERCP alone. There is much variability in the risk factors for complications after ERCP depending on the study, however, one of the main risk factors for complications is Sphincter of Oddi dysfunction [46]. Severity of complications is evaluated according to a grading system proposed by Cotton et al. for the major complications of ERCP and endoscopic sphincterotomy based on need for further intervention and length of hospitalization [46].

Pancreatitis is the most common complication following ERCP with or without sphincterotomy, occurring in 2.6–5.4 % [45, 46]. In the vast majority of cases, pancreatitis is conservatively managed. Bleeding is seen in 0.3–2.0 % of ERCP procedures with or without sphincterotomies [45, 46], however is more common after biliary sphincterotomy [45]. Bowel perforation occurs in less than 1.1 % of cases [45, 46]. Perforations following ERCP are classified based on the criteria proposed by Stapfer et al.; Type I perforations occur in the lateral or medial duodenal wall and are secondary to the endoscope; Type II are perivaterian (periampullary) perforations related to sphincterotomy; Type III perforations are located in the distal bile duct secondary to manipulation of the guidewire; and Type IV perforations are not true perforations as they represent only retroperitoneal air. Although perforation is rare, it can be a devastating consequence [48] (Fig. 24.1). Management is done with either observation, endoscopically or surgically depending on the size and location of the perforation and most importantly, the hemodynamic stability of the patient. If a perforation is suspected at the time of the procedure, fluoroscopic imaging can be utilized to evaluate integrity of the biliary-enteric system, and further imaging should subsequently be obtained [49]. If perforation is noted at the time of endoscopy, endoscopic clipping or stenting can be completed [47]. Management of perforation in all perforation cases entails nothing by mouth, nasogastric tube placement, antibiotics, and serial abdominal

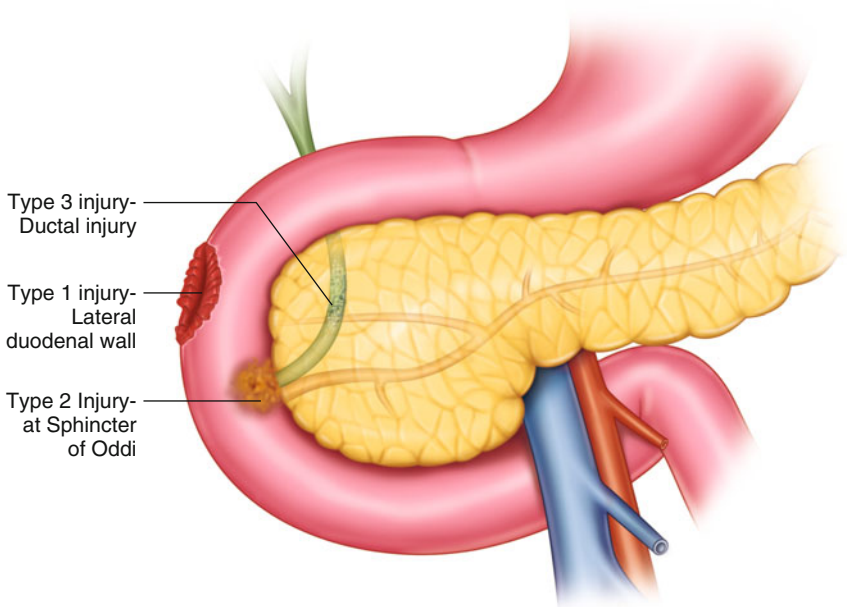

Fig. 24.1 Perforation is a rare, but devastating injury

exams. Surgical intervention is warranted in Type I perforations, where as Type II and III perforations can often be managed conservatively [48].

Bile Duct Injury Due to Blunt Trauma

Bile duct injury secondary to non-iatrogenic trauma is very rare, accounting for 0.1 % of trauma admissions [50]. It can occur secondary to both penetrating and blunt abdominal trauma, and can be broken down based on the location of the ductal injury—intrahepatic, extrahepatic (including injury to gallbladder), and intrapancreatic biliary ductal injury. Traumatic injuries to the biliary ductal system are rarely isolated and are often associated with other injuries to multiple organ systems. The management of trauma to the biliary ductal system depends on the location and extent of the injury, the hemodynamic stability of the patient, associated injuries, and the skill level and comfort of the operating surgeon. Initial evaluation of these patients should follow the Advanced Trauma Life Support (ATLS) protocol, prioritizing the clinical stability of the patient.

The location of bile duct injury plays an important role in the presentation and management of these patients. Intrahepatic bile duct injuries are associated with liver parenchymal injuries, and are graded based on the American Association for the Surgery of Trauma (AAST) Liver Injury Scale [51]. Initial management of hepatic injury and concomitant injuries in the unstable patient warrants exploratory laparotomy and packing, whereas stable patients can often undergo nonoperative management. This can include observation, percutaneous drainage or endoscopic intervention if persistent biliary damage, and angiography with embolization if concomitant vascular injury. Although there has been a paradigm shift to nonoperative management of liver trauma, hepatic resection is warranted at times, including in cases of persistent intraparenchymal bile leak to reduce the risk of developing biloma, bile peritonitis, abscess, or fistula [52].

Isolated injuries to the extrahepatic biliary ductal system and gallbladder are very rare. Injuries to the gallbladder include contusions, avulsion, perforation and rupture, and are managed with cholecystectomy [50, 53, 54]. Injuries to the extrahepatic bile ducts include transection of the CBD or hepatic ducts, occlusion, or stricture of the biliary ducts. Repair of traumatic extrahepatic ductal injury is done by means of a primary repair +/– T-tube, roux-en-Y hepaticojejunostomy, or choledochojejunostomy [50, 54], although the gold standard of repair of extrahepatic bile duct injury is a roux-en-Y hepaticojejunostomy [50]. Special attention must be paid to intrapancreatic biliary ductal injury, as these are often associated with pancreatic and duodenal injuries. Appropriate surgical management may warrant a biliary-enteric anastomosis or rarely a pancreaticoduodenectomy [50, 54].

The general principles of trauma management are of utmost importance in the initial management of patients with traumatic biliary tract injuries as they are frequently associated with injuries to other organ systems. In penetrating trauma or hemodynamically unstable patients, an exploratory laparotomy should be performed with immediate control of bleeding. In such cases, source control is warranted and definitive repair can be delayed until the patient has been stabilized. If the patient is not showing signs of hemodynamic instability, imaging can be obtained and patients can often be managed nonoperatively by percutaneous or endoscopic techniques.

Common complications following traumatic biliary ductal injury include bile leak, biloma, bile peritonitis, cholangitis, and biliary strictures following direct injury to the bile duct, as well as bleeding and hematoma formation secondary to damage to surrounding vascular structures. Prolonged bile leak and bile peritonitis can result in significant complications, including abscess formation, ileus, and sepsis. Any liver injury, with or without arterial embolization, can result in liver necrosis and the subsequent sequela, including abscess or delayed rupture. Although non-iatrogenic injury to the biliary tract is very rare, it can result in debilitating outcomes if not appropriately managed.

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Liver Abscesses

25

Edie Chan, Lia Jordano, and Marc Mesleh

There are three types of liver abscesses or cysts that may necessitate surgical intervention: pyogenic, amoebic, and echinococcal cysts. This chapter reviews the epidemiology, clinical presentation, diagnosis, and management of these diseases.

Pyogenic

Epidemiology

Pyogenic abscesses are bacterial in origin and are caused by either direct extension into the liver from the abdominal cavity, via the bile ducts, via the portal vein, hematogenously via the hepatic artery, or direct trauma. In the early twentieth century, appendicitis was the most frequent cause of hepatic abscess [1]. However, with the advent of antibiotics, biliary disease, whether benign or malignant, became the most common source of pyogenic abscesses. A case review by Huang et al. spanning 42 years at a single institution identified biliary malignancy to be the most common cause in the latter period of the study [2].

The incidence of pyogenic liver abscesses appears to vary depending on the geographic region. In the USA, a recent population-based study calculated an annual incidence of 3.6 cases per 100,000 people, whereas population-based reports in other countries have varied from 1 to 17.6 per 100,000 people [3]. More recent studies have also shown an increasing slight male preponderance for the disease that was not seen in earlier published studies and it is more often seen in patients older than 50 years of age [1, 3–5]. The incidence of hepatic abscesses appears to be increasing and this may be attributable to the use of newer immunosuppressive drugs, the increase in immunocompromised patients, the more frequent use of indwelling biliary stents, and the use of hepatic artery embolization. Other risk factors include diabetes, immunocompromised state (human immunodeficiency virus (HIV), liver transplantation), intra-venous drug abuse, and biliary malignancies [6].

Clinical Presentation

The majority of patients (~90 %) present with fever as their first clinical sign. Approximately half of the patients will also present with chills. Other symptoms include jaundice, right upper quadrant pain, emesis, anorexia, weight loss, hepatomegaly, and weakness. The most common laboratory abnormalities include an elevated WBC (white blood cell count), hypoalbuminemia, anemia, and prolonged prothrombin time. Many patients will also demonstrate abnormal liver function tests including total bilirubin, alkaline phosphatase, aspartate aminotransferase, and alanine aminotransferase. However, these changes may not be present if the patient has an indwelling biliary stent.

Abscess cultures are positive approximately 2/3 of the time, whereas blood cultures are positive approximately only 60 % of the time. The most common organisms isolated are gram-negative aerobes with *Klebsiella pneumoniae*, *Escherichia coli*, and *Pseudomonas aeruginosa* being the most commonly isolated organisms. *Streptococcus* is the most common gram-positive aerobe isolated and usually indicates a biliary source. Anaerobes are isolated 10–30 % of the time and include *Bacteroides* and *Clostridium*. Approximately half of the patients will demonstrate a single isolate; however, multiple organisms are cultured approximately 33 % of the time. Patients who are blood culture positive have concordant cultures with the abscess only 50–60 % of the time [2, 5].

Diagnosis

Approximately half of the patients will have an abnormal chest X-ray (CXR). Typical findings include an elevated right hemidiaphragm, a right pleural effusion, or gas or fluid

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_25

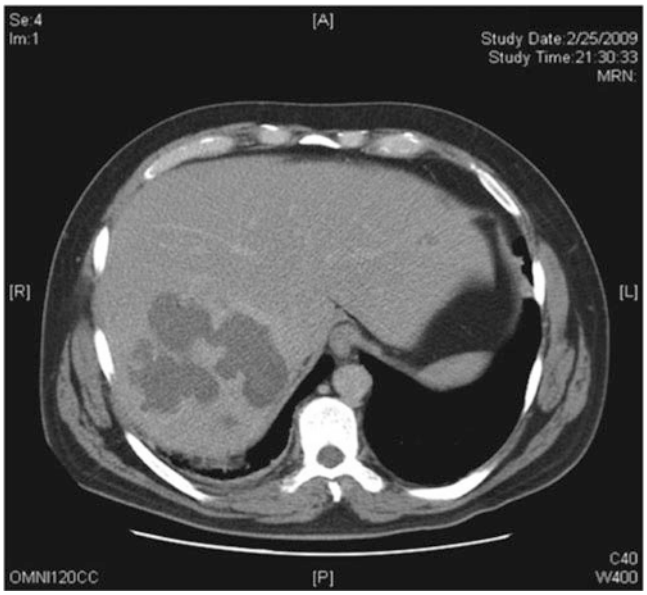

Fig. 25.1 A 52-year-old Mexican male who presented with RUQ pain and jaundice with pyogenic abscess

collection below the diaphragm. An ultrasound of the liver is often obtained and is an appropriate first step in diagnosis. It is less expensive, faster, and no radiation side effects, however, it is often operator-dependent and not able to determine the location of smaller lesions especially near the diaphragm. The diagnostic test of choice is a computed tomography (CT) scan. It can differentiate small abscesses from small cysts, determine the presence of air within the abscess, and clearly delineate multiple loculations as well as multiple separate abscesses. On CT, hepatic abscesses have a lower attenuation than normal liver parenchyma and the abscess wall demonstrates enhancement on a contrast enhanced CT (Fig. 25.1). Hepatic abscesses more commonly occur in the right lobe, followed by the left lobe, and less frequently bilateral. Most recent reports have noted that liver abscesses also tend to be solitary now compared to multiple abscesses. This may reflect the changes associated with indwelling biliary stents, hepatic artery embolizations, and malignancies [2, 5].

Treatment

The initial treatment of any patient suspected of having a possible liver abscess is initiation of broad spectrum antibiotics. The development of broad spectrum single agents (imipenem, piperacillin/tazobactam) has replaced the traditional treatment of the combination of ampicillin, aminoglycoside, and an anaerobic drug such as metronidazole [7]. The duration of antibiotic use remains debatable, and is usually based on treatment response and the abscess characteristics.

Percutaneous drainage was first reported in 1953 but did not become accepted as standard therapy until the 1980s. It has now become the treatment of choice for pyogenic hepatic abscesses. It is usually performed either with ultrasound or CT guidance, and success rates range from approximately 60–90 %. There is still some debate, however, as to percutaneous aspiration alone versus catheter drainage. Several studies have demonstrated the efficacy of percutaneous aspiration alone. Giorgio et al. reviewed 39 patients with hepatic abscesses who were treated with aspiration alone; 36 of the 39 (92.3 %) were successfully treated with a single aspiration, and the other three patients only required one more aspiration. There were no deaths or complications in his study [8]. Yu et al. demonstrated a 96.8 % success rate in 64 patients with aspiration alone; approximately half (49.5 %) required a single aspiration and the rest of the patients required multiple aspirations. In his study, two patients died of overwhelming sepsis and another required surgical intervention for a liver laceration. However, other studies have demonstrated superiority of catheter drainage [9]. Rajak et al. randomly assigned 50 patients to aspiration or catheter drainage. Residual abscess after two aspirations was considered failure in the aspiration group, and residual abscess after catheter drainage was considered failure in the catheter group. Only 60 % responded to the needle aspiration, whereas 100 % responded in the catheter drainage group [10]. Zerem et al. prospectively randomized patients to percutaneous aspiration versus catheter drainage. Similar to the last study, percutaneous aspiration was successful in 67 % of patients, whereas catheter drainage was successful 100 % of the time [11].

Catheter drainage appears to also be successful in patients with multiloculated or multiple abscesses. A series by Liu et al. found no difference between single and multiple abscesses and had very high clinical success rates of treatment of 87 % for a single abscess and 92 % for multiple abscesses with catheter drainage. That study also found an 88 % success rate for treatment of a single multiloculated abscess as well as a 90 % success rate for multiple multiloculated abscesses [12]. Failure of catheter drainage appears to be decreasing but still exists in approximately 10 % of patients. A recent case series by Mezhir et al. demonstrated only a 66 % success with catheter drainage; however, in this study, 88 % of patients had a history of gastrointestinal malignancy. Nine percent of these patients required surgical intervention, whereas the rest of the patients who failed percutaneous drainage died with indwelling catheters. Independent predictors of failure of catheter drainage included positive yeast cultures and communication with the biliary tree [7].

Surgical therapy is rarely necessary as the first line of intervention. If necessary, it is usually in patients with an obstructed biliary system than is not amenable to nonsurgical decompression or a ruptured abscess with sepsis. More com-

monly, surgical intervention is now reserved only when percutaneous drainage has failed, the abscess is not amenable to percutaneous drainage (multiloculated or large), or when there is a complication from percutaneous drainage [6].

Surgical Therapy

If the cause of the hepatic abscess is unknown, a careful exploration of the abdomen should be performed to rule out any other abdominal pathology. Surgical drainage of the abscess is then performed by localization of the abscess via ultrasound or needle localization with ultrasound guidance. The abscess is then bluntly opened and the pus evacuated. Blunt finger manipulation can be used to break up loculations and adhesions. Careful hemostasis should be obtained to prevent residual fluid collections or recurrent abscess. Large bore drains are then left in place for irrigation and suction of the abscess cavity. Tan et al. retrospectively reviewed 80 patients with pyogenic abscesses >5 cm who were treated either with surgical drainage (44 patients) or percutaneous drainage (36 patients). Eighty percent of these patients had multiloculated abscesses. In this study, the surgical drainage group had less treatment failure, less secondary procedures, and a shorter length of stay. The mortality for the surgical drainage group was 4.5 % and 2.8 % for the percutaneous group, which was not statistically significant [13].

Some case reports have advocated primary liver resection for hepatic abscess. Hope et al. retrospectively reviewed patients with >3 cm multiloculated pyogenic abscess who were treated with percutaneous drainage along with antibiotics versus treatment with partial liver resections. The resection group had a 100 % success rate of treatment and 7.4 % mortality in this group, whereas the drainage group only had a 33 % success rate for treatment and 4.7 % mortality. Eight patients in the latter group required repeat drainage and five required surgical resection. The mortality rates between the two groups also did not reach statistical significance. The authors concluded that for large multiloculated abscesses, surgical treatment may be the primary mode of treatment of the disease [14]. Strong et al. reviewed 49 patients who underwent resection for hepatic abscesses after either failed conservative treatment or underlying hepatobiliary pathology. All of the patients had resolution of their abscesses and no patients required reoperation. The authors did report 4 % mortality in their group after abscess rupture in two patients [15].

Conclusion

Pyogenic abscesses are bacterial in origin and more likely to be associated with a hepatobiliary pathology. Primary treatment is broad spectrum antibiotics along with percutaneous treatment via aspiration or catheter drainage. Rarely, a patient may need surgical therapy for failed percutaneous treatment. Mortality for this disease is approximately 10 % and appears to be improving from previous early reports. However, appropriate management with antibiotics and consideration of appropriate drainage are still required for best outcomes (Fig. 25.2).

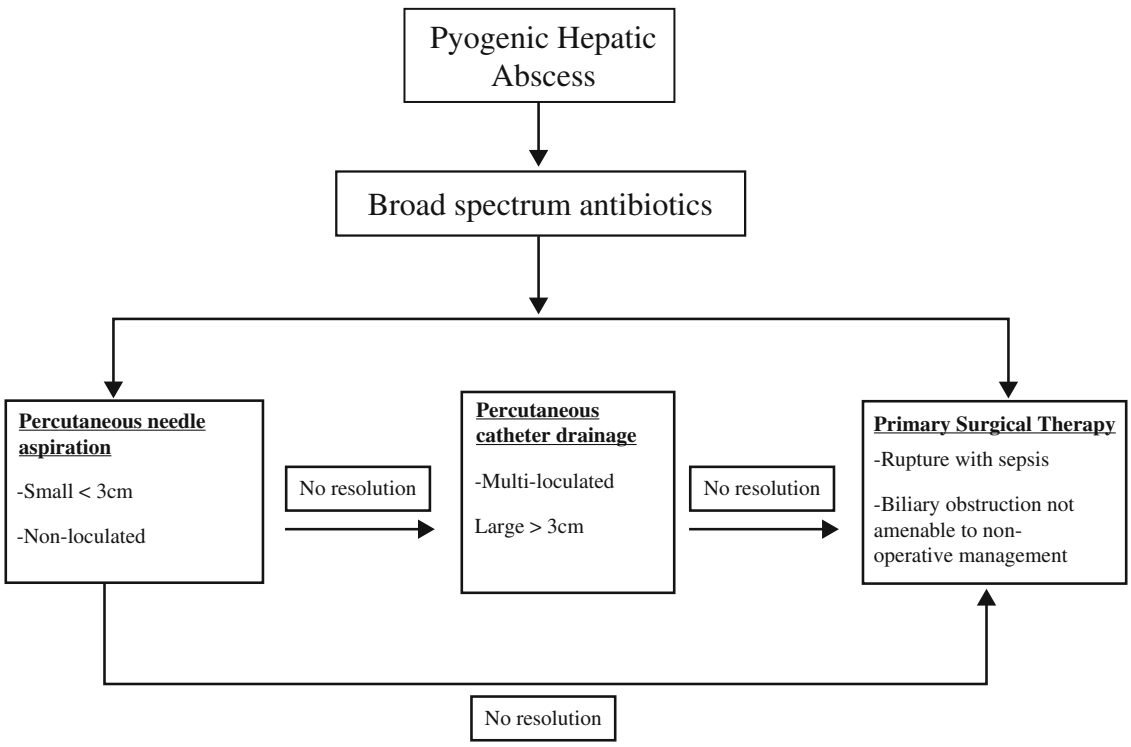

Fig. 25.2 Algorithm for treatment of pyogenic liver abscesses

Amoebic

Pathogenesis

Amoebic liver abscesses are caused by the protozoan *Entamoeba histolytica*, which is endemic in tropical or developing countries. Humans are both the principal hosts and the infective carriers and the disease is usually transmitted fecal–orally. Infected cysts may be passed through water or produce contaminated with feces, foods contaminated by food handlers or by direct transmission. Most infected patients are asymptomatic but some patients will develop invasive disease of the colon. The liver is the most common extra-intestinal site for infection [16].

Once ingested, the cysts are capable of resisting acid degradation in the stomach. They are then released in the trophozoite form from the cysts, triggered by the neutral intestinal juice in the small intestine. Passing into the large intestine, they adhere to the colonic mucosa and invade into the tissue. These infections may manifest as mucosal thickening or more classically, as ulcerations through the mucosa and into the submucosa [17]. It is believed they cause hepatic disease by ascending through the portal system or via direct extension into the liver. Amoebic abscesses consist of three stages: acute inflammation, granuloma formation, and advancing necrosis with subsequent abscess formation. The abscess itself contains necrotic proteinaceous debris with a rim of trophozoites invading the surrounding tissue.

Since the abscess is essentially composed of blood and necrotic hepatic tissue, its appearance is typically described as *anchovy sauce*. It is usually odorless and sterile, unless there is secondary bacterial infection. The abscess will continue to progress and grow until it reaches Glisson's capsule since the capsule is resistant to hydrolysis by the trophozoites. This lends to the classic imaging appearance of the lesion abutting the liver capsule (Fig. 25.3).

Epidemiology

Amoebic liver abscesses usually occur in developing or tropical countries with poor sanitation systems. Areas of the world with endemic disease include Central and South America, Mexico, India, and East and South Africa. The best estimate of the prevalence of amebiasis was by the World Health Organization (WHO) in 1995 that estimated approximately 40–50 million people become symptomatic per year with intestinal colitis or hepatic abscess, resulting in 40,000–100,000 deaths from the disease. A more recent population-based study in the USA identified the incidence to be 1.38 per million population with a 2.4 % average decline during the course of the study (1993–2007) [16]. The mortality in that study was also lower than what has been previously reported and was approximately 1 %.

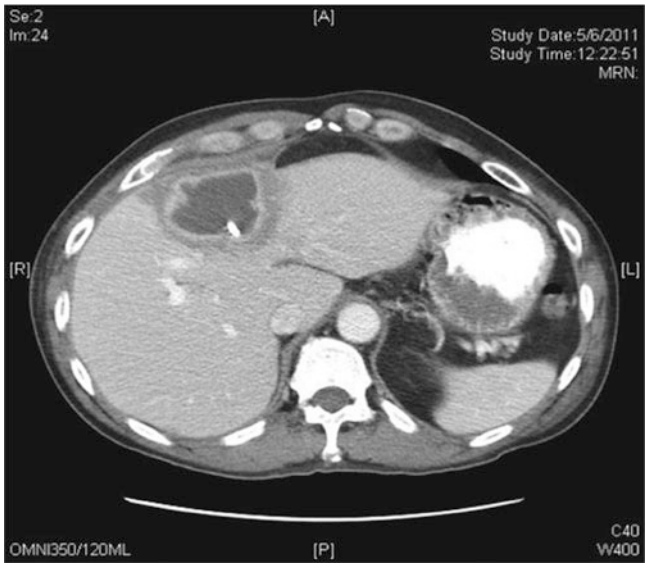

Fig. 25.3 A 49-year-old Chinese female who presented with RUQ pain caused by an amoebic abscess

Hispanic males between the ages of 20 and 40 with a history of travel to endemic regions of the world are most commonly affected by amoebic liver abscess, which is in contrast to pyogenic abscesses, which tend to occur in older patients [16]. There is also a heavier preponderance in the male gender although this is not well understood. One theory is alcohol use in men may lead to impaired Kupffer cell function or impaired immune response. Immunosuppressed patients are also at greater risk for amoebic liver abscess; predisposing conditions include HIV, steroid use, malnourished patients with severe hypoalbuminemia, and post-splenectomy patients.

Clinical Presentation

The most common clinical features of amoebic liver abscesses include fever and abdominal pain. Hepatomegaly with pain on palpation over the liver or below the ribs is one of the most important clinical signs that may help distinguish this disease from pyogenic abscesses. Other symptoms include chills, nausea, weight loss, and diarrhea. Jaundice is seen less commonly with amoebic abscesses.

Common laboratory findings include an elevated white blood cell (WBC) count and anemia. Patients with acute amoebic abscess tend to have an elevated AST and a normal alkaline phosphatase, whereas patients with chronic amoebic abscess will have a normal AST and almost always an abnormal alkaline phosphatase. In contrast, patients with pyogenic abscesses tend to have an elevated bilirubin and abnormal liver transaminases [17].

Diagnosis

Amoebic abscesses need to be distinguished from pyogenic abscesses. Like pyogenic abscesses, the majority of patients with amoebic abscesses will have an abnormal CXR, which may demonstrate an elevated hemidiaphragm, pleural effusion, or atelectasis. An abdominal ultrasound can help make the diagnosis of amoebic abscess and has an accuracy of 95 %; however, it is operator dependent. Typical ultrasound findings include a round or oval lesion that is hypoechoic and homogenous in appearance without wall echoes and abutting the liver capsule. In addition, the majority of lesions (>80 %) are found in the right lobe of the liver.

Abdominal CT is another imaging modality that is extremely sensitive for detecting liver abscesses. Its advantage is the ability to distinguish an abscess from benign or malignant tumors; however, it does not always distinguish between pyogenic and amoebic abscess. The lesion is typically peripheral in the liver without an enhanced rim. Magnetic resonance imaging (MRI) may also be utilized, but like CT, cannot distinguish between amoebic and pyogenic abscesses. Additionally, it is more expensive and is relatively inaccessible from an emergent standpoint.

Serologic testing is a useful adjunct to making a diagnosis of amoebic liver abscess. The majority of patients will not have any detectable parasites in their stools; however, >90 % of patients will have antibodies to *E. histolytica* [18]. The enzyme-linked immunoassay test has largely replaced all tests for *E. histolytica* as it is fast, highly sensitive, and widely available. Its sensitivity is ~99 % with a specificity of 90 %. Although the test cannot distinguish between acute and chronic infections, it is helpful in a patient with a typical story for amoebic hepatic abscess and a mass on imaging studies for making a determination of amoebic abscess.

Treatment

Metronidazole is the treatment of choice for amoebic abscesses. The drug enters the parasite by diffusion and is converted by reduced ferredoxin or flavodoxin into reactive cytotoxic nitro radicals. A 10-day treatment of 750 mg orally three times per day has a >95 % efficacy in most patients [17]. Symptomatic improvements are usually seen by 3 days of treatment and there is little, if any, resistance to the drug. If the patient is unable to tolerate metronidazole, emetine hydrochloride or chloroquine phosphate can be substituted. Emetine hydrochloride is limited in its usefulness since it is administered intramuscularly and has significant cardiac side effects. Chloroquine phosphate can be used in pregnancy and has some associated side effects such as gastrointestinal upset, headaches, and pruritis. The majority of its use is limited to recurrent or resistant hepatic amebiasis.

After the patient has been treated for the amoebic abscess, they should be treated for the intestinal colonization with an agent such as iodoquinol, paromomycin, or diloxanide furoate. The risk of hepatic relapse is approximately 10 % in patients not treated for their colonization.

Percutaneous drainage or aspiration of the abscess has been debated in the literature. A recent Cochrane review of image-guided percutaneous drainage plus metronidazole versus metronidazole alone did not demonstrate any benefit to drainage [19]. The authors did note that the majority of studies were of low quality and that further confirmation with larger trials would be necessary to confirm their results. In a recent population-based study on amoebic abscess in the USA, percutaneous drainage was performed in 48 % of cases and surgical drainage was performed in another 7 % [16]. The indications for drainage were not noted in the study. There was no mortality associated with percutaneous drainage but the authors did report a 0.09 % mortality when treated conservatively without drainage (either percutaneous or surgical). Other studies have reached mixed conclusions and there is currently no consensus on the placement of drains or aspiration.

Complications

Approximately 3–17 % of the time, the abscess can rupture into the peritoneum, pleural cavity, hollow viscera, or pericardium. The majority of these ruptures are contained by the diaphragm, omentum, or abdominal wall. Free rupture into the abdominal cavity is rare as is rupture into a hollow viscus; however, there are reports of ruptures into the stomach and the colon. Most authors now advocate free ruptures into the peritoneum to be managed by percutaneous drainage of the pus. Aggressive surgical management in early published reports led to very high mortality rates, whereas patients who are conservatively managed tended to fare better.

Exploratory laparotomy is indicated when the diagnosis is uncertain, when there is life-threatening hemorrhage, or failure of conservative management. However, published mortality rates are high with surgical management. The abscess is usually seen to be on the surface of the liver. The portal triads will be traversing within the abscess since they are covered by Glisson's capsule and are not degraded by the amoeba. Care must be taken to not disrupt these triads or significant hemorrhage can occur. Since the bile ducts also are found here, disruption can lead to postoperative bile leaks. The abscess cavities can be irrigated gently with saline and then instilled with emetine hydrochloride. Drains should be left in place to widely drain the residual cavity.

Amoebic abscesses can also spontaneously rupture into the pleural cavity or pericardium. Patients will develop an acute shortness of breath with opacification of their lung on CXR.

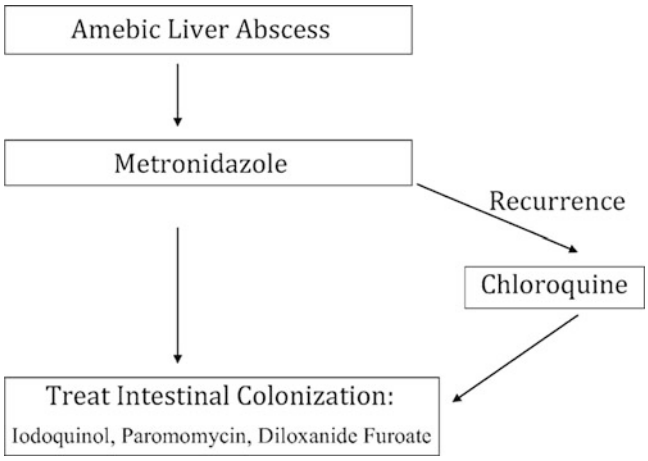

Fig. 25.4 Algorithm for treatment of amoebic liver abscesses

An ultrasound or CT imaging will reveal the hepatic abscess near the dome of the liver with a large opacified fluid collection in the lung. The treatment of choice for the pleural cavity is adequate drainage of the fluid. Left untreated or poorly drained, the patient will develop a secondary infection requiring decortications. If a patient develops a rupture into their pericardium, it can be difficult to diagnose unless there has been abdominal imaging. A high index of suspicion is often necessary to make the diagnosis. Treatment of the pericardial effusion either with percutaneous drainage or subxiphoid window is necessary in cases of tamponade or impending tamponade.

Conclusion

Amoebic abscesses are caused by the protozoan *E. histolytica*. The typical patient is a young Hispanic male with recent travel to endemic areas of the world. Primary treatment is with metronidazole. The majority of patients will respond within 3 days of treatment. Uncomplicated amoebic abscesses are easily treated with a low mortality; however, complications can arise which can significantly increase mortality (Fig. 25.4).

Echinococcal Cysts

Echinococcal cysts (hydatid cysts) of the liver are caused by the adult or larval stages of the tapeworm *Echinococcus granulosus*. This zoonotic disease occurs mostly in areas of the world associated with sheep grazing, but is common worldwide because dogs are the definitive host.

Pathogenesis

The adult tapeworm (*E. granulosus*) inhabits the small intestine of the definitive host (usually dogs). Eggs from the tapeworm are released into the feces, which are then ingested by an intermediate host. This can include sheep, cattle, goats, horses, or humans. Within the intestine, the egg hatches and releases an oncosphere larva. This oncosphere larva contains hooks that allow it to penetrate the bowel mucosa and enter the bloodstream where it then migrates to the liver or other solid organs, such as the lungs. There, the oncosphere larva develops into a two-layer cyst surrounded by a host-derived fibrous capsule, referred to as the pericyst. The two layers consist of an inner germinal layer and an outer gelatinous membrane. This cyst continues to enlarge as protoscolices bud from the germinal layer and fill the interior of the cyst. With enough time, the cysts will form internal septations and other daughter cysts. In the intermediate host, such as humans, the protoscolices can only develop into more daughter cysts and cannot further differentiate into tapeworms. After the cyst containing organs of the infected intermediate host are ingested by the definitive host, such as a dog or sheep, the protoscolices then evaginate and attach to the intestinal mucosa. Within the intestine, they develop into the adult tapeworm, ready to be transmitted to its next host (Fig. 25.5).

Epidemiology

Echinococcal disease is found worldwide especially in areas involved with sheep farming, but is most common in temperate regions such as the Mediterranean areas, South America, China, the Soviet Union, Central Asia, and Africa. In the USA, the majority of cases are found in immigrants from countries where echinococcosis is prevalent. The actual incidence and prevalence of echinococcosis is variable depending on the area of the world, and most estimates are thought to be misleading secondary to the lack of structured data collection. In most countries where the disease is prevalent, echinococcosis is not considered to be a reportable disease and rural settings present a challenge to acquiring epidemiologic data. The estimates may also be false as this disease is difficult to detect early on, and it is prevalent in areas with a weak healthcare systems, with a high population of stray dogs, and illegal slaughtering. However, several retrospective reviews demonstrate the incidence to be similar in many countries despite geographical difference. Reported data on the annual surgical incidence in Turkey was estimated to be 6.4 per 100,000 inhabitants, the incidence in Sardinia from 2001 to 2005 was 6.2 per 100,000 inhabitants, and the incidence in Tanzania was 10 per 100,000 [20, 21].

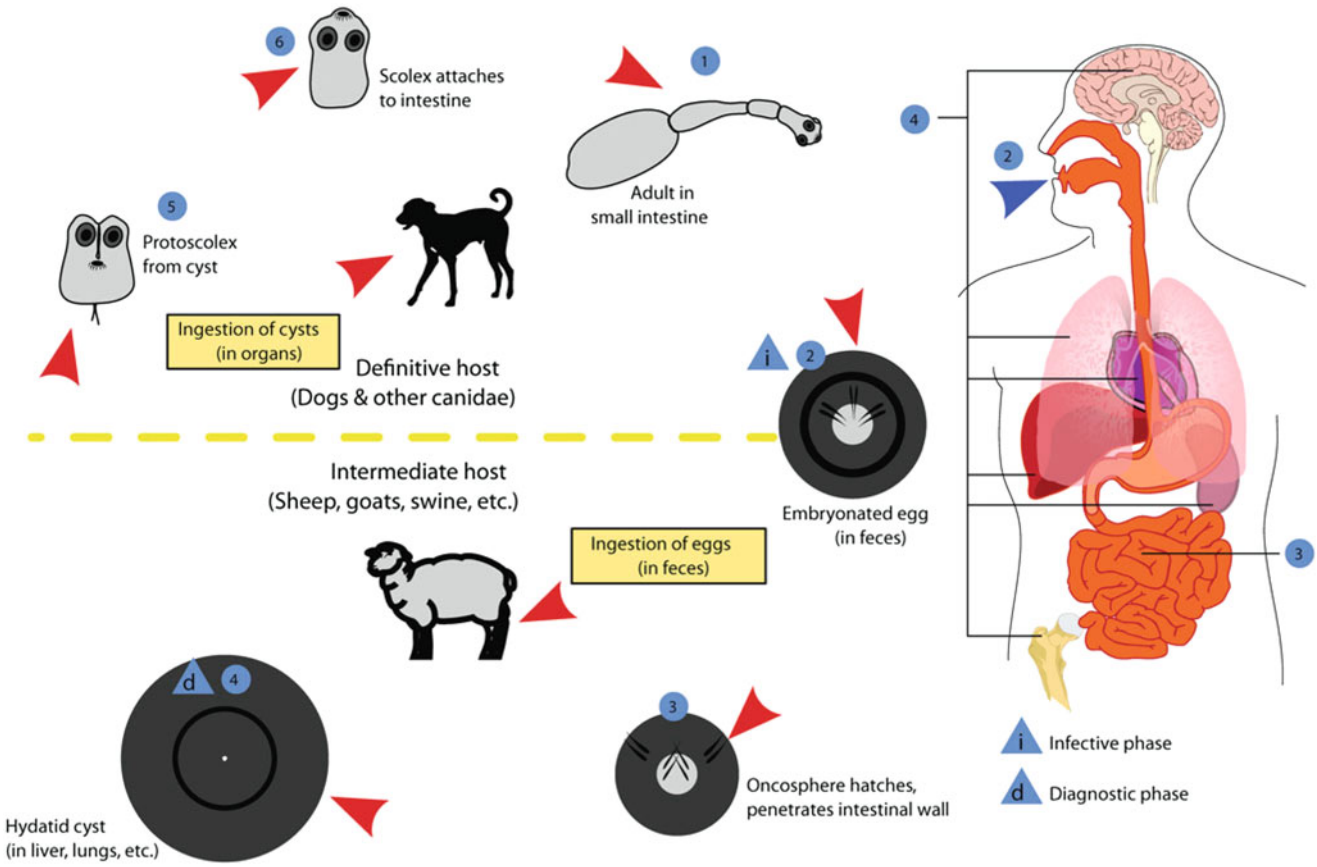

Fig. 25.5 Life cycle of *Echinococcus granulosus*. Reproduced via Wikimedia Commons from User:Slashme (Redrawn from file: CDC Echinococcus Life Cycle.jpg) [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC-BY-SA-3.0-2.5-2.0-1.0 (http://creativecommons.org/licenses/by-sa/3.0)]

Clinical Presentation

Most hydatid cysts are asymptomatic and slow growing, and therefore are present for years before being detected. Most primary infections in humans consist of a single cyst, and the liver is the most common location, accounting for over 70 % of cases, with the lung being the second most likely, seen in 25 % of cases [22] (Fig. 25.6). Signs and symptoms are vague and typically due to the mass effect of the large cyst on the involved and surrounding organs; these include hepatomegaly, abdominal pain, nausea, vomiting, and jaundice. Often, patients will present with a complication of the cyst as their initial presentation, which can include cyst rupture or secondary infection appearing similar to a pyogenic abscess [23].

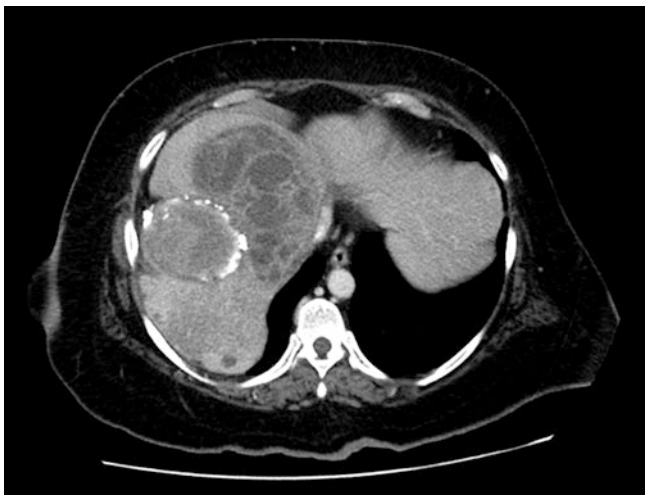

Fig. 25.6 A 55-year-old female who presented with fever/chills, cough, and early satiety due to pyogenic abscess and echinococcal cyst

Diagnosis

Abdominal ultrasound has become the diagnostic method of choice for imaging of hydatid cysts. It is easily available and can determine the number of cysts, the size, and the viability of the cyst based on the morphology of the cyst wall. It has been used worldwide because of its availability, portability, and accuracy. Typical findings include a well-circumscribed

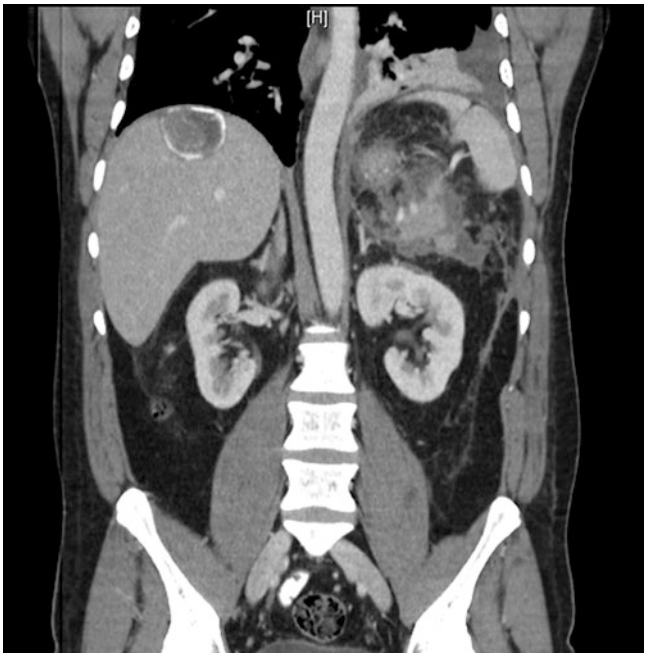

Fig. 25.7 A 42-year-old male immigrant from Mexico who presented with RUQ pain due to an echinococcal cyst

cyst with budding lesions on the cyst membrane. The cyst fluid may be simple or heterogeneous with classic hyperechoic contents creating a "snowflake sign." When the cyst is degenerating, it may be filled with an amorphous mass, which is composed of the degenerating membrane. CT or MRI is also often used, and these reveal large cystic lesions and when present, calcifications in the wall are nearly diagnostic for hydatid disease (Fig. 25.7). In addition, immunologic serum assays to detect antibodies to *E. granulosus* are used to confirm the diagnosis. However, this test may be limited in its utility due to the fact that antigens are sequestered within the cyst cavity and therefore do not illicit an immune response from the host [22]. But, this modality is also helpful in the follow-up surveillance of patients after surgical or pharmacological treatment.

Treatment

Surgical treatment for hydatid cysts within the liver is the most successful method of treatment with the lowest incidence of recurrence [22]. The goal of surgery is complete removal of the cyst wall and contents with a surrounding rim of hepatic parenchyma, referred to as pericystectomy. In addition, larger or more complicated cysts may be best resected via partial hepatectomy or hepatic lobectomy. Other more conservative operative techniques include simple drainage, marsupialization of the cyst wall, or placing omentum within the cyst. Reported recurrence rates vary from 2 to 25 %, while more radical interventions have the lowest rate of recurrence at the cost of higher operative risk [23]. Any communication with the biliary system must be recognized and treated in the operating room, and it is often repaired with a simple suture-ligature of the exposed ducts. Failing to recognize and repair this will lead to biliary leak and likely infected biloma.

The most severe consequence of surgery for hydatid cysts is the incidence of anaphylactic reaction due to spillage of the cyst contents. One important step is preoperative preparation and communication, as the anesthesia team should have epinephrine and steroids prepared to treat any anaphylactic reaction [1]. Other methods employed to minimize this risk include aspirating the cyst at the start of the operation and instilling ethanol or hypertonic saline within the cavity. The intra-abdominal surgical field should be isolated with laps so that any spillage is contained and interaction of the cyst contents and other tissues are minimal. In addition, soaking the laps in hypertonic saline has been described. Due to the pathogenesis of liver cyst formation, surgeons must be aware that the cyst contains two layers that must be removed en masse. Pericystectomy involves creating a dissection plane through healthy liver parenchyma, thus ensuring complete resection of both layers, and decreasing the risk of entering the cyst cavity.

In addition, there are an increasing number of reports of minimally invasive laparoscopic approaches to resection or drainage of hydatid cysts [24]. The same principles of surgery apply, including packing the liver to control drainage and complete removal pericyst tissue with normal hepatic parenchyma and detecting and treating any biliary communications.

Contraindications to surgery include pregnancy, patient refusal, or medical comorbidities. In these cases, medications used in the treatment of hydatid disease include albendazole and mebendazole. Medical therapy is effective in 60–80 % of patients, and most often in those with small (<7 mm), isolated cysts, surrounded by minimal adventitial reaction [22]. Treatment typically lasts a minimum of 3 months, and patients must be monitored for adverse reactions such as neutropenia and hepatic toxicity.

"PAIR" (Puncture–Aspiration–Injection–Reaspiration) is gaining popularity as a third method of treatment of hydatid cyst disease. The procedure begins with image-guided puncture of the cyst, and can be done with either sonography or CT. Following aspiration of the entire cyst contents, the cavity is injected with a protoscolicidal agent such as 95 % ethanol or hypertonic saline for 15–30 min, completed by reaspiration of this fluid. Reports indicate that the incidence

of anaphylaxis is only 8 %, compared to 25 % during surgical resection [25]. When used as a part of a multimodality approach, the technique has been shown in a large meta-analysis to be slightly more effective than surgery with decreased rates of morbidity, mortality, hospital stay, and recurrence [25]. This approach includes a 7-day pretreatment course of albendazole or mebendazole, followed by at least 1 month of these medications post-procedure. Importantly, PAIR must not be used in patients whose cysts communicate with the biliary system as injection of the sclerosing agents can induce a severe sclerosing cholangitis. The presence of biliary communication must be detected with pre-procedural ERCP, cholangiography during the procedure, or testing the cyst fluid for bilirubin.

Complications

Initial symptoms of hydatid cysts are often vague; therefore often the first presentation is due to a complication. Most commonly cysts rupture freely into the peritoneal cavity, causing disseminating echinococcosis creating cysts in multiple intra-abdominal organs. In addition, the sudden release of cyst contents can precipitate allergic reactions that vary from mild to fatal anaphylaxis. It is reported that there is a 10 % rate of severe anaphylactic reactions [23]. When recognized early, patients are treated with epinephrine or steroids to support them through this reaction. Within the liver, the cyst can rupture into the biliary tree and cause secondary cholangitis. Other complications include biliary obstruction by daughter cysts or simple extrinsic compression. In addition, the cyst cavity is a potential site of secondary bacterial infection. These are diagnosed and treated as pyogenic liver abscesses.

Conclusion

Echinococcal cysts (hydatid cysts) of the liver are caused by the tapeworm *E. granulosus*. While detected worldwide, they are more prevalent in temperate climates where humans are in contact with the definitive hosts, sheep and dogs. They most often cause cysts within the liver, detected by imaging and immunoassays. Symptoms are often due to mass effect; however, rupture and spillage of contents are associated with severe anaphylaxis. Primary treatment involves complete surgical resection of the cyst either via laparotomy or laparoscopic approach. Newer methods such as Percutaneous Aspiration–Injection–Reaspiration (PAIR) are growing in popularity as an effective and safe treatment option (Fig. 25.8).

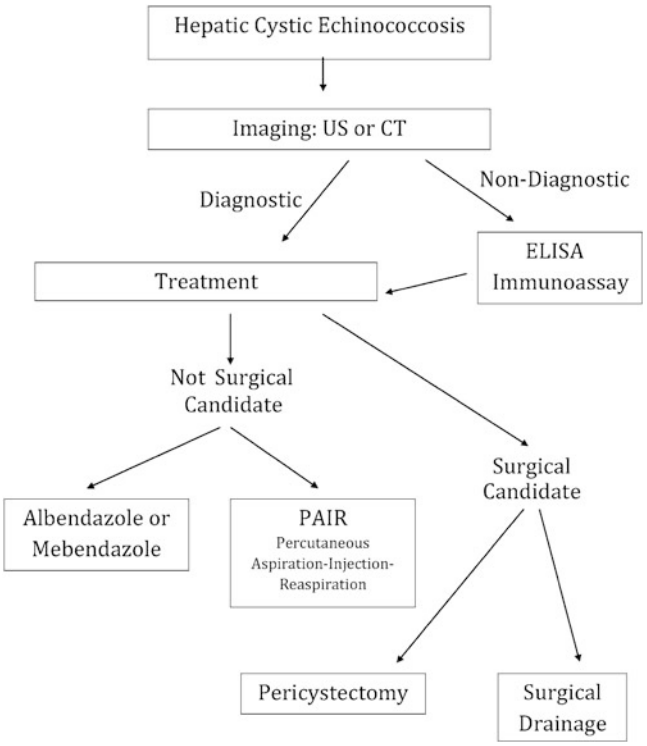

Fig. 25.8 Algorithm for treatment of echinococcal cysts (hydatid cysts) of the liver. *US* ultrasound, *CT* computed tomography, *ELISA* enzyme-linked immunosorbent assay

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Acute Pancreatitis

26

Curtis J. Wray and Tien C. Ko

Acute pancreatitis presents with rapid onset of severe epigastric pain often radiating to the back associated with nausea and vomiting. Localized pancreatic inflammation induces a spectrum of clinical significance. Most cases are self-limited, whereas a minority may produce systemic effects with distant organ failure. Gallstones and alcohol ingestion are the most common etiologies of pancreatitis, although medications, infection, and metabolic causes are less frequent. The pathophysiology is thought to originate in the acinar cells with co-localization of pancreatic zymogens and lysozymes in the cytoplasm. The resulting inappropriate activation leads to acinar cell damage, followed by a significant leukocyte infiltration which propagates the cycle of inflammation and injury. Most cases of acute pancreatitis are self-limiting whereas a smaller percentage can progress to severe systemic inflammatory response syndrome, organ failure, shock, and death.

Epidemiology

Acute pancreatitis remains a significant source of morbidity in the USA [1, 2]; however, there has been a recent trend in increasing incidence of acute pancreatitis in epidemiological studies in the USA. According to the National Hospital Ambulatory Medical Care Survey, acute pancreatitis resulted in approximately 821,772 ambulatory and inpatient visits [1, 3]. This resulted in 275,000 admissions which is a 15 % increase over the last decade. The total hospital length of stay was almost 1.3 million days at an estimated cost of 2.6 billion dollars. In-hospital death occurred in less than 1 % of cases.

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The increasing incidence over the past two decades may be attributed to improvements in imaging technologies and laboratory tests aiding in the diagnosis. More recent increases in incidence of AP over the last decade may be related to the prevalence of obesity and associated increase in gallstone-related pancreatitis. Acute pancreatitis may be under-reported as mild cases may be subclinical and whereas other patients with severe acute pancreatitis are diagnosed only at autopsy.

Historically, acute pancreatitis had a high mortality rate. Studies in the 1940s reported a mortality rate of 25 % in patients managed conservatively, with a mortality rate of 54 % for those managed surgically. In a landmark paper, Ranson et al. reported an overall mortality rate of 15 % in acute pancreatitis [4]. At present, high rates of mortality in AP are frequently cited, although some rates refer to specific patient sub-population [5]. In recent systematic reviews, overall mortality of acute pancreatitis ranged from 2 to 5 %. However, mortality approached 17 % for those diagnosed with necrotizing pancreatitis. In this subset of patients with necrotizing pancreatitis, mortality was 12 % for those with sterile necrosis and 30 % for infected necrotizing pancreatitis. Patient with infected necrosis and multisystem organ failure had mortality rates approaching 50 %. The patients with highest risk of mortality in pancreatitis are those requiring intensive care unit admissions. However, in studies conducted at medical centers with specialized medical and surgical expertise in the management of pancreatic disease, the mortality in severe acute pancreatitis may be under 10 % and as low as 6 %, even when considering only the patients with necrotizing pancreatitis [6].

There are a number of etiologies of acute pancreatitis. Gallstone-related pancreatitis remains the most common cause accounting for 35–40 % of cases. This thought to be due to mechanical ampullary obstruction induced by gallstones passing into the cystic duct and subsequently retained in the distal common bile duct. Blockage of the ampulla of Vater may result in biliary fluids and bile salts refluxing into Wirsung's duct. This exposure may cause damage to pancreatic acinar

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_26

cells. In the general population, however, there is a high prevalence of asymptomatic gallstones and less than 10 % of patients with symptomatic gallstones actually develop pancreatitis [7, 8]. Well-defined risk factors associated with gallstone pancreatitis include female gender, pregnancy, and obesity. Biliary sludge which is viscous in nature may also contain small stones <5 mm. Sludge and microlithiasis form cholesterol monohydrate crystals, calcium bilirubinate granules or calcium carbonate microspheres.

The second most common cause of acute pancreatitis is due to chronic and excessive alcohol consumption [9–11]. Alcohol accounts for approximately 30 % of cases of pancreatitis in the USA. The mechanism by which alcohol causes acute pancreatitis is presently unknown, recently it has been hypothesized that the expression and cellular localization of the ion channel cystic fibrosis transmembrane conductance regulator is disrupted by chronic alcohol exposure [12]. This may in turn lead to pancreatitis. Interestingly, pancreatitis associated with alcohol use rarely occurs with "binge drinking," but more typically occurs in patients with chronic alcohol intake, who already have either changes of chronic pancreatitis or alcoholic cirrhosis. Patients with alcoholic cirrhosis rarely also have pancreatitis and vice versa. Alcoholic pancreatitis may have a more severe clinical course than gallstone-related pancreatitis. In a recent study, length of stay and pancreatitis-induced complications were higher in the alcohol group [13]. Alcoholic pancreatitis has been associated with greater mortality compared to gallstone pancreatitis, although this may be due to lower baseline nutrition and health status that occurs with chronic alcohol abuse.

Metabolic, anatomical, and iatrogenic causes account for 20–25 % of acute pancreatitis. Serum hypertriglyceridemia at concentrations above 100 mg/dl can also precipitate acute pancreatitis. These typically arise in patients with lipoprotein metabolism defects and a secondary precipitating factor (e.g., diabetes, alcohol, or medications). In addition, there is evidence that treatment with statins may decrease episodes of acute pancreatitis at the population level [14–16].

Pancreas divisum is an anatomic anomaly where the majority of the pancreas drains by the duct of Santorini [17] (Fig. 26.1). At autopsy it is estimated the prevalence of pancreas divisum ranges from 5 to 7 % [18]. However, only small proportion of patients with pancreas divisum experience symptomatic disease due to recurrent bouts of idiopathic pancreatitis. It has been postulated that pancreatitis occurs secondary to outflow or a "relative obstruction" of the small minor papilla that may not be able to excrete large volumes which leads to high pressure during active secretion.

In the absence of chronic alcohol abuse or gallstones in the biliary system, other causes of pancreatitis must be investigated. These other causes include tumor, infection, anatomic anomaly, trauma, iatrogenic injury, medication, metabolic dysfunction, autoimmune disease, or genetics. With resolution of symptoms in mild acute pancreatitis, it is permissible to defer an extensive investigation in the absence of clear etiology. However, with severe acute pancreatitis, repeated bouts of acute pancreatitis, or other more worrisome signs, a more thorough investigation is appropriate.

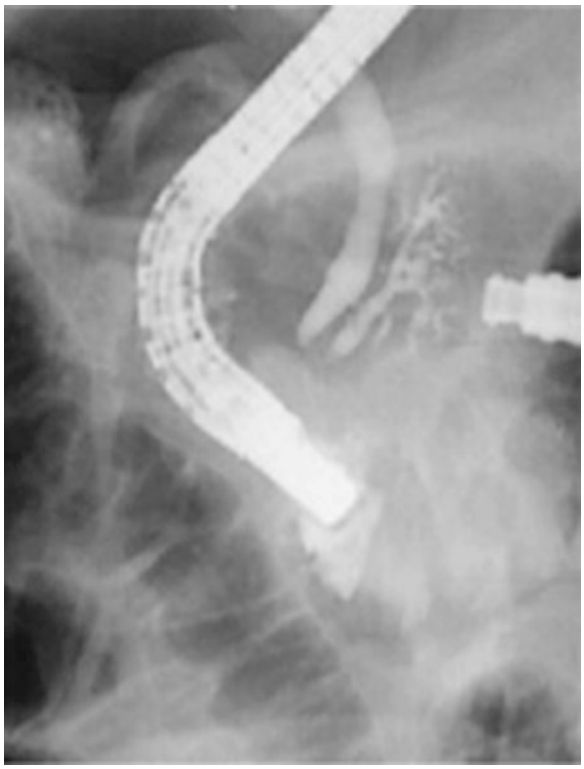

Fig. 26.1 ERCP demonstrating pancreas divisum. Injection of contrast only fills the ductal network in the head of the pancreas

Tumor obstructing the main pancreatic duct is a rare, but serious cause of acute pancreatitis. Most frequently, ampullary tumors may cause pancreatitis, although masses anywhere along the pancreatic ducts may be a source for disease. Mucous from intraductal papillary mucinous neoplasm can also cause obstruction. Pancreatitis associated with weight loss, jaundice, steatorrhea, and pale-colored stools is concerning for a mass obstructing the pancreatic duct.

Pancreatitis following endoscopic retrograde cholangiopancreatography (ERCP) is a well-recognized clinical complication. Up to 70 % of patients undergoing an ERCP will develop asymptomatic hyperamylasemia [19–21]. The incidence of abdominal pain and pancreatitis is reported to be less than 5 %. Multiple studies have shown benefit of short-term prophylactic pancreatic stent placement for the prevention of post-ERCP pancreatitis [22, 23].

Medications are another infrequent cause of pancreatitis, accounting for less than 1 % of cases of acute pancreatitis [24]. It is often difficult to deduce a causative relation between medications and disease, as pancreatitis tends to be

self-limiting and resolution may occur spontaneously, coincidentally at the same time of medication cessation. However, there are a number of medications that have consistently been associated with pancreatitis such as those for acquired immunodeficiency syndrome (didanosine, pentamidine), antibiotics (metronidazole, tetracycline), diuretics (furosemide, thiazides), inflammatory bowel disease drugs (6-mercaptopurine, sulfasalazine, 5-ASA), immunosuppressives (L-asparaginase, azathioprine), valproic acid, and steroids.

In younger patients, pancreatitis may occur from genetic causes, together categorized as "hereditary pancreatitis." In 1996, Whitcomb et al. reported a single-gene missense mutation affecting cationic trypsinogen, leading to clusterings of pancreatitis in an autosomal dominant pattern of inheritance [25, 26]. Mutations in the cystic fibrosis transmembrane conductance regulator (CFTR) gene, causing defects in chloride ion channel and the disease cystic fibrosis is another genetic cause of pancreatitis [27]. Serine protease inhibitor Kazal type I (SPINK-1) has also been found to be a hereditary cause of pancreatitis [28].

Infectious causes of acute pancreatitis include various viruses, bacteria, and fungi. Viruses causing pancreatitis include mumps, Coxsackie virus, hepatitis B, cytomegalovirus, and varicella-zoster virus. Bacterial causes of pancreatitis tend to be exceedingly rare, but cases caused by Mycoplasma, Legionella, and Salmonella have been reported. Of fungi, aspergillus has been reported to rarely cause acute pancreatitis. Additionally, bites from various vectors, including the brown recluse spider, a scorpion found in the region surrounding Trinidad (*Tityus trinitatis*), and the Gila monster have been known to induce pancreatitis in their victims, via hyperstimulating cholinergic innervations to the pancreas, resulting in hypersecretion and sphincter spasm.

Clinical Presentation

The classic clinical presentation of acute pancreatitis is acute onset of severe epigastric pain. The pain often radiates to the back and in the majority of cases is associated with nausea and vomiting. In patients with gallstone pancreatitis, the pain is localized to the epigastrium and reaches maximum intensity in 10–20 min [13, 29]. Up to 70 % of patients with acute pancreatitis will have this classic pattern of symptoms. At onset, the pain typically develops quickly and is characterized as a pressure-like, dull and constant, or even throbbing epigastric abdominal discomfort. Patients may notice that the pain is better appreciated in the supine position and may be mildly alleviated in the classic sitting position and leaning forward. In mild cases of acute pancreatitis, pain may resolve within 1 or 2 days, or can potentially persist for weeks.

Physical exam findings will vary depending upon the severity of acute pancreatitis. In patients with a mild variant, the upper abdomen may be minimally tender on exam. However, patients with severe acute pancreatitis may have profound pain upon abdominal exam. In severe cases, patients may be febrile, tachycardic, occasionally jaundiced, in respiratory distress, and hypotensive. While rarely noted on physical exam, signs of retroperitoneal hemorrhage due to acute pancreatitis may include bruising around the umbilicus (Cullen's sign), along the flanks (Grey–Turner's sign), or along the inguinal ligaments (Fox's sign).

Diagnosis of acute pancreatitis relies on the patient's history and clinical presentation. The diagnosis of acute pancreatitis should be suspected in patients with rapid onset epigastric pain accompanied by nausea and vomiting. Further evaluation of acute pancreatitis to confirm diagnosis would begin with laboratory tests of serum pancreatic enzymes, such as amylase and lipase. The elevation of these pancreatic enzymes is thought to occur when there is a physical blockade in secretion via the ducts, followed by leakage of pancreatic enzymes from acinar cells via the basolateral membrane and into the systemic circulation. Another diagnostic means would be characteristic findings on abdominal imaging (ultrasound or CT scan) [30].

Amylase is the most commonly used biochemical marker to aid in the diagnosis of acute pancreatitis. Mild elevations can be nonspecific as other sites/glands (salivary glands, fallopian tubes, and small bowel) also secrete amylase. A level of three times the upper limit of normal is typically used as the cutoff for raising the likelihood of a diagnosis of pancreatitis. The half-life of amylase is 10 h and elevations of serum amylase in acute pancreatitis occur rapidly within 12 h of symptom onset and similarly fall rapidly within 3 days [31]. In patients with renal insufficiency, elevations in amylase may last longer or may be falsely elevated. Alternatively, in mild acute pancreatitis in the context of chronic pancreatitis or hypertriglyceridemia, amylase may remain within the normal limits during the duration of disease as the elevated triglycerides often interfere with the assay.

Measurement of serum lipase is both more sensitive and specific for acute pancreatitis. It has a shorter half-life 4 to 8 h; however, it remains elevated for much longer [32, 33]. Elevations in serum lipase originate from the pancreas, making this laboratory study more specific compared to the standard serum amylase assay. Sensitivity has been found to be as high as 100 % with 96 % specificity [34, 35]. Similar to amylase, lipase is cleared by the kidneys and may remain abnormally elevated in patients with renal insufficiency.

Diagnostic imaging has demonstrated significant improvements over time with improved technology. Historically the findings on plain abdominal radiograph were nonspecific.

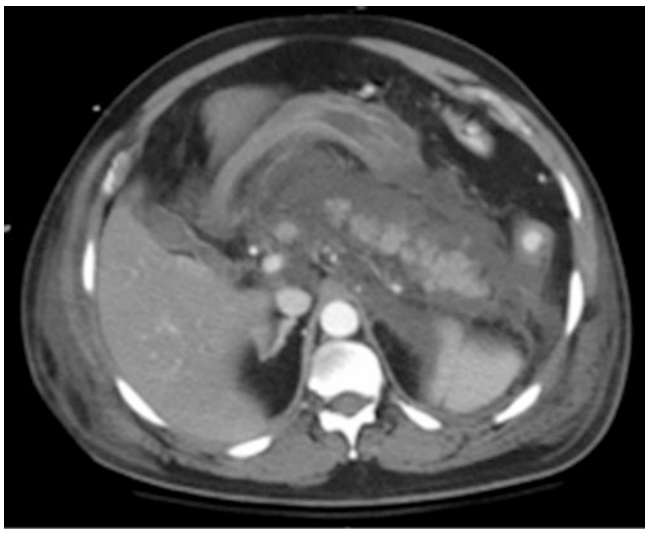

Fig. 26.2 CT scan demonstrating retroperitoneal, peripancreatic fluid, and enhancement of distal pancreas

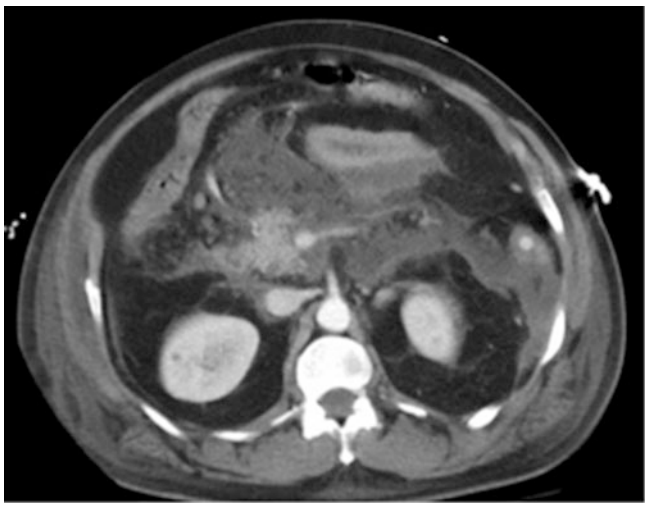

Fig. 26.3 CT scan with significant retroperitoneal fluid tracking along left colic gutter

The "colon cut-off" sign can be observed as a lack of large bowel gas distal to the splenic flexure. It was thought that this was due to colonic spasm as a result of nearby pancreatic inflammation.

Abdominal ultrasound can also be used to evaluate acute pancreatitis. On ultrasound, the pancreas may appear enlarged and hypoechoic. Peripancreatic fluid collections identified by ultrasound can also indicate the severity of disease. During ultrasound, the presence of gallstones can be seen in the extra-hepatic bile duct. A newer ultrasound modality, endoscopic ultrasound (EUS) has also used in patients with acute pancreatitis [36, 37]. In these studies, EUS was able to visualize hypoechoic within the pancreatic parenchyma. However, the utility of EUS in cases of standard acute pancreatitis remains investigational at this time.

Computed tomography (CT) is the most conventional and valuable imaging modality for determining the diagnosis and severity of acute pancreatitis. All patients scanned for pancreatitis should receive oral and intravenous contrast when safe and follow a CT protocol for optimal visualization of the pancreas [38, 39]. Intravenous contrast is particularly helpful because of the dense vascular network of the pancreas, allowing the identification of pancreatic edema and/or necrosis in areas of abnormal contrast enhancement. CT scan is also accurate in the identification of peripancreatic fluid collections (Fig. 26.2). CT imaging may also demonstrate retroperitoneal inflammation and stranding from the intense inflammatory reaction (Figs. 26.3 and 26.4). While imaging studies may aid in early diagnosis, CT scan of the pancreas should be delayed 48–72 h after symptom onset [40, 41]. Earlier scans can miss developing complications such as pancreatic necrosis that takes up to 4 days to develop, so an early normal scan may be falsely reassuring. Pancreatic necrosis is recognized as lack of enhancement after dynamic

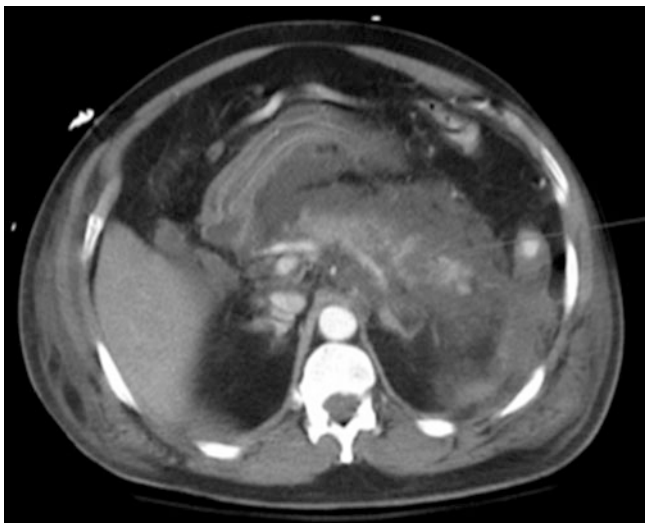

Fig. 26.4 CT scan demonstrating peripancreatic edema and areas of nonenhancing pancreas consistent with necrosis

intravenous contrast administration (Fig. 26.5). A well-timed study may distinguish between edematous inflamed pancreas and necrotizing pancreatitis. Necrotic pancreatic parenchyma is not perfused and does not enhance with intravenous contrast. A contrast-enhanced CT scan is indicated for patients who are clinically deteriorating and in whom a diagnosis of infected necrotizing pancreatitis is being considered [42].

Although not a standard imaging mode in the evaluation and management of acute pancreatitis, the use of magnetic resonance imaging (MRI) and magnetic resonance cholangiopancreatography (MRCP) is increasing. An MRI with gadolinium IV contrast can identify pancreatic necrosis and peripancreatic fluid collections [43, 44]. There are a few advantages of using MRI over CT scan. Gadolinium contrast is a less nephrotoxic compared to iodinated contrasts used

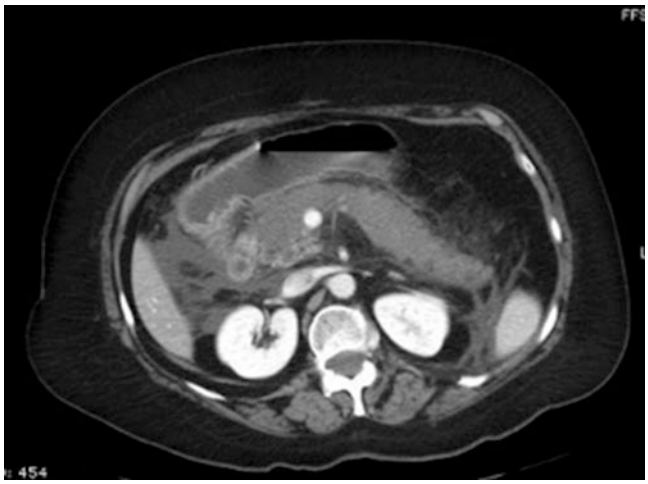

Fig. 26.5 Dynamic contrast CT scan depicting no enhancement of the pancreatic parenchyma consistent with sterile pancreatic necrosis

with CT imaging. In addition, the MRI does not expose patients to the high levels of radiation from the CT scanner. Additionally, studies have found that MRI may be better than CT at assessing peripancreatic fluid collections [45, 46]. Limitations of MRI include resource availability, time required for the study, and patient participation. Thus, CT remains the primary imaging modality for the evaluation of the severity of acute pancreatitis.

Prognosis

Prior to confirming the diagnosis of acute pancreatitis, early management should include assessment of severity. The clinical course of pancreatitis can be unpredictable and the severity of prognosis is vital. In select acute pancreatitis patients with hypoxia, alteration of mental status, hypotension, tachycardia, significant gastrointestinal bleeding, or other signs of multiple organ failure, immediate intensive care unit admission is appropriate.

Several scoring systems have been proposed for assessing and predicting the severity of acute pancreatitis. Significant research has focused on risk, prognostic factors, and universal definitions of acute pancreatitis and related complications. In 1992 a consensus conference was held in Atlanta in order to develop a universal applicable classification system [47, 48]. Based upon new understanding of sepsis, multisystem organ failure, and systemic inflammatory response syndrome (SIRS) criteria, the Acute Pancreatitis Classification Working Group revised the earlier criteria. The revised 2012 Atlanta classification stratified patients into two types: interstitial edematous pancreatitis and necrotizing pancreatitis (Table 26.1)[30]. In addition, the revised criteria included three grades of severity (Table 26.2).

The majority of patients experience mild acute pancreatitis. In cases of mild pancreatitis, there is interstitial homogeneous enhancement and peripancreatic stranding seen on abdominal CT scans. Symptoms associated with acute pancreatitis typically resolve in less than a week [49]. A smaller proportion of patients (5–10 %) will develop necrosis of the pancreatic parenchyma and/or peripancreatic tissues. In those patients with a more severe form of pancreatitis, impaired glandular perfusion, inflammation and peripancreatic necrosis evolve over several days. Clinically, it is important to understand that an early CT scan with 48 h of symptom onset may underestimate the severity of disease. The natural history of pancreatic and peripancreatic necrosis is variable, some will become solid or liquefy, persist as sterile, or become infected. There is no correlation between the development of infected necrosis and the severity of disease at presentation [50].

Accurate diagnosis of infected pancreatic necrosis is important because of the implications for antibiotics and surgical intervention [50]. The diagnosis of infected necrosis should be strongly considered if there is extraluminal gas in the pancreatic or peripancreatic tissues on CT scan images (Fig. 26.6). In addition, fine needle aspiration of the fluid that is positive for bacteria on Gram stain confirms the diagnosis of infected necrosis [51].

While the Atlanta classification sets the ground work for categorizing and accurately defining acute pancreatitis, the clinical challenge is early identification of those at risk for pancreatic necrosis and the more significant disease course [52–54]. Perhaps the most widely quoted clinical scoring system designed to assess the severity of acute pancreatitis is the Ransom criteria (Table 26.3). John H. Ranson's original study was conducted and included 100 consecutive patients diagnosed with acute pancreatitis between 1971 and 1972 [55]. Forty-three objective findings were recorded during the first 48 h of admission. These patients were stratified into three groups: those who died, those who were "seriously ill" (≥7 days in the intensive care unit), and those who were without significant serious illness. From these data, Ranson identified 11 prognostic factors that predicted severe disease with 5 measured at admission and 6 measured within 48 h of admission. In the study, the presence of 3 or more positive signs was more consistent with severe disease, which included those patients that died or were "seriously ill." Although Ranson's criteria is more than 35 years old, it still is frequently used in discussion of severity of acute pancreatitis.

Following Ranson's criteria, a number of similar scoring systems have been developed with similar clinical criteria [56]. These scores are easily applied to patients based on clinical and biochemical markers. There are several limitations to Ranson's criteria. Since it depends on parameters

Table 26.1 Revised definitions of morphologic features of acute pancreatitis

Interstitial edematous pancreatitis
1. Acute inflammation of the pancreatic parenchyma and peripancreatic tissues, but without recognizable tissue necrosis
2. Pancreatic parenchyma enhancement by intravenous contrast agent
3. No findings of peripancreatic necrosis (see below)
Necrotizing pancreatitis
1. Inflammation associated with pancreatic parenchymal necrosis and/or peripancreatic necrosis
2. Lack of pancreatic parenchymal enhancement by intravenous contrast agent and/or
3. Presence of findings of peripancreatic necrosis (see below—ANC and WON)
Acute peripancreatic fluid collection
1. Peripancreatic fluid associated with interstitial edematous pancreatitis with no associated peripancreatic necrosis
2. This term applies only to areas of peripancreatic fluid seen within the first 4 weeks after onset of interstitial edematous pancreatitis and without the features of a pseudocyst
3. Occurs in the setting of interstitial edematous pancreatitis
4. Homogeneous collection with fluid density
5. Confined by normal peripancreatic fascial planes. No definable wall encapsulating the collection. Adjacent to pancreas (no intrapancreatic extension)
Pancreatic pseudocyst
1. An encapsulated collection of fluid with a well-defined inflammatory wall usually outside the pancreas with minimal or no necrosis
2. This entity usually occurs more than 4 weeks after onset of interstitial edematous pancreatitis to mature
3. Well circumscribed, usually round or oval
4. Homogeneous fluid density
5. No non-liquid component
6. Well-defined wall; that is, completely encapsulated
7. Maturation usually requires >4 weeks after onset of acute pancreatitis; occurs after interstitial edematous pancreatitis
ANC (acute necrotic collection)
1. A collection containing variable amounts of both fluid and necrosis associated with necrotizing pancreatitis; the necrosis can involve the pancreatic parenchyma and/or the peripancreatic tissues
2. Occurs only in the setting of acute necrotizing pancreatitis
3. Heterogeneous and non-liquid density of varying degrees in different locations (some appear homogeneous early in their course)
4. No definable wall encapsulating the collection
5. Location—intrapancreatic and/or extrapancreatic
WON (walled-off necrosis)
1. A mature, encapsulated collection of pancreatic and/or peripancreatic necrosis that has developed a well-defined inflammatory wall
2. WON usually occurs >4 weeks after onset of necrotizing pancreatitis
3. Heterogeneous with liquid and non-liquid density with varying degrees of loculations (some may appear homogeneous)
4. Well-defined wall, that is, completely encapsulated
5. Location—intrapancreatic and/or extrapancreatic. Maturation usually requires 4 weeks after onset of acute necrotizing pancreatitis

Table 26.2 Grades of severity

Mild acute pancreatitis
No organ failure
No local or systemic complications
Moderately severe acute pancreatitis
Organ failure that resolves within 48 h (transient organ failure)
Local or systemic complications without persistent organ failure
Severe acute pancreatitis
Persistent organ failure >48 h
Single organ failure
Multiple organ failure

measured at admission and within 48 h, it has limitations evaluating the severity of disease immediately upon admission or later in the patient's disease course [57, 58].

Since Ranson's has limitations within the first 48 h, other scoring systems, such as the APACHE II score, can be used to assess severity later in the hospital course. The APACHE II score was originally developed to stratify a broad range of critically ill patients [48]. Severe disease in pancreatitis presents similarly to severe disease by other mechanisms such as sepsis, accompanied with multi-organ dysfunction. Thus, the APACHE II score is useful in the assessment of acute

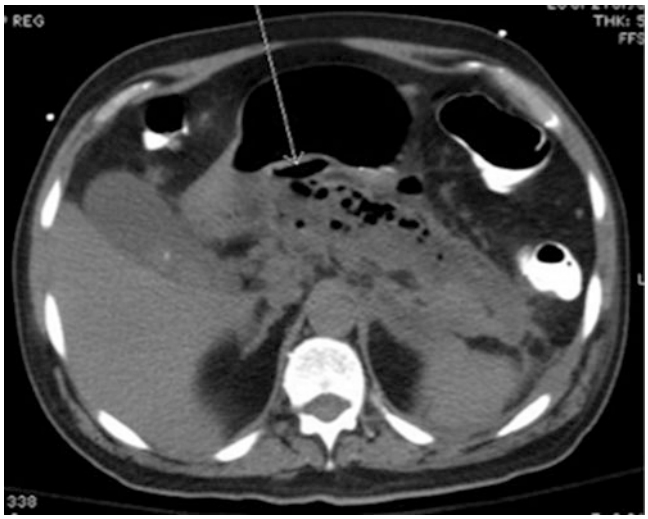

Fig. 26.6 CT scan with air bubbles in pancreatic fluid collection demonstrates signs of infected necrotizing pancreatitis

Table 26.3 Ranson's criteria

At admission
Age: >55 years old
WBC: >16,000/μl
Glucose: >200 mg/dl
LDH: >350 U/l
SGOT (AST): >250 U/l
At 48 h
Calcium: <8 mg/dl
BUN change: >1.8 mmol/l (5 mg/dl)
Hct fall: >10 %
Base deficit: >4 mEq/l
PaO_2: <60 mmHg
Fluid seq: >6 l

pancreatitis severity. The APACHE II score consists of 12 physiologic and biochemical measures, including temperature, mean arterial pressure, heart rate, respiratory rate, alveolar-to-arterial oxygen gradient, pH, sodium concentration, potassium concentration, creatinine, hematocrit, white blood cell count, and Glasgow coma score. While different cutoffs may be used to assess severity, typically, APACHE II scores greater than 7 indicate more severe disease with sensitivities ranging from 65 to 76 % and specificities ranging from 76 to 84 % [47]. Another scoring system that is useful is the modified Marshall score [59–61]. Using the modified Marshall score, points are assigned based upon dysfunction of respiratory, renal, and cardiovascular (systolic blood pressure) (Table 26.4).

Management

Following assessment of severity and triage, aggressive fluid resuscitation should be started immediately for any patient with acute pancreatitis. The rationale for early aggressive hydration arises from the observation of frequent hypovolemia related associated conditions. Concomitant hypovolemia is seen with patients due to vomiting, reduced oral intake, third spacing of fluids, increased respiratory losses, and diaphoresis. In cases of severe acute pancreatitis with necrosis, an array of inflammatory mediators are released into the circulation, leading to increased vascular permeability, resulting in fluid collecting outside in the interstitial space as well as peritoneal and pleural cavities. Fluid resuscitation may help prevent cardiovascular collapse, pre-renal azotemia, as well as improve blood flow to the pancreatic microcirculation. Under-resuscitation during the early phase of acute pancreatitis has been associated with an increased risk of necrosis

Table 26.4 Modified Marshall scoring system for organ dysfunction

	Score				
Organ system	0	1	2	3	4
Respiratory (PaO_2/FiO_2)	>400	301–400	201–300	101–200	≤101
Renal[a]					
(Serum creatinine, μmol/l)	≤134	134–169	170–310	311–439	>439
(Serum creatinine, mg/dl)	<1.4	1.4–1.8	1.9–3.6	3.6–4.9	>4.9
Cardiovascular (systolic blood pressure, mmHg)[b]	>90	<90, fluid responsive	<90, not fluid responsive	<90, pH < 7.3	<90, pH < 7.2
For non-ventilated patients, the FiO_2 can be estimated from below					
Supplemental oxygen (l/min)	FiO_2 (%)				
Room air	21				
2	25				
4	30				
6–8	40				
9–10	50				

A score of 2 or more in any system defines the presence of organ failure

[a]A score for patients with preexisting chronic renal failure depends on the extent of further deterioration of baseline renal function. No formal correction exists for a baseline serum creatinine ≥134 μmol/l or ≥1.4 mg/dl

[b]Off inotropic support

and mortality [62]. Crystalloid fluids, such as normal saline or Lactated Ringer's solution, are typically delivered at rates ranging from 250 to 1000 ml/h, depending on the clinical scenario. While the optimal volume of intravenous fluids to be delivered has yet to be determined, the importance of aggressive fluid resuscitation, evaluated by timely resolution of hemoconcentration, has been well studied. Urine output of at least 0.5 ml/kg body weight per hour and resolution of hemoconcentration can be monitored as measures of adequate fluid resuscitation. During aggressive fluid delivery, patients should be closely monitored with regular lung exams, especially in more vulnerable patients with preexisting cardiac or pulmonary dysfunction. A balanced intravenous fluid composition, such as Lactated Ringer's solution, reduces the incidence of SIRS when compared to saline resuscitation [63]. Over-resuscitation should also be avoided if possible as it can lead to pulmonary complications and worsen morbidity [64].

In acute pancreatitis, mild hypoxia may occur and require supplemental oxygen. Respiratory failure is the most common form of end-organ dysfunction seen in acute pancreatitis patients [65]. The disease course can be complicated by severe diffuse respiratory disease such as acute lung injury and acute respiratory distress syndrome, complications associated with mortality rates as high as 30 %. These processes are largely mediated by inflammatory leukocytes and the production of cytokines like tumor necrosis factor-alpha (TNF-α) and other chemokines. Severe inflammation in the lung parenchyma results in microvascular injury and alveolar damage. Clinically, the nearby inflammation of the pancreas and the local cellular driven inflammatory response within the lungs may result in pleural effusions and acute respiratory distress syndrome. Patients with signs of respiratory failure or hypotension that do not respond to initial resuscitation efforts should be considered for ICU admission. In cases of severe acute pancreatitis, arterial blood gas measurement as well as continuous pulse oximetry may aid management. With persistent hypoxia and respiratory compromise, intubation and mechanical ventilation may be necessary. Elderly patents and those with preexisting respiratory disease should have respiratory status monitored closely as these patients are at greatest risk of more significant respiratory complications.

Pain management should be implemented along with fluid resuscitation in acute pancreatitis. Severe pain is often one of the primary complaints, due to the rich afferent sensory network surrounding the pancreas. With severe nausea, oral pain medications are often not well tolerated. Parenteral analgesia with morphine, hydromorphone, or other narcotics is most commonly used in acute pancreatitis for controlling pain. Morphine had been avoided in the past due to concerns of sphincter of Oddi spasm, which is thought to exacerbate pancreatitis, but these concerns are unfounded [66]. With severe pain requiring frequent dosing of parenteral medications, patient-controlled analgesia may be appropriate. Increasing dosages and more frequent administration may be required for adequate relief.

Nutrition is important in acute pancreatitis, especially when patients have been NPO for several days. Most patients at admission are ordered for nothing by mouth, due to nausea, vomiting, and poor oral tolerance. In mild acute pancreatitis with a short hospital course, patients may resume a normal diet once nausea resolves. Two randomized controlled trials have demonstrated benefit to early low-fat diet for patients with mild pancreatitis [67, 68]. For patients who are unable to tolerate oral nutrition for over 7 days, artificial feeding should be considered. Recently, there has renewed focus upon enteral feeding rather than total parenteral nutrition (TPN) [69]. TPN had been originally standard care as it was thought to reduce stimulation of the pancreas. However, there is no good evidence that such strategies of pancreatic rest reduce organ failure or other complications [70]. Additionally, nutrition by TPN has the additionally risks of catheter-related infections and severe hyperglycemia [71]. In cases of persistent ileus, TPN may be a practical solution to delivering nutrition, when any enteral nutrition would be poorly tolerated. Enteral feeding has the additional benefit of maintaining gastrointestinal immunity. A naso-jejunal tube should be placed to feed distal to the ligament of Treitz. Currently, there is limited data regarding the type of enteral diet that should be delivered in acute pancreatitis, although elemental diets are often used with the thought of minimizing pancreatic stimulation.

In cases of severe acute pancreatitis, there has been much debate concerning the use of prophylactic antibiotics. Several RCTs have demonstrated there was no benefit of routine prophylactic antibiotics in patients with necrotizing pancreatitis [72, 73]. Updated meta-analysis has confirmed that lack of evidence suggesting a benefit of routine antibiotic use [74]. With infected pancreatic necrosis, broad antibiotic coverage should cover the endogenous gastrointestinal flora, which would be the most likely source of bacterial infection. Consideration of prophylactic antibiotics should be reserved only for acute pancreatitis with evidence of extensive pancreatic necrosis >50 % of the gland. The risk of infected necrosis tends to be low when necrosis is limited to less than a third of the pancreas. Thus, it is not recommended to prophylactically start patients on antibiotics for acute pancreatitis.

Operative management in acute pancreatitis is infrequently required, but can be lifesaving in select cases. Patients with mild acute pancreatitis typically need to be managed conservatively with supportive care. Those requiring operative management tend to be limited to either gall-

stone pancreatitis or severe acute pancreatitis complicated by infected necrosis.

In gallstone pancreatitis, operative management should be considered for (1) cases where the causative gallstone remains in the biliary tract during active disease or (2) following an episode of gallstone pancreatitis with an elective cholecystectomy. In most cases of gallstone pancreatitis, the causative gallstone has already passed through the common bile duct and into the duodenum. Some patients, however, may still have one or more gallstones in the common bile duct. In these circumstances, removal of the gallstone is appropriate, especially if disease is complicated by cholangitis. If the patient is stable, endoscopic therapy with an ERCP and sphincterotomy is appropriate. If the less invasive approach fails (e.g., endoscopist cannot cannulate the ampulla of Vater), surgical management may be necessary. In cases of mild, uncomplicated pancreatitis associated with gallstones, laparoscopic cholecystectomy is appropriate once symptoms resolve or within 2 weeks of discharge [75, 76]. Historically, cholecystectomy during index admission for gallstone pancreatitis was preferred. However, there has been a recent trend away from "early-cholecystectomy." Failure to complete cholecystectomy following an initial episode of gallstone pancreatitis puts the patient at risk of recurrent pancreatitis.

Laparoscopic cholecystectomy with cholangiogram can be safely performed in the majority of cases. As previously mentioned, this has been performed historically during the index admission. There are a few important clinical points to consider. Surgeons typically wait for the epigastric pain to resolve prior to cholecystectomy. However, there is no universally accepted waiting period. Early cholecystectomy has the potential advantage of decreasing length of stay and cost associated with the index admission.

In severe acute pancreatitis complicated by infected pancreatic necrosis, surgical intervention to remove necrotic tissue is usually necessary. Diagnosis of infected necrosis can be made with the identification of air or gas within the pancreatic necrotic collections or by a fine needle aspiration with evaluation of necrotic tissue. CT or ultrasound-guided fine needle aspiration should be performed in patients with greater than 30 % pancreatic necrosis with clinical suspicion of sepsis and aspirate samples should be sent for gram stain and culture. In cases of severe acute pancreatitis complicated by sterile pancreatic necrosis, surgical debridement and drainage is typically not required. However, patients with infected necrosis do require debridement or drainage, which can be approached endoscopically, radiologically, or surgically. Endoscopic drainage has become more common, involving placement of transgastric stents to drain of necrotic fluid into the gastrointestinal tract. Radiological drainage may also be appropriate with softened or liquefied pancreatic abscess, although, similar to endoscopic drainage, there is a high rate of failure due to obstruction of drainage by solid necrotic debris. Success of radiological drainage ranges from 30 to 50 % [70, 71] (Fig. 26.7). Surgical debridement may be preferred, in addition to drainage, thorough debridement of necrotic tissue while leaving viable pancreatic tissue can be performed. The abdomen can be closed over drains, packed and left open, or closed over drains with pancreatic irrigation. These decisions depend largely on clinically derived experience, local expertise, and considerations regarding the patient anatomy and condition.

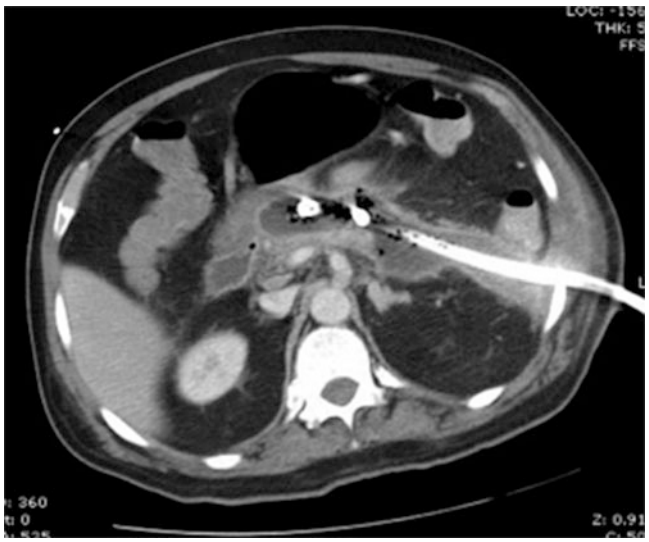

Fig. 26.7 Successful placement of percutaneous catheter to drain infected pancreatic necrosis. Percutaneous catheter placement into pancreatic fluid collection as component of "step-up" approach.

Recently a "step-up" approach to surgical debridement of infected necrosis has been suggested [77]. This involves placement of percutaneous drains into the necrotic pancreatic tissues followed by intravenous antibiotics [78]. Percutaneous catheters are irrigated and upsized as needed by interventional radiology. If patients fail to improve within 72 h, minimally invasive debridement was performed via a retroperitoneal approach. This method was studied in a multicenter RCT from Europe and compared traditional open necrosectomy to the "step-up" approach [79]. The step-up arm had 29 % decreased major complications and lower rate of developing diabetes. Interestingly, resource utilization and ICU length of stay was lower in the "step-up" arm. The benefit to the less invasive approach may be lower.

Over time, sterile pancreatic necrosis may evolve into a collection of pancreatic debris. Six to eight weeks following the episode of acute pancreatitis, pancreatic necrosis can become walled off with the formation of a fibrotic capsule, much like a pseudocyst. The so-called walled-off necrosis has become a recognized sequelae of acute pancreatitis. These collections may behave similar to pseudocysts and cause symptoms such as persistent abdominal pain, anorexia,

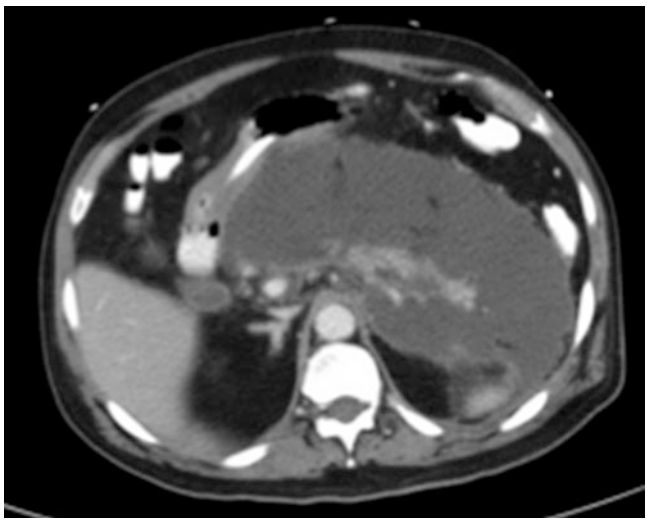

Fig. 26.8 Immature pancreatic pseudocyst with thin wall to the capsule. A small amount of viable, enhancing pancreatic tissue is noted within the pseudocyst

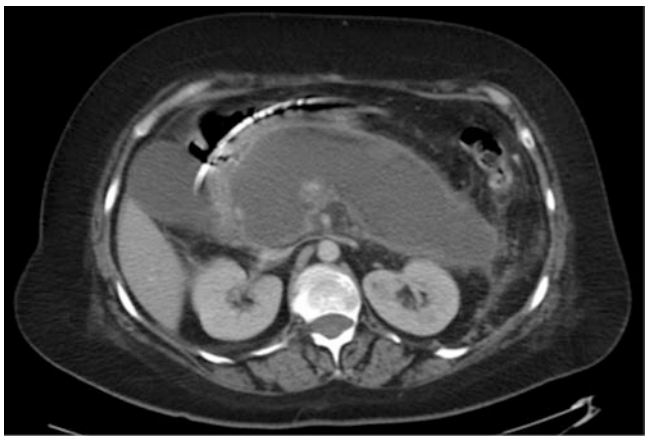

Fig. 26.9 Developing pseudocyst in patient three weeks following the episode of acute pancreatitis. Feeding tube is seen to course into duodenum and past the ampulla of Vater

nausea, gastric outlet obstruction, or secondary infection. If this walled-off necrosis contains purely liquid contents, endoscopic drainage may be possible; however, with any solid debris, surgical drainage by laparotomy or a laparoscopic approach may be taken [80, 81].

Pseudocysts are collections of pancreatic fluid over time that can form a non-epithelial fibrous lining (Figs. 26.8 and 26.9). These typically develop following disruption of the pancreatic duct in pancreatitis. While many of these fluid collections resolve spontaneously, others may persist and cause symptoms. Small pseudocysts, typically less than 6 cm in diameter, can be managed conservatively, especially if asymptomatic. Many smaller lesions will resolve without invasive interventions (Fig. 26.10). Larger pseudocysts should be evaluated with CT, MRI, or endoscopic ultrasound

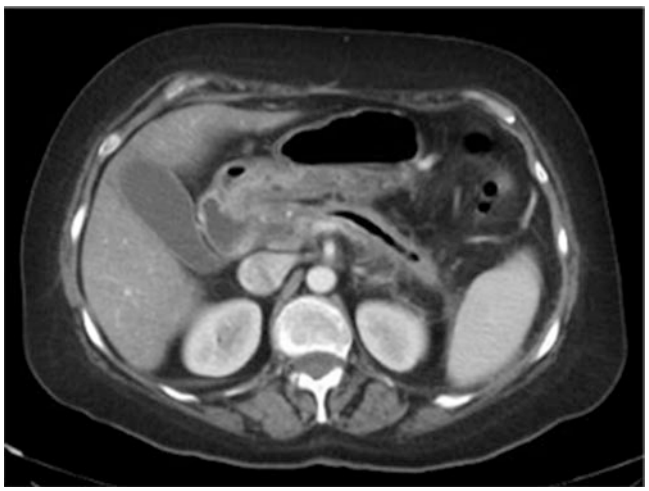

Fig. 26.10 Near resolution of pseudocyst nearly 3 months after the acute episode of pancreatitis

to assess pseudocyst contents and potentially evaluate for a means of drainage [82]. In addition, MRCP may be useful to screen patients for the presence of persistent ductal disruption. A small percentage of patients may develop proximal main pancreatic duct stricture and distal ductal disruption. This may lead to ongoing communication to the cyst. In this situation, operative drainage may fail to completely resolve the pseudocyst. Anecdotally, these patients may undergo ERCP, sphincterotomy, and pancreatic duct stent placement to facilitate closure of the ductal disruption [83].

Persistent pseudocyst causing pain or obstructive symptoms should be managed operatively [84]. Drainage procedures should be performed after the pseudocyst has a well-developed lining which typically can take up to 6 weeks following the episode of acute pancreatitis and formation of the pseudocyst. If pseudocysts are without pancreatic debris, transgastric endoscopic stenting may relieve symptoms, although drainage may fail if debris occludes the stents. Open and laparoscopic procedures may be preferred, but specific technique and approach depends on patient-specific anatomy and disease. During operative drainage procedures, biopsy of pancreatic pseudocyst wall should be completed and sent to pathology for exclusion of cystic neoplasm of the pancreas.

Potential Complications

The major complications in acute pancreatitis are classically described by a bimodal distribution with separate peaks during the first and second weeks of the disease course. This distribution in pancreatitis has changed with improvements in critical care medicine and ICU monitoring. Within the first week, severe pancreatitis may be characterized by a significant rise in serum cytokines, which clinically results in SIRS

and distant organ dysfunction. Organ dysfunction often resolves within 48 h, although for other patients with persistent organ failure, they may continue along a poor clinical course.

SIRS Criteria

Temperature >38°C or <36°
Resp rate >20 or $PaCO_2$<32 mmHg
Pulse >90 beats/min
WBC<4000 cells/mm^3 or >12,000 cells/mm^3 or >10 % immature bands

Severe local pancreatic inflammation can lead to SIRS and subsequent multisystem organ failure [85, 86]. Studies have shown that persistent SIRS is associated with MSOF and mortality [87]. In a recent study by Singh et al. the incidence of SIRS was investigated in 252 consecutive patients. A majority (62 %) had SIRS on hospital day 1 and 75 % met SIRS criteria within the first 5 days. In this report, the majority of patients that experienced significant morbidity or mortality all had SIRS at admission. The presence of all four criteria was associated with 22 % rate of persistent organ failure, 17 % pancreatic necrosis, 50 % rate of ICU admission, and 13 % mortality rate.

With the intense inflammation of the pancreas, other acute complications local to the pancreas and the lesser sac occur. Acute fluid collections located in the pancreas or in peripancreatic regions are not uncommon. These often resolve spontaneously or persist and become pseudocysts. Also secondary to nearby inflammation, the splenic vein may develop a thrombus, which rarely can contribute to the development gastric variceal bleeding. Splenic vein thrombosis is relatively common, occurring in up to 19 % of patients with acute pancreatitis [88]. However, in most situations no intervention is required. Only patients with history of gastric varices may need further evaluation and treatment.

Later complications following a bout of acute pancreatitis may include pseudocyst, fistula, recurrent pancreatitis, and chronic pain. Pseudocyst formation, as discussed earlier, occurs by leakage of pancreatic fluid that persists and becomes walled off by non-epithelial layers of fibrous tissue. While some may spontaneously resolve, those that cause nausea, obstructive symptoms, or abdominal pain need to be drained [89, 90]. Pseudocysts may also become further complicated by infection, which require external drainage.

Pancreatic fistulas are abnormal communications between the pancreas and other organs. Fistula often occurs following surgery, such as following necrosectomy or pseudocyst drainage [91]. However, fistula may also occur following pancreatic duct trauma or chronic pancreatitis. Pancreatic fistula often present in the context of abnormally high abdominal drain outputs in the postoperative period [92]. The drain fluid can be sent for amylase or lipase studies to confirm suspicions. Treatment may include dietary restriction, octreotide to reduce secretions, and possibly surgical intervention. With a stable pancreatic fistula, conservative management can result in spontaneous resolution in approximately three-quarters of patients. In patients who have a persistent pancreatic fistula, operation to reroute pancreatic duct drainage with a Roux-en-Y operation or partial pancreatectomy can be performed.

In some patients after a first bout of acute pancreatitis, pancreatitis may recur. In the absence of gallstones or history of alcohol abuse, a more extensive workup is appropriate. Untreated recurrent pancreatitis can lead to chronic pancreatitis, characterized by parenchymal fibrosis and damage to the pancreatic duct. These patients frequently experience chronic pain that may require definitive treatment by pancreatic resection.

Conclusion

In the majority of cases, acute pancreatitis occurs as a solitary, isolated event, not requiring extensive follow-up. For those with mild gallstone pancreatitis, patients should undergo laparoscopic cholecystectomy during the index admission or within 2 weeks of discharge. Patients with alcohol-induced pancreatitis should be counselled concerning abstinence. In patients with SIRS criteria at admission, a high index of suspicion should focus on early identification of those at-risk for potential organ dysfunction. These more severe cases require significant supportive care and may be prone to potential complications of acute pancreatitis. In cases where multisystem organ failure occurs, prompt identification and potential transfer to a higher level of care may be needed. Specialists should be routinely involved in complicated cases for the treatment of infected necrosis or infected peripancreatic fluid collection. This typically involves a multidisciplinary approach of surgery, gastroenterology, and interventional radiology. Operative debridement/open necrosectomy as first-line surgical therapy is indicated if (1) interventional radiology does not have a window for percutaneous catheter placement, (2) has failed the "step-up" approach or (3) unstable requiring significant vasopressors with large volume of infected fluid. Necrosectomy should only be performed by an experienced surgeon. Patients with pancreatitis of unknown etiology may not require serial follow-up or surveillance unless symptoms recur. For patients who progress to chronic pancreatitis, regular follow-up may be required for management of chronic pain symptoms and nutritional deficiencies.

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Small Bowel Obstruction

27

Alicia J. Mangram, Alexzandra Hollingworth, and James K. Dzandu

Small bowel obstruction is a common clinical condition that accounts for 20 % of all surgical admissions for acute abdomens [1]. Late, misdiagnosis, or even appropriate management of small bowel obstruction has likely been a source of frustration for many practicing general surgeons at some time during their surgical careers. Because of the acute onset of small bowel obstruction the majority of these patients present in the emergency room (ER), usually with nausea, vomiting, and abdominal pain; therefore, patient evaluation, subsequent operations, and management are often performed by the "surgeon on call." With the new paradigm shift regarding the management of surgical emergencies, the majority of patients with small bowel obstruction are now being managed by the Acute Care Surgeon (ACS). The ACS is accustomed to dealing with difficult cases, and operating on a patient with small bowel obstruction is often a complicated procedure. There are multiple issues to address when operating on patients with small bowel obstruction including entering hostile abdomens, enterostomies, fistulas, wound infections, short bowel issues, and recurrent obstructions, just to name a few of the problems. The traditional surgical dictum "the sun should never rise and set on a complete small bowel obstruction" is no longer considered an entirely valid statement. This caveat may be attributed in part to the surgeon's diagnostic ability to differentiate complete obstruction, which could compromise intestinal viability, from a partial obstruction, which could be amenable to non-operative management. Thus in the absence of signs suggesting strangulation, i.e., peritonitis, a patient with partial obstruction can be treated and managed effectively using non-operative modalities.

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Complex patients with multiple medical problems with indeterminate SBO are initially observed until deteriorating patient clinical conditions force the hand of the surgeon. The availability of 64-plus slice computed tomography (CT) scans now allows accurate determination of the site and cause of complete obstructions. In addition, there are now national guidelines for the management of small bowel obstruction [2] and each individual surgeon's experience adds needed refinement to this knowledge base.

Epidemiology

Small bowel obstruction is a clinical condition defined as a blockage of the small bowel loops resulting in an impairment, stoppage or reversal of the normal flow of intestinal contents towards the anus. Small bowel obstruction accounts for 20 % of all acute surgical admissions [1]. Among acute surgical obstruction admissions, 80 % are due to small bowel obstruction and large bowel obstruction accounts for the remaining 20 % [3].

The etiology of small bowel obstruction is multifactorial and includes three major causes: extraluminal, intrinsic, and intraluminal [4]. Extraluminal obstructions are caused by adhesions, neoplasms, hernia, constrictive bands, malrotation, and intra-abdominal abscesses.

Adhesions

The most common cause of SBO is adhesions, accounting for 60 % of all cases. The risk of developing SBO secondary to adhesions postoperatively has been estimated to be 9 % in the first postoperative year and then increases to 19 % by 4 years postoperatively and 35 % by 10 years [5]. Thus, informed consent for any abdominal operation should include the risk of developing adhesions and the potential need for future surgeries. It is difficult to predict when the patient will develop SBO. In a study of 446,331 abdominal

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_27

Table 27.1 Association between surgical type or surgical procedure and the incidence of adhesion-induced small bowel obstruction

Procedure type/group	Incidence of SBO
Ileal pouch-anal anastomosis	19.3 % (1018/5268)
Open colectomy	9.5 % (11,491/121,085)
Gynecological procedures	11.1 % (4297/38,752)
Open adnexal surgery	23.9 %
After cesarean section	0.1 %
Cholecystectomy	
Open	7.1 %
Laparoscopy	0.2 %
Hysterectomy	
Total hysterectomy	15.5 %
Laparoscopy	0.0 %
Adnexal operations	
Open	23.9 %
Laparoscopy	0.0 %
Appendectomy	
Open	1.4 %
Laparoscopy	1.3 %

Adapted from Barmparas G, Branco BC, Schnuriger B, Lam L, Inaba K, Demetriades D. The incidence and risk factors of post-laparotomy adhesive small bowel obstruction. J Gastrointest Surg. 2010;14:1619–28, with permission

operations, Barmparas et al. showed a strong and independent association between surgical procedure type and the proportion of patients with adhesion-induced SBO (Table 27.1) [6]. The identification of surgical procedure type as an independent risk factor for SBO may have a predictive value for stratifying patients. A recent report by Angenete et al. suggests that factors such as age, previous abdominal surgery, and comorbidities are important predictors of risks of hospitalization for SBO or surgery for SBO [7]. The incidence of SBO among patients who have had bariatric surgery, including gastric bypass, was 3.2 %. The estimated overall incidence of SBO among patients who underwent abdominal trauma surgery operations was 4.6 % [6].

Neoplasm

Neoplasms are the second most common cause of SBO, comprising 20 % of all cases [8]. If an adult patient presents with an SBO and has a virgin abdomen (meaning the patient has not had any previous abdominal procedures), the etiology of a neoplasm as the source of obstruction must be entertained. Other causes could include inflammatory bowel disease, gallstones, ileus, or intussusception. More common origins of neoplasms include colorectal carcinoma, and ovarian carcinoma in women. Extrinsic compression, adhesions, and carcinomatosis are often seen as the etiology of SBO in these cases.

Hernias

Hernias are the third leading cause of SBO, comprising 10 % of all cases [8]. When examining a patient with an SBO, the surgeon must be cognizant of the potential hernia etiologies. A meticulous examination of the groin, femoral region, parastomal region, and old surgical scar sites is warranted. In thin females an obturator hernia can be the cause of SBO. One must have a high index of suspicion and this type of hernia can be identified with abdominal CT.

Other Extrinsic Causes

Malrotation and congenital or acquired hernias are less common causes of SBO. Malrotation can present in both the pediatric and adult populations. Congenital hernias include transmesenteric, transomental, and paraduodenal hernias [9]. Acquired hernias develop after a resection of bowel where there exists a mesenteric defect. Bowel can herniate through this defect and cause an SBO. The idea has been proposed that with the increase in laparoscopic procedures, defects are not closed as often, and the incidence of internal hernia increases. Experience with laparoscopic Roux-en-Y gastric bypass (LRYGB) has attempted to answer these questions about SBO and internal hernia incidence. However, the literature is mixed. What is important for the ACS to realize is that you will be seeing these patients come into the emergency department with SBO secondary to internal hernias. There are three potential spaces: Petersen's space, the mesocolic space, and the mesomesenteric space. The Petersen's hernia occurs in a potential space posterior to the gastrojejunostomy (for example, see Fig. 27.1). Laparoscopic Roux-en-Y gastric bypass is done with an antecolic or retrocolic anastomosis. If a retrocolic anastomosis is performed, a defect in the mesocolon is necessary and a potential space exists there. The mesomesenteric potential space at the jejunojejunostomy is another area where an internal hernia can develop. Furthermore, intra-abdominal abscesses may cause SBO via extrinsic causes by kinking the bowel as it adheres to the abscess cavity or even within it.

Intrinsic Causes

Intrinsic obstructions are due to such causes as aganglionic megacolon, primary tumors, Crohn's disease, tuberculosis, and intussusception. Crohn's disease causes strictures responsible for SBO. Multiple resections of small bowel in patients with Crohn's can eventually lead to the endpoint of short bowel syndrome. Strictures can also be caused by

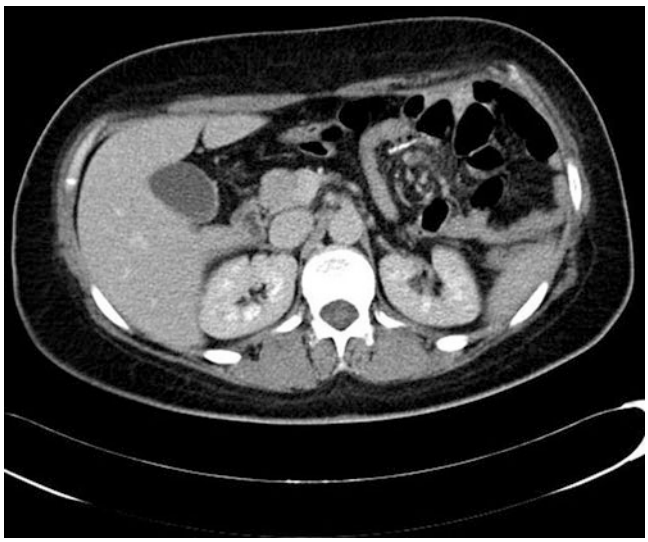

Fig. 27.1 Axial CT demonstrating Petersen's hernia with swirling of the mesentery evident in this image. Small bowel is seen herniating above the level of the stomach. There is a potential space posterior to the gastrojejunostomy where this herniation occurs. Radiopaedia.org (http://radipaedia.org/cases/peterserns-hernia), case ID: 14053

radiation and ischemia. Irradiated bowel is very friable and the risks of enterotomies and subsequent fistula development are high. Intussusception is commonly identified with CT scans; however, the clinical significance can be questionable. When the intussusception is the lead point for SBO in an adult, malignancy should be ruled out. In trauma, small bowel hematomas can cause SBO. The duodenum is particularly susceptible because a portion is fixed in the retroperitoneum. Most duodenal hematomas resolve without the need for operative interventions.

Intraluminal obstructions are caused by impacted feces, gallstones, enterolith, bezoar, tumors, large polyps, and ingested foreign bodies. Small bowel tumors are rare but an important etiology of SBO. They present with vague abdominal symptoms and ultimately cause SBO. These include small bowel adenocarcinoma, carcinoid tumors, and lymphoma.

There is clinically significant morbidity associated with SBO, although the mortality rate for patients with mechanical obstruction has been dramatically reduced in recent years. The observed improvements in mortality rate have been attributed to early diagnosis, appropriate strategic use of isotonic fluid resuscitation, gastric tube decompression, antibiotics, and surgery.

Clinical Presentation and Diagnosis

A well-conducted patient history is essential for formulating an initial working diagnosis for SBO. Informative patient signs and symptoms include: abdominal pain, nausea, vomiting, abdominal distension, obstipation, fever, tachycardia, or diarrhea secondary to increased peristalsis. Pain paroxysms at 4–5 min intervals are associated more frequently with distal obstructions whereas nausea and vomiting are sometimes more common in patients with more proximal obstructions. The past surgical history should be detailed. As shown in Table 27.1, there is strong association between surgical procedure type/group and the risk of developing an SBO. On physical examination, a patient with an SBO can present with tachycardia, fever, a distended abdomen, and surgical scars. The time course of development of an SBO is often reflected in an early rise in hyperactive bowel sounds (e.g., borborygmi) followed by significant reduction or complete cessation of bowel sounds. In refining the diagnosis for SBO, it is important to exclude specific explanatory etiologies such as incarcerated hernias in the groin, the femoral triangle, and the obturator triangle. Extraluminal masses need to be excluded and distal colon obstruction can sometimes be excluded by rectal examination. Patients with positive rectal exam results should prompt a test for occult blood to assess for the possibility of a malignancy, intussusception, or infarction. The abdominal exam is extremely important in the diagnosis of an SBO. Patients with suspected SBO often have abdominal distension and tenderness. The tenderness may be localized but more often is diffuse. The reason the physical exam is so important is because patients with SBO will either resolve or progress leading to intestinal ischemia and possible perforation if not taken to the operating room in a timely manner. A worsening physical exam may be a signal of bowel necrosis. Consequently, the patient may begin to exhibit signs of peritonitis, diffuse tenderness, rebound tenderness, and guarding. Laboratory data should be obtained to include a complete blood count (CBC) and a basic metabolic panel at a minimum. Other helpful tests include an arterial blood gas (for base deficit) and lactate level. An increasing white blood cell (WBC) count, increasing base deficit or lactate, intravascular volume depletion, and low urine output are measures of a patient that is getting worse clinically (for treatment algorithm see Fig. 27.2).

Patients who present with a partial SBO or low-grade SBO are treated with nasogastric decompression, nothing per os (NPO), and intravenous fluids. If no resolution occurs with this treatment, then a repeat CT with water-soluble contrast, CT enteroclysis, CT enterography, or small bowel series with oral contrast is indicated to further delineate the area of obstruction. The small bowel series should be done with water-soluble contrast in case the patient needs to go to the operating room for a bowel resection. Computed tomography enteroclysis is valuable in low-grade and partial SBOs where the etiology is not clear on regular CT. The CT enteroclysis has the advantage of active luminal distension whereby the lumen can be evaluated. Thus, cross-sectional analysis of the bowel is feasible. It involves the insertion of a nasojejunal tube that lies at the duodenojejunal junction. Barium is directly injected into the bowel. Computed tomography

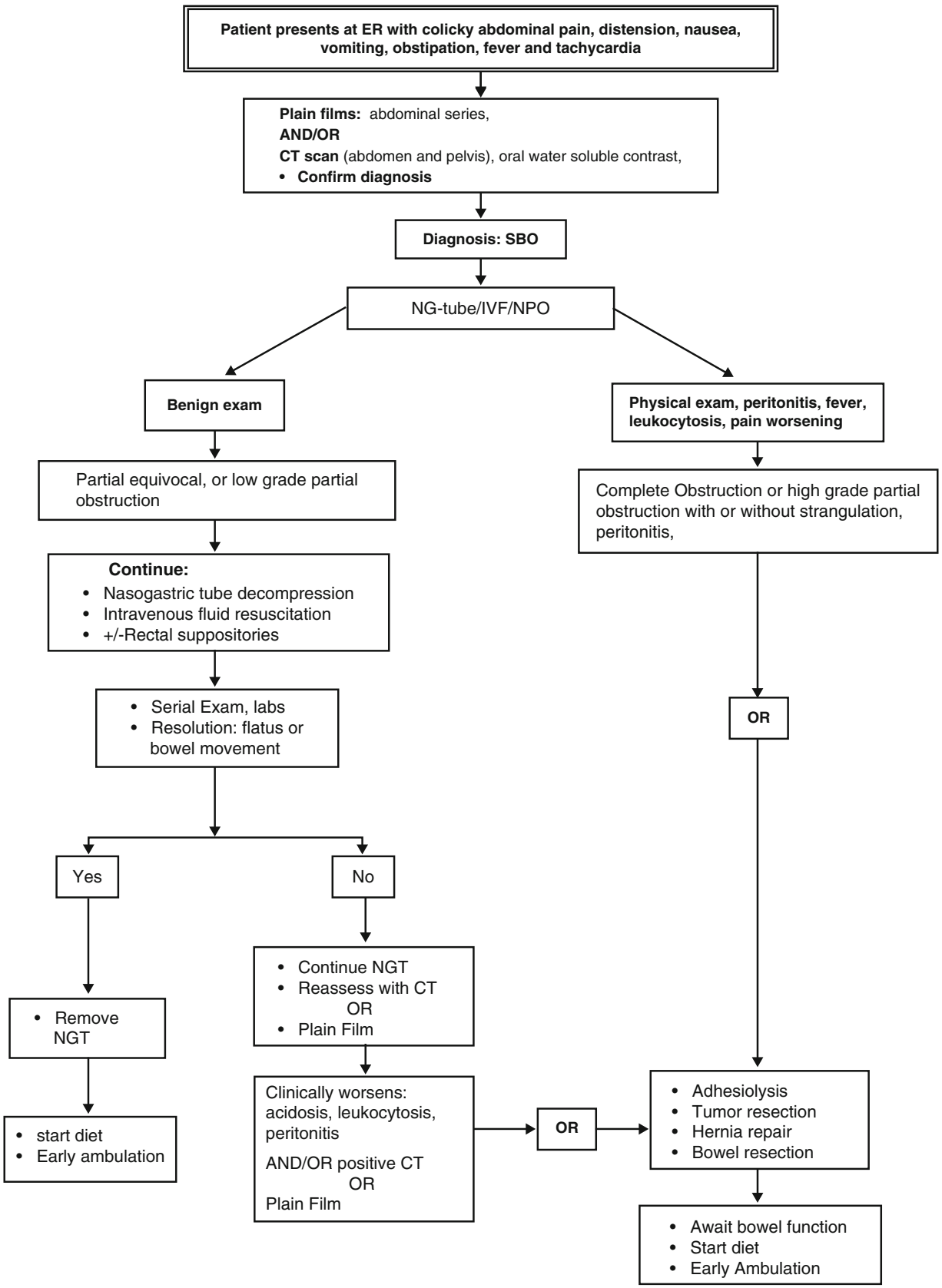

Fig. 27.2 An algorithm for the diagnosis and management of small bowel obstruction

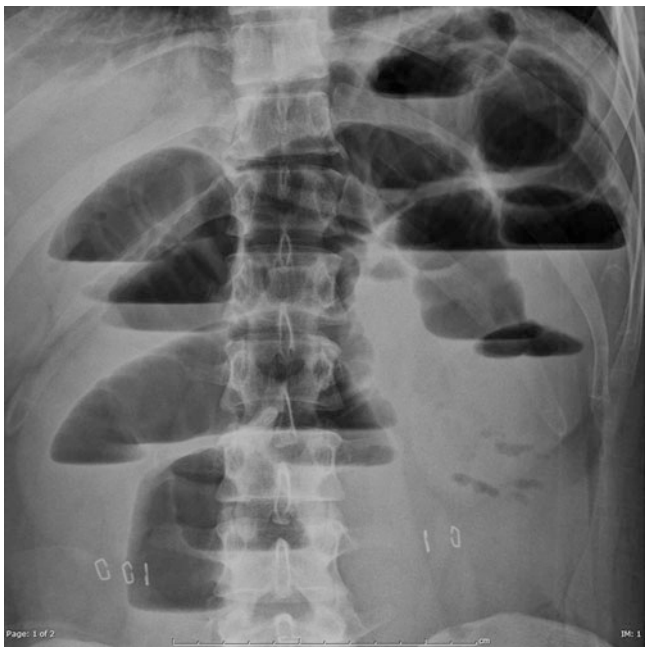

Fig. 27.3 Plain abdominal X-ray demonstrates air-fluid levels in small bowel obstruction

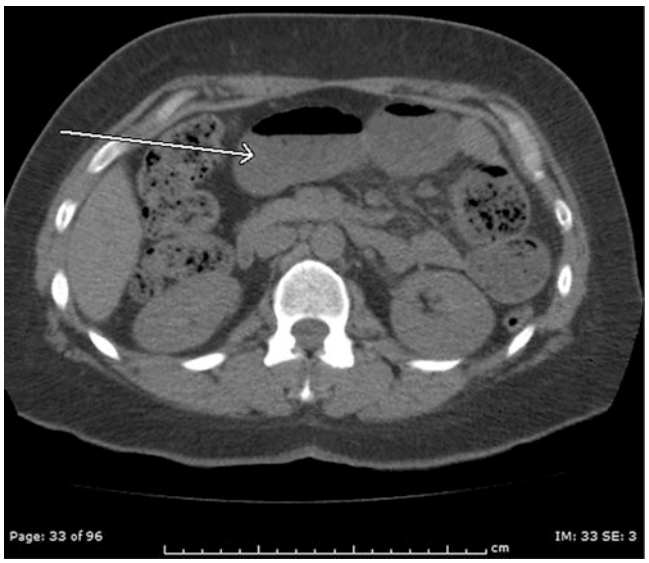

Fig. 27.4 Axial CT demonstrating dilated small bowel in a patient with SBO. Note surgically proven adhesion

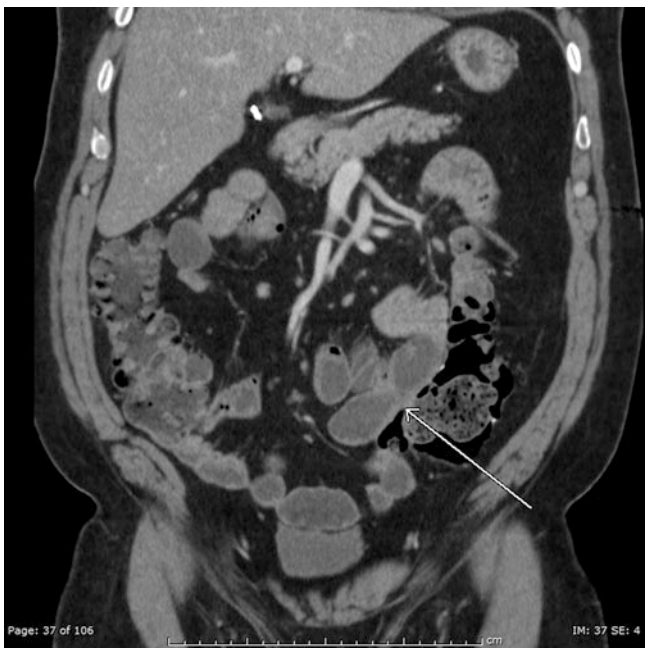

Fig. 27.5 Coronal CT showing dilated and fluid filled small bowel in partial small bowel obstruction. Note non-dilated proximal small bowel and non-dilated distal small bowel

enterography with large volume contrast compares in accuracy to enteroclysis without the need for a nasojejunal tube. The sensitivity of CT enteroclysis is 93.1 % and specificity 96.9 % as reported by Dixon and coworkers [10].

There seems to be some controversy over the use of plain films in patients with SBO; however, plain films can be extremely useful (see Fig. 27.3). The Eastern Association for the Surgery of Trauma (EAST) practice management guidelines recommend plain films on all patients who are being evaluated to rule out SBO [2]. The plain films should consist of flat and upright abdominal films along with a chest X-ray (CXR) also known as an acute abdominal series. Serial plain films can be a useful adjunct to the physical exam during the hospital course. Computed tomography scans of the abdomen and pelvis are commonly obtained during the initial evaluation in the ER. The use of CT scans has largely replaced plain films in many hospitals and has proven to be very sensitive for the diagnosis of SBO [2]. The sensitivity increases when the CT is performed with oral and intravenous contrast. As with plain films, the CT scan may need to be repeated during the hospital course to assess SBO progression or resolution. There are certain characteristics on CT scans that are helpful in planning the management of a patient with a small bowel obstruction. Identification of a transition zone between normal and abnormal intestinal diameter may localize the area of the obstruction and the probable cause of the obstruction. Similarly, proximal dilation of the small bowel (diameter >2.5 cm) and the presence of multiple air-fluid levels are highly suggestive of an SBO. Thus specific CT findings include the following: (1) dilated small bowel loops usually greater than 2.5 cm, (2) small bowel feces, (3) extrinsic causes such as hernias, (4) gas-filled loops, (5) intussusception, and (6) mesenteric vessel abnormalities such as haziness, obliteration, congestion, or hemorrhage. The CT findings are best in determining the site and cause as well as complications of small bowel obstruction (Figs. 27.4, 27.5, 27.6, 27.7, 27.8, and 27.9).

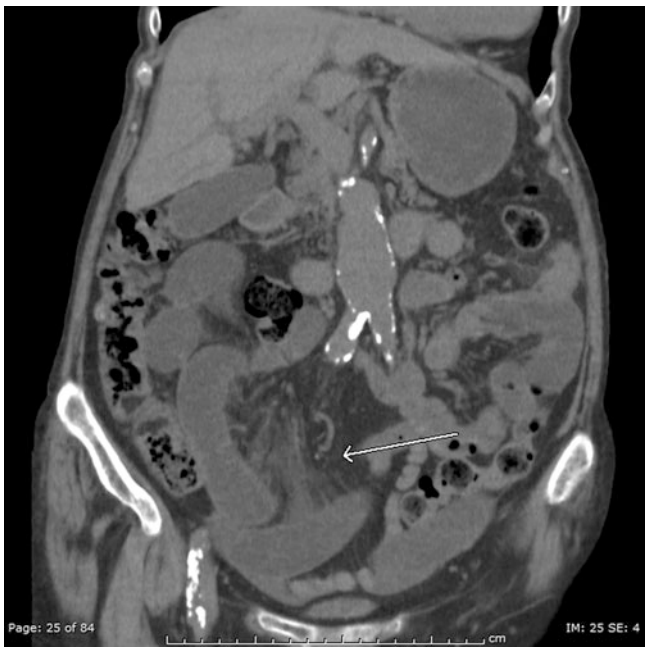

Fig. 27.6 Coronal CT showing closed loop obstruction with mesenteric twists. Note fluid filled dilated small bowel obstruction

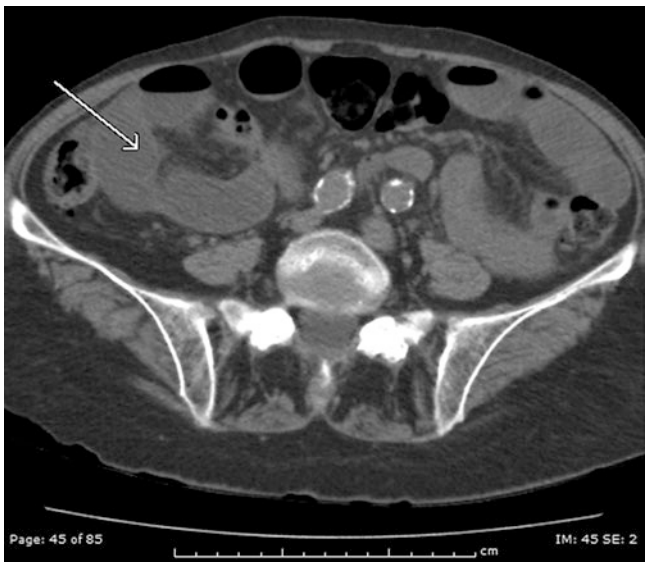

Fig. 27.7 Axial CT view showing the closed loop obstruction

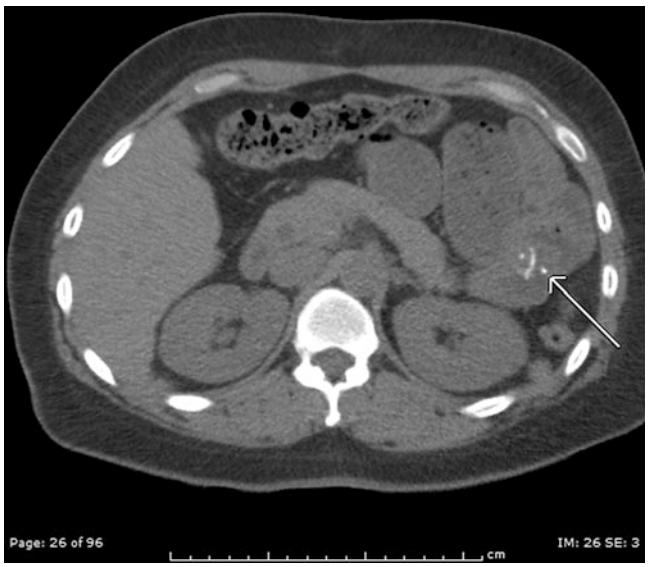

Fig. 27.8 Axial CT showing jejunojejunal anastomosis as site of obstruction

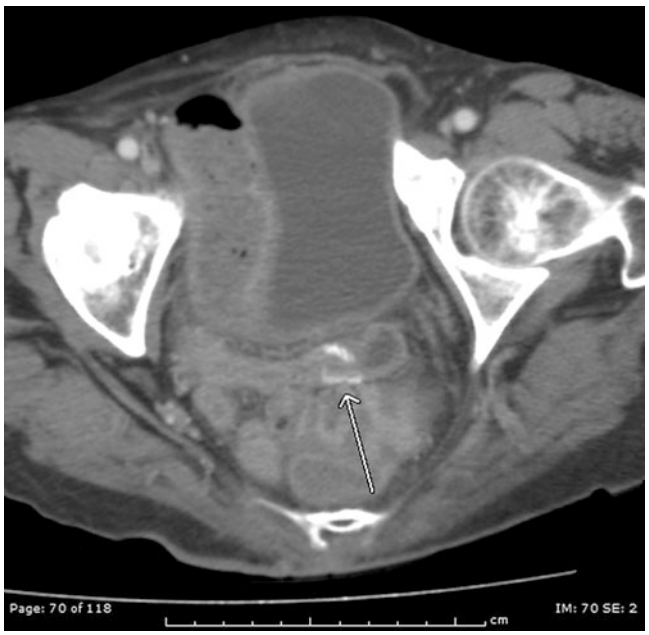

Fig. 27.9 Axial CT revealing transition zone at the anastomosis

Bedside and formal ultrasound has emerged as a useful modality in the hands of the skilled operator. In a study by Taylor et al., ultrasound was found to have a "+LR of 14.1 (95 % CI = 3.57 to 55.66) and a negative likelihood ratio (−LR) of 0.13 (95 % CI = 0.08 to 0.20) for formal scans and a + LR of 9.55 (95 % CI = 2.16 to 42.21) and a −LR of 0.04 (95 % CI = 0.01 to 0.13) for beside scans." [11].

Jones et al. performed a retrospective study to attempt to answer the question regarding the usefulness of a CT scoring system in predicting the need for surgery in patients with SBO [12]. The results demonstrated that CT can successfully predict the necessity for surgery 75 % of the time. The CT scoring system when used in combination with specific criteria increased the ability to predict the need for surgery from 75 to 79 %. Other modalities that have been used to aid in the diagnosis of SBO include ultrasound and magnetic resonance imaging (MRI), but these are not commonly used and have not proved to be as sensitive as the previously mentioned studies. The presence of pneumatosis intestinalis on

CT scan is often a late finding and an ominous sign of bowel ischemia. Air in the portal system also may indicate gangrenous bowel in the face of SBO.

The diagnosis of SBO is not a difficult diagnosis to make. A diagnosis is made when a patient presents with a history consistent with SBO and is confirmed with a CT scan or plain films. The challenge is the management of this patient.

Management

A patient with a CT scan showing complete obstruction in the presence of peritoneal signs on physical exam will need operative intervention, particularly in the presence of fever, leukocytosis, and tachycardia. A well-timed decision to manage SBO surgically is crucial to minimize the morbidity and mortality associated with intestinal strangulation. Thus surgery before onset of irreversible ischemia is a priority. This is prudent because the distinction between a patient with simple obstruction and a patient with strangulation cannot always be made reliably based on laboratory, clinical, and imaging findings. Standardized and appropriate surgical procedures are performed based on the cause of the SBO. These include lysis of adhesions, resection of tumors, and reduction and repair of hernias. Invariably, viability of the intestine must be assessed by visual inspection and when necessary Doppler probe studies and arterial perfusion evaluations, including the use of Woods lamp.

The majority of patients with SBO can initially be managed safely by conservative non-surgical treatment as previously described. Additionally, the placement of a nasogastric tube should be considered if the patient has significant emesis or if the patient has abdominal distension. The performance of serial abdominal exams to evaluate for worsening abdominal pain or the presence of peritonitis is also key to non-operative management. The exact definition of serial abdominal exams is controversial. Should serial exams be performed every 4, 6, 8 h, or longer? This is a complicated question because how often the serial exam is performed should be based on the patient's clinical presentation at the time of the exam. If the exam continues to improve, the time interval between serial exams may increase. If the patient's abdominal exam is not improving or worsening, then the frequency of examination should increase. During this time, daily monitoring with laboratory testing including a CBC and electrolyte panel is a useful adjunct to track response to conservative treatments. Repeat CT scan and/or plain films are usually done in the first 48 h to monitor progression or resolution.

In a 2015 review article on SBO, the authors noted that in patients without evidence of strangulation, early administration of water-soluble contrast (Gastrografin) in the ER was an effective intervention [13]. According to the authors, Gastrografin administration was able to resolve partial obstructions and to identify patients who are likely to fail non-surgical management [13]. In this paper, those patients in whom the contrast reached the cecum within 24 h had their nasogastric tube removed and they were started on a clear liquid diet. In those patients where the contrast did not reach the cecum in 24 h, surgery was recommended. These two observations are seen as major advances in the field. It is inferred from chemistry that the high osmolarity of the water-soluble contrast allows water to be drawn into the bowel lumen and thus unblock partial SBOs.

The use of enemas, suppositories, and cathartics is controversial. Patients with bowel obstruction are contraindicated for enemas including those containing sodium phosphate [14]. However, in the case of partial SBO, there have been reports of success with all of the above interventions.

Prior to the evolution of laparoscopic surgery, the surgical management of SBO was accomplished through an exploratory laparotomy. A midline incision is made when feasible, the peritoneum entered, and dissection performed until the point of obstruction is identified. The etiology of the obstruction will dictate the procedure. If the obstruction is due to adhesions, adhesiolysis is performed. Small bowel obstruction can present at the previous suture line or at anastomotic sites (Figs. 27.8 and 27.9). If the obstruction is due to tumor, then resection should be performed if possible. In the event that resection is not possible, then diversion is an option. In those patients with malignancy affecting large segments of the small bowel performance an enteroenterostomy (bypass) may be the only option available at the time of laparotomy. Indeed, cancers of the colon, stomach or metastasis from the lung or breast are often common causes of SBO. If a hernia is present, reduce the hernia, examine the bowel for viability, and perform a hernia repair. In the case of internal hernias, the defect must be closed and a bowel resection is often necessary. When taking a patient to the operating room for an SBO that has previously undergone a Roux-en-Y gastric bypass, remember the mesomesenteric potential space at the jejunojejunostomy is often the site of the internal hernia. Closed loop obstructions pose a special problem. In this situation the surgeon must obtain control of the mesentery prior to untwisting the mesentery. The mesentery of the ischemic bowel must be clamped off proximally and distally in order to prevent the release of toxic substances within the closed loop. If the loop is released prior to obtaining control, then bacteria and toxins can be released into the systemic circulation. This will cause septic shock during the procedure.

In the case of foreign body ingestion, usually operative management is warranted if the foreign body causes overt obstruction or perforation. Intra-abdominal abscesses causing an SBO can often be managed non-operatively with a drain placed by interventional radiology, nasogastric tube, and antibiotics.

Practical Operative Considerations

There are a few key issues to take into consideration when entering the abdomen for an SBO:

1. Enter the abdomen in an area away from the prior scar or known hernia defect. Entering the abdomen above or below previous incisions can help avoid inadvertent enterotomies.
2. When the bowel is adherent to the undersurface of the abdominal wall use scissors (Metzenbaum or Cooley scissors) or a knife to sharply take down the adhesions. Avoid the use of electrocautery in these areas, as it may result in inadvertent thermal injury to the bowel that may be unrecognized at the time of operation.
3. When it is difficult to take down an area you have worked in without making much progress, it is prudent to leave the area, dissect somewhere else and then return later to complete your dissection.
4. Take your time with the dissection and get a second pair of hands if possible to facilitate exposure.
5. Resect bowel that has been "beat up" too much to avoid postoperative complications (strictures, adhesions, leaks).
6. If bowel viability is in question, "damage control" is an option. Place a temporary abdominal closure and plan to come back after 12–24 h for a second look laparotomy.

Laparoscopic surgery for patients who need operative intervention for SBO is becoming much more commonplace for those surgeons who are facile with laparoscopy. Proposed advantages of laparoscopy compared to open surgery include quicker postoperative recovery and reduced hospital length of stay. The increasing popularity of laparoscopy contrasts with experience in the past when SBO was considered a contraindication for laparoscopy. While there is good agreement on feasibility, safety, and efficacy of laparoscopy in the management of SBO, there is some debate about its appropriateness for patients with an acute obstruction. It had been reported that only 50 % of cases of SBO could be managed successfully with laparoscopy [15]. Nevertheless, there is excellent prospect for increased utilization of laparoscopy for SBO since open surgery increases the risk of the development of postoperative SBO due to adhesion formation by at least fourfold compared to laparoscopy [7].

Since postsurgical adhesions often result in SBO, there have been concerted efforts to prevent adhesions through the use of adhesion barriers during laparotomy. Currently, there are three United States Food and Drug Administration (FDA)-approved adhesion barriers including Seprafilm (Genzyme, Cambridge, MA), Adept (Baxter, Deerfield, IL), and Interceed (Ethicon, Somerfield, NJ). Seprafilm has been reported to decrease the severity but not the incidence of postsurgical adhesions [16]. Interceed has a black-box warning and is contraindicated as a hemostatic agent in laparoscopic surgery. The product labeling for Adept carries more contraindications than Seprafilm and Interceed. These include infections, laparotomy incision, bowel resection, appendectomy, and allergy to cornstarch.

Potential Complications

Potential complications of surgery for SBO include sepsis, intra-abdominal abscess, wound dehiscence, aspiration, fistula formation, colostomy, short bowel syndrome, and death. It is important for the operating surgeon to have a detailed discussion with the patient and family prior to proceeding to the operating room. The estimated overall mortality rate after surgical treatment for SBO has been reported to be as high as 5 % [17]. Some of the factors that influence postsurgical mortality in patients with SBO include: advanced age, the presence of a comorbid condition, the presence of bowel gangrene at laparotomy, and delay in diagnosis. Although comorbidity is strongly associated with older patients, it seems that comorbidity, especially cardiovascular and pulmonary comorbidities are independent predictors of death after surgery for SBO. In addition to increased mortality rates, complication rates are also higher in patients older than 60 years compared to younger patients. Treatment delays of more than 24 h, nonviable or strangulated bowel and recurrent surgeries are also factors that increase complication risk.

Follow-Up

The prognosis for non-strangulated SBO is very good, as bowel obstruction may resolve spontaneously. Patients with partial SBOs who are managed non-operatively may spend 2–5 days for recovery and the recurrence is low. However, patients who were managed surgically through resection or adhesiolysis generally spend more time in the hospital. The incidence of recurrence of SBO in patients managed surgically is 5.8 % and risk factors for recurrence are age <40 years, adhesions, and postsurgical complications [18].

Conclusion

Acute care surgeons are increasingly being relied upon to treat patients with SBO. Undoubtedly, thorough physical examination, appropriate imaging studies, close monitoring, and timely laparotomy or laparoscopy will lead to a reduction in the morbidity and mortality of patients presenting with small bowel obstruction.

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Appendicitis

28

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and Christine S. Cocanour

History

The Italian physician-anatomist Berengario da Carpi first described the appendix in 1521 [1]. The first illustration of the human vermiform appendix and its origin from the cecum dates to 1492, in an in situ depiction of the abdominal anatomy by Leonardo da Vinci, however this was not published until the eighteenth century [1]. In 1543, Andreas Vesalius published *De Humani Corporus Fabrica,* which included detailed illustrations of the appendix [1]. French surgeon Claudius Aymand performed the first successful appendectomy in 1735, removing a perforated appendix found inside a hernia sac during repair of a young boy's hernia [2]. The Harvard pathologist, Reginald Fitz, published a landmark paper in 1886 of 257 cases of acute appendicitis which was notable for the finding of inspissated fecal or foreign material within the lumen of 3/5th of appendices studied. He made the recommendation for early operative intervention to prevent frequently lethal peritonitis [3]. In 1894, Charles McBurney published his muscle-splitting operative technique and in 1889 reported the operative management of acute appendicitis to the New York Surgical Society [4, 5]. Laparoscopic appendectomy was introduced in 1980 by the German gynecologist, Kurt Semm [6].

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Epidemiology

Acute appendicitis is the most common surgical condition of the abdomen. There are an average of 11 cases per 10,000 people each year [7]. Over a lifetime, the risk of developing appendicitis is 8.6 % for men and 6.7 % for women [7]. Appendicitis has a higher incidence among Westernized countries, and a higher incidence among Caucasians [7]. A cohort study of almost 12 million Swedes found these differences persisted following immigration as well as adoption, implying a genetic factor [8]. Although acute appendicitis may occur at any age, it most commonly develops in those between the ages of ten and nineteen [7]. A retrospective study of over 600,000 Californians from 1995 to 2009 found an increased incidence over time, an increased incidence in whites and Hispanics compared to other racial groups, and an element of seasonality—higher incidence in the summer [9]. A study looking at ICD9 coded appendectomies found a gradual oscillating decrease in incidence of non-perforated appendicitis from 1970 to 1995, and then an increase in disease proportional to the rise of laparoscopic appendectomy. They also noted a gradual increase in perforated appendicitis over this time period [10].

Anatomy and Pathophysiology

The appendix develops embryonically as an outpouching of the midgut, and grows into a long and narrow form emerging from the posteromedial aspect of the adult cecum. The appendix is primarily supplied by the appendicular artery in the mesentery of the appendix, and innervated by the mesenteric plexus. The appendix can be located by the fold of Treves, where the dorsolateral and dorsomedial taenia coli of the cecum meet. The base of the appendix emerges below the ileocecal valve. The adult appendix can course in any direction (Fig. 28.1), but is most commonly found in the retrocecal position in about 65 % of cases, followed by 31 % in the

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_28

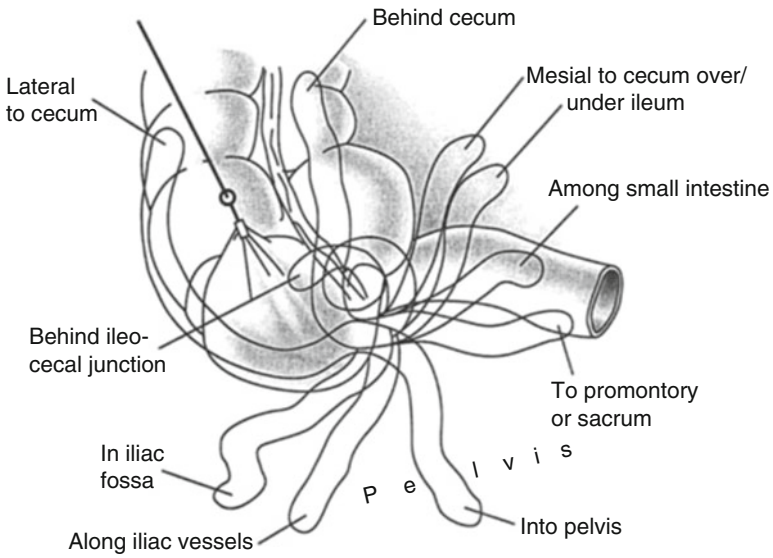

Fig. 28.1 Drawing showing the various positions which the vermiform appendix may occupy in relation to the cecum and terminal ileum. (From Soyel DI. Appendix. In: Norton JA, Bollinger RR, Chang AE, editors. Surgery: basic science and clinical evidence. Philadelphia: Springer Science + Business Media; 2001, with permission.)

pelvic brim position [11]. The majority are between 6 and 9 cm in length, but can range from sub-centimeter to over 30 cm [12]. In rare cases of situs inversus or undiagnosed malrotation, the appendix will be found on the left side of the abdomen.

The appendix has lymphoid tissue that secretes immunoglobulins, especially immunoglobulin A for mucosal defense. The pathogenesis of appendicitis is incompletely understood. It is thought to arise when the lumen becomes obstructed. Continued mucosal secretion and bacterial multiplication engender swelling and an inflammatory response. Further engorgement may cause compression of venous and lymphatic drainage, which will compromise arterial inflow and progress to ischemia and necrosis at the distal appendix. Obstruction of the lumen is often from a fecalith or immune hyperplasia which is more commonly found in children. Other possible etiologies include undigested food, tumors, and scarring. Incidence over time indicates a cyclic pattern with times of widespread disease, suggesting an infectious pathogen may be a causal factor [10].

Appendiceal inflammatory disease can be divided into simple and complicated appendicitis. Simple disease is in situ; complicated disease is accompanied by perforation, abscess, or phlegmon. Fecaliths have been associated with perforation in pediatric patients but this has not been found in the adult population [13, 14]. Beginning with Fitz in the nineteenth century, pathophysiology has traditionally treated simple and complicated appendicitis as stages along the progression of disease: inflammation progresses to perforation with possible abscess formation if surgical intervention is delayed. However, there is evidence that these do not simply represent stages along a disease process, but rather distinct entities—simple appendicitis has a low tendency to perforate even if treatment is delayed, while complicated appendicitis has a high likelihood of rupture, commonly occurring prior to presentation to the hospital. Further, the patterns of disease are divergent—gradually increasing incidence of perforated appendicitis that does not correlate with the decrease in non-perforated appendicitis from 1970 to 1995, nor the post-laparoscopic increase in incidence of non-perforated appendicitis [10]. In a study randomly comparing clinical observation with exploratory laparoscopy, rates of appendicitis were significantly higher in the latter group, indicating appendicitis that self-resolved in a significant proportion of the monitored group, without progression to perforation [15].

Presentation

The classic presentation of the patient with acute appendicitis begins with diffuse, periumbilical pain due to appendiceal distension triggering the visceral stretch fibers. This pain progresses and localizes in the right lower quadrant as the parietal peritoneum somatic pain receptors activate. The typical patient with appendicitis has associated gastrointestinal symptoms that are mild and present following development of pain: nausea, vomiting, and anorexia. Because this presentation is not exclusive to appendicitis, the differential diagnosis should include gastroenteritis, bowel obstruction, inflammatory bowel disease, right-sided diverticular disease, ectopic pregnancy, or pelvic inflammatory disease. Because acute appendicitis may present with an atypical pain location, pattern, and/or accompanying symptoms, it should be on the differential for any patient that presents with abdominal pain and/or gastrointestinal dysfunction.

Early in the course of acute appendicitis, there will be diffuse periumbilical abdominal pain without peritoneal signs, and vital signs are commonly normal. As the disease progresses, the

classic right lower quadrant pain with point tenderness develops. It is often accompanied by signs of systemic inflammation—fever and tachycardia. On abdominal exam, there is point tenderness in the right lower quadrant, and right lower quadrant pain may be exacerbated by deep palpation. Charles McBurney in 1889 published that the point 1/3rd of the distance from the anterior superior iliac spine to the umbilicus is the foci of acute appendiceal pain in a classic case [5]. Patients may voluntarily tense the abdominal muscles in protection against palpation—guarding, and feel pain with sudden release of deep palpation—rebound tenderness. Advanced cases may present with rigidity—involuntary tension of the abdominal wall musculature. Other physical findings suggestive of appendicitis include Rovsing's sign, the psoas sign, and the obturator sign. Rovsing's sign is worsening right lower quadrant pain in response to deep palpation of the left lower quadrant. The psoas sign is pain elicited in the right lower quadrant upon flexion of the thigh against the examiner's resistance or thigh extension in the left lateral decubitus position. The obturator sign is pain elicited on internal rotation of the flexed hip due to localized inflammation affecting the obturator muscle. A retrocecal appendix may engender more posterior irritation, resulting in a patient with flank pain greater than abdominal pain. An appendix heading into the pelvis may cause somatic pain referred deeper into the pelvis than the abdomen, possibly left-sided, and may have associated urinary or defecation symptoms. Some examiners assess for right rectal wall tenderness on rectal examination. Table 28.1 gives the predictive power of select elements of the history and clinical examination in the diagnosis of appendicitis [16].

Diagnosis

Laboratory Studies

Patients presenting with possible appendicitis merit simple blood studies to assess for a systemic inflammatory response. A leukocytosis with increased proportion of neutrophils, elevated C-reactive protein, and elevated erythrocyte sedimentation rate support a diagnosis of acute appendicitis. Mild elevations are often present early in the disease, and will increase in a patient with perforated appendicitis. Likelihood ratios of a diagnosis of acute appendicitis by inflammatory markers from meta-analysis are in Table 28.2 [16]. Electrolyte abnormalities may be found in the patient with significant emesis, but are not revealing of the underlying diagnosis. Other laboratory examinations that address other disease processes on the differential are important, including urinalysis and pregnancy testing. Depending on presentation, hepatic panel and/or lipase and amylase may be merited to evaluate for pathology of regional organs.

Clinical Scoring Systems

Although not widely used, clinical scoring systems have been established to assist in the clinical diagnosis of acute appendicitis. These may have a role in atypical presentation of acute appendicitis: when the physician seeks to rule out

Table 28.1 Sensitivity, specificity, and positive and negative likelihood ratios for clinical examination findings in appendicitis

Procedure	Sensitivity	Specificity	LR+ (95 % CI)	LR– (95 % CI)
Right lower quadrant pain	0.81	0.53	7.31–8.46[a]	0–0.28[a]
Rigidity	0.27	0.83	3.76 (2.96–4.78)	0.82 (0.79–0.85)
Migration	0.64	0.82	3.13 (2.41–4.21)	0.50 (0.42–0.59)
Pain before vomiting	1.00	0.64	2.76 (1.94–3.94)	NA
Psoas sign	0.16	0.95	2.38 (1.21–4.67)	0.90 (0.83–0.98)
Fever	0.67	0.79	1.94 (1.63–2.32)	0.58 (0.51–0.67)
Rebound tenderness	0.63	0.69	1.10–6.30[a]	0–0.86[a]
Guarding	0.74	0.57	1.65–1.78[a]	0–0.54[a]
No similar pain previously	0.81	0.41	1.50 (1.36–1.66)	0.32 (0.24–0.42)
Rectal tenderness	0.41	0.77	0.83–5.34[a]	0.36–1.15[a]
Anorexia	0.68	0.36	1.27 (1.16–1.38)	0.64 (0.54–0.75)
Nausea	0.58	0.37	0.69–1.20[a]	0.70–0.84[a]
Vomiting	0.51	0.45	0.92 (0.82–1.04)	1.12 (0.95–1.33)

LR+ positive likelihood ratio, *LR–* negative likelihood ratio

[a]In heterogeneous studies the likelihood ratios are expressed as ranges

From Andersson RE. Meta-analysis of the clinical and laboratory diagnosis of appendicitis. Br J Surg. 2004;91(1):28–37, with permission

Table 28.2 Likelihood ratios of a diagnosis of acute appendicitis by inflammatory markers from meta-analysis

	LR+	*P*	LR-	*P*
Laboratory tests and fever				
WBC (×109/l)				
≥10	2.47 (2.06, 2.95)	<0.001	0.26 (0.18, 0.36)	<0.001
≥12	2.75 (1.99, 3.80)	0.041	0.48 (0.41, 0.55)	0.215
≥14	2.96 (2.48, 3.53)	0.945	0.69 (0.55, 0.86)	<0.001
≥15	3.47 (1.55, 7.77)	0.012	0.81 (0.69, 0.95)	0.008
Granulocyte count (×109/l)				
≥7	1.64 (0.87, 3.09)	<0.001	0.31 (0.23, 0.40)	0.670
≥9	2.66 (1.39, 5.09)	0.015	0.45 (0.37, 0.54)	0.094
≥11	4.36 (2.83, 6.73)	0.085	0.60 (0.53, 0.69)	0.154
≥13	7.09 (4.06, 12.37)	0.328	0.74 (0.68, 0.81)	0.277
Proportion of PMN cells (%)				
>75	2.44 (1.60, 3.74)	0.001	0.24 (0.11, 0.50)	<0.001
>85	3.82 (2.86, 5.08)	0.158	0.58 (0.51, 0.66)	0.166
CRP level (mg/l)				
>10	1.97 (1.58, 2.45)	<0.001	0.32 (0.20, 0.51)	<0.001
>20	2.39 (1.67, 3.41)	0.042	0.47 (0.28, 0.81)	0.001
Body temperature (C)				
>37.7	1.57 (0.90, 2.75)	0.002	0.65 (0.31, 1.36)	<0.001
>38.5	1.87 (0.66, 5.32)	0.023	0.89 (0.71, 1.12)	<0.001
Perforated appendicitis				
WBC (×109/l)				
≥10	4.20 (2.11, 8.35)	0.005	0.20 (0.10, 0.41)	0.082
≥15	7.20 (4.31, 12.00)	0.317	0.66 (0.56, 0.78)	0.595
Granulocyte count (×109/l)				
≥7	2.89 (2.41, 3.46)	0.977	0.14 (0.08, 0.26)	0.923
≥9	4.16 (3.15, 5.51)	0.491	0.39 (0.28, 0.54)	0.176
CRP level (mg/l)				
>10	4.24 (1.16, 15.53)	<0.001	0.11 (0.05, 0.25)	0.335

From Andersson RE. Meta-analysis of the clinical and laboratory diagnosis of appendicitis. Br J Surg. 2004;91(1):28–37, with permission

the diagnosis of acute appendicitis or to pursue further diagnostic evaluation. The appendicitis inflammatory response score presented in 2008 uses eight signs such as white blood count, proportion of neutrophils, C-reactive protein, and right lower quadrant pain to segment patients into low-probability, indeterminate and high-probability groups [17]. The purpose is an objective validated score to help determine which patients merit further evaluation for acute appendicitis, with the goal of reducing the use of diagnostic imaging or diagnostic laparoscopy. This is pre-dated by the more used but not as accurate Alvarado scoring system, with similar strategy and purpose [18]. The Alvarado score also has eight criteria, which are differentially weighed by clinical predictive power for a sum for the goal of reducing laparotomies that reveal a normal appendix.

Imaging

In the patient with a clinical presentation consistent with appendicitis, urgent management should be sought without imaging studies. However, in ambiguous cases, imaging by ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI) can identify an inflamed appendix. Plain films are not helpful in the diagnosis of appendicitis, but may be useful in exploring an alternative diagnosis. The goals of identifying appendicitis by imaging are twofold: reduce rate of negative appendectomy and avoid untreated appendicitis.

Computerized tomography with intravenous contrast has been the gold standard for visualizing appendicitis in the adult patient, once pregnancy has been ruled out. The patient

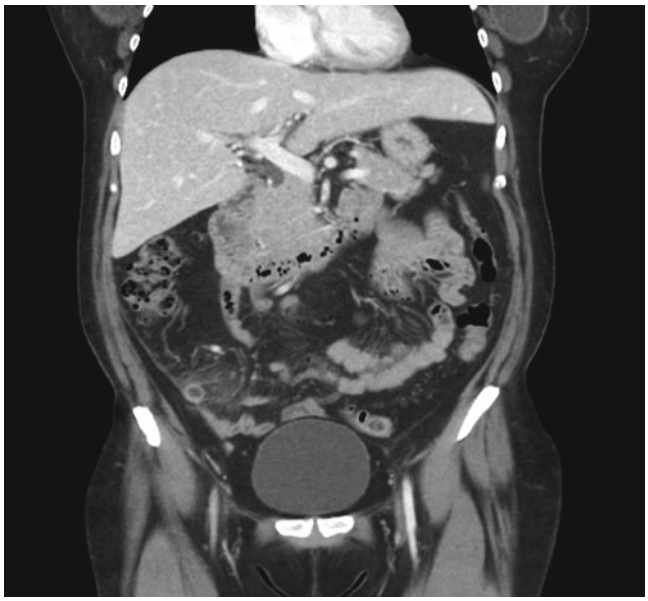

Fig. 28.2 Coronal CT of the abdomen showing the inflamed appendix in the right lower quadrant

with acute, simple appendicitis on CT scan will have increased luminal diameter (>6 mm), increased appendiceal wall width (>2 mm) and inflammatory compression of adjacent tissue (Fig. 28.2) [19]. Periappendiceal free fluid and fat stranding localizing to the appendix may also be present. Those with complicated disease will reveal perforation with possible abscess formation, most commonly in the right iliac fossa. The sensitivity of CT scan for acute appendicitis is 0.94 and the specificity 0.95 [20].

Ultrasound imaging has the advantage of avoiding radiation, and is a rapid and less expensive imaging study. However, it provides lower sensitivity than CT imaging, 0.86, and also lower specificity, 0.81 [20]. Ultrasound visualization is operator-dependent. The sonographer is looking for suggestive signs of diameter >5 mm and periappendiceal fluid [20]. Abdominal ultrasound may not reveal the state of the appendix in those with significant visceral obesity or bowel gas which obscures the sonographer's view. Ultrasound is used by many as the primary imaging modality in children to avoid exposure to ionizing radiation.

MRI is less frequently used for detection of appendicitis due to its greater cost, longer acquisition time, and lesser clinical availability. However, MRI is useful when trying to avoid ionizing radiation. It has an important role in the pregnant patient with an inconclusive ultrasound study. MRI in evaluating for acute appendicitis offers strong sensitivity, 97 %, and specificity, 97 % [21].

There are differing opinions as to the best imaging practice. The American College of Radiology Appropriateness Criteria recommend the use of CT as it is the most accurate imaging study for evaluating suspected appendicitis and alternative etiologies of right lower quadrant pain [21]. In children, ultrasound is the preferred initial examination. In pregnant women, data support the use of MRI following an equivocal or inconclusive ultrasound.

Management

Open Versus Laparoscopic Appendectomy

Much debate has evolved regarding the best operative approach for appendicitis. There has been a significant increase in the number of surgeons performing laparoscopic appendectomy in the past decade. Data from the United States Nationwide Inpatient Sample database indicates that more 60 % of appendectomies were performed laparoscopically between 2004 and 2011 [22]. The same data shows a 66 % increase in the use of laparoscopy as an initial approach to appendectomy [22]. Adult and pediatric populations more often undergo laparoscopic appendectomy than the elderly [22]. Multiple randomized studies have been performed to compare open versus laparoscopic appendectomy. The most recent Cochrane review meta-analysis of 67 randomized studies concluded that the advantages of laparoscopic appendectomy included reduced surgical site infections, lower visual analogue scale pain scores, shorter length of stay by 1.1 days, and earlier return to normal activity [23]. The same analysis found that open appendectomy had a lower incidence of intra-abdominal abscess, shorter operative time by 10 min, and significantly lower operative costs [23].

There are no hard indications for choosing laparoscopic versus open appendectomy. In general, the approach taken is determined by the surgeon's preference or patient factors that may limit each approach. Open appendectomy can be performed in any patient; however, it is considerably more challenging in obese patients, making laparoscopic appendectomy a more favorable approach. Laparoscopy has a few limitations, particularly in smaller pediatric patients that are too small to facilitate multiple laparoscopic instruments in the peritoneal cavity. This can be overcome by using single port laparoscopy and a non-stapler technique. Laparoscopic appendectomy may be preferred in certain clinical settings. When a patient has an uncertain diagnosis, laparoscopic appendectomy allows evaluation of other organs and potential etiologies of pain. In obese patients, laparoscopic appendectomy is preferable to avoid a potentially larger, morbidity-prone incision. In a retrospective review of obese patients undergoing appendectomy, laparoscopic appendectomy was associated with a 57 % reduction in overall morbidity compared to open appendectomy. Mortality in these patients was also significantly lower in the laparoscopic group (5.23 versus 13.49) [24]. Elderly patients may benefit from the laparoscopic approach. In patients over 65, a

retrospective review found that the laparoscopic approach was associated with a shorter length of hospital stay, and a higher rate of discharge home rather than to a step-down facility in both uncomplicated and complicated appendicitis [25]. In elderly patients with uncomplicated appendicitis, the laparoscopic approach had fewer complications and lower mortality. In patients with a perforated appendix, the mortality rates were equivalent [25].

While the national trend favors laparoscopic appendectomy for the initial approach to suspected appendicitis, open appendectomy remains an acceptable approach to suspected appendicitis.

Antimicrobial therapy active against facultative and aerobic gram-negative organisms and anaerobic organisms should be started once a patient receives a diagnosis of acute appendicitis. Post operative antibiotics will depend upon findings at the time of operation. If there is no appendiceal perforation, antibiotics should not be continued past 24 h postoperatively. If a perforated appendix is encountered, antibiotics should be provided for 3–4 days after its removal.

Operative Technique

Like many operations, the principles of open and laparoscopic appendectomy are the same.

Objectives

1. Access the peritoneal cavity.
2. Identify the appendix, cecum, terminal ileum, and ligament of Treves.
3. Mobilize the appendix and mesoappendix.
4. Isolate and transect the appendix at the base.
5. Isolate and transect the mesoappendix with ligation of the appendicular artery.

Laparoscopic Appendectomy

Positioning for a laparoscopic appendectomy is determined by the surgeon's port placement. If the operating surgeon and assistant are to perform the procedure as described in this text, then the most favorable position is supine with the patient's left arm tucked. This will allow the surgeon and assistant to work from the patient's left side simultaneously.

Gaining access to the abdomen is best achieved by placing a 10 mm umbilical port first. The umbilical port can be inserted above or below the umbilicus depending on the patient's habitus and the surgeon's preference. The Hasson technique or the Veress needle are both excellent methods for gaining initial access [26]. After establishing an umbilical port and insufflation, a thorough laparoscopic exploration should be performed. Two additional ports are then placed for appendectomy. The authors place one 5 mm suprapubic port 2 fingerbreadths above the pubic symphysis in the midline and one 5 mm port lateral to the left rectus muscle half way between the umbilical and suprapubic port. This port positioning is favorable for laparoscopic triangulation during appendectomy and the position of the 10 mm port will facilitate a favorable angle for stapling across the base of the appendix. Rotating the bed to the patient's left and placing the patient in the Trendelenburg position allows the small bowel to drop away from the appendix and cecum. Blunt graspers are used to retract the omentum and small bowel if the appendix cannot be visualized. If the appendix is not visualized and terminal ileum, cecum, and ligament of Treves are visible, then the cecum should be mobilized to expose the retrocecal appendix. This can be achieved with blunt or sharp dissection; however, this is frequently difficult in an inflamed field. If the field is severely inflamed, the use of a laparoscopic bipolar energy device or a laparoscopic harmonic scalpel can be of significant advantage. Although these devices are costly, their expense can be countered by minimizing operative time and eliminating the need for an additional laparoscopic staple load to transect the mesoappendix.

Once the appendix has been exposed and mobilized from adherent structures, it should be grasped at an area with remaining integrity so that it can be elevated with a blunt grasper inserted through the suprapubic port. This exposes the base of the appendix and the mesoappendix. A fine dissecting instrument, such as the Maryland dissector, is placed through the supraumbilical port. With the appendix elevated, a window is created in the mesoappendix adjacent to the base of the appendix. Care must be taken to avoid disturbing the nearby appendicular artery or its small branching arcades. Once a window has been established at the base of the appendix, the Maryland dissector can be exchanged for an endoscopic gastrointestinal anastomosis (GIA) stapler containing a load of 3.5 mm staples. Upon closing the stapler, pause should be taken to ensure that the stapler is not tenting up the cecum. Once the appendix has been stapled and transected, the appendix remains the point of retraction. With the mesoappendix elevated by retraction of the appendix, the mesoappendix can now be taken in a variety of methods. If a bipolar or ultrasonic energy device has already been opened for mobilization of the appendix, it can be used to transect the mesoappendix including the appendicular artery. In the absence of an advanced energy device, the mesoappendix and appendicular artery can be transected with the endo GIA stapler using a vascular staple load (2.5 mm). If there is bleeding from the staple line, it can be addressed using 5 mm clips.

The appendix should be removed from the abdomen with minimal contact to the abdominal wall port site. This can be

achieved using a laparoscopic retrieval bag, or the more cost efficient sterile glove. If perforation has occurred, the spilled contents should be removed using a laparoscopic suctioning device. Irrigation should be avoided to prevent dispersion of the perforated contents and seeding of potential intra-abdominal abscesses. The lateral port should be removed first under direct visualization. Injury to the epigastric vessels during trocar insertion is the most likely cause of significant or even life-threatening hemorrhage that fortunately occurs infrequently. Once all ports are removed, the fascia at the umbilical port site is closed and the wounds are irrigated with saline. The skin is then closed using subcuticular dissolvable monofilament suture.

Open Appendectomy

Open appendectomy remains an acceptable approach for removing the appendix. It is particularly favorable in thin patients, patients who cannot undergo general anesthesia, and pediatric patients who are too small to facilitate the use of laparoscopic staplers. Open appendectomy is generally performed under general anesthesia. The patient is positioned supine with both arms out. The classic incisions for open appendectomy are the McBurney [4] incision or the cosmetically more favorable, Rockey-Davis [1] incision, which can also be extended to facilitate better exposure. If conversion from laparoscopic to open is necessary, we find that a lower midline incision is preferable as an appendix that cannot be removed laparoscopically will likely be just as challenging to remove through a McBurney or Rockey-Davis incision. The incision is commonly 2–10 cm in length depending on the patient's habitus. The skin is incised sharply and the underlying fat is dissected using electrocautery down to the level of the external oblique fascia. The fascia is incised sharply in-line with the fibers. The incision can be extended using Metzenbaum scissors. The internal oblique muscle is split by spreading with a hemostat or Kelly clamp in parallel with the muscle fibers. The tranversus abdominus muscle is spread in the same fashion. If the transversalis fascia is not violated, it should be elevated with clamps and incised sharply. The same maneuver may be required for the underlying peritoneum if it has fallen away. Once the peritoneal cavity has been entered, foul smelling fluid may be evacuated if perforation has occurred. Gentle palpation is typically sufficient to locate the appendix. If the appendix cannot be easily located, the cecum can be retracted gently. Mobilization of the cecum may be necessary to expose a retrocecal appendix. Once the appendix is located, a viable portion is grasped with a Babcock. A small defect is created in the mesoappendix adjacent to the base of the appendix. Clamps are then placed across the mesentery and the base of the appendix. Both are transected and the appendix delivered off the field. The base of the appendix and the mesoappendix are ligated with absorbable suture. The mucosa at the appendiceal stump can be fulgurated with electrocautery and invaginated with a purse string absorbable suture. The external oblique fascia is closed with absorbable 2–0 suture in a running fashion and Scarpa's fascia approximated using interrupted absorbable 3–0 suture. If perforation of the appendix has occurred, the skin may be closed with staples as there is increased risk of a surgical site infection.

Appendiceal Abscess

The management of patients with appendicitis who present late and have developed abscess or phlegmon is controversial. The use of percutaneous drainage for source control and administration of antibiotics is an alternative to immediately operating with the intent to reduce operative morbidity. A randomized controlled study of antibiotics for intra-abdominal infection found that 4 days of antibiotics coupled with adequate source control was equivalent to longer antibiotic courses [27]. Patients who fail conservative management undergo appendectomy and sometimes require right hemicolectomy. The controversy in this algorithm lies in whether or not interval appendectomy should routinely be performed after successful nonoperative management. Limited retrospective studies indicate that the rate of recurrent appendicitis is between 6 and 20 % [28, 29]. A recent pathologic study of specimens from interval appendectomies counters this argument as it revealed the 91 % of specimens from interval appendectomy were abnormal with evidence of ongoing disease [30]. More than 50 % of the specimens analyzed showed evidence of chronic appendicitis and 29.4 % showed evidence of acute appendicitis. When considering need for interval appendectomy, consideration should be given to the patient profile and the suspected etiology. Currently, there are no strong consensus guidelines regarding interval appendectomy for patients that present with an appendiceal abscess and are treated nonoperatively.

In patients that have been treated nonoperatively and an interval appendectomy is not planned, there is a risk of missing other potential pathologies such as Crohn's disease or neoplasms, most commonly appendiceal carcinoids. The widespread use of computed tomography for diagnosis and imaging improvement has diminished the risk of misdiagnosis; however, patients over the age of 40, those who present with atypical initial symptoms, or in the presence of other suspicious findings such as anemia should undergo follow-up colonoscopy or computed tomography to exclude malignancy.

Medical Management of Uncomplicated Appendicitis

Medical management of uncomplicated appendicitis has been suggested as an alternative to operative management since the 1950s [31]. Several recent randomized, controlled trials of antibiotics versus surgery have shown that treatment of appendicitis with antibiotics is safe and can be successful in 73–86 % of patients [32–34]. Recurrence rates ranged from 4.4 to 27 %. In a study of over 230,000 patients, with 3236 patients managed nonoperatively, 5.9 % had treatment failure and 4.4 % had recurrence [35]. Costs were not significantly different between operative and nonoperative groups, the length of stay was significantly longer in those treated with antibiotics alone (2.1 vs 3.2 days). The most recent Cochrane database systematic review of five randomized control trials comparing antibiotics versus appendectomy demonstrated a primary treatment success rate of 73.4 % for patients who received antibiotics alone and 97.4 % for patient who underwent appendectomy [36]. Surgical appendectomy remains the standard approach for uncomplicated appendicitis; however, antibiotic treatment for uncomplicated appendicitis is safe, and may be considered in specific patients or in conditions where surgery is contraindicated.

Normal Appearing Appendix

The proportion of operations revealing a normal appendix can be interpreted as a marker of diagnostic accuracy. These cases include both the discovery intra-operatively of another source of pathology, or no apparent abnormality. The rate of negative appendectomy has decreased from 14.7 % in 1998 to 8.47 % [37]. If an operation is begun for presumed appendicitis, and upon operation the surgeon encounters a normal appearing appendix, an exploration for alternative intra-abdominal pathology should be undertaken. In women of reproductive age, the most common pathology found is benign ovarian disease, in women greater than 45 years old it is malignant ovarian disease; in men it is diverticulitis [37]. Histological studies of the removed appendix are more sensitive for acute inflammation than the surgeon's intra-operative macroscopic evaluation, and routine removal may reduce rates of recurrent disease [38], without an increase in morbidity, mortality, or length of hospital stay [39].

Chronic Appendicitis

There have been a number of case studies of patients with recurrent or subacute right lower quadrant pain, who with time, underwent imaging and appendectomy with discovery of chronic inflammation of the appendix and resolution of symptoms post-operatively [40, 41]. Subacute appendicitis or symptoms for greater than 3 weeks is estimated to be 1.5 % of appendicitis cases; recurrent appendicitis 10 %. The pathophysiology is thought to be partial obstruction of the appendiceal lumen; management is the same as acute appendicitis. Recognition of this uncommon condition reminds the diagnostician to consider appendiceal pathology in a patient with an atypical history.

Appendicitis in Pregnancy

Appendicitis is the most common non-obstetric surgical emergency in pregnancy [42, 43]. Multiple large scale population based studies indicate that appendicitis most commonly occurs in the second trimester of pregnancy and that appendicitis is least likely to occur during the third trimester [44–46]. Large scale population based studies also indicate that the rate of negative appendectomy is highest during the second trimester [46].

Early identification of the pregnant patient with appendicitis is critical to preventing fetal loss or premature labor. Diagnosis of appendicitis can be misguided by cephalad displacement of the gravid uterus [47] similar to altered presentation of the retrocecal appendix. Despite anatomical variation, the most common presenting complaint of pregnant women with acute appendicitis is right lower quadrant pain [48]. When considering imaging in the pregnant patient, ultrasound is the preferred diagnostic modality as it does not expose the mother or fetus to ionizing radiation. MRI can also be utilized but should not be used over computed tomography if doing so will create a significant delay in diagnosis. Management of the pregnant patient with appendicitis most commonly occurs by open appendectomy. Laparoscopic appendectomy is feasible in all trimesters of pregnancy, but becomes increasingly more difficult in the third trimester [48]. Laparoscopic appendectomy provides a benefit over open appendectomy as it may serve a diagnostic tool for other etiologies of abdominal pain in the absence of appendicitis. Medical management of acute appendicitis during pregnancy results in higher rates of preterm labor, fetal loss, and maternal morbidity when compared to open and laparoscopic appendectomy [48].

Appendicitis in the Immunocompromised Patient

Patients with HIV infection have increased risk of acute appendicitis, and increased risk of rupture [49]. Outcomes from appendectomy demonstrate increased risk of complications, mortality, and length of stay; outcomes are better with

laparoscopic approach than open [50]. Known HIV infected patients merit rapid diagnostic and, if indicated, therapeutic intervention.

Children

Children less than 5 years of age with appendicitis have about a 40 % risk of presenting with an already perforated appendix [51]. Graded compression ultrasound (US) of the appendix is the test of choice in children with suspected appendicitis, to avoid subjecting these patients to ionizing radiation. Meta-analysis calculates a sensitivity of 85 % and specificity of 92 % for the US diagnosis of acute appendicitis, with technically sufficient exam in 95 % [52]. Bedside ultrasound performed by surgeons will be variable, but has shown about 90 % accuracy for diagnosis of acute appendicitis in children in one recent series [53]. Laparoscopic appendectomy is the preferred operative intervention in children, to reduce incidence of wound infection and ileus as well as for shorter hospital stay and improved cosmesis [54, 55]. Meta-analysis comparing conventional multi-port laparoscopic appendectomy with newer single-incision laparoscopic appendectomy for acute appendicitis indicates similar outcomes despite longer intra-operative time for single-site technique [55]. Nonoperative management shows high success rates in children, but with about a 25 % recurrence rate [56].

Elderly

With increased life expectancy and increase in population over age 60, the incidence of appendicitis has risen. Morbidity and mortality rates are greater in older patients with acute appendicitis [57, 58]. The elderly have a significantly longer delay from symptom onset to hospital admission and from admission to surgery when compared to younger patients [57]. They often have an atypical presentation and as a consequence have a higher rate of perforation and intra-abdominal infection. Comorbidities increase their operative risk.

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Diverticulitis

29

Winston M. Chan and Amit Agarwal

Epidemiology

Diverticular disease is one of the most common causes of abdominal pain in the Western world. In addition, it appears to be increasing in incidence and demonstrates an age-dependent distribution. For example, diverticulosis affects only 5 % of people age 40, but can be found in two-thirds of adults by age 85 [1]. Approximately 20 % of patients with diverticulosis will suffer from at least one episode of diverticulitis. In fact, the prevalence of diverticulitis across all age groups in the USA is 60 per 100,000 [2]. Over a 7-year period from 1998 to 2005, Etzioni et al. demonstrated a 26 % increase in hospital admissions secondary to diverticulitis. In this study, the largest increase (82 %) was in the youngest cohort of patients age 18–44 [3]. The etiology for this increase is unknown, but may be related to dietary considerations. A gender predilection for diverticulitis has been demonstrated in some studies, but not duplicated in others [1, 4]. Obesity has been implicated but these findings have been inconsistent as well. In contrast, geographic patterns have been firmly established. While diverticular disease is predominately left sided (98.5 %) in Western societies, it is much more common on the right (70 %) in Asia [5].

Clinical Presentation

Colonic diverticula are classified as "false" or pulsion diverticula since they do not contain all layers of the bowel wall. The colon is predisposed to develop diverticulosis at four well-described points secondary to a weakness of the bowel wall where the vasa recta penetrate the circular muscle layer (Fig. 29.1) [6]. Although the vast majority of patients with diverticulosis will remain asymptomatic throughout their lives (70 %), others will suffer severe and sometimes repeated bouts of diverticulitis (20 %) and diverticular bleeding (10 %). Diverticulitis occurs when obstruction of the diverticulum by a fecolith causes localized perforation of the diverticulum and subsequent intra-abdominal infection. The patient with diverticulitis will commonly present with fever, leukocytosis, and left lower quadrant pain; however, the absence of these does not preclude a diagnosis of diverticulitis as about half of patients will not have a fever or leukocytosis [7]. The presence or absence of symptoms can be attributed to the severity of the underlying inflammatory process. Therefore, the diagnosis of diverticulitis is further characterized into uncomplicated and complicated to reflect the severity of the episode. With uncomplicated diverticulitis, there is colonic inflammation but without gross perforation (i.e., localized or diffuse pneumoperitoneum), phlegmon, abscess, obstruction, or fistula. Histologically, there is often micro-perforation of the colon. It accounts for the majority (75 %) of cases and is usually amenable to medical therapy. Conversely, complicated diverticulitis presents with gross perforation, phlegmon, abscess, obstruction, or fistula. Patients with complicated diverticulitis are at higher risk for requiring surgery during that admission. Bleeding is the other major complication of diverticulosis. The etiology of a lower gastrointestinal bleed in this setting is secondary to progressive weakening of the vasa recta as the diverticulum forms. The vessels are placed under tension and the protective layers are progressively thinned, ultimately leaving them exposed to injury and rupture [8]. Diverticular disease accounts for approximately 40 % of all lower gastrointestinal (GI) bleeding and is self-limiting 90 % of the time. Massive bleeding occurs in 5–7 % of cases and risk factors are anticoagulation, ischemic heart disease, and the use of nonsteroidal anti-inflammatory drugs. Despite accounting for only 10 % of diverticula, the right side of the colon is the bleeding source in 50 % of cases. Diverticulitis does not increase the risk of diverticular bleeding and inflammation is not classically present during a bleeding episode [9].

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_29

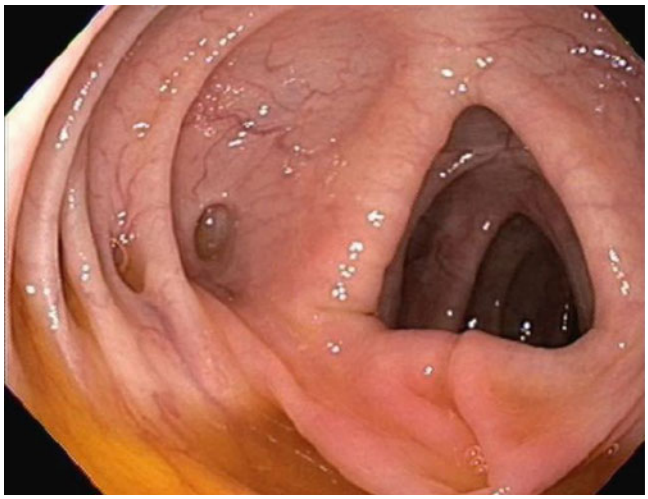

Fig. 29.1 Diverticulosis seen on colonoscopy

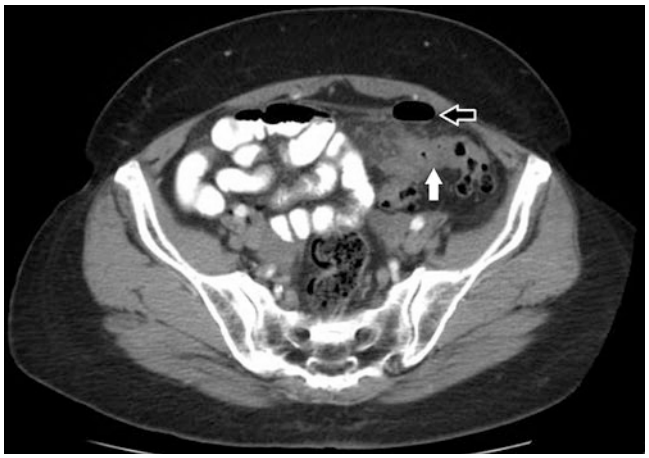

Fig. 29.2 CT scan showing perforated diverticulitis. Thickened inflamed colon (*solid white arrow*). Localized free air (*outlined black arrow*)

Diagnosis

The initial evaluation of a patient with suspected acute diverticulitis includes a history and physical examination, a complete blood count (CBC), electrolyte panel, urinalysis, and plain abdominal radiographs in selected clinical scenarios. A diagnosis of acute diverticulitis can often be made based on history and physical exam findings, especially in patients with a history of diverticulitis. Typically, patients will describe a several day history of left lower quadrant abdominal pain, fever, and ileus. On physical exam, focal peritonitis to the left lower quadrant is common, though suprapubic or right lower quadrant tenderness may be present if the perforation is within that region. The patient may have diffuse peritonitis with gross uncontained perforation. However, in many cases of abdominal pain, it may be unclear whether diverticulitis is the causative etiology and adjunctive studies may be helpful and warranted. Alternative diagnoses include irritable bowel syndrome, gastroenteritis, bowel obstruction, inflammatory bowel disease, appendicitis, ischemic colitis, infectious colitis, colorectal cancer, urinary tract infection, kidney stone, and gynecologic disorders. With recurrent diverticulitis, patients may present with a chronic history of large bowel obstruction, frequent urinary tract infections and pneumaturia when a colovesical fistula is present, and/or infrequently colovaginal fistula for female patients.

Plain upright abdominal films may show pneumoperitoneum from a grossly perforated colon, or an obstructive bowel pattern. In the modern era, computerized tomography (CT) scan of the abdomen and pelvis is usually the most appropriate imaging modality in the assessment of suspected diverticulitis (Fig. 29.2). Accuracy is enhanced with oral and intravenous contrast. In this setting, CT is both highly sensitive and specific, with a low false-positive rate [10].

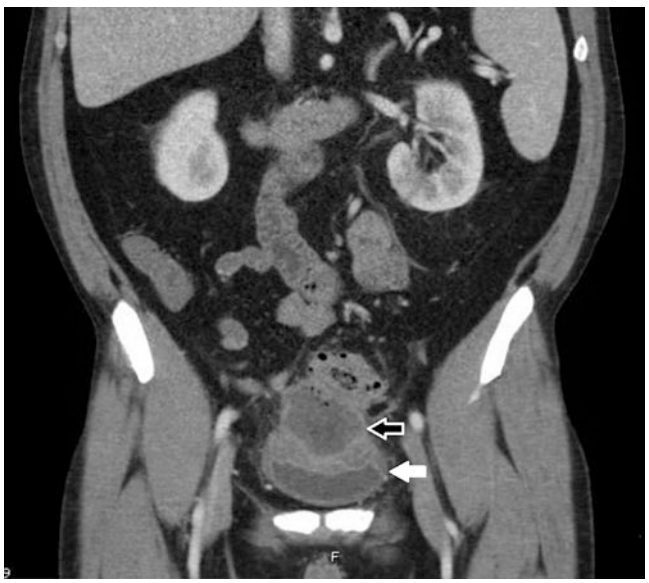

Fig. 29.3 CT scan showing diverticulitis with abscess abutting bladder. Pericolonic abscess (*outlined black arrow*). Bladder compressed by adjacent abscess (*solid white arrow*)

Features typical of diverticulitis on CT are: presence of diverticula in descending or sigmoid colon, surrounding fat stranding, and bowel wall thickening. Complications, such as pneumoperitoneum, phlegmon, abscess, adjacent organ involvement and fistula, can also be identified and may alter the treatment regimen (Fig. 29.3). Percutaneous drainage of an intra-abdominal abscess, if large (>3 cm) and accessible by interventional radiology, is an adjunct to conservative management to avoid the need for emergency surgery.

Severity staging, most commonly utilizing the Hinchey classification system, aids in the selection of patients who are most likely to respond to conservative therapy (Table 29.1) [11]. The severity of diverticulitis at the time of the first CT

Table 29.1 Modified Hinchey classification

Hinchey stage	
Ia.	Confined pericolic inflammation-phlegmon
Ib.	Confined pericolic abscess
II.	Pelvic, distant intra-abdominal, or retroperitoneal abscess
III.	Generalized purulent peritonitis
IV.	Fecal peritonitis

scan not only predicts an increased risk of failure of medical therapy on index admission but also a high risk of secondary complications after initial nonoperative management [12]. The incidence of a subsequent complication is highest in patients with severe disease on the initial CT scan [13].

After a diagnosis of diverticulitis is made with a CT scan, additional imaging with a water-soluble contrast enema can be used selectively to evaluate for the presence of stricture, obstruction, fistula, and severity of perforation. Diverticular strictures are usually longer and more regular than in carcinoma [14]. This diagnostic modality, once used frequently to diagnose diverticulitis, is infrequently used now in the acute setting with the advent of CT. Theoretically, the increased colonic pressure by the enema may cause or worsen colonic perforation in complicated diverticulitis and thus, should only be used very selectively. Similarly, colonoscopy in the acute setting may exacerbate inflammation or cause perforation. As a follow-up modality, however, endoscopy traditionally has been utilized to exclude a malignant component to the inflammatory disease process. A recent systematic review on routine colonoscopy after radiographically confirmed diverticulitis challenges this notion. In the meta-analysis, those with CT diagnosed uncomplicated diverticulitis reported a 0.7 % yield of malignancy with colonoscopy whereas a 10.8 % yield was reported for complicated diverticulitis. They concluded that high-quality data regarding this issue is lacking and current practice guidelines recommend routine endoscopic evaluation 6–8 weeks after resolution to exclude malignancy [15, 16].

Management of Diverticular Disease

Uncomplicated Diverticulitis

The treatment of patients with diverticulitis has changed significantly in recent years. Patients may be treated on an outpatient basis in the absence of systemic inflammatory response syndrome (SIRS). If they demonstrate mild abdominal tenderness, low-grade fever, and the ability to tolerate oral intake, reliable patients can be treated with oral antibiotics, low-residue diet, and close follow-up[17]. Antibiotics should be directed toward typical lower gastrointestinal flora. Oral antibiotic regimens, based on consensus rather than randomized trials, include gram-negative coverage typically with a fluoroquinolone or sulfa-based drug. Anaerobic coverage should be provided with metronidazole or clindamycin. Patients not meeting outpatient criteria will need to be hospitalized for intravenous fluids, intravenous antibiotics, and bowel rest. Immunocompromised patients will also benefit from inpatient treatment. Intravenous antibiotic regimens such as piperacillin/tazobactam or ciprofloxacin and metronidazole are appropriate in this setting. Although antibiotic therapy for uncomplicated diverticulitis has been the mainstay treatment, a recent systematic review comparing antibiotics versus no antibiotics for uncomplicated diverticulitis found no significant differences in outcomes between the two arms. Until further research is this area is conducted, antibiotics for this infectious process is still recommended [19]. Subsequent to successful treatment of acute diverticulitis with conservative therapy, a recent multicenter study demonstrated that recurrence occurred in 13.3 % of patients and a second recurrence occurred in 3.9 % of patients [18]. Elective resection can be safely performed 4–6 weeks after the most recent episode has resolved. Practice guidelines from the American Society of Colorectal Surgeons (ASCRS) taskforce in 2014 recommend that elective sigmoid colectomy after recovery from uncomplicated diverticulitis should be individualized [16]. Patients are not at an increased risk for morbidity and mortality after more than 2 episodes compared with fewer attacks of uncomplicated diverticulitis [19]. Thus, individualization for elective colectomy requires investigation of the patient's comorbidities, impact on lifestyle by recurrent attacks, inability to exclude malignancy, and chronic symptoms such as abdominal pain [20].

Traditionally, patients afflicted with an episode of diverticulitis are initially treated with bowel rest. Once the clinical picture begins to improve, they are instructed to consume a clear liquid diet. The diet is then advanced as tolerated. A more aggressive approach limits the concept of bowel rest, with immediate resumption of a low-residue diet instead. Once an acute flare has subsided, a high fiber maintenance diet has been advocated. This may decrease both the formation of diverticula and the chance of a symptomatic recurrence. This recommendation is based on the idea that long-term fiber supplementation produces a bulky stool that results in a larger diameter colon, thereby decreasing segmentation and subsequent pressure, which may be protective in the formation of diverticula. The data in support of this and other dietary measures is not conclusive. Other anecdotal recommendations are to avoid caffeine, alcohol, and tobacco but the data do not indicate that these are risk factors [21]. Additional dietary restrictions frequently given to patients are to avoid seeds, corn, and nuts. While this advice makes intuitive sense, these small difficult to digest

particles could become lodged in a diverticulum and predispose a patient to diverticulitis or perforation, a large observational study did not reveal an association with diverticular disease [22].

Complicated Diverticulitis

Patients with complicated diverticulitis are recommended to undergo sigmoid colectomy due to high recurrence rates of up to 40 % [23, 24]. The dilemma that the acute care surgeon is faced with is whether or not surgery can be performed in an elective fashion. Sigmoid colectomy for acute diverticulitis typically involves a multi-stage operation in which the initial surgery is a damage control operation to obtain source control (i.e., sigmoid colectomy and end colostomy). Subsequent operations aim to restore bowel continuity. The surgeon must determine if a patient with complicated diverticulitis can be medically managed to avoid non-elective surgery so that a one-stage operation can be performed electively after resolution of the infectious process.

Small localized and intramural abscesses may resolve without intervention. Larger abscesses (>3 cm) are best managed with percutaneous drainage. After source control has been achieved, clinical improvement should occur within 48 h [24–28]. In the absence of clinical improvement or if the condition of the patient worsens, repeat imaging may identify a new abscess, or worsening of an existing abscess, which would prompt a change of therapy, including replacement of existing drains or placement of additional drains. Conservative management of diverticulitis has grown more aggressive, recognizing the benefits of converting an emergency surgical intervention into an elective one. Advances in imaging, critical care, parenteral nutrition, and interventional techniques have lent themselves towards this goal. Dharmarajan et al. examined the efficacy of nonoperative management in acute complicated diverticulitis [29]. Complicated diverticulitis was defined as having an associated abscess or free air diagnosed by CT scan. Out of 136 patients, 28 % required percutaneous drainage, and 27 % required parenteral nutrition. In total, only 5 % (seven patients) failed medical management and required urgent surgery. Forty-eight percent then went on to have elective resections of their diverticular disease. Urgent surgery is reserved for patients with diffuse peritonitis, significant pneumoperitoneum, failure of nonoperative management, or immunosuppression [30].

Operative Approaches

The principles surrounding non-elective operative intervention focus on control of sepsis and determination of proper intestinal continuity. Preoperative considerations consist of aggressive intravenous fluid resuscitation, correction of electrolyte abnormalities, and early initiation of antibiotic therapy [31]. Bowel preparation is not indicated in the emergent setting. Historically there have been four basic approaches:

1. Staged procedure of (a) proximal diversion and drainage, (b) subsequent resection, and (c) final restoration of bowel continuity at a third procedure.
2. Resection and colostomy (Hartmann procedure)
3. Resection with primary anastomosis and diversion
4. Resection with primary anastomosis

The first has largely been abandoned secondary to high infectious complications resulting in substantial morbidity and mortality [32, 33]. Rarely, it can be utilized as a temporizing procedure in a patient with severe diverticulitis and a frozen hostile operative field. By diverting the fecal stream, diverticulitis that has been recalcitrant to antibiotic therapy may respond, rendering the subsequent operation less hostile. Options for fecal diversion include a loop transverse colostomy or loop ileostomy, both of which can be performed laparoscopically if feasible. Nevertheless, a fecal burden may exist between the diverting stoma and the perforated colon and thus, the operation may not divert all contaminate from the perforation.

In the case in which resection is attempted, preoperative placement of ureteral stents may prove useful during dissection [34]. The stoma site may be marked preoperatively in the likely scenario that an end colostomy is formed. It may be prudent to mark the stoma slightly more lateral since midline laparotomy wound complications may make stoma bag application more difficult in the future. The patient should be positioned in the supine position or in modified lithotomy if a primary anastomosis is considered. In the appropriate setting, a laparoscopic or laparoscopic-assisted approach may be entertained but traditionally, a lower midline laparotomy is advised in the septic patient. A dense inflammatory reaction frequently precludes the usual lateral-to-medial dissection. A more appropriate conduct of operation is to go from proximal to-distal, beginning the dissection along the lateral peritoneal reflection of the descending colon and distally in the rectum. Careful dissection is often necessary to separate the attached viscera, often a “pinching” or finger fracture maneuver aids in this endeavor. The proximal resection margin should incorporate the entire thickened segment. The distal margin should always extend to the recto-sigmoid junction, as the extension of the tenia coli around the rectum prevents diverticula from occurring at this level and future recurrent diverticulitis [35]. The rectal stump should be labeled with a long, nonabsorbable suture and pelvic drains may be considered. Extensive pelvic dissection beyond what is required for resection should be minimized if a Hartmann

procedure is performed in order to preserve anatomical planes for when the colostomy is reversed at a future operation.

Once the sigmoid colectomy is performed, an end colostomy is matured to complete the Hartmann procedure. It is advisable to not perform immediate primary closure of the midline skin incision in the setting of a wound class III (contaminated) or IV (dirty) colorectal case due to the high risk of surgical site infection. Alternatively, a primary coloproctostomy anastomosis and diverting loop ileostomy may be performed. The only multicenter randomized control trial comparing the two procedures in the setting of Hinchey III and IV acute diverticulitis concluded that both procedures had comparable overall complication rates. The initial colon resection for Hartmann's procedure versus primary anastomosis demonstrated non-significant differences in mortality and morbidity. However, the Hartmann procedure arm suffered from significantly higher rates of serious complications (20 % vs. 0 %, $P=0.046$), operating time, hospital stay (9 days vs. 6 days, $P=0.016$), and hospital costs. Those patients who had a Hartmann procedure were less likely to have their stoma reversed compared to those with a loop ileostomy (57 % vs. 90 %, $P=0.005$) [36]. The decision to perform a primary anastomosis should be based on patient factors (i.e., severity of sepsis, co-morbid conditions), intraoperative factors (i.e., hemodynamic stability), and surgeon preference/comfort level (i.e., low pelvic dissection and anastomosis in a hostile environment) [16]. If an anastomosis is anticipated prior to surgery, the patient should be positioned in modified lithotomy position.

Infrequently, a one-stage non-elective surgery (i.e., primary resection and anastomosis without diverting loop ileostomy) for acute diverticulitis may be performed. Richter et al., in a retrospective study, reported that a one-stage surgery can be safely performed in Hinchey III/IV patients in the absence of immunosuppression or chronic kidney disease. However, this study suffered from selection bias, imprecise methodology (3 of 36 patients in the one-stage group had a diverting loop ileostomy), and an unacceptably high mortality rate in the Hartmann's procedure group (60 %) [37]. There are no randomized control trials to date comparing primary resection and anastomosis with diversion and without diversion. Anastomotic leak may lead to a permanent colostomy and current practice guidelines have not recommended a true one-stage operation for acute diverticulitis [16].

Laparoscopic lavage has emerged as an alternative treatment to sigmoid colectomy. The operative technique and indications vary in the literature but initially involve performing a diagnostic laparoscopy and classifying the Hinchey classification of diverticulitis. For Hinchey I–III, the technique varies from copious laparoscopic lavage and drain placement without attempts at unroofing abscesses or identifying the perforation to abscess drainage by extensive bowel manipulation and adhesiolysis and sigmoid perforation identification with the intention to patch it. For Hinchey IV diverticulitis identified on laparoscopy, the general consensus is to proceed with resection [38–45]. Systemic reviews on the topic suggest that laparoscopic lavage is safe and feasible for complicated diverticulitis but that the current quality of data is insufficient to make recommendations [46]. Subsequently, two multicenter randomized control trials comparing laparoscopic lavage to sigmoid colectomy for Hinchey III diverticulitis have published their results. In the "Ladies trial," 90 patients were randomly assigned when the study was prematurely terminated due to an unacceptable increase in adverse events in the group (37 events) compared to the resection group (10 events) [44]. In the "DILALA trial," 83 Hinchey III patients were randomized and short-term results demonstrate no significant difference in short-term (30 and 90 days) mortality, morbidity, and reoperation. The primary endpoint number is reoperations within 12 months, which has not been completed yet [45]. Other randomized control trials are currently ongoing and until the results are published, sigmoid colectomy may be the safest operation for Hinchey III diverticulitis.

Other Considerations

Emergent colorectal resections carry with them high risk of morbidity and mortality, especially in the rapidly growing elderly population. A retrospective review of 292 patients 65 years and older undergoing emergency colorectal procedures revealed a 35 % overall complication rate. Pneumonia (25 %), persistent or recurrent respiratory failure (15 %), and myocardial infarction (12 %) were the most frequent complications. Operative time, shock, renal insufficiency, and significant intra-abdominal contamination were independent risk factors associated with morbidity. Age, septic shock at presentation, large estimated intraoperative blood loss, delay to operation, and development of a complication were associated with in-hospital mortality [47].

The operative management of diverticulitis in young patients had been more controversial. Older studies have pointed towards diverticulitis being more aggressive in younger patients, and hence, these patients were more likely considered for elective resection. A recent review of the literature has not supported this hypothesis [48]. Current ASCRS practice guidelines do not recommend routine elective resection based on newer data [16].

Long-term complications of diverticulitis can present in the form of strictures, fistulas, or persistent inflammation. Strictures often do not present as complete bowel obstruction, but rather with recurrent partial obstructive symptoms. Patients should be evaluated endoscopically and radiographically to exclude a malignant process and undergo resection

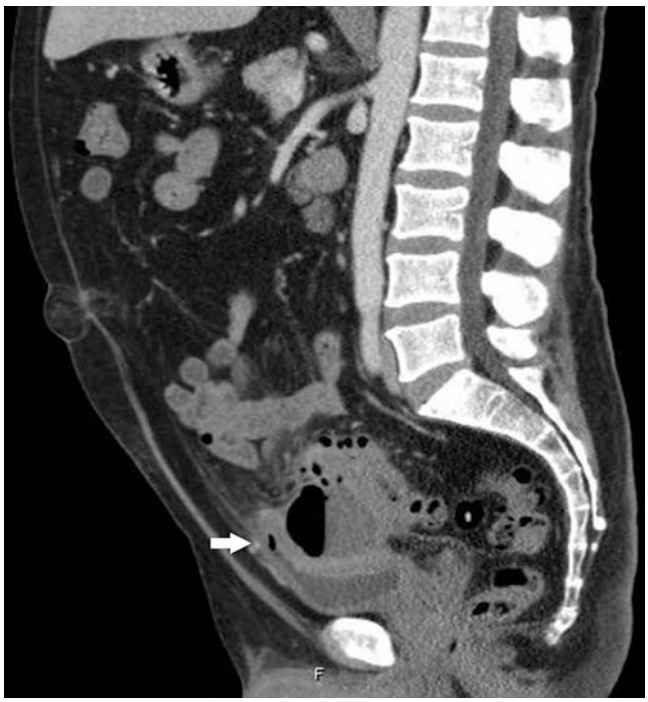

Fig. 29.4 CT scan showing suspected colovesical fistula. Air within the bladder (*solid white arrow*)

when appropriate [15]. Colocutaneous fistulas usually present as a complication of percutaneous drainage tracts. In men, fistulas are often associated with the genitourinary tract and symptoms such as pneumaturia or recurrent urinary tract infections may be present on history and physical exam. A CT scan may confirm the diagnosis of a colovesical fistula when the air is seen in the non-instrumented bladder (Fig. 29.4). Similarly, a cystogram may identify the fistula tract with contrast extravasating into the colon. Women can also have colovesical fistulas, but if a prior hysterectomy has been performed, they are also at risk for a colovaginal fistula. Symptoms include passage of flatus or stool per vagina, vaginitis, or recurrent urinary tract infections. Workup with a barium enema or sigmoidoscopy can aid in the diagnosis.

Conclusion

The treatment of diverticulitis is more "complicated" than ever before. What was once straightforward and amenable to a simple algorithm now requires thoughtful consideration of individual patient comorbidities, physiology at the time of presentation, and the treating surgeon's experience with an ever-expanding number of treatment options.

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Mesenteric Ischemia for the Acute Care Surgeon

30

Rebecca JoAnne Weddle, Justin J.J. Watson, and Jennifer Marie Watters

Mesenteric ischemia remains one of the most challenging diseases for the acute care surgeon to care for. Identification of the disease process and expedient progression to therapy are the key components of successful management. Depending on etiology, early treatment with revascularization, anticoagulation, resuscitation, antibiotics, and early surgical intervention remain paramount to improve outcomes and prevent disease progression. The mainstays of therapeutic advancement in the recent era have focused on evolution of endovascular techniques. Despite these advancements over the past 30 years, mesenteric ischemia remains a devastating disease with high mortality rates. This chapter describes a multidisciplinary approach to caring for these challenging patients, reviewing classical and novel therapeutic methodologies.

Splanchnic Vascular Anatomy and Physiology

Adept diagnosis and treatment of mesenteric ischemia requires a thorough understanding of splanchnic anatomy and physiology. The splanchnic viscera is a unique vascular network, adapted for absorption and distribution of nutrients. It is important for the surgeon to note significant blood flow variations of splanchnic arteries, veins, and collateral vessels during assessment for mesenteric ischemia.

Splanchnic vascular anatomy has well-documented patterns and variations. In normal anatomy, the superior mesenteric artery (SMA) originates 1–2 cm below the celiac trunk (CA) with extensive branches to the jejunum and ileum as well as the colon. The inferior mesenteric artery (IMA) arises 5–6 cm below the SMA and normally supplies the left half of the transverse colon and entire descending colon via the left colic artery. It continues with several sigmoid branches with terminal branching to paired superior hemorrhoidal arteries. Venous anatomy parallels the arterial blood supply and partially perfuses the liver via the portal vein. The portal vein arises from the confluence of the splenic vein and superior mesenteric vein (SMV).

Within the gastrointestinal vasculature, there are areas with redundancy and extensive collateralization that are important to consider in the evaluation of mesenteric ischemia. Collateral vessels occur at several different levels. These include large vessel anastomoses such as the Arc of Riolan and the marginal artery of Drummond. The Arc of Riolan, also known as Haller's anastomosis or the meandering mesenteric artery, connects the proximal middle colic artery with the left colic artery [1]. This provides anastomoses between the SMA and IMA [1]. The marginal artery of Drummond is nearly always present, and runs near the bowel wall in the mesentery anastomosing the IMA and the SMA. The gastroduodenal artery and pancreaticoduodenal vessels provide important collateral flow between the CA and SMA [2]. There are also large anastomotic arcades between the jejunal and ileal branches supplying important small bowel anastomoses. Smaller collaterals occur in the bowel wall with the unnamed intestinal arcades, which comprise the short-segment collaterals.

Certain presentations involve regression or persistence of primitive visceral circulation, which can result in a common celiacomesenteric trunk or in replaced hepatic branches from the celiac artery or superior mesenteric arteries [3]. There is a replaced right hepatic artery via the SMA in approximately 15–20 % of individuals, and replaced left hepatic artery from the left gastric artery in 25 % [3–5]. Other anatomic variations, as seen in Fig. 30.1a, b with the left gastric directly arising from the aorta also occur. Furthermore, a persistent ventral anastomosis between the proper hepatic and replaced right hepatic artery from the SMA, called an arch of Buhler, can be encountered [3]. In the event of occlusion or stenosis of either the CA or SMA, the gastroduodenal artery and/or alternate vessel become important collaterals when assessing the splanchnic circulation for mesenteric occlusive disease [2]. (Fig. 30.1a, b).

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_30

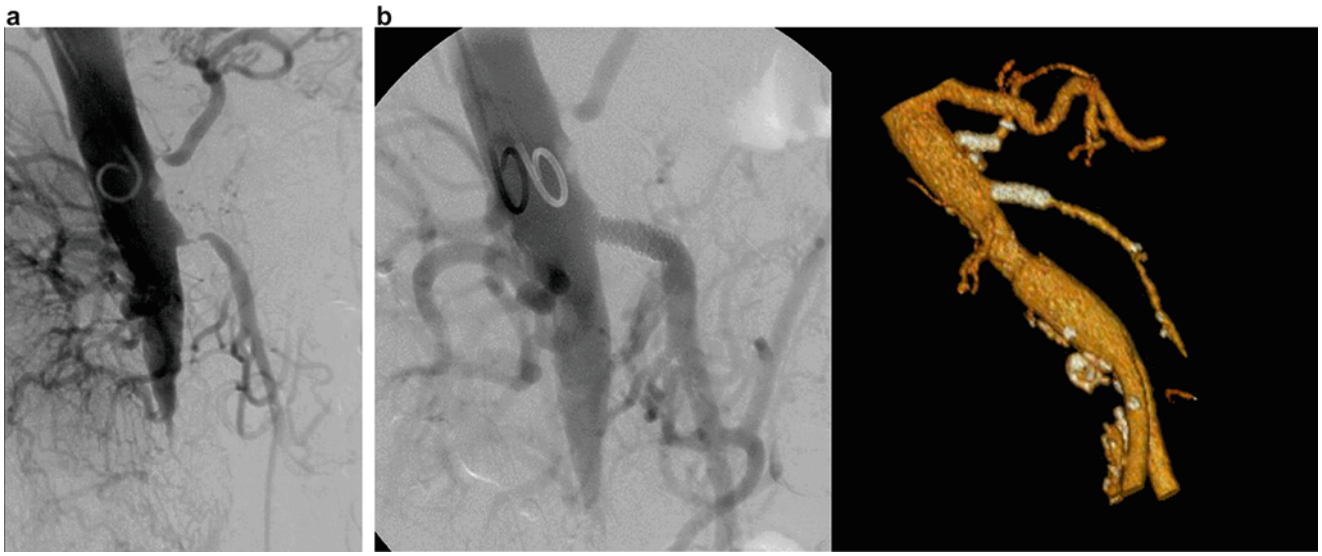

Fig. 30.1 (**a**) Occlusion of infrarenal aorta. Aberrant left gastric artery arises directly from aorta between celiac and SMA and has a 90 % stenosis. Proximal SMA with 75 % stenosis. (**b**) *Left*: Post stenting of SMA stenosis. *Right*: 3D reconstruction of open celiac artery and aberrant left gastric and SMA stents in place

Pathophysiology

Mesenteric ischemia was first recognized in 1895 after 2 reported cases of bowel resection for compromised arterial inflow [6]. Over time, the understanding of mesenteric ischemia has evolved considerably, though the need for prompt and accurate diagnosis remains essential to avoid common catastrophic complications. Despite advances in understanding and therapeutic options, recent studies still report in-hospital mortality rates of 60 % or higher [7–10]. Currently, there are two main categories of mesenteric ischemia in the literature: acute and chronic. The resultant ischemia may be the result of interrupted arterial supply or the result of occluded venous outflow.

Mesenteric circulation comprises three main branches from the abdominal aorta: the CA, SMA, and IMA. The final common pathway in mesenteric ischemia, regardless of etiology or location, involves insufficient blood perfusion to small bowel or colon leading to transmural ischemia and eventually necrosis with potential perforation [11]. Acute vascular insufficiency of the small bowel and/or right colon may result from five main types: mesenteric arterial occlusion (embolus or thrombosis), mesenteric venous occlusion, processes such as septic or cardiogenic shock leading to non-occlusive mesenteric ischemia (NOMI), and iatrogenic [8, 11–15]. More chronic etiologies of mesenteric ischemia are often related to either chronic arteriosclerotic splanchnic ischemia or median arcuate ligament syndrome (MALS) [7, 10, 16, 17]. The pathophysiology of mesenteric ischemia is dependent on etiology, though patients can present with an acute on chronic etiology.

In the developed world, mesenteric ischemia occurs in approximately 2–3 cases per 100,000 population [8]. The incidence has been slowly increasing over time [14, 18]. Acute mesenteric ischemia is more common than chronic mesenteric ischemia with a prevalence of 0.1 % of all hospital admissions [10].

Risk factors include generalized atherosclerosis, arrhythmias, hypovolemia, CHF, recent MI, valvular heart disease, advanced age, inflammatory bowel disease (IBD), intra-abdominal malignancy, mesenteric vascular instrumentation or endovascular procedures, and certain medications [7, 8, 10, 11, 16, 17]. The average age at presentation of chronic mesenteric ischemia is between 50 and 60 years old [8, 17]. In addition, approximately 75 % of patients with chronic ischemia have a current, or former, history of smoking [8]. Each of these risk factors is important when evaluating patients, and can inform the clinician regarding potential etiologies including embolus versus thrombus.

Control of blood flow in the splanchnic circulation is vitally important for survival of intestinal mucosa as it receives 75 % of the resting blood flow, while the muscular and serosal layers receive the remaining 25 %. Splanchnic blood flow is affected by the sympathetic nervous system, metabolic, myogenic, and extrinsic factors as well as by a number of intrinsic hormones including cholecystokinin, glucagon, gastrin, secretin, vasoactive intestinal peptide, serotonin, bradykinin, histamine, and prostaglandins. Other combined natural occurring hormones and common pharmacologic medications such as epinephrine, norepinephrine, and angiotensin also play a role in splanchnic vascular flow [19].

Presentation

The clinical presentation of mesenteric ischemia is often nonspecific and diagnosis can be challenging without a high index of suspicion for the disease. Patients typically present with a constellation of symptoms that mimic multiple alternative diagnosis including acute pancreatitis, acute cholecystitis, or small bowel obstruction [14]. Characteristics most associated with the diagnosis include elderly patients with a smoking history who may also have history of thrombotic or embolic events, recent myocardial infarction, weight loss with post-prandial abdominal pain, and atrial fibrillation [8, 17]. Up to 25 % of patients will report a previous embolic event [20]. The history will likely include clues that will differentiate between an acute thrombosis, embolism versus non-obstructive ischemia or mesenteric vein thrombosis. NOMI and mesenteric vein thrombosis typically present with a history of slow progression of pain or discomfort which may not be readily apparent due to the patients' mental status and clinical condition [9, 18].

Acute Mesenteric Ischemia

Acute thrombosis or embolism is typically dramatic in presentation. Patients describe a very acute onset unrelenting intolerable epigastric or diffuse pain [8, 11]. Pain can be associated with nausea or vomiting, distention, or bowel urgency including explosive diarrhea. Physical exam can be normal on presentation, with signs of acute abdomen or peritonitis developing later. The classic finding in acute mesenteric ischemia is pain out of proportion to clinical exam, which is to say they describe more pain than can be elicited with palpation. Late and ominous signs in the disease process include peritoneal signs and blood in the stool. Laboratory testing is often unhelpful as acute mesenteric ischemia has no pathognomonic laboratory tests, and is often only useful later in the disease process. Hemoconcentration, leukocytosis, acidosis, elevated transaminases, and alkaline phosphatase may be present, but need not be evident. Patients with SMA thrombosis may have underlying chronic vascular disease and may be thin with a history of chronic intestinal insufficiency [13].

Arterial Embolism

Nearly 50 % of acute mesenteric ischemia cases are the result of an arterial embolus, usually from a cardiac source [8, 11, 12, 15]. The most common embolic sources are due to cardiac mural thrombus development secondary to atrial fibrillation or myocardial infarction. In reality, most arrhythmias and even anatomic cardiac defects can lead to mesenteric embolus. Rare causes of acute ischemia include embolism of atrial myxoma or other intracardiac tumor, and paradoxical embolus due to venous thromboembolism with a right-to-left shunt.

Arterial Thrombus

Arterial thrombus causing acute mesenteric ischemia is less common than arterial embolus, accounting for 20 % of the incidence [8, 12]. It is the second most common cause of acute mesenteric ischemia behind embolic phenomena, and often occurs in patients with underlying disease of the SMA. Presentation is usually less abrupt than that of ischemia secondary to emboli. Patients may present with a vague history of long-standing nausea, diarrhea, or constipation, which has minimal diagnostic value. They often have concomitant nutritional deficiencies and wound healing compromise as well as chronic weight loss. The resultant occlusive disease can be extensive due to the underlying and often associated chronic disease of the mesenteric vessels.

NOMI

Non-occlusive mesenteric ischemia is due to splanchnic vasoconstriction and decreased splanchnic blood flow, commonly occurring due to shock, low cardiac output, hypovolemia, dehydration, or use of vasoactive medications for blood pressure augmentation [8, 21]. NOMI is more common in the elderly with underlying atherosclerosis [8]. In addition, patients who are already critically ill and experience decreased perfusion with intestinal ischemia may then become more dramatically ill without additional obvious insult. Nearly 20 % of patients with acute mesenteric ischemia present with NOMI [8]. (Fig. 30.2) Resuscitation and treatment of the underlying etiology are initial keys to treatment. Careful selection of pharmacologic support can help improve systemic circulation while relatively increasing splanchnic blood flow.

Venous Thrombus

Approximately 10 % or less of acute mesenteric ischemia is due to mesenteric venous thrombosis (MVT) [9, 18]. Presentation is often subacute with vague prodromal symptoms of cramping abdominal pain, distension, nausea, and malaise over days to weeks sometimes associated with hemoccult positive stools. MVT can be primary, or secondary to an associated condition including hypercoagulable state, intra-abdominal

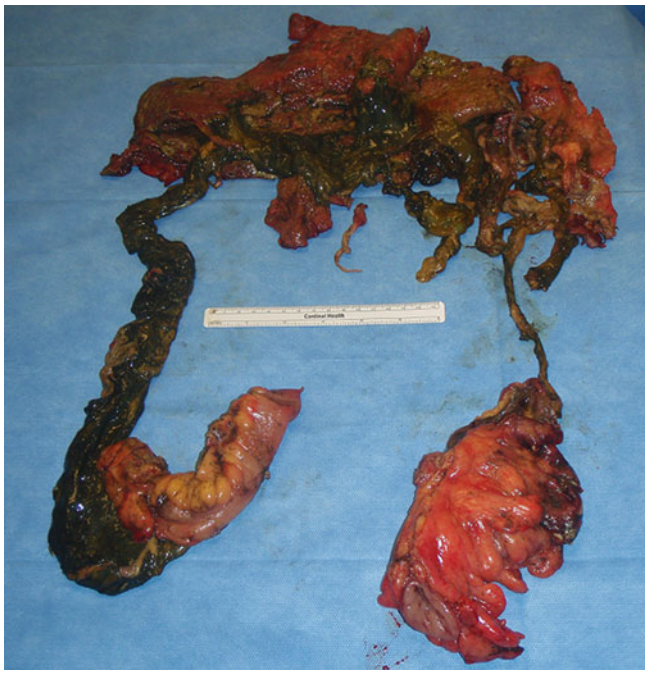

Fig. 30.2 Non-occlusive mesenteric ischemia with necrotic colon secondary to verapamil overdose

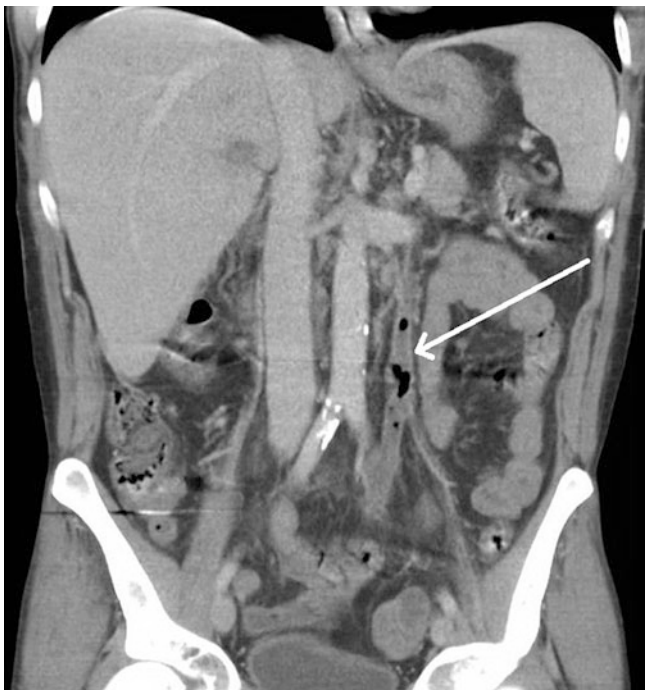

Fig. 30.3 Delayed CT imaging of mesenteric venous thrombosis with pneumophlebitis

inflammation such as severe pancreatitis, diverticulitis, portal hypertension, and the use of oral contraceptives [9, 18]. In a prospective study the most common risk factors for splanchnic venous thrombosis were liver cirrhosis and solid cancer [9]. Of these patients 77% had thrombosis of the portal vein followed by mesenteric veins [9]. Furthermore, patients with deficiency of antithrombin III, protein C and S or factor V Leiden mutation or anticardiolipin antibodies are at increased risk of MVT [9, 18]. Recurrence of MVT if untreated is 30–40% while anticoagulation reduces the risk to 3–5% [9]. (Fig. 30.3).

Iatrogenic

The incidence of splanchnic ischemia resulting from iatrogenic injury is increasing due to higher utilization of invasive endovascular procedures. Arterial dissections or thromboembolic events can follow endovascular treatment for aortic occlusion, aneurysm repair, or other endovascular procedures. Far from being limited to splanchnic vessels, these atheroembolic showers can result in multifocal ischemic necrosis to bowel, kidneys, and extremities. Classic repair of aortic aneurysm resulted in ligation of the IMA during the operation. Due to previously discussed collateral vessels, most patients tolerated this without negative sequelae. In 1–2% of cases colonic ischemia is noted clinically though it has been detected via endoscopically in 6–8% of cases [22]. Patients typically present with grossly bloody diarrhea postoperatively or positive guaiac positive. These findings should prompt endoscopy for further evaluation. If ischemia is confined to the mucosa or submucosa, it may heal with or without localized stricture. If ischemia is found to be more significant with transmural infarction requiring resection, there is a 16-fold increase in mortality [22].

Other

Mesenteric ischemia also occurs following aortic dissections, traumatic injuries or secondary to significant splanchnic vascular inflammation. The clinical presentation is quite variable depending on etiology and may be associated with abdominal distension, bleeding, and peritonitis. Treatment is specific to the presenting etiology. Branch revascularization or fenestrated graft may be used for aortic dissection repair to improve outcomes. Surgery may be required following traumatic injuries. Intervention must be tailored to optimize patient survival and outcome. Inflammatory arteritis requires treatment of the underlying medical condition and comorbidities while operative intervention is reserved for nonviable bowel only (Fig. 30.4).

Chronic Mesenteric Ischemia

Chronic Arteriosclerotic Splanchnic Ischemia

Chronic mesenteric ischemia (CMI) is often characterized by long-standing postprandial pain, chronic weight loss, "food fear," and early satiety [7, 8, 16, 17]. Due to the significant

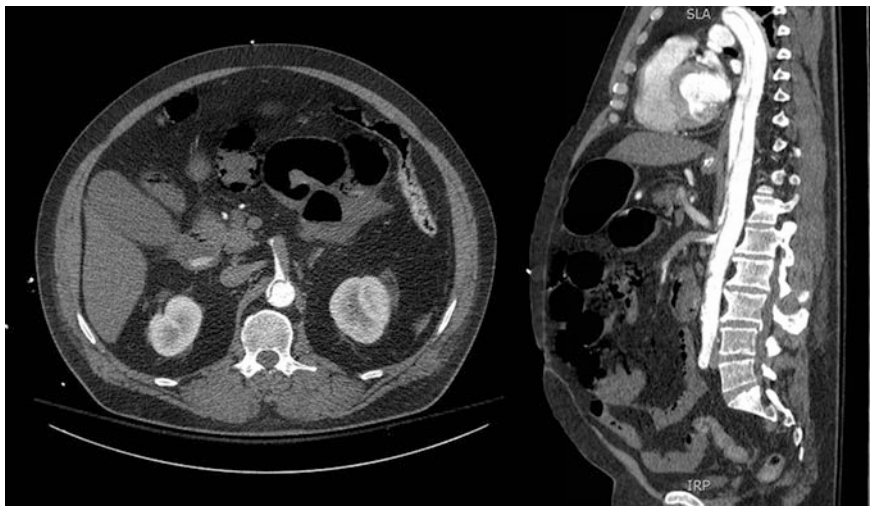

Fig. 30.4 Axial and sagittal CT images of superior mesenteric artery occlusion arising from the false lumen in aortic dissection

collateralization between mesenteric vessels, chronic mesenteric ischemia usually requires significant disease of at least 2 branches [8]. Lesions causing chronic intestinal angina are often arteriosclerosis extending from the aorta into the CA, SMA, and IMA. Up to 60 % of patients with chronic mesenteric ischemia are female, in contrast to other cardiovascular conditions [8]. Average age is 50–60 years old and more than 75 % have current or former tobacco exposure with concurrent HTN, CAD, prior CVA, and RI [8]. Patients typically develop "food fear" and modify eating patterns to eat multiple small meals to limit discomfort [7, 8, 16, 17]. Patients may have periumbilical discomfort beginning 15 to 30 min following ingestion and lasting from 1–4 h. Significant weight loss frequently occurs in this patient population and intra-abdominal malignancy should be excluded from the differential prior to intervention. The IMA is frequently the only remaining source of significant intestinal blood flow while the CA and SMA are often occluded or significantly diseased. Early recognition of mesenteric ischemia in these patients is paramount, even though many patients have long-standing symptoms. If patients present with perforation secondary to transmural infarction, the mortality rate approaches 80 %.

Median Arcuate Ligament Syndrome

Median arcuate ligament syndrome (MALS) is a rare disorder characterized by postprandial abdominal pain, weight loss, and celiac stenosis [23]. Diagnosis can be challenging, leading to delayed treatment. Median arcuate ligament syndrome is the result of entrapment of the CA by the median arcuate ligament and is a rare and controversial cause of postprandial periumbilical pain [23].

Diagnosis

Prompt diagnosis is paramount in mesenteric ischemia, as any delay in identification of the disease can result in ongoing infarction and loss of bowel. A high index of clinical suspicion is the cornerstone of making the diagnosis [14, 24, 25]. Delays in diagnosis can have a dramatic effect on survival, with delays of surgery also contributing to mortality [26].

Leukocytosis, hemoconcentration, and acidosis may be evident on presentation. Hyperkalemia may be found later in the disease process. Elevated lactate levels are common, but a normal lactate level should not exclude the diagnosis. A lactate of greater than 2.7 mmol/l is an independent risk factor for mortality [27]. Patients may also have elevations in amylase levels or D-dimer, but these are not very specific findings. Many patients also present with altered mental status, particularly if they have a late presentation and have already developed sepsis.

If a patient presents with sepsis, surviving sepsis guidelines should be immediately initiated and the patient should undergo urgent radiographic evaluation. Plain abdominal films are nonspecific in making the diagnosis and may be normal in the early stages of disease. Intestinal dilation or thickening of loops may be present, but are nonspecific findings. Ultrasound is of limited utility until very late in the diagnosis when there may be portal venous gas. Contrast studies such as barium enema are also of no use. Endoscopy has been used for colonic ischemia, but rarely will that be an associated finding in mesenteric ischemia.

Computed tomography (CT) is a very rapid study that can yield a lot of important clinical information at once. Communication with the radiologist reading the exam will result in a more useful study—diagnosis of acute mesenteric

ischemia was missed in 16 % of patients in whom this clinical concern prompting the study was not relayed [28]. When the radiologist was given the diagnosis and then shown the film, more subtle findings were identified.

CT angiography has become one of the best tools available, with rapid capture of images, and multiple angles it can give similar data to a conventional angiogram. Magnetic resonance angiography (MRA) is also specific and has the advantage of not using ionizing radiation. This procedure is slow and as a result may delay treatment and is therefore not appropriate in the acute setting [29].

Diagnostic peritoneal lavage has been associated with a decreased need for operative intervention, and a reduced mortality in the case of exceptionally ill patients in whom the diagnosis is not confirmed [30]. In this retrospective review, patients too unstable for CT imaging in the medical or surgical ICU, in whom intra-abdominal pathology was suspected, a DPL was used to delineate the need for further surgical management. Outcomes showed patients who had a negative laparotomy could be safely and effectively evaluated for surgical necessity without radiologic examination while simultaneously minimizing radiological delay on the way to the operating room [30]. These patients were more ill than their counterpart comparison group who underwent CT evaluation, or operation for diagnosis, obviating the need for a bedside analytic procedure.

Treatment

Preoperative Considerations

Once the diagnosis of acute mesenteric ischemia is established, treatment should be immediately initiated. In the case of mesenteric venous thrombosis (Fig. 30.5), cornerstones of therapy remain systemic anticoagulation and directed endovascular therapy in extreme cases. For the more common incident of mesenteric arterial thrombosis, a variety of techniques can be employed to gain resolution. Therapy should focus on resuscitation, preventing clot propagation, reestablishing blood flow to the bowel, minimizing reperfusion injury, and finally resection of nonviable bowel. Septic shock with multisystem organ failure, when present at the time of presentation, contributes to the high mortality rate of the disease [31]. One recent study has shown that patients who received early revascularization before bowel resection dramatically reduced their 1 year mortality [32]. The mechanism for restoration of mesenteric blood flow has been the most dynamic change in therapy over the last 30 years with the expansion of endovascular techniques.

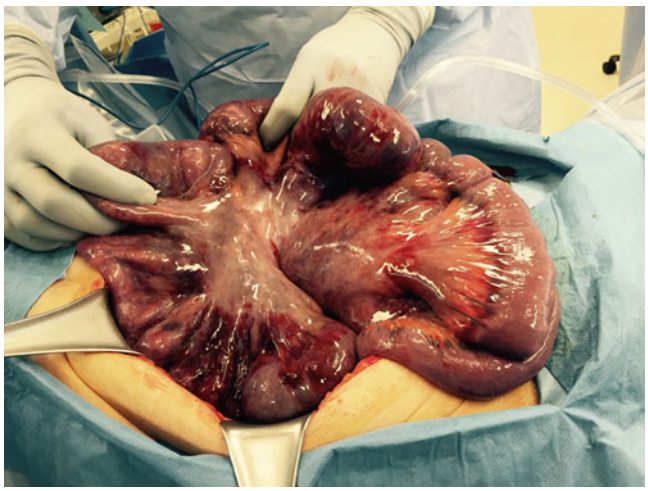

Fig. 30.5 Ischemic bowel secondary to mesenteric venous occlusion

Expeditious resuscitation is paramount in these cases, as any loss of time before revascularization can have devastating consequences. Reliable intravenous access should be obtained, whether central or peripheral, and volume resuscitation started. Electrolyte abnormalities are common, and should be corrected during the resuscitative process. During the establishment of hemodynamic monitoring (i.e., IV access, Foley catheter placement, nasogastric tube placement, arterial line placement), the patient should be prepared for emergent intervention (surgical or interventional radiology). Broad spectrum antibiotics are frequently given empirically before definitive diagnosis, as patients present with sepsis or septic shock in some cases. Antibiotic administration with a broad spectrum of anti-bacterial coverage, such as a third generation cephalosporin and metronidazole, is an important adjunct that can also help with wound prophylaxis.

Patients with known or suspected thrombosis of their mesenteric vasculature should be systemically anticoagulated as soon as possible. Utilization of heparin infusion ensures anticoagulation and can be readily reversed at any time if necessary. Heparin levels or PTT should provide accurate monitoring during the patient's care. Monitoring of activated clotting times throughout surgery will ensure ongoing therapeutic levels of heparin. Preparation of typed and crossmatched blood products is highly recommended, particularly if the patient has any baseline anemia or presents with gastrointestinal bleeding.

A very open and honest discussion should be undertaken at the outset of diagnosis and treatment with the patient and their loved ones or surrogate decision maker regarding the emergent nature of the procedure. The need for potentially prolonged hospitalization and critical care services, and the possibility of poor outcome, including surgically uncorrectable findings of infarction of the entirety of the bowel should all be discussed (Fig. 30.6). The majority of patients who will proceed for surgical therapy will progress to having intestinal continuity restored. However, patients are at risk of fistula formation and breakdown, as in all critically ill patients who undergo bowel resection and anastomosis.

Endovascular Therapy

Advancements in endovascular therapy have changed the management of mesenteric ischemia in the early stages. Endovascular infusion of urokinase was described as early as 1985, and similar techniques have become increasingly popular since that time [33–35]. If a patient is diagnosed with SMA occlusion or thrombus and does not exhibit peritonitis, they may be best served by either interventional radiology or vascular surgery with intravascular therapy. A multitude of studies report successful revascularization of the mesentery with a combination of intravascular techniques.

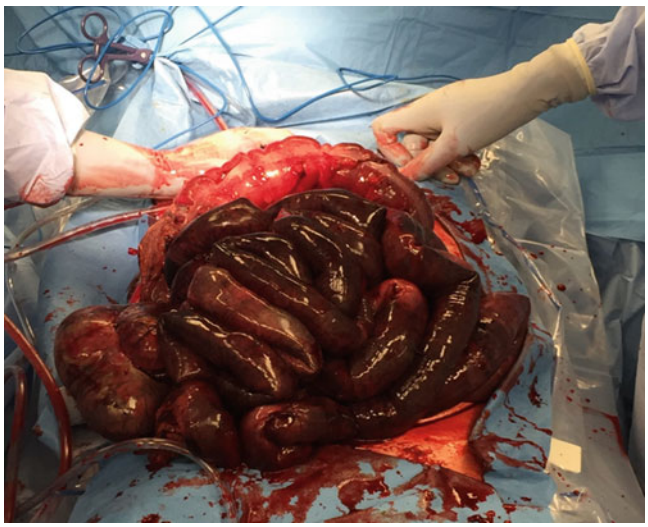

Fig. 30.6 Devastating bowel ischemia secondary to mesenteric occlusion

Balloon angioplasty, vascular stenting, thrombolysis catheters, and even suction catheter embolectomy have all been used in an acute setting for revascularization [35–37]. (Fig. 30.7). Various techniques have shown promise and operator comfort should be considered when deciding which technique to use. Thrombolytic agents vary, and several have shown utility, including streptokinase, urokinase, and tissue plasminogen activator (TPA). Some studies suggest that urokinase is the most favored thrombolytic agent secondary to a half-life of only 16 min, which will help with hemostasis if bowel resection is required [38].

Some studies have demonstrated improved mortality for patients undergoing intravascular as opposed to open therapy, despite increased baseline comorbidity [39]. The crucial predictor for improved outcomes throughout all reported cases appears to be early recognition of the diagnosis and expedient intervention. Resolution of abdominal pain is described as the best indicator of success in intravascular treatment of thromboembolism [38].

While endovascular therapy provides good success in revascularization, many patients will still need exploration to determine bowel viability. Studies report that even with successful revascularization, bowel resection is still necessary in upwards of 40 % of patients [40]. This exploration has been described using a laparoscopic approach when distention is not a limitation. In the event bowel cannot be fully evaluated via minimally invasive techniques, exploratory laparotomy should be pursued without delay. Hybridized operating rooms are an ideal place for the therapy of these difficult cases, as they allow for both endovascular and open techniques under the same anesthetic.

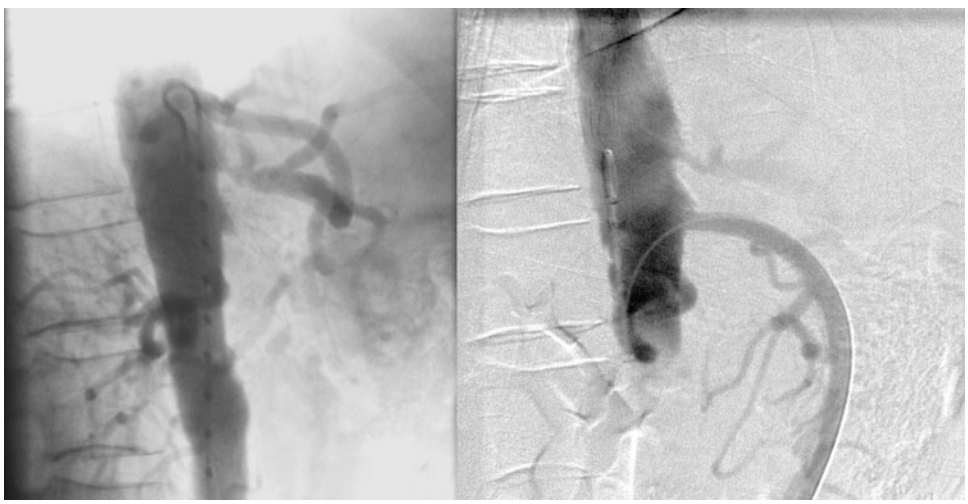

Fig. 30.7 *Left image* demonstrates severe stenosis of the superior mesenteric artery origin. *Right image* is angiography of SMA post angioplasty

Open Therapy

While endovascular therapy has assisted in the provision of rapid revascularization, there is no substitute for open operative management in the case of necrotic bowel. While some studies suggest that endovascular therapy has a lower mortality rate, others would suggest that the final outcome has more to do with the need for exploration and resection of bowel [39]. In the event exploratory laparotomy is needed for peritonitis or findings of ischemia on CT scan, the patient is best served by rapid treatment in the operating room after rapid preoperative preparation.

A midline incision is made, the length depending on the known need for therapy and body habitus. We recommend moving toward a large incision from the xiphoid to the pubis if there is any question of poor exposure or need for better visualization. Once the abdomen is open, bowel should be evaluated for signs of ischemia. If there is frank necrosis with spillage into the abdomen, quick suture closure of the perforation will suffice, while moving toward revascularization as the highest priority [20]. The pattern of ischemia then needs to be observed as it can provide clues to the location and extent of arterial occlusion.

Ischemia involving the entire jejunum, ileum, and right colon is the hallmark for occlusion at the origin of the superior mesenteric artery. Sparing of portions of the proximal small bowel may indicate an embolic event along the ileocolic artery. Patchy distributions of necrosis suggest showering of emboli from upstream. The blood supply should be interrogated in all of these cases.

With appropriate visualization within the abdomen, the omentum and transverse colon are retracted cephalad while the small bowel is retracted to the right side of the abdomen. The sigmoid colon should stay to the left side of the abdomen. The ligament of Treitz should be sharply divided in order to mobilize the duodenum. Once the duodenum is mobilized, the surgeon should be able to hold the small bowel mesentery at the root, with four fingers behind the mesentery palpating the origin of the SMA. At this point, intraoperative Doppler evaluation of the SMA is necessary. If you choose to rely on palpation of the artery at the origin, you can easily be misled by a pulse at the level of occlusion. For this reason, the objective use of Doppler is more helpful.

If there is no pulse in the SMA, the origin of the SMA should be exposed by carefully removing tissue surrounding the origin near the base of colonic mesentery. The SMV is in near proximity during this process and care should be taken to avoid any damage to the vein. Once approximately 3–4 cm of the SMA is exposed, vessel loops are used for proximal and distal control of the vessel. At this point the surgeon must determine if they will open the artery transversely or longitudinally.

With chronic disease and the potential need for bypass, a longitudinal incision into the vessel may be preferred to allow a bypass anastomosis. If the surgeon suspects thrombus only, a transverse incision is easiest to close without narrowing the vessel. If in doubt, a longitudinal incision can always be closed using patch angioplasty with autologous vein or bovine pericardium [13, 20].

Once the arteriotomy is made, Fogarty balloon catheters should be passed both proximally and distally to complete mechanical thrombectomy. This should be a dynamic process, using tactile clues to help clear the vessel of any occlusion and to prevent any iatrogenic damage. In other words, the catheter should never remain in one place as it is inflated. Following completion of thrombectomy, the arteriotomy is closed with interrupted nonabsorbable monofilament suture. If a longitudinal incision is made, patch angioplasty is recommended to reduce the possibility of stenosis. For the majority of acute thrombosis this will be adequate therapy. If the SMA is still not receiving adequate flow, a bypass may be necessary.

Multiple techniques are described for this process, as it can be technically demanding. The patient should be prepped preoperatively such that the femoral vein or saphenous vein (although this may be a poor choice in patients with chronic vascular insufficiency) can be exposed and harvested in case of need for bypass. Endogenous vein is always preferred in the management of mesenteric ischemia secondary to the frequent need for bowel resection and contamination from ischemic bowel. The conduit can be supplied from either the right iliac or the supraceliac aorta. The supraceliac aorta is the preferred location based on antegrade flow dynamics, but the iliac may be more technically feasible at the time of operation [20]. Alternatively described is a hybrid approach of catheter lysis performed in a retrograde fashion with or without stenting, which in the hands of some operators provided equivalent outcomes [41].

Once the vascular supply has been restored, the surgeon should await at least 15 to 30 min to allow reperfusion. During this time, vasodilatory adjuncts such as papaverine (30–60 mg) or glucagon (0.25–0.5 mg) may be injected to help with vasospasm. The surgeon must then determine how much bowel requires immediate resection. Clearly necrotic bowel should of course be removed. Bowel with questionable perfusion may need to be observed longer. We recommend temporary abdominal closure with early takeback. A variety of techniques for temporary abdominal closure are available [42].

Timing of the takeback is important. In general, it is preferred to go to the intensive care unit with ongoing monitoring, anticoagulation, warming, and resuscitation for 24 to 48 h before return to OR. The patient may need to return to the operating room sooner for further evaluation of vascular perfusion and possible resection if the patient's metabolic derangements or hemodynamic instability persist. Attempts at anastomosis of bowel should not be made during the ini-

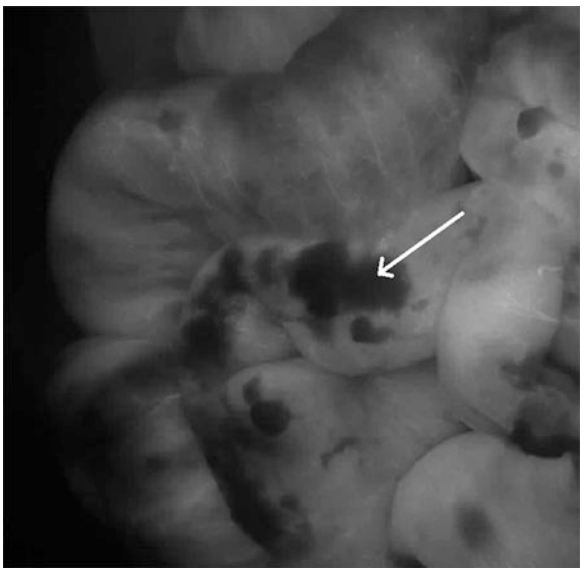

Fig. 30.8 Intraoperative fluorescent imaging of patchy ischemia in the small bowel

tial operation if the patient remains cold, coagulopathic, acidotic, or otherwise unstable.

Second look laparotomy is beneficial even in patients who are dramatically improved, and up to 50 % of patients who return undergo additional resection [20]. Bowel viability should be established through traditional clinical judgement such as peristaltic activity, color, and texture.

If bowel viability is still unclear, additional mechanisms such as fluoroscopic evaluation can be undertaken (Fig. 30.8). Because of the limited use of this technology, large studies have not been initiated, but preliminary evaluations and case series suggest that this technology can help determine resection length accurately, without need for additional resection [43]. Even with fluoroscopic analysis and Doppler, clinical judgement is equally effective in determining bowel viability in some studies [44]. Some patients may require multiple laparotomies for additional bowel resection if they are experiencing clot propagation, which should prompt evaluation of the anticoagulation therapy effectiveness. Once the patient has stabilized and is felt to be fully resuscitated, intestinal reconstruction can be undertaken and the abdomen closed.

Postoperative Considerations

Patients should be supported in an intensive care unit with continuous monitoring when being treated for mesenteric ischemia. Resuscitation parameters can be challenging, as sepsis and hemodynamic instability may worsen in many patients after they are revascularized with subsequent release of free radicals and toxic metabolites. This is likely the reason for additional bowel resection as well. Additionally, activation of phospholipase A2 during reperfusion seems to be instrumental in the development of hemorrhagic lesions in intestinal mucosa [45]. Ongoing resuscitation, with careful attention to evidence of end organ perfusion, is important during the early postoperative phase.

Goals for resuscitation may vary in this population, as not all patients will arrive with the same metabolic profile. An elevated lactate has been determined to be an independent risk factor for mortality in mesenteric ischemia, although it may not always be elevated [27]. Using correction of elevated lactate as an end point of resuscitation in severe sepsis and septic shock has been validated by multiple authors. In the LACTATES trial, patients randomized to a lactate-guided resuscitation (10 % or greater clearance) versus $S_{vc}O_2$ guided strategy in the emergency department demonstrated a 6 % lower in-hospital mortality [46]. Another prospective randomized trial of medical intensive care patients showed that lactate-guided resuscitation (decreasing lactate by 20 % or more per 2 h for initial 8 h of hospitalization) resulted in lower in-hospital mortality, shorter ICU stays and faster wean from mechanical ventilation than the control group [47].

Many patients with mesenteric ischemia may never exhibit high lactate levels, however, in which case this is clearly not a useful adjunct in the determination of adequate resuscitation. Recently, a fourth resuscitation strategy of "damage control" has been discussed as an endpoint, although this has largely been used in the trauma patient to describe control of hemorrhage [48]. It is likely that the endpoint of "damage control" used in terms of the control of thrombosis and clearance of necrotic bowel would be a reasonable goal in these patients. Following mesenteric revascularization and resection of necrotic bowel, intensive care unit support and resuscitation efforts should be directed toward reversal or prevention of end-organ dysfunction.

Nutrition

Mesenteric ischemia can be the result of an exacerbation of a chronic process, and it is important to evaluate patients for previous indicators of vascular insufficiency such as food fear and frequent abdominal pain. These patients may have significant baseline malnutrition, which should be addressed. Parenteral nutrition should be considered early in patients who are malnourished at baseline. As soon as intestinal continuity has been restored, enteral nutrition should be started at a trophic rate.

Some degree of malabsorption and malnutrition with associated complications can develop in adults with less than 180 cm of small intestine. Patients with less than 60 cm of small bowel are generally dependent on TPN. It is important to remember that in patient with less than 100 cm of small bowel, enteral nutrition may result in significantly increased fluid loss. Guidelines for nutritional support in short gut syndrome are available [49]. Retaining a functional ileocecal

valve improves the chances of maintaining adequate nutrition from enteral sources alone. This should be considered when making decisions regarding reconstruction. If a patient is going to be left with an exceptionally short gut, they may require parenteral bridging and intestinal adaptation. In extreme cases, patients may even need to be bridged to small bowel transplantation. Small bowel transplantation is reserved for patients who fail parenteral management. Patient outcomes have shown 80% survival for greater than 3 years after starting this therapy [50].

Other Considerations

Catastrophic bowel infarct is not an uncommon finding in the spectrum of this disease. This is also a disease that is common in the elderly, with an age adjusted incidence higher than acute appendicitis in those older than 75 years [51]. Patients also frequently have vascular disease and other underlying comorbid conditions such as cardiac disease and atrial fibrillation. With this clinical picture, it is perhaps not surprising that there remains an incredibly high mortality rate, reported at 58% in the ICU in a recent multicenter analysis of this condition [27].

Knowing that patients are high risk of death or complication, surgeons should have frank conversations with patients and their surrogate decision maker about potential outcomes. In one series from outside the SA, 33% of patients elected for palliative therapy when provided with information about the potential course of treatment [36]. Palliative care allows for a comfortable and dignified ending of life. An alternative to moving directly toward palliation would be a time-limited trial to direct goals of therapy. A time-limited trial allows the patient, and their family, to determine what level of treatment they desire. Furthermore this approach allows for evaluation of interval improvement and time to define what goals, or outcomes, are in line with how they want to be able to coexist and recover from their disease [52]. In the extreme case, this is not even optional, as occasionally the bowel is so damaged that nutritional support would not be possible. Upon finding catastrophic visceral ischemia, the patient's abdomen is closed and goals of care are transitioned to comfort care with support of the family. While this is always emotionally challenging for the surgeon and the family, the use of an open discussion preoperatively can help lay the foundation [53].

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Large Bowel Obstruction

31

Laura A. Kreiner

While representing only 15 % of bowel obstructions in the adult population, there are multiple etiologies one must consider when presented with a patient with large bowel obstruction. The incidence of large bowel obstruction increases with age, and can include mechanical problems (volvulus, incarcerated hernia), intraluminal factors (fecal or foreign body impaction), malignancy, strictures (benign and malignant), and functional obstruction (Ogilvie's syndrome). Despite their varied pathologies, symptoms typically consist of deep, visceral, cramping pain often referred to the hypogastrium. Obstipation is common though can be unclear if passage is from material distal to the obstruction. Vomiting is often a late sign, and only present in the absence of a competent ileocecal valve. The clinical course depends on the competence of the ileocecal valve, which if incompetent will allow decompression of the colon into the ileum. Most patients however have a competent valve, thus resulting in a closed loop obstruction. This allows for rapid increase in intraluminal pressure, eventually resulting in impaired capillary circulation, mucosal ischemia, with potential progression to gangrene and perforation. Having the largest diameter, the cecum is at the greatest risk of perforation. Risk of cecal perforation is significant if the diameter increases to more than 10–12 cm. The duration of symptoms varies with the location and cause of obstruction.

For the acute care surgeon, obstruction of the large bowel can present as either an acute pathology or the late presentation of a chronic pathology. When presenting emergently with obstruction, need for surgical intervention is associated with higher morbidity and mortality [1]. The immediate concern is to assess for ischemia, frank necrosis, or perforation, which will require emergent laparotomy. In the absence of these clinical findings, it is the goal of the acute care surgeon to determine the cause of the obstruction, whether it be functional or mechanical, and apply the needed steps in management including both operative and non-operative therapies. The specific etiology and treatment options of common presentations will be further discussed.

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Colonic Pseudo-Obstruction (Ogilvie Syndrome)

Ogilvie's syndrome represents acute colonic distention in the absence of mechanical obstruction, thought to be secondary to disturbance and imbalance of the autonomic nervous system. It is theorized that a physiologic stress results in either direct innervation of the sympathetic nervous system, or in production of inflammatory mediators which stimulate the sympathetic nervous system, while suppressing the parasympathetic innervation. This results in an overall inhibitory outcome on colonic motility. Physiologic stressors can include trauma, surgery, severe burns, sepsis, and neurologic insults. Additionally metabolic factors as well as pharmacologic effects can affect normal colonic function. Of medications associated with colonic dysmotility, opiates are by far the most common offenders, however multiple commonly prescribed agents are listed in Table 31.1 [2].

Ogilvie's syndrome typically presents with complaints of abdominal pain, distention, constipation, or diarrhea. Plain film abdominal radiographs demonstrate diffuse colonic distention (Fig. 31.1). It is important to remember that Ogilvie's syndrome is a diagnosis of exclusion. In the evaluation of patients with suspected Ogilvie's syndrome, other causes of obstruction such as toxic megacolon as a result of acute colitis or mechanical obstruction must first be excluded. A water soluble enema is useful, and has been considered the gold-standard test to evaluate for mechanical causes of obstruction as it has both diagnostic and therapeutic advantages in evacuating stool from the distal colon and rectum. Computed tomography (CT) of the abdomen and pelvis with intravenous contrast is a useful test, now often replacing

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_31

Table 31.1 Common medications associated with Ogilvie's syndrome

Narcotic analgesics
Anticholinergics
Tricyclic antidepressants
Antiparkinson agents
Calcium channel blockers
Clonidine

From Halverson, AL. Acute Colonic Pseudo-Obstruction (Ogilvie's Syndrome). In: Cameron JL editor. *Current Surgical Therapy*. Philadelphia, PA: Mosby;2008: 189–192, with permission.

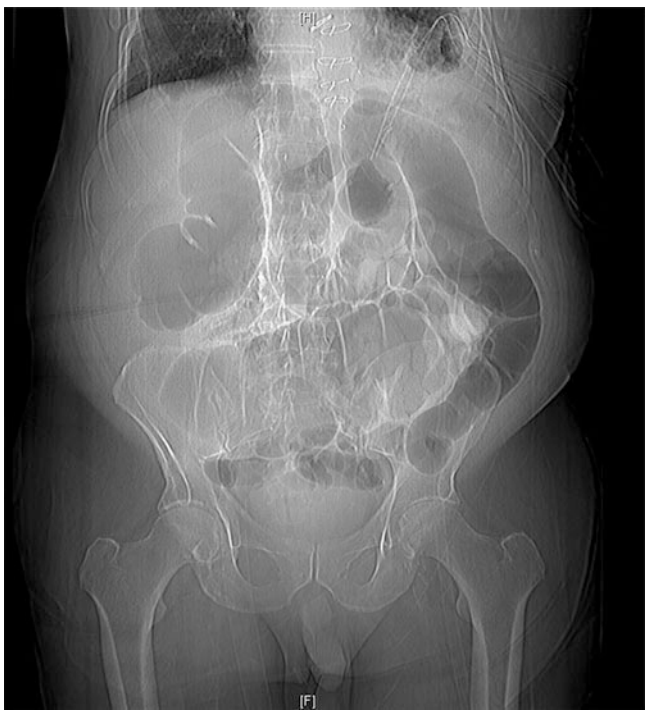

Fig. 31.1 Plain film abdominal radiographs demonstrate diffuse colonic distention in Ogilvie's syndrome

contrast enema. It has a sensitivity of 96 % and specificity of 93 % for diagnosing pseudo-obstruction [3]. It is able to demonstrate proximal colonic dilatation while excluding intrinsic or extrinsic mechanical obstruction. Still others have advocated for proctoscopy as a preferred diagnostic tool which can assess for colitis or distal obstruction, however at this time given the ease of obtaining CT imaging, this is the most commonly used diagnostic tool.

Treatment strategies include supportive care, pharmacologic interventions, as well as procedural and surgical therapies. The clinician should first determine contributing factors and take action to correct these. Electrolyte abnormalities should be aggressively corrected. Narcotic medications should be decreased as tolerated, or eliminated if possible as determined by the patient condition. Additional steps in conservative management can be used as adjuncts dependent on the acuity of the patient's condition. These include rectal tube decompression, nasogastric tube decompression with elimination of oral intake. Patients will often require intravenous fluid resuscitation, depending on the duration of symptoms and underlying disease. In approximately 80 % of patients, colonic dilation will be resolved within 48 h of initiation of supportive therapy and conservative measures [2].

In those who don't respond to conservative therapies, pharmacologic therapies are additionally considered. Neostigmine, a reversible acetylcholinesterase inhibitor can be administered. Neostigmine accentuates the action of acetylcholine on the muscarinic parasympathetic receptors in the colon, which results in increased colonic motility. Neostigmine is reported to be nearly 90 % effective in treating initial presentations of Ogilvie's syndrome [4]. A single dose of 2 mg is administered intravenously over 3 to 5 min. The onset of action is within minutes, and duration of action is 1 to 2 h, but can be much longer in those with renal insufficiency. Neostigmine should not be used those patients with concern for colonic ischemia or perforation. Because of the parasympathetic actions of neostigmine, profound bradycardia can result, therefore it is recommended that the patient should be supine and with continuous cardiac monitoring prior to administration. Atropine should be available should symptomatic bradycardia occur. Contraindications to neostigmine include pregnancy, cardiac arrhythmia, renal failure, and active severe bronchospasm [5]. Recurrent colonic dilatation after successful neostigmine induced decompression has been described to occur in approximately 35 % of patients [6]. A second dose of neostigmine can be administered to patients who did not respond to the initial dose, or to those who responded but recurred.

Multiple studies have reported approximately 61–95 % success with the use of colonoscopic decompression [3]. When deciding to proceed with colonoscopy for the management of Ogilvie's syndrome it is important to remember that oral bowel preparation should not be administered. Colonoscopy is indicated for patients whose colonic dilatation persists despite 24–48 h of supportive therapy, or for those who have failed treatment with neostigmine or are otherwise unable to receive neostigmine. Colonoscopy should not be performed if there is a concern for perforation. The procedure can be technically challenging secondary to the severe distention of the colon, and minimal insufflation should be used. Colonoscopy is reported to be more successful when the colonoscope can proceed beyond the hepatic flexure. A rectal decompression tube can be placed at the time of colonoscopy, which helps to decrease the recurrence rate which otherwise is reported to be approximately 30 %.

The risk of perforation increases beyond six days of conservative therapy [3]. If non-operative management fails to relieve colonic dilatation, or if ischemia, perforation, or peritonitis occurs, surgical intervention is indicated.

Clinical predictors of perforation include advanced age, increased cecal diameter, and delayed colonic decompression [2]. Frequency of cecal perforation was reported in a review of 400 cases. In this they found that cecal diameter greater than 14 cm experienced a 23 % perforation rate, as compared with a 7 % rate in cecal diameters between 12 and 14 cm. There were no perforations in patients with cecal diameter less than 12 cm [7].

Surgery for Ogilvie's syndrome is associated with high mortality, up to 50 % in some reports [3]. The high mortality and morbidity is likely influenced by the co-morbidities in these patients which influenced its initial development. The procedure of choice is dependent on the presence of necrosis of the intestine. If there are no signs of ischemia, tube cecostomy or blow-hole cecostomy has classically been described. Alternatively a right transverse or left lower quadrant sigmoid colostomy can be created for similar decompression [7]. If colonic necrosis or perforation is present, a segmental colon resection should be performed with end ileostomy and mucous fistula. Overall mortality for acute pseudo-obstruction is reported to be 15 %, which is increased to 30 % in patients who have progressed to ischemia or colonic perforation.

Colonic Volvulus

Volvulus of the colon occurs when a portion of the large intestine including its mesentery wraps around a fixed point in the abdomen resulting in closed loop obstruction of the intestines and strangulation of vascular structures. For this to occur, a segment of the colon must be excessively mobile, allowing it to rotate about a fixed point or fulcrum. Predisposing risks for torsion include: redundant colon and mesentery, incomplete fixation of colon to abdominal wall, mesenteric foreshortening from congenital bands, or adhesive bands. The most common locations include sigmoid colon (60 %) and cecum (40 %) [8].

Sigmoid Volvulus

The most common form of volvulus, sigmoid volvulus is most commonly seen in men, the elderly, and institutionalized patients, and has a reported mortality rate ranging from 7 to 20 %. It is theorized that in the elderly and institutionalized population that the frequent use of laxatives and chronic constipation necessitating their use, result in chronic distention of the colon, stretching the sigmoid and its mesentery, resulting in increased redundancy. Although multiple manners of torsion exist, most commonly the mobile sigmoid rotates axially around the inferior mesenteric vessels between the fixed points at the proximal and distal segments of the colon. Obstruction occurs after the colon has rotated 180°.

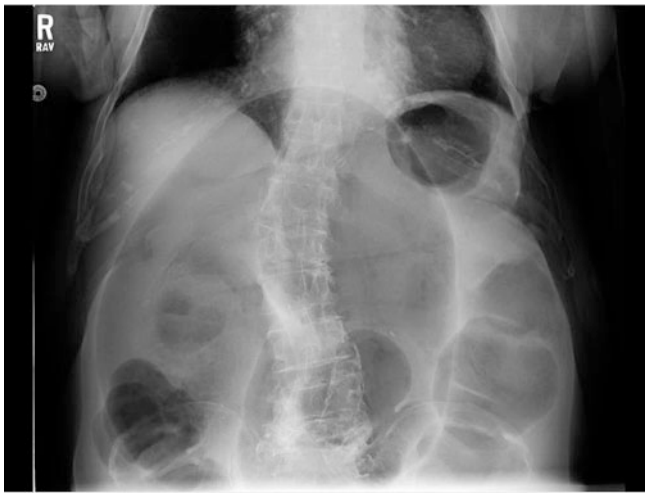

Fig. 31.2 In some patients with sigmoid volvulus, plain radiographs demonstrate a distinctly dilated colon projecting to the right upper quadrant that is often referred to as the "omega loop" or "bent inner tube" sign

Incomplete obstruction allows peristalsis to continue to move gas and fluid antegrade into the colon, distending the colonic wall. As the lumen distends, venous occlusion occurs, and as the distention increases arterial occlusion occurs, resulting in progressive ischemia and necrosis with eventual perforation.

Patients present with acute onset of colicky abdominal pain and distention, as well as obstipation. Physical exam demonstrates a distended, tympanic abdomen, often with minimal tenderness if ischemia has not yet begun. Bowel sounds can be normal to high pitched. Plain radiographs demonstrate a distinctly dilated colon projecting to the right upper quadrant, and is often referred to as the "omega loop," or "bent inner tube" sign (Fig. 31.2). Though this is classically described, it is found in less than 60 % of patients with sigmoid volvulus [9].

All patients should be evaluated for signs of ischemia and necrosis including fever, significant acidosis, leukocytosis, peritonitis, or pneumoperitoneum. In those patients with findings highly suspicious for ischemia, laparotomy should be urgently performed. During the initial evaluation, if the patient does not exhibit signs of ischemia or perforation, rigid or flexible sigmoidoscopy should be pursued. Both methods allow for the decompression of the effected loop as well as inspection of the colonic mucosa for signs of ischemia. The area of volvulus is often encountered approximately 15–20 cm from the anal verge, and which time rapid decompression of air and stool will be noted. A 25-F to 32-F rectal tube should be placed into the dilated portion of the bowel and be left in place for 48–72 h.

During laparotomy, if obvious gangrene is encountered the bowel is resected while avoiding detorsion. If the patient is hemodynamically stable, with adequate nutrition, and without severe acidosis, resection with primary anastomosis

can be considered. In an unstable patient, or those with greatest surgical risk a Hartmann's procedure performed. Maintaining the torsed state preserves the obstructed venous outflow and theoretically minimizes release of inflammatory mediators and toxins. In severely ill patients, it may be necessary to resect the effected bowel, leaving in discontinuity for a planned second look laparotomy after resuscitation. If upon laparotomy there is no obvious necrosis, the bowel is detorsed and observed for signs of improved vascular flow. These findings include return of peristalsis, pink coloration, and dopplerable signals at the mesenteric border. If the bowel remains viable, segmental resection with primary anastomosis is performed, unless age or co-morbidities suggest the patient would benefit from colostomy.

Recurrence of the volvulus after endoscopic detorsion occurs in more than half of patients in whom definitive procedures are not subsequently performed. Morbidity and mortality increase with each repetitive detorsion. It is for this reason, after successful decompression, most patients will be prepared for resection within the same hospitalization. Open and laparoscopic resections have been shown to be equally safe and effective, and the procedure of choice depends on patient factors as well as surgeon preference. Although simple sigmoid pexy was once considered standard surgical procedure, its high recurrence rate has led to the procedure falling out of favor.

Cecal Volvulus

Lack of tight fixation of the cecum to the retroperitoneum allows for an extremely mobile ileocecal complex. Cadaveric studies suggest this occurs in approximately 25 % of the population [8]. The cecum can volvulize along two axes, most commonly seen is axial torsion around the ileocolic pedicle which represents 90 % of occurrences. Less commonly, a folding of the cecum from inferior to superior, often referred to as a cecal bascule, can occur. Despite a relatively common lack of fixation, large bowel obstruction secondary to cecal volvulus represents only 1 % of all causes of large bowel obstructions. Similarly to sigmoid volvulus, patients present with abdominal distention and colicky abdominal pain. In contrast to sigmoid volvulus, these patients frequently present with nausea and emesis. Abdominal exam demonstrates distention with tympany and minimal tenderness to palpation. Abdominal plain radiographs typically suggest small bowel obstruction with loops of distended small bowel on the right side of a distended colon. These images are typically less diagnostic than in sigmoid volvulus due to the variable positioning of the cecum. The classically described radiograph known as the "coffee-bean" or "comma" sign represents a distended cecum with air-fluid level and haustral markings pointing toward the left upper quadrant (Fig. 31.3).

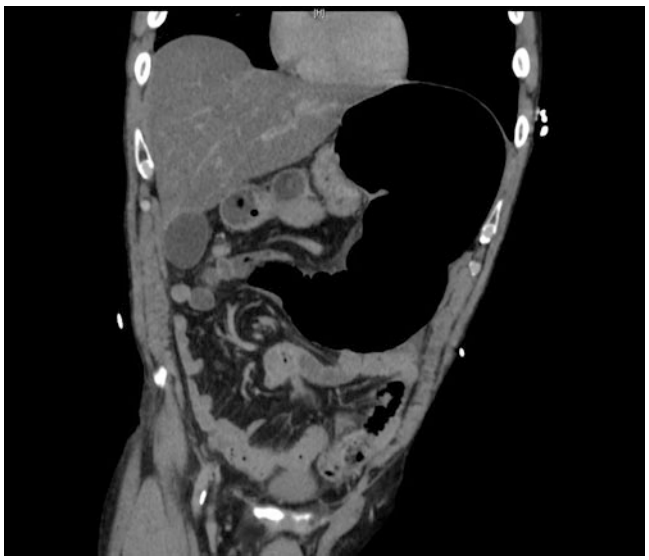

Fig. 31.3 This radiograph shows the "coffee-bean" or "comma" sign, representing a distended cecum with air-fluid level and haustral markings pointing toward the left upper quadrant

Endoscopic procedures are rarely successful, therefore treatment typically requires laparotomy. Intraoperative management is similar to that of sigmoid volvulus. Frankly necrotic bowel is resected, and right hemicolectomy is performed. In severely ill patients ileostomy is created, however if hemodynamically stable, anastomosis of ileum to transverse colon is a safe option. Anastomosis should be avoided if hemodynamically unstable, gross peritoneal contamination, or significantly dilated transverse colon. Bowel of questionable viability is detorsed and observed. Once viability has been determined detorsion alone is not significant given its 22–25 % recurrence rate [10]. Cecopexy without resection has similar recurrence rates to detorsion alone, and therefore resection with primary anastomosis is recommended in patients who can tolerate the procedure.

Diverticular Stricture

Diverticular disease involving the sigmoid colon has become a substantial problem for the western world, however only one third of patients with diverticulosis will present with symptomatic diverticular disease [11]. Incidence rates are rising, and the main increase is seen among younger population [12]. Less than ten percent of patients admitted with acute diverticulitis will require operative intervention during the index hospitalization [13]. Recommendations for elective management of diverticular disease following non-operatively managed active disease remain in evolution. Known formation of fistulas to hollow organs and intestinal luminal stenosis causing large bowel obstruction are known

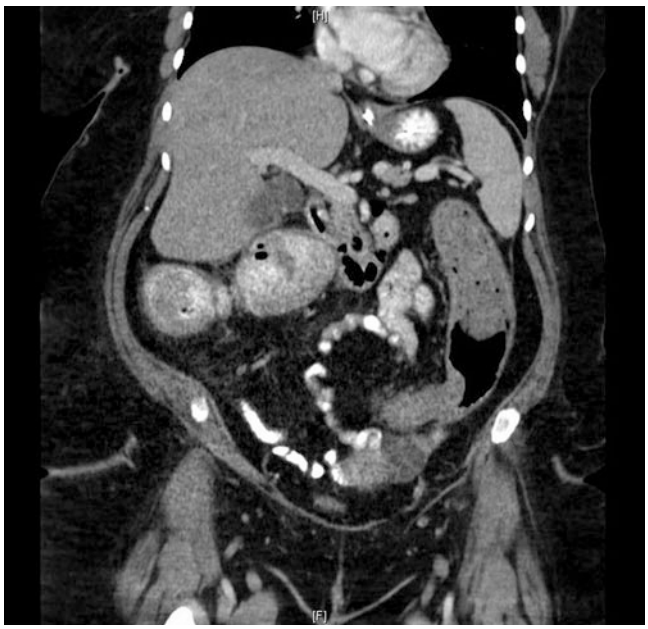

Fig. 31.4 Diverticular strictures often show decompressed bowel distal to the stricture and dilated stool filled bowel proximal to the stricture

sequelae of this management paradigm. Diverticular strictures are often found in locations similar to prior episodes of diverticulitis, and show decompressed bowel distal to the stricture, and dilated stool filled bowel proximal to the stricture (Fig. 31.4).

Diverticular disease ranks third among causes of large bowel obstruction in the western world. It often presents with left lower quadrant pain which can be acute or insidious in onset. Although the indications for timing of surgical intervention in the non-acute setting continues to be in evolution, it is generally recognized that in patients who are medically able to undergo surgery, obstruction related to diverticular disease is a definite indication [14].

An episode of acute diverticulitis can result in both small and large bowel obstruction. A segment of small bowel can become densely adhered to the inflamed portion of the colon, inflammatory mass, or abscess itself, thereby resulting in paralytic ileus. Obstruction of the large bowel, however, is often incomplete and more insidious. It results acutely from edema in the colonic wall, colonic spasms, or external compression from the nearby abscess. Complete obstruction can be caused by fibrotic changes and stricture formation, typically associated with recurrent attacks [13]. Obstruction can result secondary to acute inflammation, but more commonly is secondary to the sequela of prior episodes of diverticulitis. In a recent retrospective review, Klarenbeek et al. found that in a cohort of 72 patients undergoing elective resection for diverticular disease, 40 % had complaints related to stenosis, as compared to a group of 108 patients undergoing acute resection of whom the indication of obstruction or stenosis was found in only 11 % [12]. Obstruction in the acute case will often resolve with non-operative management, percutaneous drainage of abscess, and supportive care. Surgical intervention is indicated when the obstruction is complete or non-operative management fails. The evaluation of large bowel obstruction in the case of diverticular disease should additional include exclusion of carcinoma.

Most reports discussing the use of intraluminal stenting as a bridge to elective resection extrapolate from their use in malignant obstruction. In a recent study, Small et al. reviewed 23 cases in which stents were placed for benign disease, 16 of which were diverticular disease. They demonstrated stent placement was associated with up to 38 % rate of complications including re-obstruction, stent translocation, or perforation. Eighty-seven percent of these complications occurred within seven days of stent placement [15]. A more recent study of 21 patients with benign obstruction (ten of which were diverticular) and had endoluminal stents placed had similar results. Although clinical success was reported in 76 %, an adverse event developed in 43 % of patients. The study suggested that patients with diverticular disease were more likely to develop an adverse event than other causes of obstruction [16]. Boyle et al. recently published the results of 126 patients who underwent intraluminal stent placement for obstruction related to a variety of causes. They concluded that stenting is more likely to be successful in shorter, malignant strictures with less angulation, than longer benign strictures which were not only less successful clinically, but were associated with higher risk of perforation [17]. As the use of intraluminal stents for benign diverticular strictures is associated with increased complications, their use should be considered on a case by case basis dictated by the patient's underlying medical co-morbidities. If semi-elective procedure is planned, it should be performed within 7 days of stenting. A recent Practice Management Guideline from the Eastern Association for the Surgery of Trauma on the topic of surgery versus stenting for colonic obstruction conditionally recommends the use for malignant obstruction, but was unable to make a recommendation in benign disease secondary to paucity of data [18].

Endoscopic balloon dilatation for benign colonic strictures has proved useful in management of obstruction associated with anastomotic strictures, those from inflammatory bowel disease, however rarely are used for those following an episode of acute diverticulitis [16]. It is therefore difficult to make a recommendation at this time for its use in diverticular disease.

Colorectal Cancer

The breadth of knowledge required to treat the varying stages and complexities of colorectal cancer is beyond the scope of this text. Focusing on colorectal cancer as it pertains to the acute care surgeon, the most frequently encountered diagnosis

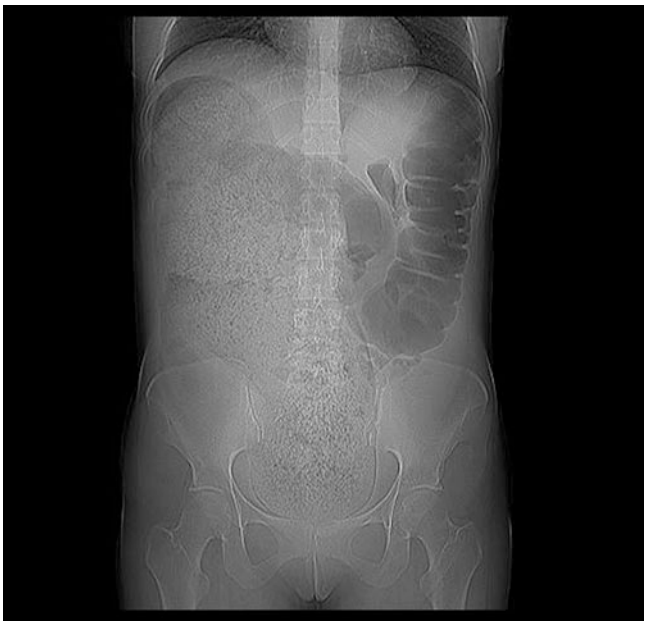

Fig. 31.5 In colorectal cancer, imaging studies demonstrate narrowed lumen with thickened colonic wall associated with dilated, stool filled colon proximally

is large bowel obstruction. As with many disease states faced by the acute care surgeon, the management of malignant obstruction is rapidly changing as technology evolves and presents additional options. Colorectal cancer is the third most common cancer in the USA, and is the second leading cause of cancer related deaths [19] Worldwide it is the most common cause of large bowel obstruction [20].

As with other clinical presentations of obstruction, patients will present with abdominal pain and distention, associated with the absence of bowel movements. Nausea and vomiting may be present depending on the competency of the ileocecal valve. Depending on the duration of symptoms this can be associated with severe imbalances in fluids and electrolytes. This can be associated with acute kidney injury, sepsis, or septic shock if perforation occurs. In the acute presentation, clinicians are frequently faced with obstruction or perforation secondary to tumor necrosis or obstruction. Imaging studies will demonstrate narrowed lumen with thickened colonic wall associated with dilated, stool filled colon proximally (Fig. 31.5). Computed tomography has replaced water soluble contrast enema as the diagnostic modality of choice. It has a sensitivity of 96 % and specificity of 93 %, and can locate the obstructing mass in 96 % of cases [21].

Obstructing colorectal cancer has a more aggressive clinical course, and a poorer prognosis [20]. Acute large bowel obstruction is the initial clinical presentation in 7–29 % of patients with colorectal cancer [22]. The sigmoid colon is the most common location for obstructing colorectal center, and greater than 75 % of tumors are located distal to the splenic flexure [23]. Right hemicolectomy is the standard of care for proximal tumors. Primary anastomosis between the distal ileum and colon has an anastomotic leak rate between 2.8 % and 4.6 %, and is considered safe in the emergency setting, however patient stability and co-morbid conditions should still be evaluated when considering anastomosis [24].

Perforations at the tumor site present as either free perforation with peritonitis or locally contained abscess. Perforation secondary to obstruction can result in perforation of any portion of colon proximal to the tumor including the cecum [25]. Perforations which are contained can be percutaneously drained, allowing for source control and resuscitation and staging investigations, prior to semi-elective oncologic resection. Free perforation with peritonitis represents a true surgical emergency, requiring aggressive fluid resuscitation followed by surgical intervention. The surgical procedure of choice is highly dependent on patient stability, co-morbid conditions, and location of tumor. In the face of gross fecal contamination resection of the tumor and perforation are performed if possible, followed by proximal colostomy or ileostomy. If the patient remains unstable secondary to septic shock, a damage control operation may be necessary. In the otherwise stable patient with minimal fecal contamination, primary anastomosis can be performed. Proximal diverting ostomy should be strongly considered in this situation, as the inherent cardiovascular, metabolic, and infectious changes related to perforation make the risk of anastomotic leak significantly higher.

Treatment of distal obstructing tumors in the absence of perforation has evolved significantly over the last 50–60 years. What was previously a three-staged procedure (proximal colostomy, second stage tumor resection, third stage stoma closure), can now at times be managed with a one-stage procedure. Previous studies have demonstrated the three-staged approach did not improve survival, and is associated with significant morbidity and mortality [21]. Currently a staged approach is reserved for obstruction resulting from mid to low rectal cancers prior to neoadjuvant treatment. It additionally is considered as a palliative measure in patients with unresectable tumors, or the severely ill patients in whom perforation has been excluded.

Oncologic resection remains the gold standard for treatment of malignant obstruction, however over the past twenty years introduction of endoluminal self-expanding stents to the treatment paradigm has shown moderate clinical success. The goal of endoluminal stenting can be a permanent stent with attempts towards palliation in patients with unresectable disease, or as a “bridge to surgery” in patients who have tumors amenable to surgical resection that present in the face of large bowel obstruction. When deployed, the stent is placed allowing for decompression of the proximally obstructed bowel, in attempts to avoid emergent surgery.

Surgery is then planned as a second stage, definitive procedure after the acute resuscitation is complete, and the bowel decompressed. Endoluminal stenting has been associated with complications such as bowel perforation (3.76–4 %), stent migration (10–11.8 %), and re-obstruction (7.34 %) [26]. A 2013 meta-analysis included 197 patients, 97 treated with endoluminal stent, and 100 who had emergency surgery. The analysis suggests clinical success (definition of which varies) significantly higher in the emergency surgery group as compared with the stent group (99 % vs. 52.5 %, $p<0.00001$). They noted no difference in the overall complication rate, or 30-day postoperative mortality rate. When used as a bridge to surgery, stents provided advantages as compared to emergency surgery group including significantly higher primary anastomosis rate (64.9 % vs. 55 %, $p=0.003$) and lower overall stoma rate (45.3 % vs. 62 %, $p=0.02$) [26].

Colonic stenting appears to be an effective treatment strategy for both patients needing palliation, and when used as a bridge to surgery. Used as a solitary therapy it is associated with less clinical success, and equivalent complication rates. However, the sample size in many of the studies is small, and further randomized studies are required. Determining if the patient will benefit most from emergent surgery or bridge to surgery will depend on the severity of the patients current illness, their co-morbid conditions, the location and resectability of the tumor.

To assist with these difficult decisions, guidelines have recently been published following a consensus conference of the world society of emergency surgery, and peritoneum and surgery societies. The paucity of good quality data is noted, and the recommendations apply only to intraluminal obstructions distal to the splenic flexure. When comparing loop colostomy with staged procedure to Hartmann's procedure, Hartmann's procedure is recommended as loop colostomy and subsequent staged procedures have longer overall hospital stays without reduction in preoperative morbidity [27]. In extremely ill patients in whom a "damage control" type approach needs to be considered, in those with unresectable disease, or when neoadjuvant multimodality therapies are expected, staged procedures should still be considered. When comparing Hartmann's procedure to primary resection with anastomosis, review of the currently available published data suggests that Hartmann's procedure doest not offer an overall survival benefit compared to immediate resection with anastomosis. Therefore Hartmann's procedure should be reserved for those patients with high surgical risk [27]. Increased surgical risk has been demonstrated across multiple studies to include increasing age, American Society of Anesthesiologists (ASA) grade, operative urgency, and Duke's stage. These risks primarily contribute to the risk of anastomotic leak, which is the primary concern in resection with immediate anastomosis. Depending on the operative findings, primary anastomosis can be performed with diverting proximal stoma, however few studies compare these options.

With regard to self-expanding metal stents (SEMS), the European Society of Gastrointestinal Endoscopy has produced a guideline which was subsequently endorsed by the American Society for Gastrointestinal Endoscopy. The guidelines suggest that SEMS placed as a bridge to surgery in symptomatic left sided malignant obstruction should not be the standard treatment. However, in those patients with potentially curable disease, SEMS can be considered as an alternative to emergency surgery in those with increased preoperative risk (age >=70 ASA>=3) [28]. Stent related complications include colonic perforation (10 %), stent migration (9 %), and re-obstruction (18 %) [28]. Oncologic effects should be considered when deciding for stenting versus operative therapy. Although the studies are small and few, there is concern of increased local recurrence in patients who are initially stented, and had stent associated perforation, as evidenced by the Stent-in 2 trial [28]. In those who SEMS are chosen as a bridge to surgery, that surgery should occur within 5–10 days given the known risk of perforation and stent migration [28]. Meta-analysis of randomized and non-randomized studies regarding the palliative placement of SEMs demonstrated a lower 30 days mortality rate for SEMS when compared to surgery (4 % vs. 11 %), shorter hospitalization (10 vs. 19 days), and shorter time to chemotherapy (16 vs. 33 days), however there is no difference in overall morbidity (34 % vs. 38 %). It should be noted that in patients receiving antiangiogenic agents (i.e., bevacizumab), an increased risk of stent related perforation (12.5 %) has been noted, and stents are therefore not recommended in this group. Stent placement in patients receiving chemotherapy agents which are not antiangiogenic agents is associated with standard risks.

Conclusion

Although the etiologies are varied, patients with large bowel obstruction often present with similar complaints. These include mild, generalized abdominal pain, distention, and obstipation. Depending on duration of symptoms and competency of the ileocecal valve, nausea and emesis may be additional complaints. The workup of large bowel obstruction should seek to evaluate for signs of ischemia, necrosis, or perforation, which require urgent laparotomy. In the absence of these symptoms, further imaging modalities should be employed to determine the nature of the obstruction. After identifying the cause, the appropriate operative and non-operative therapies can be identified. In all cases of obstruction, malignant neoplasm as a source of obstruction should be considered. Operative considerations include

diverting ileostomy/colostomy, primary resection with creation of colostomy, primary resection with anastomosis. Age, co-morbidities, hemodynamics, and acute fluid and electrolyte imbalances should be assessed, as these often influence the procedure of choice.

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Lower Gastrointestinal Bleeding

32

Andrea Weitz and Daniel Vargo

Management of Lower Gastrointestinal Bleeding

The lower gastrointestinal tract consists of all gastrointestinal elements distal to the ligament of Treitz, including the jejunum, ileum, cecum, appendix, colon, rectum, and anus. Lower gastrointestinal bleeding can originate from any of these locations and thus represents a broad range of clinical entities. Most studies of lower gastrointestinal hemorrhage specifically reference lesions of the colon, rectum, and anus, and the majority of studies cited herein adhere to this convention.

Within the acute care surgical setting, these patients may present anywhere along the spectrum extending from occult bleeding demonstrated on fecal testing to frank, even massive, gastrointestinal hemorrhage. Although upper gastrointestinal bleeding is found to account for approximately three to five times the number of annual hospital admissions due to hemorrhage from lower gastrointestinal sources [1], lower gastrointestinal bleeding remains a frequently encountered clinical entity and can represent a diagnostic and therapeutic challenge for the acute care surgeon.

Epidemiology

Lower gastrointestinal bleeding accounts for a significant number of hospital admissions; the reported annual incidence rate in the adult US population is about 22–36 cases per 100,000, representing approximately 0.7–0.9 % of all US annual hospital admissions in the acute care setting [2]. The incidence of lower gastrointestinal bleeding is directly correlated with increasing patient age [3], with patients in the ninth decade of life experiencing an annual lower gastrointestinal bleeding rate approximately two hundred times greater than comparable patients in the third decade of life due to increased incidence of diverticulosis and malignancy [4–6]. As the US demographic shift toward an older population continues, lower gastrointestinal bleeding can be expected to increase in overall incidence in coming years.

Although hospitalization for acute lower gastrointestinal bleeding used to somewhat more common in males than females, with reported annual incidence of about 24 per 100,000 in males versus 17 per 100,000 in females back in the 1990s [4], trends have shifted to a higher female preponderance and in 2009 the incidence in men was 35.3 per 100,000 and in women 41.0 per 100,000 [3].

It should be intuitively obvious that certain etiologies of lower gastrointestinal bleeding are more common in particular age groups and patient age is certainly a factor to be taken into account when developing a reasonable differential diagnosis for lower gastrointestinal bleeding. For example, bleeding due to angiodysplasia, diverticular disease, and colorectal malignancy are all markedly more common in older individuals, a reflection of the increasing incidence of these diagnoses in older populations.

Patients with lower gastrointestinal bleeding are more likely to require surgical intervention in comparison with those with upper gastrointestinal bleeds [5]. Severity of lower gastrointestinal bleeding varies widely, and a number of predictive models have been developed to identify which of these patients are at greatest risk for massive bleeding. Strate and colleagues have identified seven factors which, taken together, predict the severity of lower gastrointestinal bleeding, including tachycardia, hypotension, syncope, benign abdominal examination, rectal bleeding, aspirin usage, and the presence of greater than two significant comorbidities [7]. According to this model, the risk of severe bleeding, defined generally as a requirement for two units of

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_32

packed red blood cells and/or a decrease in hematocrit of 20 % or greater within the first 24 h after presentation, patients with four or more risk factors were classified as high risk (approximately 80 % were expected to experience severe bleeding), patients with one, two, or three risk factors were classified as moderate risk (approximately 43 % were expected to experience severe bleeding), and patients with no risk factors were classified as low risk, with an expected rate of severe bleeding less than 10 % [8]. Velayos and colleagues studied patients admitted with lower gastrointestinal hemorrhage in an acute care setting and found three factors noted within the first hour after initial presentation that were associated with severity of bleeding and adverse outcomes: abnormal vital signs (hypotension or tachycardia) 1 h after initial evaluation, initial hematocrit at or below 35 %, and gross blood on initial rectal examination [9].

Fortunately most patients who present with lower gastrointestinal hemorrhage will stop bleeding spontaneously without any procedural or surgical intervention; in some series, estimates range as high as 80–85 % [10]. Estimates of mortality from major lower gastrointestinal bleeding in the acute setting vary widely, with reported rates from 2.1 to 21 % in various case series [9, 11–13]. Higher mortality is seen in patients who initially present with lower gastrointestinal bleeding while already hospitalized for treatment of another condition; in this circumstance, reported mortality rises to about one in four [4].

Clinical Presentation

The clinical presentation of a patient with lower gastrointestinal bleeding can run the gamut from occult bleeding identified on a stool guaiac assay to frank, even profuse, bleeding per rectum. Alternative presentations include fatigue, syncope, anemia, abdominal pain, and hemodynamic instability [5]. In many cases a patient may report a history of bright red blood per rectum which occurs intermittently and may not be present to any degree at the time of the actual clinical examination. The majority of patients presenting with a complaint of hematochezia or melena will be clinically stable at the time of presentation, and a thorough and complete diagnostic workup can be performed.

In some cases, however, particularly in a patient presenting with significant hematochezia, there may be significant vital sign abnormalities and other evidence of physiologic derangement, such as electrolyte imbalances and/or altered mental status, evident at the time of presentation. In these patients, as with all patients presenting with instability in the acute care setting, the detailed, comprehensive workup is briefly and appropriately deferred while initial stabilization and resuscitation measures are instituted.

Diagnosis

The diagnostic algorithm pertaining to a patient with lower gastrointestinal bleeding will to some extent be dependent on the severity and acuity of presentation; a patient experiencing torrential lower gastrointestinal hemorrhage would of course represent a differing set of initial management priorities compared with a patient who reported intermittent bright red droplets of blood with defecation (Fig. 32.1). However, in the acute care setting, the initial management priorities for all patients would always prioritize ensuring hemodynamic stability and adequate resuscitation prior to more detailed evaluation and workup. If there is any concern that a patient presenting with a stable clinical picture is at risk of significant deterioration, the prudent clinician will establish intravenous access and have crystalloid and, possibly, blood products available to support resuscitation. If resuscitation is begun, a urinary catheter should be placed to monitor urine output as a marker for adequacy of resuscitation. For patients with known or suspected lower gastrointestinal bleeding, unless contraindicated, a nasogastric tube should also be placed to help rule out an upper gastrointestinal source. The presence of bilious nasogastric aspirate is an important indicator that upper gastrointestinal bleeding is unlikely; conversely, clear aspirate is not useful in eliminating upper gastrointestinal sources from the differential [14].

An important diagnostic caveat must be kept in mind in the evaluation of lower gastrointestinal bleeding, specifically that multiple sources of bleeding are not infrequently identified in this patient population. Among patients admitted in the acute care setting for lower gastrointestinal bleeding, the number of patients with multiple sources of hemorrhage is estimated at 4.4–40 % [6]. In a prospective study of patients presenting with a chief complaint of intermittent bright red blood per rectum, Graham and colleagues documented additional abnormal findings on colonoscopy in 27 % of patients with identifiable abnormalities on rectal examination [15]. The workup is therefore not complete once a single likely source of bleeding is identified; rather, optimal patient care dictates that a comprehensive evaluation be completed and other reasonably likely etiologies ruled out clinically. It should also be kept in mind that up to 15 % of cases of significant lower gastrointestinal bleeding can be traced to an upper gastrointestinal source [16]. Unless there is a specific contraindication, patients presenting with lower gastrointestinal bleeding should have a nasogastric tube placed to help rule out the possibility of an upper gastrointestinal source.

As with any clinical situation, a thorough evaluation must begin with a detailed history and physical examination. A relevant history for the evaluation of lower GI bleeding should, at a minimum, address the following areas:

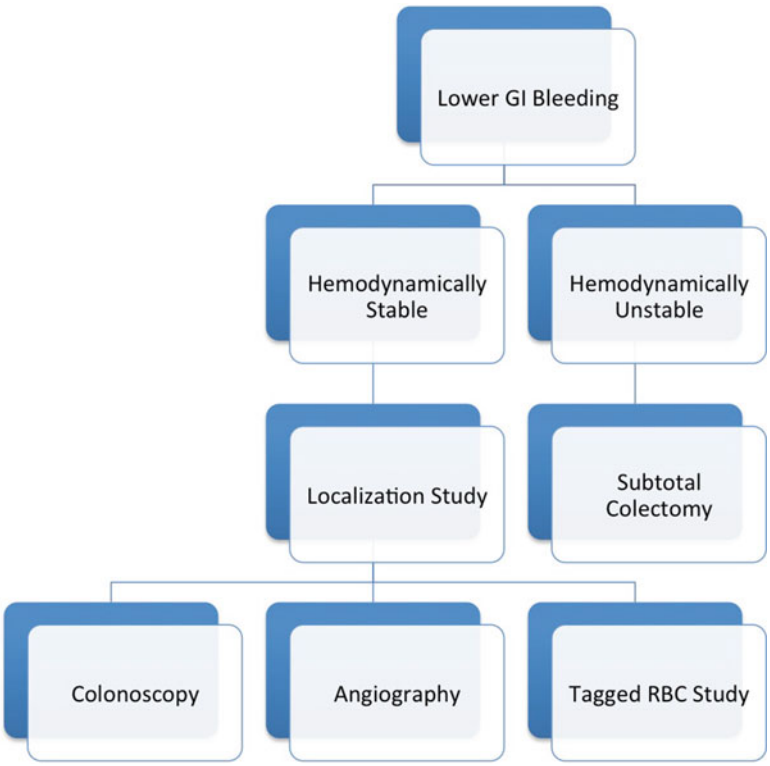

Fig. 32.1 Initial assessment of lower gastrointestinal bleeding

- Acute bleeding symptoms: What is the nature of the bleeding? Is the patient experiencing hematochezia or melena? While traditional clinical dogma holds that hematochezia signifies a lower gastrointestinal bleed while melena is indicative of an upper gastrointestinal source of hemorrhage, the clinical reality is frequently less clear-cut, and it is widely acknowledged that particularly brisk upper gastrointestinal bleeding can present with hematochezia. Is the bleeding continuous or intermittent? Most lower gastrointestinal bleeds are, in fact, intermittent in nature, making localization a true diagnostic challenge. How long has the bleeding been occurring? Has the patient experienced previous episodes of upper or lower gastrointestinal bleeding? Is there any pain associated with the bleeding?
- Possibly related systemic symptoms: Is the patient experiencing angina, palpitations, syncope of unusual fatigue? Does the patient report any fevers or chills? Is nausea or vomiting present? Is there associated diarrhea or constipation? Does the patient report a history of gastroesophageal reflux or antacid use? Has there been any recent unintentional weight loss?
- Relevant medical history: Has the patient previously experienced any type of upper or lower gastrointestinal bleeding? Any history of inflammatory bowel disease, diverticulosis, hemorrhoids, gastrointestinal neoplasm, liver disease? Does the patient report any history of gastric or duodenal ulcer? Is there a known history of atrial fibrillation or other cardiac dysrhythmia? Does the patient report a history of peripheral vascular disease or ischemia? Any history of hematologic disorders, including thrombocytopenia or clotting cascade abnormalities? Has the patient ever experienced a transient ischemia attack or stroke? Has the patient recently been treated with radiation therapy?
- Medication history, including both prescription and nonprescription agents as well as herbal preparations. Specific inquiry regarding warfarin, aspirin, NSAIDs, or other anticoagulant and antiplatelet agents is of obvious paramount importance.
- Health maintenance: Has the patient undergone any health screening that might reveal GI disease, such as fecal occult blood testing, flexible sigmoidoscopy, or colonoscopy? When were these studies done, and what were the results? Has the patient recently had a polypectomy performed?
- Family history: Any relatives with any form of cancer, particularly cancers of the gastrointestinal tract? Any relatives with a history of inflammatory bowel disease? Any record of hereditary coagulopathies or other hematologic abnormalities?
- Social history: Is there any history of alcohol and/or tobacco usage? Recent travel, particularly to less-developed countries or regions? Recent sick contacts?

A focused yet thorough physical exam is also indicated as a key element of the initial workup. Vital signs will often be within normal limits in the setting of a lower gastrointestinal bleed unless the rate of bleeding is so substantial as to cause a significant volume depletion effect; in that case, tachycardia would be observed somewhat earlier in the process as the initial phase of physiologic compensation, while hypotension and/or altered mental status would represent a later finding associated with the acute loss of greater than 15 % of circulating blood volume (class II or higher hemorrhagic shock) [17]. Any evidence of vital sign alteration due to blood loss should prompt immediate placement of large-bore peripheral access, if such has not already been established, and the institution of aggressive resuscitation with crystalloid or, in especially severe cases, blood products. In this circumstance, restoration and stabilization of volume status is the clinician's priority, and further detailed physical exam is accordingly briefly deferred until physiologic stability is achieved.

A generalized visual inspection of the patient should reveal any pallor, jaundice, or cachexia which might be present and associated with particular underlying conditions which could be associated with lower gastrointestinal bleeding. Abdominal examination should evaluate for generalized or focal tenderness, firmness or rigidity, any peritoneal signs such as guarding or rebound, organomegaly, and the presence of palpable masses. Presence of pain on abdominal exam generally argues in favor of an inflammatory process, while lower gastrointestinal bleeding due to diverticular disease or angiodysplasia is more commonly associated with a benign abdominal examination. Importantly, in the setting of a lower gastrointestinal bleed of unclear etiology, the examining clinician should perform a cardiac and peripheral pulse examination with particular attention to evidence of atrial fibrillation.

The rectal exam is among the most critical components of the physical examination in the patient with an acute lower gastrointestinal bleeding. A thorough and complete rectal exam should establish the presence or absence of gross blood, the existence of internal or external hemorrhoids or other perianal lesions including fistulae or fissures, and the presence and position of any palpable rectal masses. If no gross blood is apparent upon rectal examination, a stool guaiac test can be quickly performed in either the clinic or emergency department setting to establish the presence of occult gastrointestinal bleeding. Be aware, however, that sensitivity of this assay is relatively low [18], and is further reduced in patients who take iron supplements or who have recently consumed red meat or peroxidase-rich fruits and vegetables, and specificity is reportedly diminished if a patient's diet is rich in citrus fruits or other concentrated sources of vitamin C [19, 20].

Initial laboratory studies should be sent to aid in the immediate evaluation of both the etiology and magnitude of a lower gastrointestinal bleed. A CBC might be expected to reveal decreased hematocrit in a patient with an active GI hemorrhage; however, if the hemorrhage is of particularly acute onset, the intravascular volume may not yet be fully re-equilibrated and thus the hematocrit may be artificially elevated relative to true oxygen-carrying capacity. CBC would also be expected to reveal evidence of thrombocytopenia, albeit with the same caveat that a hyper acute process might not permit an adequate intravascular re-equilibration interval before the laboratory study is drawn. Presence of a significant leukocytosis on CBC should prompt further consideration of an infectious process as an inciting etiology versus an inflammatory or ischemic mechanism.

Basic laboratory studies of electrolyte status as well as hepatic and renal function may serve the dual purposes of elucidating underlying comorbidities which may contribute to a gastrointestinal bleed while also identifying physiologic imbalances which could potentially be corrected prior to a surgical or other procedural intervention. Likewise, routine evaluation of coagulation parameters in this patient population can both uncover underlying coagulopathies which may be contributing to the presenting problem and permit the practitioner to plan for a safer operation by preoperatively ordering products such as cryoprecipitate or fresh frozen plasma where appropriate. It should be noted that the routine administration of vitamin K to patients on chronic warfarin therapy should be avoided in the setting of a lower gastrointestinal hemorrhage due to the difficulty and delay this presents when attempting to re-establish therapeutic anticoagulation once the acute hemorrhagic episode has resolved [21].

Imaging may in certain cases play an important role in establishing a definitive diagnosis in a patient presenting with lower gastrointestinal bleeding. Most patients presenting with lower gastrointestinal bleeding who report concurrent abdominal pain in an acute care setting will typically receive plain film abdominal radiography. The information which can be gleaned from this study is, of course, somewhat limited; however, findings such as pneumoperitoneum or signs of closed-loop obstruction can help to narrow the differential diagnosis if they are, in fact, present on the study. However, most patients presenting with abdominal pain due to perforation or closed-loop obstruction will not typically report a complaint of hematochezia or melena; therefore, the utility of plain film abdominal radiography is of limited utility in the evaluation of lower gastrointestinal bleeding.

Most patients presenting in the acute care setting for lower gastrointestinal bleeding with concurrent abdominal pain will, if hemodynamically stable, be appropriate candidates for computed tomography (CT) scanning of the abdomen and pelvis, and this study can be somewhat more useful than plain film abdominal radiography. CT with oral and intravenous contrast can help to identify mass lesions, such as colorectal adenocarcinomas, as well as sites of inflammation or potential perforation, as is seen with acute diverticulitis or

inflammatory bowel disease. Bowel wall thickening or pneumatosis may also be noted in the case of an ischemia or hypoperfusion-mediated bowel injury; an acute thromboembolic process would be expected to demonstrate these types of pathologic changes within a discrete vascular territory, while a more global low-flow mechanism would be expected to generate corresponding diffuse bowel involvement. Patient history should be reviewed for mention of impaired renal function or radiographic contrast allergy; initial laboratory studies including BUN and serum creatinine should also be reviewed prior to contrast administration.

Ultimately a large proportion of patients undergoing workup for lower gastrointestinal bleeding will benefit from colonoscopy. In addition to its utility as a diagnostic modality for localizing the source of a lower gastrointestinal bleed, colonoscopic evaluation offers the advantage of potential therapeutic intervention during the course of the procedure. In the setting of acute lower gastrointestinal bleeding, the reported diagnostic utility of colonoscopy ranges between 45 % and 89 % [16, 19–25]. In a study by Church at al., the etiology of lower GI hemorrhage was found by colonoscopy in 70 % of cases [26]. Complications of colonoscopy in the acute care setting, most significantly perforation, can occur in up to 5 % of cases and in patients over 75 years old, the risk increases 4–6 fold compared to their younger counterparts [27].

The utility of colonoscopy in the acute care setting is influenced by a number of factors including the quality of bowel preparation prior to the procedure, the rate of active bleeding (very slow bleeds may be below the diagnostic threshold of the procedure, while very brisk bleeding may impair adequate visualization and source localization), whether or not the bleeding is continuous or intermittent, the skill and experience level of the endoscopist, and questions pertaining to resource availability. Additionally, not all medical facilities have 24-h availability of this procedure; if the patient is experiencing a clinically significant bleed and there will be a considerable delay prior to availability of colonoscopy, other diagnostic and treatment modalities may need to be preferentially considered, in addition to consideration of transfer to a center where these modalities are available.

The quality of bowel preparation which can be achieved prior to colonoscopy has a clear influence on the success of the procedure from both a diagnostic and therapeutic perspective. However, lack of bowel preparation does not preclude the successful use of endoscopic techniques in the diagnosis and treatment of lower gastrointestinal bleeding. In fact, some clinicians report that lower gastrointestinal bleeding actually acts to help purge the colon, and any impaired visualization on colonoscopy can be addressed via flushing the scope during the procedure, although diagnostic yield in this circumstance is only about 35 % [25]. If a routine oral electrolyte-polyethylene glycol prep solution is administered prior to colonoscopy in the setting of an acute lower gastrointestinal bleed, improved diagnostic yields, in some cases approaching 80 %, are reported [28].

If colonoscopy is performed on the patient with acute lower gastrointestinal bleeding and a definitive hemorrhage source is identified, therapeutic options including sclerotherapy via direct epinephrine injection in a 1:10,000 concentration, bipolar or monopolar coagulation, or endoscopic clip application, may be utilized during the procedure. Jensen and colleagues directly compared urgent colonoscopic intervention versus surgical treatment in a prospective study of patients with severe diverticular bleeding; this study demonstrated comparable efficacy for colonoscopic intervention in comparison with surgery [29]. In a recent study, early vs delayed colonoscopies were performed in lower gastrointestinal bleeding; early being within 24 h of identification and delayed being after 24 h. While there was no difference in mortality between patients receiving an early vs delayed colonoscopy, but in the early cohort, they had a shorter length of hospital stay, a decreased need for blood transfusions, and lower hospital costs [30].

In cases where resource issues or other patient factors make colonoscopy an unsuitable clinical option at a particular point in time, flexible sigmoidoscopy is sometimes utilized for visualization of the distal lower gastrointestinal tract. In cases in which a hemorrhagic lesion is identified within this segment of the colon, sigmoidoscopy can prove to be a valuable clinical adjunct for both diagnostic and treatment purposes. However, keeping in mind that a significant proportion of patients with distal lesions are also found to have more proximal sources of hemorrhage [15], performance of flexible sigmoidoscopy does not obviate the requirement for a more thorough examination via a complete colonoscopy at a later point in time.

If an anorectal source of bleeding is evident on exam or is suspected based on the clinical history and patient presentation, anoscopy is another tool which may be utilized to facilitate direct visualization and examination of hemorrhoids, anal fissures, fistulous tracts, or distal stercoral ulcers. Again, the same caution applies to this patient population as applies to patients undergoing flexible sigmoidoscopy, namely that identification of a distal lesion as a source of lower gastrointestinal hemorrhage does not in any way preclude the existence of a more proximal lesion. Therefore, it is advisable that these patients also be scheduled for a complete colonoscopy at a later date.

While colonoscopy is generally the preferred initial investigation in evaluation of lower gastrointestinal bleeding [16, 31], if colonoscopy is unavailable or is otherwise an inappropriate or impractical choice in a specific clinical situation, angiography is another modality that offers the advantage of both diagnostic specificity and therapeutic intervention. The most commonly reported sensitivity threshold for visceral angiography in the detection of active gastro-

intestinal bleeding is approximately 0.5 ml/min [32, 33]. Hemorrhage at a rate significantly below this is unlikely to be detected through angiography. Angiography is also less able to detect venous bleeding, intermittent bleeding, and bleeding from very small vessels. Finally, angiography is associated with potentially serious complications, including hemorrhage at the catheter insertion site, arterial dissection, microembolization, pseudoaneurysm formation, puncture site infection, allergic reaction to contrast, and contrast-induced acute renal failure [22, 34].

Reported success rates for angiography in the localization of lower gastrointestinal bleeding vary widely, with recent studies citing rates between 30.5 % and 86 % [35]. If angiography is able to detect a discrete bleeding source, a number of therapeutic interventions are possible, including embolization therapy as well as direct injection of vasopressin or sclerosant agents at the site of bleeding. Of course, angiographic capabilities are not available universally on a 24-h basis at all acute care facilities. If there will be a significant delay in the availability of angiographic capability, other diagnostic and treatment modalities may be more appropriate if the bleeding is particularly brisk or the patient is otherwise unstable or marginally stable.

Radionuclide scintigraphy is yet another diagnostic modality for identification of the site of hemorrhage in a patient presenting with lower gastrointestinal bleeding. This technique can utilize either technetium-99m sulfur colloid or technetium-99-m-labeled red blood cells. The latter technique, commonly referred to as a tagged red blood cell (TRBC) scan, is more commonly employed. Sulfur colloid scanning has the advantage of relative ease of preparation in comparison with preparation of tagged red blood cells. Sulfur colloid also clears quickly, however, in comparison with the longer half-life seen with tagged red blood cells; by implication, the greater longevity of the blood cell-tagged tracer allows for repeat scanning following a single infusion. This would suggest that the TRBC scan might have greater sensitivity in detection of a bleeding source, although in actual clinical practice the detection rates appear quite similar [36].

Radionuclide scintigraphy is able to identify bleeding at rates as low as 0.1 cc/min [37]. Thus, the tagged red blood cell scan is of greatest utility in identifying slow bleeds that are not localizable via other diagnostic techniques. Ng and colleagues evaluated the question of whether time to positive radionuclide scan ("blush") correlates with, and can be used to predict, the yield on angiographic intervention. In their series, 60 % of patients with an immediate appearance of blush on radionuclide scan subsequently underwent a positive angiogram. Among patients in whom no blush had appeared after two minutes, only 7 % had a positive angiogram [38]. While sensitivity of the tagged red blood cell scan can surpass either colonoscopy or angiography in the setting of active bleeding and the technique can be used to predict which patients will benefit from angiogram, radionuclide scanning does have the significant disadvantage of representing a diagnostic modality only, with no capability for direct therapeutic intervention. Additionally, radionuclide scanning will not allow for precise localization of bleeding. It is difficult to plan operative intervention based on the results of a scan. Furthermore, 27 % of patients who undergo a negative radionuclide study will experience recurrent lower gastrointestinal bleeding at a later date [39].

It must be noted that despite the most thorough diagnostic evaluation and the utilization of the most sensitive imaging and diagnostic modalities, bleeding will cease spontaneously and no definitively identified source of lower gastrointestinal bleeding will ever be identified in a significant proportion of patients, ranging from 10.7 to 22.8 % in various series [4, 24, 40–42]. However, it must be emphasized that a thorough workup which fails to identify a definitive source of bleeding is not without benefit to the patient in that a number of potentially serious causes of lower gastrointestinal bleeding, such as colorectal adenocarcinoma, can be effectively eliminated from the differential after the workup is completed.

Management

It is estimated that in the majority of cases, lower gastrointestinal bleeding will cease without any therapeutic intervention, with some estimates of the percentage of patients achieving spontaneous cessation of bleeding ranging as high as 70–85 % [8, 9]. Re-bleeding is not uncommon, however, occurring in up to 25 % of cases[43]. Thus, the absence of active bleeding at a particular point in time should not preclude definitive evaluation and treatment of the underlying condition (Table 32.1).

As might be expected, severe, persistent hemorrhage is the clinical presentation of lower gastrointestinal bleeding which most frequently requires surgical management.

Table 32.1 Treatment options in lower GI bleeding

Etiology	Treatment options
Diverticular disease	Resection +/– anastomosis
	Angiography with embolization
Angiodysplasia	Colonoscopy with hemostatic maneuvers
	Angiography with embolization
	Resection +/– anastomosis
Ischemic colitis	Resuscitation and antibiotics
	Resection with diversion
Infectious colitis	Resuscitation with antibiotics
	Resection +/– anastomosis
Hemorrhoids	Anoscopy with resection
Neoplasm	Resection +/– anastomosis
Radiation proctitis	Intraluminal steroids
	Colonoscopy with hemostatic maneuvers

General indications for surgery include continued hemodynamic instability despite adequate resuscitation, requirement for transfusion of four or more units of packed red blood cells over 24 h, or severe recurrent bleeding [32]. Among patients who require any blood transfusion for management of lower gastrointestinal bleeding, approximately one in four will ultimately require surgery [44]. The operative procedure of choice is a segmental resection for those patients in whom a hemorrhage source can be localized [45]; this approach is associated with the greater success in control of bleeding and lower morbidity in comparison with the primary surgical alternative, subtotal colectomy [16].

In the event efforts at localization are unsuccessful, as is the case in 8–12 % of cases of lower gastrointestinal hemorrhage in the acute care setting [28, 46], a subtotal colectomy may be required to establish definitive control of bleeding [32]. Patients who undergo total colectomy for control of lower gastrointestinal hemorrhage are at risk for considerable morbidity and mortality; overall mortality in this circumstance is between 10 % and 20 %, and those individuals with a transfusion requirement of ten or more units are subject to a mortality rate approaching 50 %, likely mirroring the severity of underlying illness [47].

Given that a lower gastrointestinal bleed may result from a broad range of clinical conditions ranging from acute infectious processes to hemorrhoids to cancer, the ultimate management of this patient population will be obviously dependent on the underlying diagnosis. However, there are general principles which should be applied to the initial management of all patients presenting with this clinical complaint.

Diverticular disease (Fig. 32.2) is the most frequently cited etiology for lower gastrointestinal bleeding in which a definitive source is identified, accounting for approximately 40–55 % of all cases of lower gastrointestinal bleeding in the acute setting [4, 22]. The pathophysiology of bleeding due to diverticular disease is thought to relate to stretching and weakening of the vasa recta at the site of a colonic diverticulum. Diverticula are typically multiple. Diverticulosis is more commonly found in the left colon, in particular the sigmoid colon [32], but, curiously, diverticular bleeds are more commonly localized to the ascending colon [48]. Approximately one in six patients with diverticular disease will experience some degree of bleeding [32].

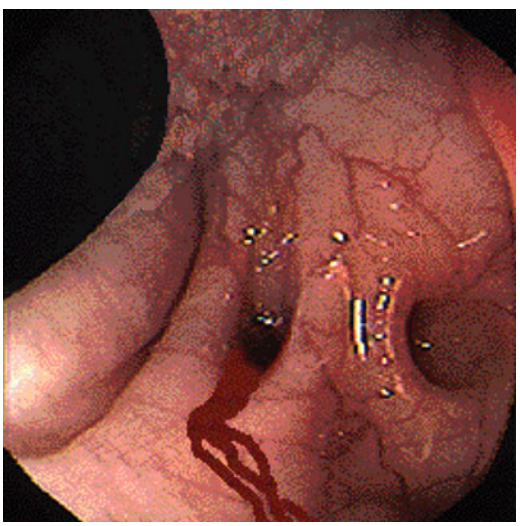

Fig. 32.2 Bleeding diverticulum

It is worth noting that lower gastrointestinal bleeding related to diverticular disease can occur within the setting of acute diverticulitis, but an acute episode of diverticulitis is by no means a prerequisite to bleeding at the site of colonic diverticula. Although it might seem intuitively that the inflammatory changes associated with an episode of acute diverticulitis might be expected to increase the risk of acute hemorrhage at the site of a diverticulum, it appears that most bleeding related to diverticular disease occurs outside the setting of acute diverticulitis. For unclear reasons, the hemorrhage is almost exclusively into the bowel lumen rather than into the extraluminal tissues [49].

Patients with active diverticular hemorrhage typically present in the acute care setting with painless, often brisk hematochezia and, in many cases, physiologic evidence of significant blood loss. The typical patient will be an older adult; diverticular bleeding is highly unusual in patients under the age of 40, but incidence rises in correlation with advancing age. Regular use of non-steroidal anti-inflammatory drugs (NSAIDs) is also correlated with increased likelihood of diverticular bleeding [50]. Ultimately only a minority of patients with diverticular disease will experience bleeding, and of those patients who experience diverticular hemorrhage, spontaneously resolution of bleeding will occur in approximately 75–80 % [11, 51]. However, re-bleeding is common. In some reports, the rate of first re-bleed is estimated at 25–30 %; once a first re-bleed has occurred, the risk of subsequent re-bleeding ranges as high as 50 % [48].

The management of diverticular disease is dependent on several factors, including the severity of bleeding at presentation, whether or not the patient is experiencing a concurrent episode of acute diverticulitis, and the patient's history of previous episodes of diverticular bleeding and/or diverticulitis. History, physical examination, vital sign, and laboratory parameters which might suggest a concurrent diverticulitis include significant abdominal pain, tenderness to palpation, rebound, or guarding, fever, and leukocytosis. Symptoms are commonly, although not universally, focal to the left lower quadrant [52]. Computed tomography imaging may also reveal inflammatory changes either localized to the involved area of the colon or, in the case of higher-grade diverticulitis, more diffuse abdominal involvement; limited or generalized pneumoperitoneum may also be apparent.

A diverticular bleed in the absence of the acute inflammatory changes seen in diverticulitis is generally well suited to an initial attempt at evaluation and treatment via colonoscopy. If bleeding is ongoing and of sufficient rate to be above the detection threshold, colonoscopy can localize the bleeding site and endoscopic treatments can be undertaken with a goal of achieving hemostasis. In patients with a history of recent diverticular bleeding who do not appear to be actively bleeding at the time of examination, colonoscopic evaluation is nonetheless worthwhile because in many, though by no means all, instances the stigmata of recent bleeding, including adherent clots and visible vessels [32], can be readily identified.

In the setting of acute diverticulitis, colonoscopy is generally contraindicated due to the acute inflammation and perforation associated with this diagnosis. For hemodynamically stable patients experiencing lower gastrointestinal bleeding concomitant with acute diverticulitis, the diverticulitis is usually managed as the primary clinical priority in accordance with evidence-based standards of care. Milder cases are generally managed with a regimen of bowel rest, appropriate antibiotics, and serial abdominal examinations. More severe cases, especially those characterized by evidence of purulent or feculent peritonitis (i.e., Hinchey grade III or IV disease), will more commonly be managed via exploratory laparoscopy or laparotomy with washout and possible resection of the involved colonic segment. Surgical resection is also indicated for patients experiencing recurrent lower gastrointestinal hemorrhage due to diverticular disease; this represents a significant portion of patients with diverticulosis. In some studies, the overall incidence of recurrent diverticular bleeding in patients who had previously been hospitalized for this problem was 10 % at 2 years and 25 % at 4 years [4].

If bleeding is severe in a patient with acute diverticulitis, angiography might be attempted as a reasonable option for localization of the hemorrhagic site and establishment of hemostasis. In the event angiographic intervention is not feasible or is unsuccessful, surgical exploration and possible segmental colonic resection may be required to control bleeding regardless of the severity of the acute diverticulitis. Approximately 5 % of patients admitted for diverticular bleeding ultimately require surgical intervention [53]. Such resection may be performed via either laparoscopic technique or standard open incision based on surgeon preference and experience. Surgical resection is also the standard of care after a second significant diverticular bleed given the high (approximately 50 %) risk of subsequent re-bleeding [2, 54].

The question of primary anastomosis at the time of initial bowel resection depends in part on whether or not the patient is experiencing active and extensive diverticulitis-mediated inflammation; if such is not present, as is true in the majority of cases, primary anastomosis of the remaining viable bowel is generally deemed safe and appropriate. If active inflammation is present to a considerable extent, however, the surgeon may reasonably elect to perform a diversionary ostomy procedure with a plan for deferred anastomosis to take place once the acute inflammatory changes have resolved.

Angiodysplasia is a common discussed cause of lower gastrointestinal bleeding. The frequency of colonic angiodysplasia as a cause of lower GI hemorrhage varies between 3 % and 40 % and it can be mild, chronic, recurrent and can stop spontaneously in up to 90 % of patients; nonetheless, it can also be life threatening [55]. The actual incidence is, surprisingly, fairly low, accounting for about 2.7 % of acute care hospital admissions for lower gastrointestinal bleeding, with age-specific bleeding rates showing a strong, positive correlation [4, 56]. Angiodysplasia is a broad term variously used to refer to the group of related lesions encompassing arteriovenous malformations, vascular ectasias, and angiomas [48]. The pathophysiology is thought to relate to normal age-related degeneration of smaller venous structures located within the gastrointestinal submucosa; angiodysplastic bleeding is therefore seen mostly in older patient populations. Boley and colleagues have hypothesized that the lesions arise largely due to chronic, low-grade obstruction of the submucosal venous system [57]. The cecum is the most common site of angiodysplastic lesions [32]. There appears to be a possible correlation between angiodysplastic lesions and aortic stenosis and/or renal failure; however, there is no strong evidence to suggest a causative relationship [56, 57].

The bleeding associated with angiodysplastic lesions often presents as a history of intermittent, painless bright red blood per rectum. In most circumstances, angiodysplasia-associated bleeding is subtle and may not be noted overtly by the patient; in these cases, signs and symptoms of anemia may be the only evidence pointing to a gastrointestinal bleed, and angiodysplasia may be discovered as part of a broader workup. In approximately 15 % of cases, however, angiodysplasia can present with significant hemorrhage [48]. Abdominal pain is infrequently associated with bleeding due to angiodysplasia, and a complaint of significant abdominal pain in a patient with known angiodysplasia should prompt a thorough workup for other diagnoses.

While angiodysplastic bleeding is estimated to cease spontaneously in roughly 90 % of cases [55], the majority of patients who present with one angiodysplastic bleed will bleed again, and many patients with angiodysplastic bleeding will eventual undergo complete workup [48]. Colonoscopy is the diagnostic and therapeutic modality of choice in the treatment of acute lower gastrointestinal bleeding due to angiodysplasia. The lesions have a characteristic stellate, bright red appearance on colonoscopic examination which facilitates ready identification. Although the right colon, in particular the cecum, is known to be the most frequent site of bleeding angiodysplastic gastrointestinal lesions [55] as might be expected given the higher wall tension in this area of the bowel, the systemic factors leading to the

development of a single angiodysplastic lesion frequently contribute to the occurrence of multiple similar lesion; a complete colonoscopic evaluation is therefore warranted to rule out other actively bleeding sources.

Angiography is sometimes used in the identification and treatment of bleeding angiodysplastic lesions. While angiography enjoys an overall greater diagnostic sensitivity in comparison with colonoscopy in identifying sources of lower gastrointestinal bleeding, angiography is thought by some authors to be somewhat less sensitive in identifying and treating the small venous lesions which are characteristic of angiodysplasia; other studies cite increased sensitivity for angiography versus colonoscopy in this setting [58]. Overall, most patients with angiodysplastic bleeding are diagnosed and treated via colonoscopy. Endoscopic treatments include electrocautery, laser, and heater probe as well the increasingly well-studied argon plasma coagulation (APC) technique. APC appears to be well tolerated and associated with fewer complications and lower risk of re-bleeding [21, 59]. Because of the documented explosive risk associated with the APC in this setting, a complete bowel prep is strongly recommended prior to utilization of this treatment modality [60, 61].

In some instances a patient with a history compatible with angiodysplasia-mediated lower gastrointestinal bleeding may present for evaluation in the interim period between active bleeds; in this circumstance, localizing the culprit lesion or lesions may prove to be difficult or impossible. The patients should be warned that angiodysplastic lesions are likely to re-bleed in a significant majority of cases (up to 80 % in some series) [62] and that timely evaluation in the event of a re-bleed may greatly increase the likelihood of successful identification and treatment of the lesion in question. Colon resection is generally employed as a last resort when recurrent angiodysplastic bleeding is unable to be controlled through colonoscopic treatment or angiography [16].

Bleeding secondary to colonic ischemia or hypoperfusion, termed ischemic colitis, is a not infrequently encountered clinical entity and should be entertained in the differential diagnosis for any patient presenting with lower gastrointestinal bleeding, particularly bloody diarrhea, and abdominal pain. Often the presentation will include the classic "pain out of proportion to physical exam" commonly associated with intestinal ischemia. In large series of patients admitted for lower gastrointestinal bleeding in the acute care setting, 8.7–11.8 % were ultimately attributed to ischemic colitis [4, 63]. Typically hemorrhage is a relatively minor component of the clinical presentation and blood loss is not of sufficient magnitude to independently affect hemodynamic stability [16]. Although acute mesenteric ischemia can also present with a similar clinical picture, colonic ischemia is in fact considerably more common secondary to the relatively poorly collateralized vascular supply to the colon in comparison with the small bowel.

As would be expected physiologically, those areas with the most poorly collateralized vascular supply are at highest risk for colonic ischemia, and clinical experience demonstrates that these areas, namely the ascending colon, splenic flexure, and rectosigmoid junction, are most commonly implicated as bleeding sources in the case of ischemic colitis. Conventional wisdom has held that Griffith's point is the single most common site of ischemic colitis, but rigorous investigation has failed to support this contention [64]. The diagnosis of ischemic colitis can typically be readily confirmed via colonoscopy; characteristic findings include mucosal edema, erythema, mucosal necrosis, and hemorrhage with a clearly demarcated boundary between involved and uninvolved regions of bowel, reflective of the underlying vascular distribution [22, 65].

The pathophysiology of ischemic colitis relates to a broad range of underlying etiologies which may be responsible for an acute hypoperfusive state experienced by all or part of the large bowel, including many cardiovascular issues, recent administration of vasopressors, thromboembolic disease or known hypercoagulability, or disease processes leading to generalized hypovolemia. Fernandez and colleagues conducted a logistic regression analysis which identified diabetes, dyslipidemia, heart failure, peripheral arterial disease, and treatment with digoxin or aspirin as variables independently associated with the development of ischemic colitis [66]. Another large series analyzed found that a majority of ischemic colitis patients reviewed had been receiving vasoactive drugs prior to development of the condition [65]. However, in many cases no specific underlying cause can be pinpointed accurately.

Fortunately in most patients with ischemic colitis the condition resolves with conservative management and surgical intervention is not required [22]. Antibiotic therapy should be utilized in patients meeting sepsis criteria. If conservative measures fail and colonic ischemia appears to be progressing to the point of irreversible bowel compromise, as evidenced by increasing abdominal pain and distention, peritoneal signs, rising lactate, and pronounced leukocytosis, surgical resection of the involved bowel segment is indicated [32]. This is reported to occur in approximately 15–22 % of all cases of ischemic colitis, and is associated with significant mortality [65, 67]. O'Neill et al. identified four factors—ischemia localized to the right colon, guarding on physical exam, lack of bleeding per rectum, and a history of chronic constipation—as having a statistically significant association with severe ischemic colitis, defined as patients who either requiring surgical intervention and/or died from the disease process [68].

The physiologic process driving ischemic colitis is diffuse rather than focal, and, as such, endoscopic and angiographic treatment modalities are not well suited to the management of this condition. In cases in which the extent of bowel compromise is uncertain, prior to proceeding to open

laparotomy and extensive bowel resection, some surgeons elect to perform a colonoscopy or diagnostic laparoscopy to directly evaluate bowel viability by visual inspection. If bowel resection is performed, the resection corresponds with the vascular territory involved, and primary anastomosis of the remaining viable tissue is usually achievable at the time of the initial operation. Patients who undergo surgery for ischemic colitis have overall higher mortality versus medically managed patients, but this seems reflective of a more severe disease process in these individuals as evidenced by variables including serum lactate, acute renal failure, duration of vasoactive drug administration, and requirement for mechanical ventilation [67, 69].

Another etiology of lower gastrointestinal bleeding which can present similarly to ischemic colitis is hemorrhagic colitis of infectious origin. There are several commonly recognized infectious agents which can present with bloody diarrhea and associated abdominal pain, including Campylobacter, Clostridium difficile, Escherichia coli O157:H7, Histoplasma, Salmonella, Shigella, and Yersinia. Recent research has investigated strains of Klebsiella oxytoca linked to antibiotic-associated hemorrhagic colitis [70]. Cytomegalovirus is also recognized as a relatively common cause of bloody diarrhea in immunocompromised individuals. Workup for infectious etiology would be dictated in large part by patient history, with a focus on possible foodborne or waterborne exposures, development of diarrhea antecedent to lower gastrointestinal bleeding, recent antibiotics administration in the case of C. difficile or K. oxytoca, and any history of immune system compromise. If colonoscopy is performed for diagnostic purposes, characteristic pseudomembranes are typically seen in cases of C. difficile colitis. However, it is unusual for colonoscopy to be utilized as the primary diagnostic modality in cases of infectious colitis. Instead, laboratory assays are available to identify the presence of each of these pathogens, and timely administration of the appropriate pathogen-specific antimicrobial or antiviral agents constitutes the cornerstone of treatment. Adjunctive treatment is largely supportive in nature, and surgical intervention is not generally required for colitis of infectious origin. A notable exception is the development of toxic megacolon in the setting of C. difficile-associated colitis; this fulminant colitis frequently necessitates urgent or emergent colectomy.

Hemorrhoids represent another significant source of lower gastrointestinal bleeding, about 5 % of all lower gastrointestinal bleeds evaluated in the acute care inpatient setting [4], and represent the majority of cases evaluated in the ambulatory outpatient setting [32]. Among younger adult patients, hemorrhoids represent by far the most common etiology for the complaint of bright red blood per rectum. While many patients with hemorrhoids will report only intermittent rectal bleeding in small amounts, in some cases hemorrhoidal bleeding can be fairly profuse and can result in clinically significant blood loss. While many patients may report typical hemorrhoidal symptomology such as anorectal pruritis, pain, a sensation of rectal fullness, and/or a history of constipation and pain with defecation, some patients with hemorrhoids are entirely asymptomatic except for bleeding. Therefore, hemorrhoids need to be ruled out on physical examination in any patient with lower gastrointestinal bleeding, regardless of the presence of typical hemorrhoidal symptoms.

Anoscopy is generally considered the diagnostic modality of choice in the detection and evaluation of hemorrhoids, with detection rates superior to flexible sigmoidoscopy [71]. This examination may be able to be performed in the clinic or emergency department, but in some cases patient discomfort may preclude effective examination. If hemorrhoidal disease is highly suspected, some surgeons prefer to perform examination under general anesthesia in the operating room; an advantage of this approach is that a full range of therapeutic interventions may be undertaken during the course of the same operation. However, it should be noted that surgical intervention is not, as a rule, required for the management of most hemorrhoidal bleeding, and most patients with this complaint will respond well to conservative measures such as Sitz baths, stool softeners, and increased dietary fiber [72]. Where conservative medical management fails, the most common treatment modalities are endoscopic band ligation, sclerosant injection, cryotherapy, electrocautery, and laser photocoagulation [73]; among these options, band ligation appears to offer the greatest efficacy [74].

Absolute indications for endoscopic or surgical therapy in patients with hemorrhoidal bleeding include hemodynamically significant hemorrhage as well as persistent lower-volume bleeding that is unable to be controlled through conservative measures. It should also be noted that, as with all patients presenting with a lower gastrointestinal bleed, multiple concurrent sources of bleeding may be present. In particular in patients with hemorrhoidal bleeding over age 40 or with any evidence of elevated risk for colorectal adenocarcinoma, a colonoscopy should be performed to rule out concurrent malignancy. It is not mandatory that this study be carried out in the acute care or emergency setting, but rather the patient can be scheduled for colonoscopy on an outpatient basis several weeks after the acute lower gastrointestinal bleeding issue has been addressed.

Other anorectal lesions may also present with bleeding, including anal fissure and fistula-in-ano. Patients with anorectal fissure may present with complaints of anal pain, particularly with defecation, and small amounts of bright red blood per rectum. It is unusual for there to be profuse bleeding due to anal fissure, and large volume blood loss in a patient with anal fissure should prompt a thorough search for an alternate, concurrent etiology. Anal fissure is frequently readily detectable on basic physical examination; anoscopy

can also prove to be an important diagnostic adjunct in this circumstance [16]. In almost all cases anal fissure will respond well to conservative management and surgical intervention will not be required to control bleeding.

Stercoral rectal ulcerations may also cause significant rectal bleeding if the ulcerative lesion erodes into a major blood vessel; in some cases, the blood loss from this etiology can be of sufficient magnitude to affect hemodynamic stability. The most common pathophysiology of stercoral ulceration relates to severe constipation and fecal impaction; patients will typically report a significant prior history of constipation. Plain film and CT imaging in this case will often reveal a considerable stool burden, and these patients are obviously at risk for stercoral perforation elsewhere in the lower gastrointestinal tract.

If stercoral ulceration has not yet progressed to bowel perforation, endoscopic therapy can be employed for both diagnostic and therapeutic purposes. The ulcers have a sharp, nodular border with associated edema and erythema; treatment consists primarily of thermal probe application, often with concomitant injection of epinephrine [75]. In cases of profuse hemorrhage due to stercoral perforation, most patients will typically require surgical correction as well as aggressive peritoneal irrigation to reduce the burden of contamination. Of course, as with all hemorrhaging patients, every effort should be made to adequately resuscitate and stabilize the patient prior to surgery.

There are a number of less common causes of lower gastrointestinal bleeding which may be seen in an acute care setting. Rectal and/or anal trauma may, depending on mechanism, result in hemodynamically significant hemorrhage; trauma to adjacent structures (e.g., pelvic fractures) may also result in lower gastrointestinal bleeding if bone fragments disrupt the bowel wall. In major traumas, the digital rectal examination performed on blunt trauma patients as part of the ATLS trauma management protocol provides an initial screen for gross blood and obvious deformities which could indicate penetration or disruption of the bowel wall. However, this examination is typically performed quickly as part of the overall initial trauma patient assessment and may well overlook more subtle injuries. Practitioners caring for trauma patients who undergo imaging which reveals significant damage to adjacent structures, particularly pelvic fractures, should prudently maintain a high index of suspicion for involvement of adjacent bowel, particularly if laboratory studies demonstrate evidence of ongoing blood loss and no other more obvious source of hemorrhage is identified. These types of bleeds may be amenable to angiographic intervention if they fail to stop spontaneously.

Some patients with anal or rectal trauma may not be evaluated in the context of a formal trauma evaluation, for example patients presenting with an isolated complaint of rectal foreign body; however, the risk of vascular injury in these patients, with associated hemorrhage, remains a real possibility that must be taken into consideration in the overall clinical evaluation. While angiography remains a possibility for control of refractory bleeding in this setting as well, in the setting of a foreign body which requires surgical intervention for extraction, the patient may be best served by having both issues, the foreign body and the hemorrhage, addressed during the same trip to the operating room.

Inflammatory bowel disease, including both Crohn's disease and ulcerative colitis, occasionally present with lower gastrointestinal bleeding in the acute care setting, most commonly as bloody diarrhea [16]. However, more commonly these disease entities present with a history of abdominal and/or anorectal pain, recurrent diarrhea, and, frequently, unintentional weight loss. Massive hemorrhage is unusual in the setting of inflammatory bowel disease, occurring in up to 6 % of patients with inflammatory bowel disease [76, 77], while occult blood loss is considerably more common. In most cases gastrointestinal blood losses in patients with Crohn's disease or ulcerative colitis are managed via treatment aimed at controlling the underlying inflammatory pathology. Lower gastrointestinal bleeding due to inflammatory bowel disease stops spontaneously in about half of patients [76], but roughly one third of these patients will experience recurrent bleeding [32]. For this reason, most surgeons will recommend resection after one episode of significant lower gastrointestinal bleeding in this clinical setting. Total abdominal colectomy is the standard operation in this setting unless the rectum is the source of major bleeding, in which case coloproctectomy would be performed [16].

Neoplasia is overall a relatively less common cause of overt lower gastrointestinal hemorrhage; however, in one large series benign adenomatous polyps and colorectal malignancies accounted for 7.8–9.1 % of all admissions for lower gastrointestinal bleeding in an acute care setting [78]. More typically, bleeding related to colorectal neoplasm will be low-grade and chronic; often the only indication of bleeding in these patients is the development of an otherwise-unexplained anemia. This type of bleed may also be detected on a routine screening fecal occult blood test. Although most cases of lower gastrointestinal bleeding are not associated with a neoplastic process, it is critically important to rule out this potentially very serious etiology in the workup of these patients. Hence, the importance of full colonoscopic examination in most patients with presenting with lower gastrointestinal bleeding, even those in whom an "obvious" explanation for the lower gastrointestinal bleed is readily apparent earlier in the diagnostic workup. Possible exceptions to this requirement for full colonoscopic examination are few, likely limited to patients under age 40, with obvious benign etiology for lower gastrointestinal bleeding, without any history or physical exam findings suggestive of neoplasm, such as change in stool caliber or palpable abdominal

mass, and without any risk factors for colorectal adenocarcinoma, including family history of gastrointestinal or related cancers or hereditary cancer syndromes.

Radiation proctitis/colitis is another unusual cause of lower gastrointestinal bleeding. This diagnosis will be either included or excluded from the differential on the basis of a thorough and accurate patient history, with special attention given to any history of prostate, rectal, bladder, cervical, or uterine cancer for which the patient was treated with radiation therapy. Confirmation is obtained in the context of the appropriate clinical history via endoscopic examination which demonstrates friable mucosa with telangiectatic lesions [22, 32]. Bleeding due to this etiology is typically lower-grade and chronic [21], and massive hemorrhage secondary to radiation proctitis/colitis is unusual, although not unheard of [22]. Nevertheless, this diagnosis must be kept in mind for that portion of the patient population who possess the appropriate history. Conservative therapy, including rectal steroids, rectal sucralfate, and short-chain fatty acid enemas [79], is successful in controlling bleeding due to this etiology in many instances. If conservative therapies fail, endoscopic applications including argon laser [80], argon plasma coagulation [81], and electrocautery are commonly employed to achieve hemostasis.

Clinically significant bleeding can also occur after recent polypectomy, and estimates of the frequency of this complication range from 2.2 % to as high as 6.1 % [82, 83]. Post-polypectomy bleeding can be either immediate or delayed. If immediate, the bleed is usually noted by the endoscopist and appropriate treatment, via either direct pressure on the residual polyp stalk, epinephrine injection, electrocautery, or clip application, is provided at that time. In other cases, bleeding after polypectomy may be delayed for up to one month after the procedure [16, 21, 84]. Use of aspirin and NSAIDs prior to the procedure does not appear to increase bleeding risk [82, 84], although warfarin therapy, even at non-supratherapeutic INR, is correlated with an increased risk [82]. Bleeding will typically cease spontaneously. If bleeding is persistent, standard endoscopic interventions (epinephrine, cautery, or clipping) are general first line therapy [85]. If the hemorrhage proves difficult or impossible to control, or the patient demonstrates signs of hemodynamic instability, urgent surgical intervention may be called for.

Complications

A number of diverse complications can arise in the treatment of patient with lower gastrointestinal bleeding, reflective of the diverse range of underlying etiologies which can contribute to this condition. Each potential treatment modality carries distinct risks which are well documented. While conservative management is often the least "risky" clinical strategy, it can only be considered as such for the appropriately selected patient population. In an acute care setting, patients with significant lower gastrointestinal bleeding may require considerably more aggressive intervention to avoid significant risk of morbidity and mortality.

Patients undergoing colonoscopy for either diagnostic or therapeutic purposes in the setting of lower gastrointestinal bleeding are at risk for bowel perforation during the procedure, in some series up to 3 % [86]. This risk is likely elevated in the setting of significant inflammatory pathology. Intuitively, it seems logically that perforation risk would also rise in the setting of brisk bleeding which might compromise effective visualization of the bowel wall during the procedure.

Angiography carries its own set of unique risks, including development of hematoma, pseudoaneurysm, or uncontrolled bleeding at the puncture site. There is also a non-trivial risk of damage to vascular structures along the path of the angiographic catheter. Additionally, there is an increased risk of thromboembolic events associated with angiographic intervention. Patients are also subject to the standard risks of contrast dye administration and associated acute renal failure. Targeted vasopressin therapy must be closely monitored due to risks of systemic cardiovascular effects, and this therapy confers a significantly increased risk to patients with severe cardiovascular disease [37]. Embolization of larger-caliber bleeding vessels can result in bowel ischemia, in some cases progressing to bowel necrosis. These risks will, of course, vary based on the underlying risk profile of the patient as well as the skill and experience of the angiographer. However, even a low risk patient in the hands of an experienced operator remains subject to some level of risk associated with the angiographic procedure. This must be weighed by the acute care practitioner relative to the risk profile of other therapeutic options.

Surgical intervention for management of lower gastrointestinal bleeding carries all the risks of major abdominal surgery, including, broadly speaking, infection, hemorrhage, and risk of damage to surrounding structures. As with all surgical procedures, the risk profile for the procedure must be adjusted based on the patient's underlying comorbidities as well as the physiologic state at the time of the operation. A patient with lower gastrointestinal bleeding of significant magnitude to warrant acute or emergent surgical intervention is, by definition, not physiologically stable to the same degree as a patient undergoing a planned, elective procedure; the risk profile is therefore elevated as with any patient undergoing an urgent or emergent procedure. In all but the most emergent of circumstances, the patient going to the operating room for management of lower gastrointestinal bleeding will benefit from appropriate pre-operative fluid resuscitation and correction of electrolyte abnormalities; patients with any evidence of coagulopathy should also be aggressively corrected prior to operative intervention if possible.

Follow-up

Appropriate follow-up for patients presenting with lower gastrointestinal hemorrhage in the acute care setting is determined in large part by the underlying etiology of the bleeding, the severity of presentation, and any operative or procedural interventions that were undertaken to address the bleeding. Patients who present with an initial lower gastrointestinal bleed are at elevated risk of a subsequent bleed, and should be counseled as such. For patients who present with recurrent bleeding, the recurrent nature of the problem should of course be weighed in considering whether surgical intervention is appropriate.

For patients who presented with chronic low-grade bleeding and anemia, it may be worthwhile to follow serial hematocrit on an outpatient basis as a non-invasive preliminary screen for recurrent bleeding. Fecal occult blood testing can also be performed intermittently, although the yield from a single test is relatively low. If this method of surveillance is selected, testing should occur at least annually. With regard to longer term surveillance, all patients over 50 who with a non-elevated risk profile should be receiving colon cancer screening per USPSTF recommendations [87] via either annual fecal occult blood testing, flexible sigmoidoscopy every 3 years, or colonoscopy every 10 years. History of lower gastrointestinal bleeding does not, per se, alter these screening recommendations. However, if the etiology of the lower gastrointestinal bleed represents a factor associated with elevated risk for colorectal adenocarcinoma (e.g., lower gastrointestinal bleeding in the setting of ulcerative colitis), screening intervals should be shortened accordingly.

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Volvulus

33

Michael S. Truitt and Tim Gutierrez

The term volvulus refers to the twisting of an organ along a pedicle. This can involve nearly any portion of the gastrointestinal tract and even other organs such as the gallbladder and spleen. Colonic volvulus is a relatively uncommon condition, but can lead to vascular congestion. When left untreated, this can progress to ischemic necrosis and perforation. Therefore, it warrants immediate identification and treatment. The cecum and sigmoid colon are the most common portions of the large intestine affected by volvulus [1, 2]. It is important for the acute care surgeon to readily recognize each condition and be aware of the proper treatment plan.

Colonic volvulus has been described for thousands of years. The *Papyrus Ebers*, written around 1500 BC, described the "rotting" of the colon unless spontaneous reduction occurred. It was later recognized that reduction of the volvulus could be induced by either placement of a rectal tube or with passage of air into the rectum. Hippocrates described each method, including the passage of a 22 cm suppository to produce detorsion [3]. It was in the nineteenth century that Gay performed a cadaver study in which he found that the insertion of a rectal tube could produce detorsion of a sigmoid volvulus. He therefore concluded that all patients with volvulus should receive rectal tube decompression, which then became the standard of care [4]. Given the ease of the procedure, operative intervention was all together avoided at that time. Later on during the twentieth century, surgeons began to note a high recurrence rate after rectal tube decompression when used as monotherapy. Therefore, a transition to surgical management began. Techniques such as open detorsion, sigmoidopexy, and sigmoidectomy were all utilized [5]. However in 1947, Bruusgaard recognized the high mortality rate associated with surgery and therefore advocated the return to nonoperative detorsion [6]. He was able to successfully demonstrate the use of proctoscopy with rectal tube placement to provide detorsion. However a high recurrence rate was again noted with nonoperative management. Therefore, the general consensus eventually became that immediate nonoperative detorsion, if possible, should be attempted and followed soon thereafter by definitive surgical therapy.

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Cecal Volvulus Epidemiology/Etiology

The cecum is the second most common portion of the large intestine to volvulize. While the vast majority of patients present with volvulus of the sigmoid, the cecum accounts for 15–30 % of all colonic volvuli. The incidence has been reported to range from 2.8 to 7.1 per million people annually [1]. Of all adult intestinal bowel obstructions, cecal volvulus is an infrequent cause. Patients with cecal volvulus are relatively young, with a mean age of 35–55 years [7]. Two types of cecal volvulus exist, the classic cecal volvulus and the less common "cecal bascule." In the classic case there is an axial twisting of the terminal ileum, cecum, and right colon usually in a clockwise direction along a mesenteric pedicle. With a cecal bascule there is actually no twisting or truly volvulized bowel. Instead there is an anterosuperior folding of a mobile and redundant cecum upwards along the fixed ascending colon. This is less likely to cause vascular compromise or ischemic changes.

The etiology of cecal volvulus is unclear and likely multifactorial. One theory is the embryonic failure of the right colon mesentery to fixate to the retroperitoneum [8]. This incomplete mesenteric fusion allows for a freely mobile right colon, which predisposes to the eventual formation of a volvulus. One cadaver study demonstrated an 11 % incidence of a completely unattached right colon [1]. Other factors thought to contribute include chronic constipation, high fiber diet, distal colonic obstruction, and previous abdominal surgery. In one case series, previous surgery was a significant finding and present 68 % of the time [9]. The thought is that an adhesive band forms a point of fixation for an already predisposed mobile cecum to volvulize around.

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_33

Pregnant women form a unique subgroup of patients with volvulus. During pregnancy, up to 40 % of large bowel obstructions are due to volvulus [7, 9, 10]. The enlarged uterus of a gravid patient actually pushes a mobile cecum upwards, causing an obstruction where the cecum kinks against its own fixed attachment. Diagnosis is often delayed because of the hesitation to use radiographic imaging and oftentimes is made only upon surgical exploration [11].

Clinical Presentation

Patients with cecal volvulus present with intermittent obstruction and abdominal pain or discomfort. A history of similar episodes is common. Abdominal distension may occur, but is much less pronounced than a more distal volvulus. Because of the involvement of the terminal ileum, a small bowel obstruction may be present and the patient may present with significant nausea and emesis. The "mobile cecum syndrome" is a condition that involves the spontaneous resolution of symptoms and the intermittent recurrence of an incomplete volvulus. These patients are particularly challenging to appropriately diagnose because of the quick resolution and frequent recurrence. A small portion of cases of cecal volvulus may progress to bowel strangulation and ischemia. These patients will present with an acute abdomen and peritonitis requiring emergent surgical exploration. They will have systemic signs of sepsis such as fever, tachycardia, and hypotension. Lab work may demonstrate a significant leukocytosis and acidosis. Otherwise in a non-strangulated case, labs are often nonspecific.

Diagnosis

The diagnosis of cecal volvulus can readily be made via radiographic imaging. Plain film abdominal radiographs will demonstrate the volvulized colon. The largely distended cecum will be evident and is typically found directed towards the left upper quadrant. This classic finding is the "coffee bean" sign. Although quite impressive when seen on X-ray, plain films will correctly diagnose a cecal volvulus only about 20 % of the time and has a specificity of only 60 % [9]. Barium enema is another study available to assist in diagnosis. The enema will display the "bird's beak" sign at the site of colonic torsion. In cases of mobile cecum syndrome, the barium enema is especially useful in identifying the volvulus. Computed tomography (CT) scan is very sensitive and clearly identifies the obstruction. Both the coffee bean and bird's beak signs can be observed. In addition, a swirl sign indicative of mesenteric twisting may be seen [12, 13] (Figs. 33.1 and 33.2). CT has a specificity approaching 100 % and therefore is considered the gold standard for the diagnosis of a cecal volvulus [14].

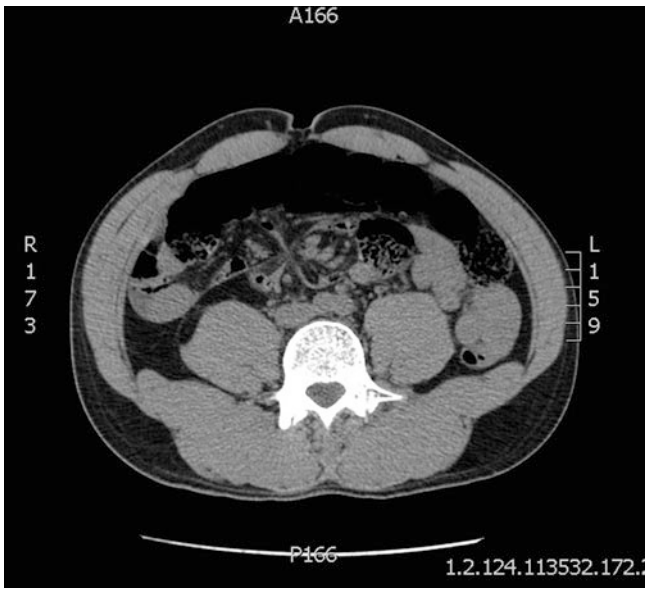

Fig. 33.1 CT demonstrating mesenteric twisting found in patient with cecal volvulus

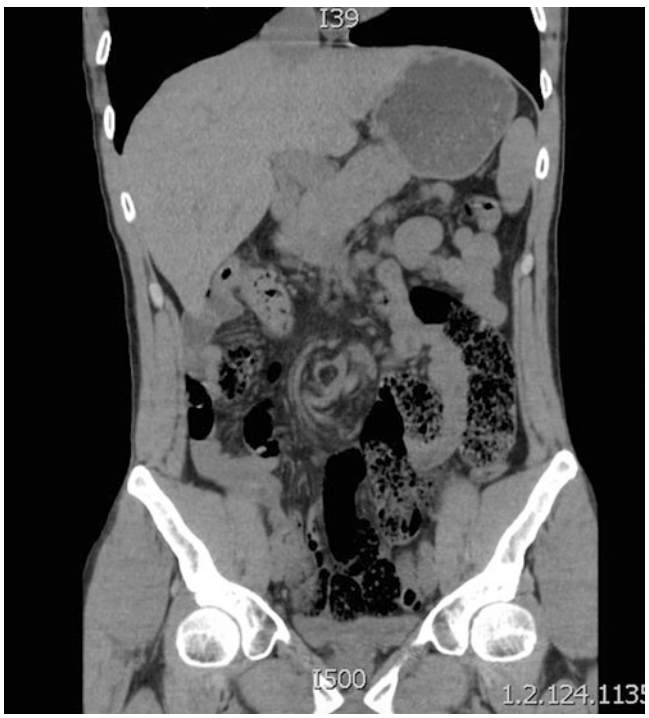

Fig. 33.2 CT demonstrating mesenteric swirl sign found in patient with cecal volvulus

Management

Unlike sigmoid volvulus, a case of cecal volvulus requires immediate surgical intervention. This should occur soon after the diagnosis is made, even in the otherwise well-appearing patient. Given the distance from the rectum, tube decompression is not feasible and blind passage may result

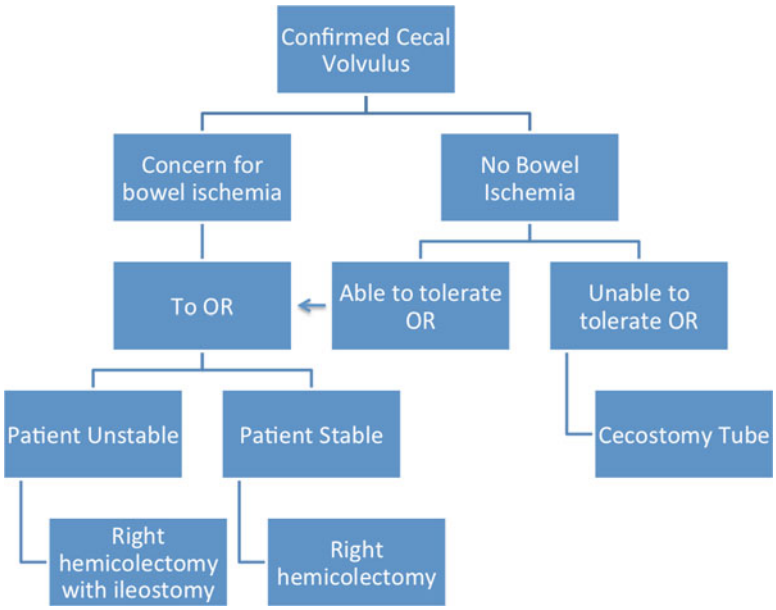

Fig. 33.3 Algorithm for cecal volvulus management

in perforation. Colonoscopic reduction has been attempted but with poor results. We recommend against routine endoscopic management, because it is only occasionally successful, and represents an increased risk of perforation. Contrast enema reduction has been shown to have similarly poor results and is essentially a relic of the past [15, 16].

Given the lack of temporizing maneuvers, the definitive treatment of cecal volvulus should not be delayed. These patients should be urgently taken for surgical intervention. Either an open or laparoscopic approach is appropriate, depending on the experience of the surgeon and clinical state of the patient. Upon surgical exploration, the volvulized colon should be grossly evaluated for viability. Any ischemic, gangrenous or necrotic changes will necessitate resection. Also in frankly necrotic cases it may be best to avoid detorsing the colon prior to taking the blood supply as this can lead to a significant inflammatory response.

A right hemicolectomy with primary anastomosis is the operation of choice. The decision to perform primary anastomosis should be made based upon the patient's physiologic state, tissue quality, and overall clinical picture. For patients who cannot tolerate re-anastomosis, an end ileostomy is an acceptable alternative. Even if the colon appears viable, it is still advisable to proceed with resection. Less radical nonresective fixation procedures have also been proposed in the setting of a viable colon. Fixation techniques include cecopexy or placement of cecostomy tube. However, these procedures have been shown to have increased complication rates and mortality when compared to resection [17]. Mortality rates for cecopexy and cecostomy tube has been reported to be as high as 14 % and 33 %, respectively [9, 16]. Therefore these fixation techniques have largely been abandoned. One instance when a cecostomy tube can be considered is the patient who cannot tolerate general anesthesia. A cecostomy tube can be placed with local anesthesia and moderate sedation. Given the recurrence rate of up to 70 % and the poor outcomes of alternative approaches, current practice recommends right-sided colon resection whenever possible [18].

Summary

Cecal volvulus is the second most common type of large bowel volvulus, but overall is a rare cause of intestinal obstruction. It warrants immediate recognition and prompt surgical treatment. Patients are younger than those with sigmoid volvulus but present similarly with abdominal pain, distension, and emesis. Unlike a distal volvulus, one occurring in the cecum is not amenable to endoscopic detorsion. Therefore these patients require immediate surgical intervention and resection of the ascending colon (Fig. 33.3).

Sigmoid Volvulus

Etiology/Epidemiology

In the USA, sigmoid volvulus is relatively rare and accounts for less than 10 % of all intestinal obstructions [19]. In other parts of the world, however, sigmoid volvulus is responsible for up to 50 % of intestinal obstruction [19]. This is explained by the prevalence of Chaga's disease and the resultant megacolon, which is rare in developed countries. The sigmoid is the most common portion of large bowel to become volvulized and is involved 60–80 % of the time [1]. Most patients are in

the 7th decade of life and are commonly institutionalized, debilitated, or afflicted by a neuropsychiatric disorder. In addition, chronic constipation and an elongated sigmoid are thought to contribute to the development of volvulus [19, 20].

Although the exact etiology of sigmoid volvulus is not well established, the pathophysiology of the disorder is believed to be multifactorial [21]. The most important factor necessary to produce a volvulus is excessive colonic mobility. The sigmoid colon is inherently predisposed to develop a volvulus secondary to the adjacent attachments at the rectum and descending colon, leaving a relatively mobile central sigmoid. Chronic constipation then produces an elongation and dilatation of the colon, further contributing to the mobility of the sigmoid [22]. Low-fiber Western diets have also been implicated and may contribute to colonic distension. This dilated and redundant colon is then predisposed to developing a volvulus, especially when coupled with an elongated and narrow mesenteric attachment. A less common group of patients who develop sigmoid volvulus are those with an inherent colonic dysmotility disorder [2]. One example includes Hirschsprung's disease. These patients can develop a volvulus as early as 4 h of age and anytime thereafter. Congenital anatomic variations may allow for a redundant sigmoid with a lengthened mesentery, these patients may develop a volvulus at any age.

Clinical Presentation

Patients with sigmoid volvulus will present with a similar clinical picture to that of a typical acute bowel obstruction. Symptoms include abdominal pain, distension, nausea, emesis, and constipation. The pain associated with sigmoid volvulus is first slowly progressing but then becomes severe and continuous. Due to its progressive nature, patients commonly present several days after the onset of initial complaints. The associated abdominal distension can be quite impressive and the patient will have an obviously tympanic abdomen. Cases of volvulus have been reported with abdominal distension so severe it leads to cardiac and respiratory compromise [23]. Since this condition affects mainly elderly institutionalized patients, it is not uncommon for presentation to be delayed several days until a primary caretaker notices symptoms. It is also possible for spontaneous reduction of the volvulized colon to occur. This may lead to a cycle of resolution followed by frequent recurrences. Rarely, a patient will present with evidence of ischemic bowel secondary to prolonged volvulus. This is evident by the presence of systemic signs including fever, tachycardia, hypotension, abdominal rigidity and guarding or rebound tenderness. These are obvious signs of peritonitis and should greatly increase the concern for bowel necrosis or perforation.

Two distinct clinical presentations of sigmoid volvulus have been previously described [24]. First is the "acute fulminant type" in which the patient is typically younger and the onset of symptoms is rapid. The patient presents with acute nonspecific complaints of severe abdominal pain. Distension may not be as evident in this case. Progression to gangrene and perforation is rapid. Oftentimes diagnosis is not apparent clinically and is made only upon surgical exploration. The "subacute progressive" variation is the second and more common type of sigmoid volvulus. This is the classic case of a slow progressive worsening of abdominal discomfort. A history of chronic constipation in an elderly institutionalized patient is a hallmark of the disease and should increase the index of suspicion. There is associated abdominal distension and the diagnosis can be made easily with radiographic imaging.

Diagnosis

Upon initial evaluation and thorough history and physical exam, there should be a high clinical suspicion for volvulus. The differential of large bowel obstruction includes conditions such as toxic megacolon, colonic pseudo-obstruction, and malignancy. In order to confirm the presumed diagnosis of volvulus, several tests are of use. Most patients with volvulus will present with nonspecific labs and in fact will often show no abnormalities at all. However, in the severe case, a profound leukocytosis or lactic acidosis can be indicative of bowel ischemia. A plain film abdominal X-ray can usually identify the volvulized colon. The distended sigmoid will be evident and seen as a large loop directed towards the right upper quadrant. This has been described as the "bent inner tube" or "omega" sign and is diagnostic of a sigmoid volvulus (Fig. 33.4). Typically the small bowel will be normal appearing, except in cases with an incompetent ileocecal valve. Abdominal X-ray is able to diagnose between 60 and 75 % of cases with sigmoid volvulus [20]. Concerning features evident on plain film include linear pneumatosis or "thumb-printing" and free air, which represent bowel necrosis and perforation, respectively.

In addition to abdominal plain films, a water-soluble contrast enema can be performed in cases that remain unclear. The combination of contrast enema along with abdominal X-ray can increase the sensitivity of volvulus identification to approach 100 % [25]. The enema will reveal a bird's beak deformity at the site of colonic twisting and a lack of contrast proceeding proximally beyond the obstruction. Also, it is possible to reduce the volvulus using a contrast enema. However, this is not typically necessary and should be performed under fluoroscopy by an experienced radiologist. There is a risk of perforation during attempted reduction

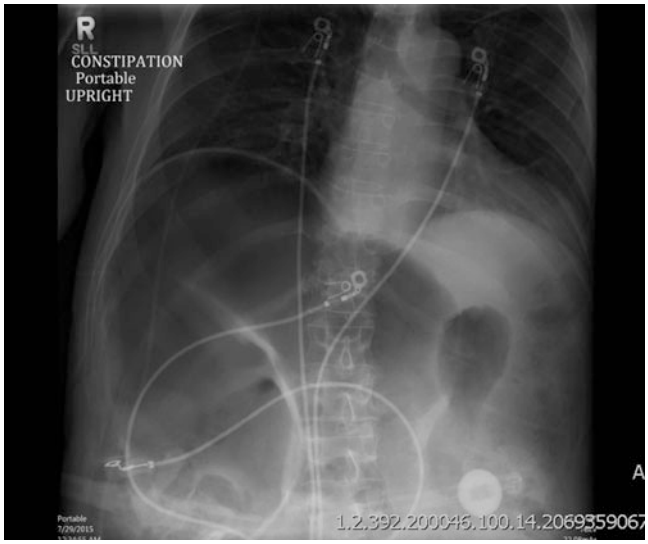

Fig. 33.4 "Bent inner tube" sign on KUB of patient with sigmoid volvulus

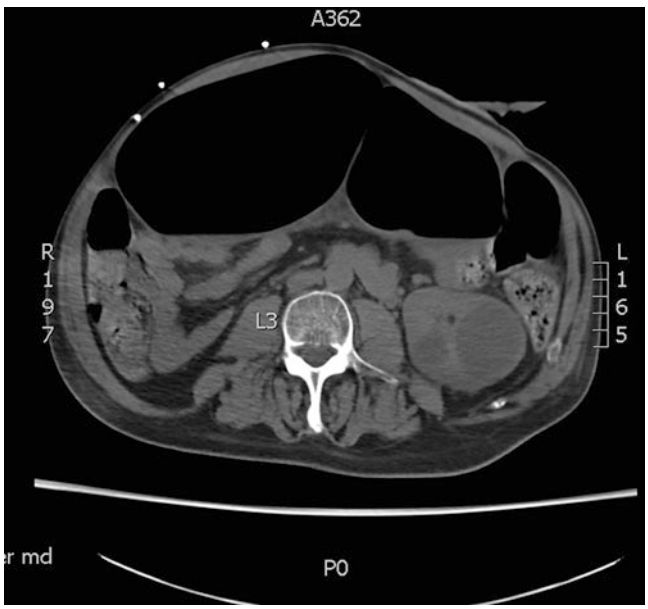

Fig. 33.5 CT of sigmoid volvulus

with contrast enema, and therefore this practice is not commonly recommended.

Abdominal CT can readily identify a sigmoid volvulus and rule out other causes of large bowel obstruction [26]. The CT will reveal the dilated sigmoid and the point of obstruction along the twisting of the colonic mesentery where a swirl sign is normally found (Figs. 33.5 and 33.6). An advantage of CT is the ease of identifying concerning features such as pneumatosis, portal venous gas, and poor bowel wall enhancement.

Management

After the diagnosis of sigmoid volvulus is made, prompt treatment is necessary. Historically the management has centered on reduction of the volvulized bowel. Today this dogma still rings true. In fact, the two primary goals for the treatment of a sigmoid volvulus are to reduce the volvulus and prevent recurrence. Due to the high incidence of recurrence, the acute reduction is only a temporizing maneuver and a definitive intervention should be pursued soon thereafter.

Once the volvulus is diagnosed, the clinician should rule out evidence of an intra-abdominal catastrophe as this would mandate immediate laparotomy. However, the vast majority of cases will present with a relatively benign course. In these cases, a thoughtful reduction of the volvulized colon with a subsequent plan for delayed definitive surgical intervention is advised. Detorsion can be accomplished by several techniques. Barium enema under fluoroscopic guidance is one method of both confirming the diagnosis and reducing the volvulus, however is not typically recommended due to the risk of perforation. Most often, the bowel is reduced via placement of a rectal tube beyond the point of obstruction either blindly or with endoscopic assistance [27]. Adequate reduction will be evident with the passage of large amounts of stool and gas. Endoscopic evaluation with rigid proctoscopy, flexible sigmoidoscopy or colonoscopy is a useful tool that not only allows reduction and rectal tube placement, but also provides a visual evaluation of the colonic mucosa in

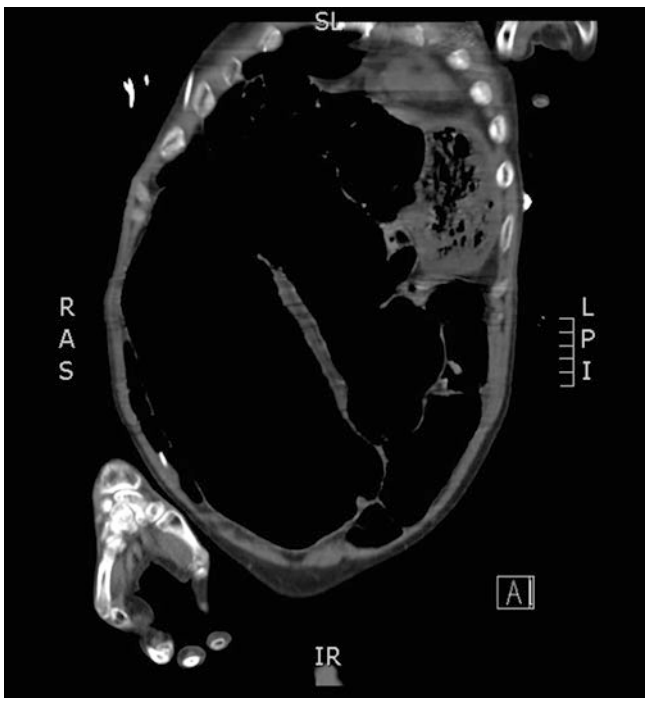

Fig. 33.6 Largely distended sigmoid colon located in the right upper quadrant of a patient with sigmoid volvulus

order to evaluate for ischemic changes. If frank necrosis is evident, this necessitates an immediate surgical intervention. Endoscopic evaluation will be able to identify the site of obstruction and with gentle pressure the scope will pass beyond revealing obviously dilated colon and the return of stool/gas. At this time, the direct placement of a rectal tube beyond the site of obstruction is easily accomplished. Care should be taken to selectively perform endoscopy only in those patients without sepsis and little concern for risk of perforation, as insufflation of an already distended colon can lead to perforation. It is not uncommon for these patients to present with electrolyte disturbances or dehydration; therefore, the patient will require IV fluid resuscitation. The patient must be observed closely with serial exams in order to ensure the rapid identification of any potential complications such as peritonitis or bowel perforation. The rectal tube can be left in place for several days if necessary while the patient is prepared for operative intervention. Occasionally the colon will re-volvulize or the rectal tube may slip out of place, it is appropriate to simply replace the tube and reduce the colon again. In fact, multiple decompressions are sometimes necessary. Up to 80 % of cases can be successfully reduced via tube decompression; however nearly 90 % of cases will eventually recur after initial tube decompression [28]. Therefore a definitive surgical intervention is always recommended and can/should be undertaken during the same hospital admission.

The surgical management revolves around the principle of preventing recurrence and the mainstay of this is resection of the sigmoid colon. However, other options exist and are usually reserved for those patients that are deemed too high risk to undergo surgical resection. The value of delayed intervention after tube decompression is that the patient can often undergo standard bowel preparation which may allow for a primary anastomosis during sigmoid resection. Either laparoscopic or open sigmoid resection can safely be performed, depending on the experience of the surgeon. A loop ileostomy can also be added in cases with an anastomosis requiring extra protection; however, this is rarely necessary and should be considered on a case-by-case basis. In the stable patient who successfully underwent decompression, sigmoid resection is the standard of care.

In most cases the patient can undergo delayed sigmoidectomy, however this is not always the case. If tube decompression is unsuccessful or the patient develops signs of peritonitis or sepsis, then the concern for gangrenous bowel should prompt immediate surgical exploration. The sigmoid colon will require resection and proceeding with either primary anastomosis or Hartmann's procedure is appropriate depending upon the clinical judgement of the operator and the clinical status of the patient. Anastomosis is not recommended in the hypotensive acidotic patient who may benefit from damage control and subsequent resuscitation in the intensive care unit. It is important to note the functional status of the patient, because in the elderly institutionalized patient a Hartmann's colostomy will often prove to be permanent. Otherwise the decision to perform an anastomosis in this setting should be made based upon standard surgical principles. A patient who presents in septic shock may benefit from a staged procedure. This consists of resection without reestablishing continuity followed by resuscitation. The patient may then return to the operating room 24–48 h later for either anastomosis or formal Hartmann's procedure.

For patients who undergo immediate laparotomy and are found to have a viable colon, the possibility exists to perform a nonresective procedure. This strategy should be reserved for the patient who is deemed unable to tolerate a formal surgical resection. Nonresective options include rectopexy, extraperitonealization of the sigmoid colon, and mesosigmoidoplasty [29]. These are viable but not ideal options and come with an increased risk of morbidity and mortality. Therefore, sigmoid resection remains the standard of care and a nonresective procedure should only be considered in unique cases.

Summary

Sigmoid volvulus, although an uncommon cause of large bowel obstruction, is a surgical emergency that requires prompt recognition and treatment. Institutionalized elderly patients with a history of a neuropsychiatric disorder are most commonly affected. Clinically the patients will present with abdominal pain and a significantly distended abdomen. Diagnosis can be readily made with abdominal radiographs and CT scan, if necessary. Treatment relies upon decompression and is followed up with surgical resection of the sigmoid colon. Less commonly a patient will present with signs concerning for bowel perforation, these cases demand immediate surgical exploration (Fig. 33.7).

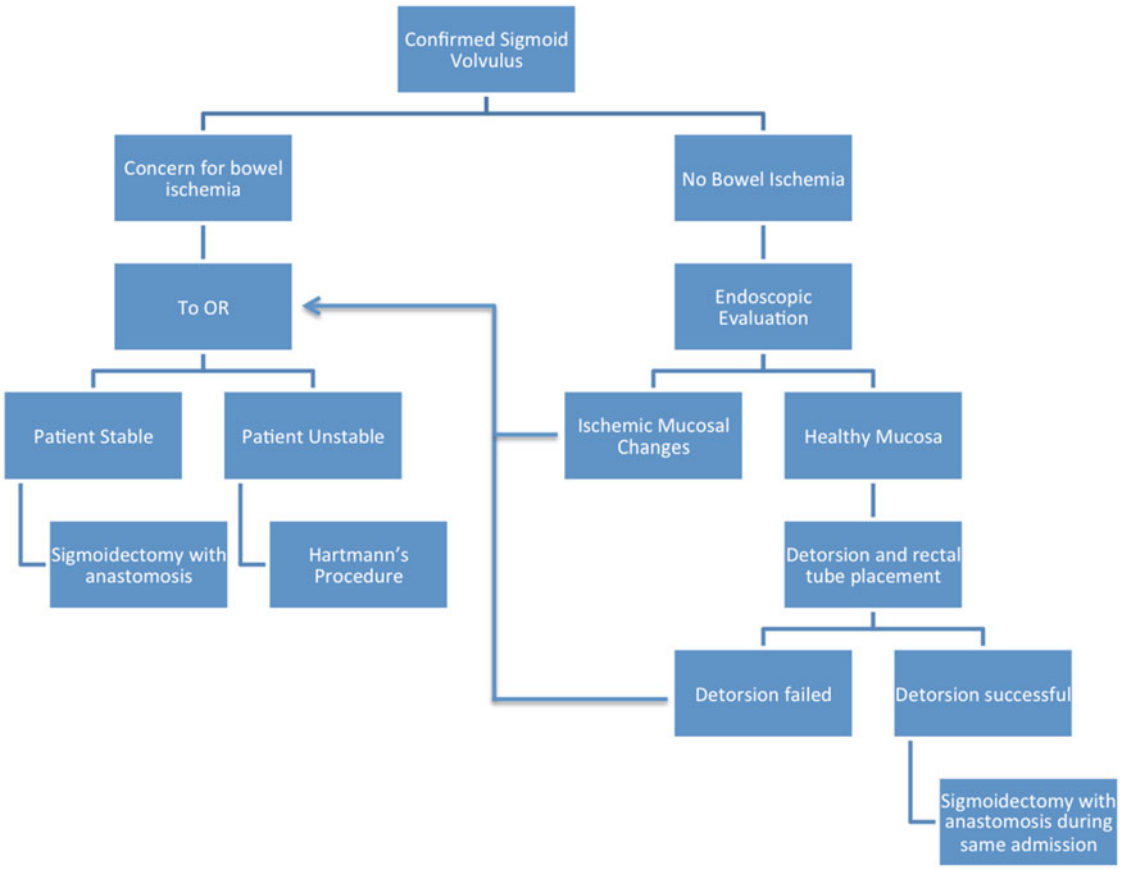

Fig. 33.7 Algorithm for sigmoid volvulus management

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Anorectal Disease

34

John C. Kubasiak and Marc I. Brand

Perianal Sepsis and Fistula

Hippocrates described anorectal abscesses and their complicating fistulas as far back as 400 BC. The most common cause of abscess is explained by the cryptoglandular theory. A fistula is the chronic manifestation of an anal abscess. As with other suppurative disease, complete drainage and wide excision of non-viable tissue has remained the treatment for centuries. New diagnostic modalities and treatments have been developed over the last 50 years and are described.

Etiology

Anorectal suppurative disease is the manifestation of a diverse list of possible etiologies. Simple skin infections to IBD and malignancy must be included on the differential; a more exhaustive list is included in Table 34.1 [1]. The majority of anorectal abscesses and sepsis have an origin in infected anal glands and ducts. Lockhart-Mummery suggested the anal glands played a role in abscess formation [2] and histologic studies from Parks in 1961 [3] led to the adoption of the cryptoglandular theory for the formation of anal abscesses and sepsis.

Anatomy/Classification

The treatment of anorectal sepsis relies on knowledge of the pelvic floor, the anal sphincter complex, and the potential spaces they afford. The classification of both abscesses and the complicating fistulas are based on the location of the abscess and the course of the fistula tract. The potential spaces include the perianal, submucosal, intersphincteric, ischiorectal, and supralevator spaces, and are shown in coronal and sagittal view in Fig. 34.1 [4]. Abscesses may involve more than one potential space by communication through a midline connection between bilateral spaces. The classic example of multi-space involvement is the "horseshoe" abscess, which extends from the midline intersphincteric or deep postanal spaces to include both intersphincteric or both ischiorectal spaces. There is limited reporting on the incidence of different locations of anal abscess. In the two largest series perianal abscesses predominate at 40–50 %, intersphincteric and ischiorectal follow with ~20 % each [5–8].

Similar to anorectal abscesses, anal fistulas are classified by the spaces traversed as well as the relationship to the anal sphincter. The location of the fistula tract has special therapeutic implications. According to the classification introduced by Parks in 1976 (Fig. 34.2) there are four types of fistula: intersphincteric, transphincteric, suprasphincteric, and extrasphincteric [4]. Fistulas with multiple tracts or abscesses are described simply by the addition of the secondary tracts and abscesses. Similar to anorectal abscesses, reports of the incidence of fistulae are sparse. The largest series place the intersphincteric fistula as the most commonly encountered type (45–53 %) followed by the transsphincteric fistula (20–30 %) [4, 9, 10].

Diagnosis

The diagnosis of anorectal abscess is predominately clinical, although certain cases benefit from additional testing. The typical presentation will include constant anal pain of a few days duration, with associated swelling or bulge and possible systemic symptoms of infection including fever and chills. The initial exam is performed trying to differentiate from other common causes of anal pain, including fissure and thrombosed hemorrhoids. The pain from an anal fissure is typically intermittent, and there are periods of comfort daily

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_34

Table 34.1 Differential etiologies for perianal abscesses and fistula

Infectious
Cryptoglandular
Tuberculosis
Actinomycosis
Lymphogranuloma venereum
Inflammatory bowel disease
Crohn's disease
Ulcerative colitis
Trauma
Foreign body
Penetrating injury
Surgical complication
Malignancy
Leukemia
Lymphoma
Carcinoma
Radiation

Adapted from Vasilevsky CA, Gordon PH. Benign anorectal: abscess and stula. In: Wolff BG, Fleshman JW, Beck DE, et al., editors. The ASCRS textbook of colon and rectal surgery. New York: Springer Science + Business Media, LLC; 2007. p. 192–3, with permission

before the next bowel movement. A thrombosed hemorrhoid is usually blue or purple in color and is able to be moved *en masse* under the skin. Physical examination of an anal abscess will normally disclose a focal area of tenderness with associated erythema or induration. When performing the digital rectal exam special attention is given to the posterior anal canal, tenderness here is typical for deep postanal space abscess. Pain on internal exam without any external findings may represent an intersphincteric abscess. A bidigital rectal examination, using one finger on the ischioanal skin to compress tissue against the rectal finger is often helpful in localizing the abscess. Patients with a consistent history and clinical findings suggestive of infection, tachycardia, fever or elevated white blood cell count, may harbor an occult ischiorectal or supralevator abscess. CT scan may aid in diagnosis and treatment planning. As with all soft tissue infections, concern for a necrotizing soft tissue infection must be entertained during the evaluation. Such an infection should be considered especially if the patient has systemic symptoms associated with skin changes of crepitus, blistering, "dishwater drainage" or overtly gangrenous tissues. If the patient does not tolerate the bedside exam, or there are equivocal findings, the patient may ultimately require an exam under anesthesia to secure a diagnosis and perform treatment.

Anal fistula is the chronic manifestation of anal abscess and therefore must be suspected in all patients with recurrent abscess formation. Typical patient history will include a previously drained abscess (spontaneous or aided by incision and drainage) with complete or partial resolution with episodic recurrence of swelling, pain, and/or drainage. Alternatively, chronic drainage may be present [6, 7]. This presentation is more indolent and systemic symptoms are rare unless an abscess has reformed, possibly months to years later. On exam a palpable cord may be noted between an external opening and the anus. Goodsall's rule is used to predict the location of the internal opening based on the location of the external opening relative to the transverse anal line. Fistulae with an anterior opening typically have an internal opening that is in a direct (radial) line. Fistulae with a posterior opening tend to have a curvilinear tract to the posterior midline. While most fistulae originate from the anal glands and have an internal opening at the dentate line, consider Crohn's disease, HIV, or malignancy, in patients with multiple tracts, or when the internal opening is not at the dentate line [11]. As with anal abscesses, fistulae require a thorough exam and an EUA is typically required. Documentation is essential and requires recording the location, the number of internal and external openings relative to the sphincter complex, and associated abscess locations.

Treatment of Anal Abscess

General Considerations

As with other suppurative processes the treatment of choice is adequate drainage of the abscess. In healthy patients with an uncomplicated abscess that is properly drained there is no role for antibiotic treatment [12]. Those who have associated cellulitis, or those with immune suppressed states (such as acquired immune deficiency syndrome, transplant or poorly controlled diabetic patients, or cancer patients receiving chemotherapy) antibiotics may be added.

A search for the internal opening may be performed if the abscess is being drained under an anesthetic in the operating room, but this should not be a primary focus of the operation. The tissue is often edematous and the internal opening is often difficult to locate. A useful maneuver is to perform anoscopy while compressing the abscess *before* it is drained, looking for the expression of pus at the internal opening.

The location for incision and drainage should be over the area of maximum fluctuance, oriented radially relative to the anus. An elliptical incision may be made initially and purulence is drained. If there are internal loculations, these are bluntly broken with a hemostat. The wound is then copiously irrigated. If needed, this ellipse can be extended into a cruciate incision. Packing of the wound should be with iodoform gauze and left in place for 24 h [8]. Alternatively a small mushroom shaped catheter (10–14 French Pezar or Malecot drain) maybe placed into the wound and secured at the skin. The drain is removed in the office 1–2 weeks later, once the abscess cavity has collapsed around the tip of the drain. We recommend TID Sitz baths for the following 3–5 days to ensure continued drainage and hygiene.

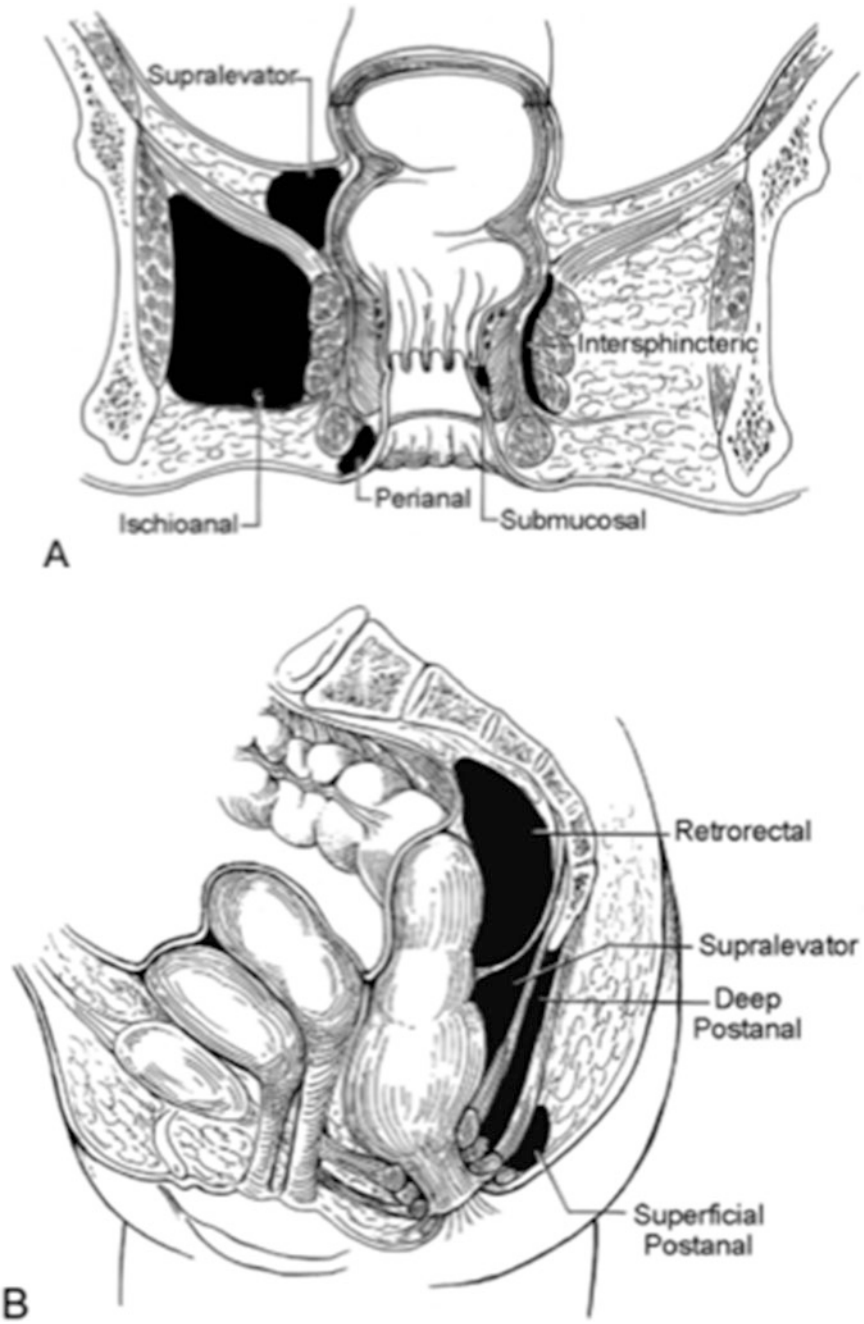

Fig. 34.1 Locations of perianal spaces and abscesses. (From Vasilevsky CA, Gordon PH. Benign anorectal: abscess and stula. In: Wolff BG, Fleshman JW, Beck DE, et al., editors. The ASCRS textbook of colon and rectal surgery. New York: Springer Science + Business Media, LLC; 2007. p. 192–3.)

Perianal Abscess

Surgical drainage of a simple perianal abscess can be performed at the bedside under local anesthesia using lidocaine with epinephrine injected into the subcutaneous tissue. Alternatively, a local field block around the abscess can be performed. Some patients may require operative drainage under anesthesia for pain control or extensive collections.

Ischiorectal Abscess

Smaller ischiorectal abscesses, which are located lateral to the anal sphincter, can be drained at bedside. Larger ischiorectal abscesses may require an exam under anesthesia as adequate local anesthesia or assessment of internal loculations may be difficult to achieve. A large ischiorectal abscess may benefit from counter incisions around the edges to avoid large wound defects. Penrose drains are placed from one to another counter incision as an "external seton" drain.

Intersphincteric, Submucosal Abscesses

Intersphincteric and submucosal abscesses will require an exam under anesthesia to properly unroof the length of the abscess. Packing with gauze can be difficult and the use of a small mushroom catheter drain secured in place with an absorbable suture may be beneficial.

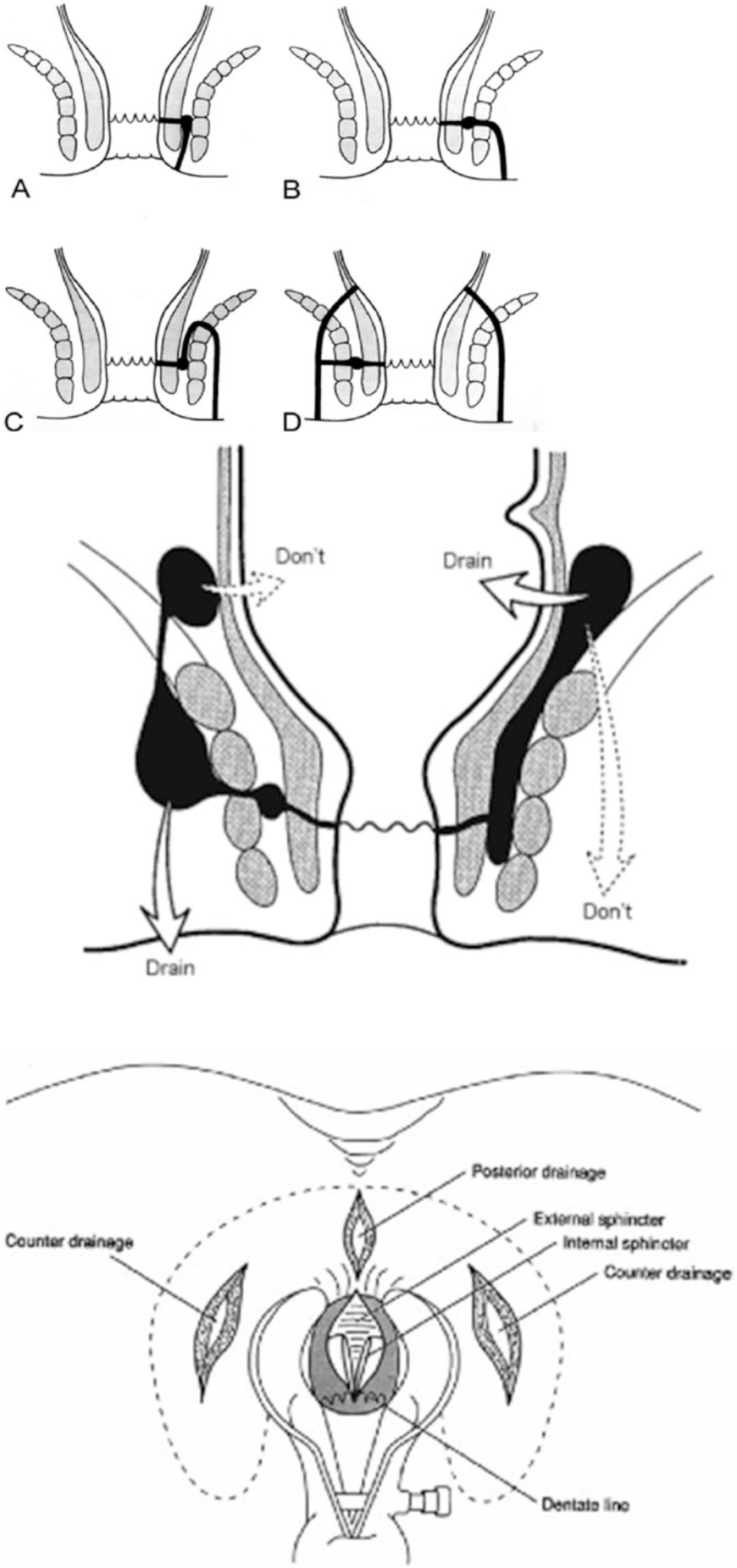

Fig. 34.2 (**a**) Park's classification of anal fistula. 1 Intersphincteric. 2 Transsphincteric. 3 Suprasphincteric. 4 Extrasphincteric. (**b**) Drainage of a supralevator abscess. Proper identification of fistula tracts and abscess cavities are required so as not to create additional transsphincteric tracts. (**c**) Drainage of a "horseshoe" abscess. Multiple counter incisions are required for the proper drainage of a horseshoe abscess. (From Vasilevsky CA, Gordon PH. Benign anorectal: abscess and fistula. In: Wolff BG, Fleshman JW, Beck DE, et al., editors. The ASCRS textbook of colon and rectal surgery. New York: Springer Science + Business Media, LLC; 2007. p. 276, 279, 280, with permission.)

Deep Postanal, Supralevator, Horseshoe Abscesses

These are the most difficult to treat and should all be performed under anesthesia to ensure adequate exposure and drainage. To access the deep postanal space, bordered by the anococcygeal ligament and levator ani muscles as well as the coccyx and external anal sphincter, a midline incision is made between the anus and the coccyx. The space is then entered and loculations are broken apart. The cavity should be gently probed for fistula tracts, and again packing or drains may be placed. If the abscess continues into the supralevator space or to both sides creating a horseshoe abscess, counter incisions can be made on the lateral aspect of the abscess to allow for further drain placement, in this situation we use Penrose drains between the wounds (Fig. 34.2b, c).

Treatment of Anal Fistula

Anal fistulae rarely spontaneously resolve, and most patients should undergo surgical treatment. If a patient wishes to observe the fistula, he/she should be counseled on the increased risk for abscess formation and that the risk for multiple fistula tracts (external openings) increases. The surgical approach is tailored to each patient with the goals of fistula resolution and preserving continence. This is the critical balance to consider when treating an anal fistula. The treatment of fistulas can be grouped as sphincter-cutting or sphincter-sparing therapies. The latter avoid dividing the sphincter. Sphincter-cutting therapies include simple or staged fistulotomy. Sphincter-sparing therapies are continuing to evolve and currently include long-term draining seton placement, advancement flaps, fibrin sealant, fistula plug, and most recently, the LIFT procedure (ligation of the intersphincteric fistula tract).

Patients should be counseled prior to surgery for a fistula regarding the balance between efficacy of fistula resolution and preserving continence. This sets the stage for informing the patient of the two treatment options to be considered at the time of EUA; fistulotomy or placement of a draining seton. The patient should also be informed that the initial surgery may not be the final surgery.

Positioning

The patient is typically positioned in prone jack-knife position and the buttock are retracted laterally with a heavy silk tape. If the external opening of the fistula is anterior, it may be easier to access the external opening with the patient positioned in lithotomy. Local blocks can be used to provide perioperative pain control.

Exam Under Anesthesia (EUA)

The initial step in fistula management is the EUA to identify the course of the fistula tract and its relation to the anal sphincter. The external opening is probed in an attempt to identify the course of the fistula tract and connect it to the internal opening. Peroxide injection into the external opening is often helpful in locating the internal opening. Once the course of the fistula tract is identified, the percent of anal fistula traversed by the fistula should be assessed. The percent involvement is estimated by digital exam estimation of the amount of external sphincter involved (distance between fistula probe and anal verge) divided by the length of the anal canal (from the anal verge to the anorectal junction). A decision is then made, based on the concern for incontinence, to perform a fistulotomy or seton drain. A seton is a "thread" that is passed into the external opening, through the fistula tract, exiting through the internal opening into the anal canal [13]. The two ends are then secured to each other to maintain a loop of "thread" through the fistula tract. The seton serves as a bridge to a delayed management of the fistula, allowing the infection within it to drain as much as possible before the next procedure.

Sphincter-Cutting Therapies

The gold standard in treatment of superficial anal fistulas is fistulotomy. In general, if less than 1/3 of the external sphincter is involved, the fistula can be treated with fistulotomy. Exceptions to this include patients with existing incontinence, chronic diarrhea, anticipated chronic diarrhea (e.g., IBD, HIV), or females with an anterior fistula.

A fistulotomy involves cutting open the roof of the fistula tract by dividing the tissue atop the fistula probe passed through the tract. This is best performed beginning at the external opening and dividing the skin and anoderm over the entire length of the tract to the internal opening. Next, the subcutaneous tissues peripheral to the sphincter are divided from the external to internal opening. Once the only remaining tissue is the anal sphincter itself, the amount of muscle to be cut is assessed most accurately before completing its division. The resultant wound is left open and allowed to heal by secondary intention. The recurrence rate is low and the risks for incontinence in properly selected patient are also low. Although fistulotomy represents the "gold standard" with a resolution rate that approaches 95 %, the incidence of incontinence ranges from 20 to 50 % [9, 14].

Due to the concerning rate of incontinence with fistulotomy, other methods of cutting the sphincter have been developed with the intent of better preservation of continence. A staged fistulotomy is one in which the fistula and sphincter is divided in more than one setting [15]. This may be done by

cutting a portion of the sphincter and then returning at a later date to cut the remainder of the sphincter. Alternatively, a cutting seton may be used to slowly transect the sphincter muscles. The seton is slowly tightened every 2–4 weeks until it completely cuts through the sphincter by ischemic necrosis [16]. This is done to allow for fibrosis to form and heal behind the seton. This slow cutting is likened to passing a wire through a block of ice, with fusion following cutting.

Sphincter-Sparing Therapies

The risk for incontinence in some patients remains prohibitive even when a staged fistulotomy is considered. In these circumstances, a sphincter-sparing therapy is advised. These have a lower rate of success in resolving the fistula, but are protective of continence. A draining seton is a loosely tied loop through the fistula tract, and can be used to provide long-term relief of the local septic process and allow for epithelialization of the tract. Other non-cutting methods include advancement flaps (mucosal or dermal), fistula plugs, and ligation of the fistula tract. These methods are effective when used after a draining seton has been present for 6 weeks allowing the infection to settle. These more complex procedures should be performed by a surgeon trained and skilled in their use.

Special Circumstances

Crohn's Disease

Patients with Crohn's disease will have anorectal involvement in up to one third of patients. Abscesses should be drained as for any other patients. Those who have fistulous connections pose a more difficult problem. Each patient requires a thorough exam under anesthesia to evaluate for all fistulous tracts, if the tract is small and little evidence of active Crohn's disease is found, a fistulotomy can be performed [17]. Complex or multiple fistulas or active Crohn's disease requires a multidisciplinary team approach [18]. The tissue conditions are less favorable and risks for failure or incontinence are higher. Referral to a trained colorectal surgeon should be provided [19].

AIDS/HIV

Patients with active HIV have a 10–34 % incidence of anorectal disease [20]. In patients with well-controlled HIV, with normal CD4 counts and low viral load abscess and fistula should be treated as any other patient [21]. Those with low CD4 counts have an increased risk of poor wound healing [22, 23]. Abscesses in these patients should be incised to treat the sepsis and fistulae benefit from non-cutting setons to control the local disease. Once the risk factors for wound healing have been addressed, a fistulotomy can be considered.

Leukemia

While less frequently encountered in patients with leukemia than in those with HIV, those with leukemia can experience anorectal sepsis ~5 % of the time which can be potentially life threatening. Reports of mortality from anorectal sepsis in patients with uncontrolled leukemia have been as high as 20 % [21, 24]. Superficial abscesses may be sharply drained, with an accepted higher risk of poor healing [25]. In those without obvious fluctuance, conservative treatments include Sitz baths, warm compresses, bowel regimen to soften stools, pain control, and broad-spectrum antibiotics directed against enteric and skin flora. Precautions to avoid further local trauma should be set in place, including avoiding rectal examinations, instrumentation, and enemas.

Hemorrhoids

Hemorrhoids and the treatment of hemorrhoids were described as early as the Egyptian and Greek civilizations. Treatments varied by culture but included a range of treatments from ointments to cauterization with a hot iron. Hemorrhoids are rarely life threatening, but the associated pain and morbidity can be significant. Treatment is reliant upon restoring the normal anatomic configuration to control symptoms while maintaining continence.

Etiology/Anatomy

Hemorrhoids are part of normal anal anatomy; three fibrous vascular cushions typically sit in the anal canal in the right anterior, right posterior position and left lateral positions. The vascular component is valveless sinusoids which allows for vascular engorgement. The fibrous tissue consists of elastin, collagen, and smooth muscle which aids in elastic recoil of the tissue and emptying of the blood [26]. Internal hemorrhoids normally fill with blood as a result of increased abdominal pressures, which leads to a tighter seal in the anal canal. This can be beneficial while coughing or sneezing. The dentate line separates internal from external hemorrhoids. Proximal to the dentate line the innervation is via the autonomic nervous system and is largely insensate. Distal to the dentate line the lining transitions to squamous epithelium, and the innervation is somatic. This leads to the significant pain patients with external hemorrhoids can experience. Hemorrhoid disease affects around 15 million patients annually, affecting men and women equally [27]. Both internal and external hemorrhoidal disease occurs in patients with conditions leading to increased intraabdominal pressures. The increase in intraabdominal pressures leads to increased venous outflow pressures, which lead to hemorrhoid distention. Common factors which lead to these increased pressures

include prolonged straining during defecation (constipation), increased frequency in defecation (diarrhea), COPD, and pregnancy.

There are two main theories to explain internal hemorrhoidal disease. One theory suggests that pathologically increased arterial inflow leads to hemorrhoidal changes and symptoms. Studies supporting this have demonstrated increased arterial flow and vessel diameter are associated with increasing severity of disease [28]. Another theory suggests that damage to the supporting elastic and connective tissue does not allow the hemorrhoid tissue to push out excess blood and instead the tissue remains engorged [29].

Symptoms/Classification/Grades

Hemorrhoids are very frequently blamed for symptoms in the anal area, often incorrectly. Symptoms will relate to the location and grade of the hemorrhoid. Both internal and external hemorrhoids can present with an asymptomatic or minimally symptomatic bulge. The typical symptoms related to hemorrhoids will involve spotting of blood on toilet paper with defecation, or blood in the toilet with defecation, with associated pain or a bulge that intermittently appears and retracts (prolapse). Careful description of the pattern of bleeding, pain, and swelling often leads to a diagnosis, and physical examination helps to support or refine the diagnosis.

External hemorrhoids typically present with a painful swelling; the somatic innervation of the anoderm renders a thrombosed external hemorrhoid particularly painful. The thrombosed external hemorrhoid will cause constant and severe pain that peaks 24–48 h after onset.

Internal hemorrhoids rarely present with severe or constant pain, unless they are in a state of incarcerated prolapse. They typically present with bleeding as the engorged internal hemorrhoids with a more fragile columnar lining become traumatized. The blood will commonly be low volume and associated with passage of stool. With chronicity the hemorrhoid connective tissue stretches and can start to prolapse. The grading of internal hemorrhoids is based on a combination of bleeding and prolapse patterns (Table 34.2). Symptoms can also include a sense of incomplete evacuation and pruritus, both being related to prolapse.

Diagnosis

It is important to recognize that many different conditions present with symptoms similar to hemorrhoids; rectal bleeding, perianal mass, and anal pain. When considered in this way, the evaluation should be directed at these symptoms with an open mind and differential diagnosis list. Hemorrhoidal disease as the cause of the symptoms is a conclusion reached at the end of a thorough evaluation of the presenting symptoms. In this way, the clinician is much less likely to overlook anal fissure, anal abscess, anal cancer, colorectal cancer, and other potential causes of the patient's symptoms.

As most internal hemorrhoids present with hematochezia, evaluation for a gastrointestinal source should be tailored to the patient's age, bowel habits, and risk factors for colorectal cancer. Those who have concurrent symptoms consistent with neoplasm or IBD may require further evaluation including colonoscopy and imaging. External anal inspection and digital rectal examination are utilized to identify fissure, fistula, abscess, prolapse, or mass. Anoscopy is important to inspect the hemorrhoidal tissue and the anal canal. The three locations of hemorrhoidal tissues, right anterior and posterior and left lateral, should all be examined, and the size, friability, and amount of prolapse should be documented. If a patient is not able to tolerate a digital exam and a diagnosis cannot be reached by inspection alone (fissure, perianal

Table 34.2 Grades of internal hemorrhoids

	Definition	Symptoms
First degree	Bulge into the anal canal	• Painless bleeding
Second degree	Protrusion during defecation with spontaneous retraction	• Painless bleeding • Anal bulge with defecation • Pruritus
Third degree	Protrusion during defecation that requires manual replacement	• Painless bleeding • Anal bulge with defecation • Pruritus • Sensation of incomplete evacuation • Fecal leakage
Fourth degree	Irreducible/incarcerated prolapsed	• Painless bleeding • Anal bulge with defecation • Pruritus • Sensation of incomplete evacuation • Fecal leakage

Adapted from Cintron JR, Abcarian H. Benign anorectal: hemorrhoids. In: Wolff BG, Fleshman JW, Beck DE, et al., editors. The ASCRS textbook of colon and rectal surgery. New York; Springer Science + Business Media, LLC; 2007. p. 158, with permission

abscess, fistula, thrombosed external hemorrhoid), an examination under anesthesia should be considered. The timing of the EUA should be rapid if the anal symptoms are acute or if constitutional symptoms such as fever or fatigue are present.

Treatments

Nonoperative

Initial management of hemorrhoids should almost always begin with nonoperative treatment. The exception to this is the patient presenting with acute symptoms of severe unmanageable pain or symptoms for which a diagnosis with potential morbid consequences cannot be excluded (i.e., abscess or cancer). Therapies to address pain control, decrease abdominal pressure, and improve bowel habits are the initial considerations. Topical anesthetics can be trialed on thrombosed external hemorrhoids at the bedside. We prefer a jelly rather than an ointment as this seems to be more effective at pain relief, even in a lower concentration. Oral analgesia can be prescribed but narcotics may worsen constipation and non-steroidal agents may promote bleeding if surgical therapy is later needed. A bowel regimen should be added to counter constipation or diarrhea. The addition of fiber can help normalize the stools in both conditions. Sitz baths will help to control pain and improve blood flow through the hemorrhoid vessels.

Thrombosed External Hemorrhoids

A patient with a thrombosed external hemorrhoid will typically present 24–48 h after the initial event as the pain crescendos. By this time the tissue can appear dark purple to black; this is the thrombosis. Conservative measures, including Sitz bath, oral and IV analgesia, and topical 2% lidocaine jelly should be attempted. If the overlying anoderm is beginning to show signs of necrosis, it will likely rupture in the near future resulting in extrusion of the clot with associated rapid decrease in swelling and pain. This finding is an indicator that the patient will likely have less pain and of a shorter duration than a surgical evacuation of the clot. If the patient presents delayed, 3–5 days after the symptoms began, the clot will be starting to dissolve and the pain should be improving in the next couple days. This is another circumstance where supportive care with comfort measures will be less painful for the patient. If initial conservative measures fail to make the pain tolerable while the thrombus resolves spontaneously, the hemorrhoid can be evacuated by a simple incision over the thrombus. The wound can be left open and packed allowing for healing by secondary intention. Complete excision of this external hemorrhoid may be performed electively. Alternatively, some surgeons prefer to excise the thrombosed hemorrhoid rather than simply evacuate the clot.

Internal Hemorrhoids

Grades I

These early hemorrhoid symptoms tend to have minor symptoms of bleeding which may be visually concerning but do not threaten the patient or affect the quality of life. A high fiber diet should be recommended and fiber supplements provided to allow for the bulking of stool. The amount is adjusted to achieve the goal of a soft bulky bowel movement. This will decrease the need for straining and improve flow through the hemorrhoidal cushions.

Grade II/III

Office based procedures such as rubber band ligation, infrared coagulation, and sclerotherapy are often used for Grade II internal hemorrhoids. Rubber band ligation is one of the most common methods to address Grade II, and some "early" Grade III hemorrhoids, which continue after conservative therapy. The application of a band can be performed in the ED or office and requires an anoscope and band applicator (Fig. 34.3). The target hemorrhoid is identified and delivered into the barrel of the band applicator either by suction or a hemorrhoid grasper. The band is deployed around the base of the hemorrhoid; this leads to ischemia at the base of the banded tissue, which heals with fibrosis. The fibrosis serves to fix the remaining hemorrhoid tissue to the deeper tissues beneath it. The ischemic tissue and rubber band typically fall off about a week later, and the patient may notice passage of the band or spotting of blood with a BM. If pain is noted on initial placement there should be concern for placement of the band below the dentate line and it should be removed and replaced. Additional band applications at the same time can lead to increased discomfort and banding of all three should be avoided. The procedure may be repeated in 3–4 weeks if additional treatments are needed.

Grade III/IV

Traditionally, Grade III/IV hemorrhoids have been treated with excisional hemorrhoidectomy. Two newer procedures have recently been developed as alternatives to excision, in an attempt to offer treatment of the more advanced hemorrhoids with less morbidity.

Hemorrhoid artery ligation is one of the newer surgical procedures for treating advanced hemorrhoidal disease. It can be used for Grade II hemorrhoids that have failed office based procedures, as well as Grade III hemorrhoids for which office based procedures are generally not advised. The device includes a modified anoscope with attached Doppler ultrasound in line with a ligating window. The ultrasound is used to detect the flow of blood in the hemorrhoidal arteries and a suture ligation is then performed on the identified artery through the ligation window. The ligation of the artery leads to decreased inflow and shrinkage in the hemorrhoidal tissues, as well as a scar that helps secure the hemorrhoidal

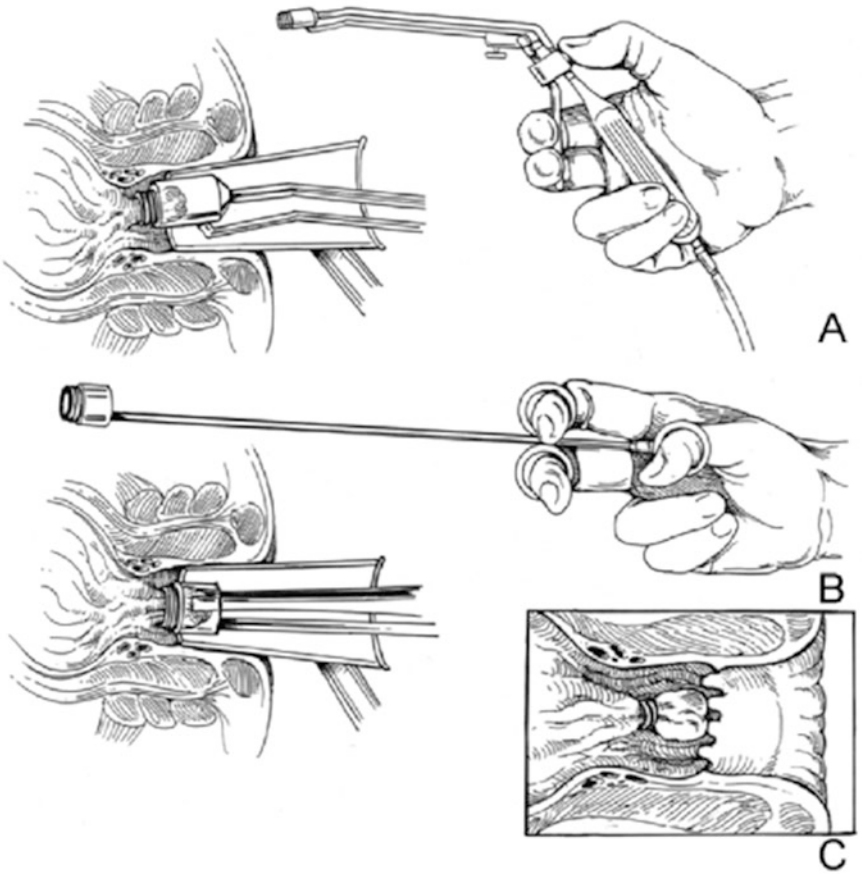

Fig. 34.3 Rubber band ligation. Banding an internal hemorrhoid. (**a**) The internal hemorrhoid is teased into the barrel of the ligating gun with a McGown suction ligator, or (**b**) a McGivney type ligator. (**c**) The apex of the banded hemorrhoid is well above the dentate line in order to minimize pain. (From Beck D, Wexner S. Fundamentals of anorectal surgery. 2nd ed. Elsevier;1998. p. 215.)

tissue to the deeper tissues beneath it. Thus, both potential mechanisms of hemorrhoidal disease, arterial overflow and loss of supportive tissue are addressed by this technique without removing hemorrhoidal tissue. Larger hemorrhoidal bundles may still have a tendency to prolapse after hemorrhoid artery ligation. A mucopexy can be performed to pull the excess tissue back up inside the anal canal and fix it to the underlying tissue by the resultant scar. Giordano et al. published a literature review of hemorrhoid artery ligation including 1996 patients. Pain was the most commonly encountered "complication" at 18.5 %. At 1 year the incidence of recurrent prolapse was 10.8 %, pain on defecation at 8.7 % and bleeding at 9.7 % [30].

The Procedure for Prolapsing Hemorrhoids (PPH) is another alternative to excisional hemorrhoidectomy for Grade III hemorrhoids and Grade II hemorrhoids failing office based procedures (Fig. 34.4). This technique uses a device system that includes an anoscope, suture guide, and modified circular stapler. A purse string suture is placed 4 cm above the dentate line using the included anoscope and suture guide. This suture is then tied between the stapler anvil and cartridge. The excess hemorrhoid tissue is pulled into an enlarged tissue chamber in the stapler and the stapler fired. In this way, redundant prolapsing hemorrhoid tissue is excised and the remaining hemorrhoid tissue is resuspended higher up in the anal canal by a ring of scar tissue. In a multicenter trial comparing the PPH with a traditional Ferguson hemorrhoidectomy, PPH demonstrated less postoperative pain, use of peri-procedure analgesics, and less pain with their first bowel movement. The need for a second procedure at 1-year was also less with PPH (2.6 % vs 13.9 %) [31]. Cochrane review of over 25 randomized controlled trials including 1,918 procedures demonstrated PPH to be safe with short-term benefits. There was less initial pain, less pain on defecation, and less analgesic use, earlier return to work and return to normal activities. The complication rate was similar for PPH versus conventional hemorrhoidectomy (20.2 % vs 25.2 %, $p = 0.06$), but PPH carried less postoperative bleeding (OR 0.52), wound complications (OR 0.19), and constipation (0.45). Over all PPH offers a safe procedure with short-term benefits although the long-term results are still accruing [32].

Summary

Anal suppuration and hemorrhoidal disease are common causes for patients to seek urgent care. A careful history and examination of the perineum and anal canal is crucial to reaching an accurate diagnosis and appropriate treatment. Multiple treatment options are available and should be tailored to the patients presenting complaints.

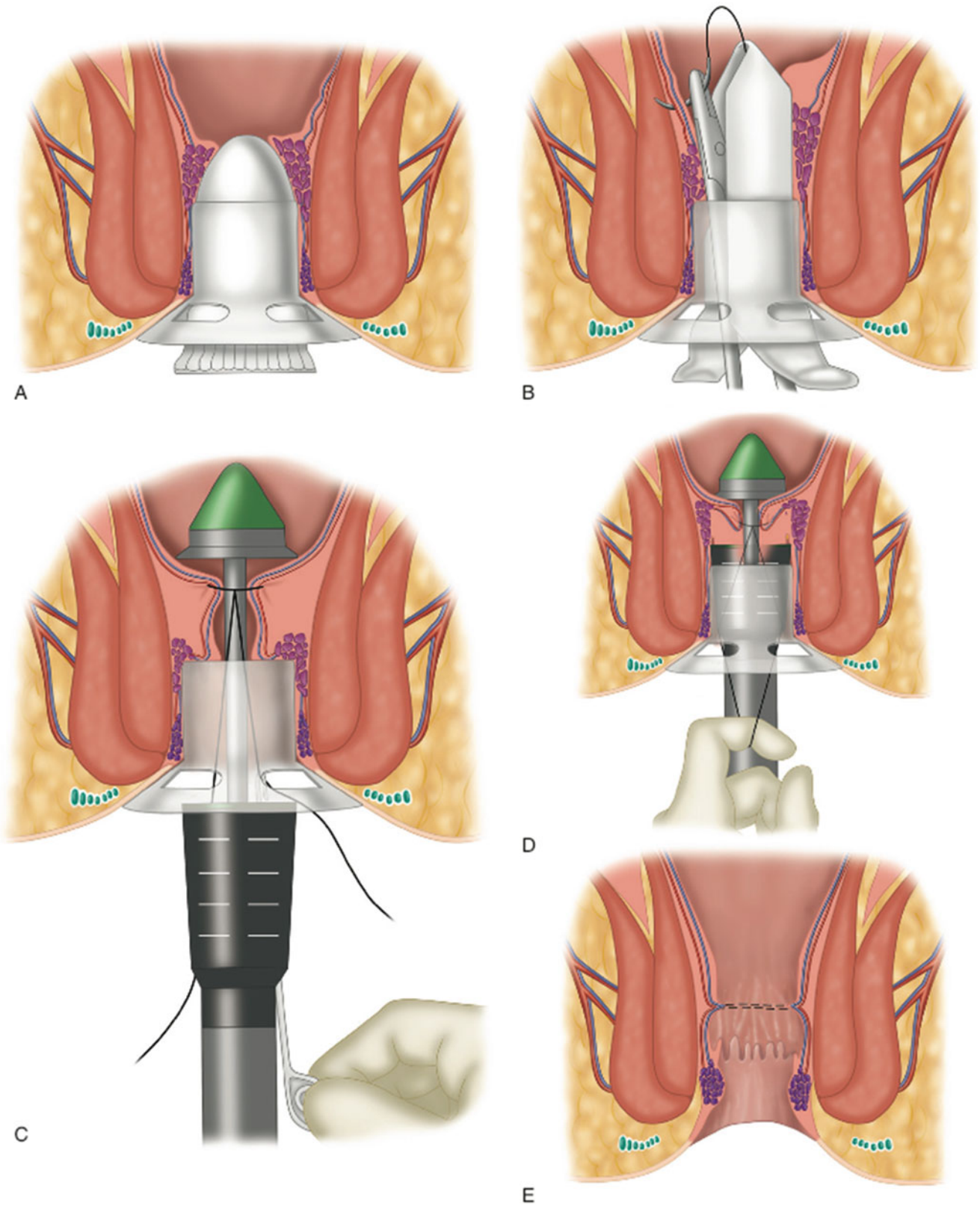

Fig. 34.4 The procedure for prolapsing hemorrhoids. (**a**) Insertion of obturator and dilator (**b**) Purse string anoscope is inserted through the dilator, leading to the placement of a circumferential purse string in the mucosa and submucosa using a 2–0 Prolene suture on a UR-6 needle. (**c**) The 31 or 33-mm hemorrhoidal circular stapler is fully opened and inserted placing the anvil proximal to the purse string. (**d**) Purse string is tied onto the anvil shaft, then entire stapler casing is advanced into the anal canal and fired. (**e**) Completed hemorrhoidopexy staple line is 2–4 cm above the dentate line. (Courtesy of Ethicon Endo-Surgery, Inc.)

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Management of Complications of Endoscopic Therapy

35

Shinil K. Shah, Nirav C. Thosani, and Peter A. Walker

The number of endoscopic procedures being performed annually continues to increase. From 2000 to 2010, there has been an over 50 % increase in the number of esophagogastroduodenoscopies (EGD) and colonoscopies, an approximately 24 % increase in the number of endoscopic retrograde cholangiopancreatography (ERCP) procedures, and an over 500 % increase in the number of endoscopic ultrasound (EUS) based procedures being performed [1]. Recent advances in flexible endoscopic technology, such as endoscopic full thickness suturing devices, continue to expand the indications for therapeutic endoscopy. A small but burgeoning field of Natural Orifice Transluminal Endoscopic Surgery (NOTES) highlights the active efforts of surgical and gastrointestinal endoscopy societies to innovate new techniques using primarily flexible and rigid endoscopic platforms. Optimal care of patients with gastrointestinal diseases requires close collaboration between surgeons and therapeutic gastroenterologists as well as a thorough understanding of the indications for and management of complications from endoscopic procedures. The objective of this chapter is to review common complications of various diagnostic and therapeutic endoscopic procedures as well as the subsequent surgical and endoscopic management. We focus on complications requiring surgical management with the realization that a significant number of complications related to endoscopy are related to cardiac or respiratory comorbidities.

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Upper Endoscopy

Perforation

The most commonly reported mechanical complications of diagnostic and therapeutic upper endoscopy are perforation and bleeding complications. Although the frequency of these complications is extremely low, best outcomes are achieved with prompt diagnosis and treatment as well as close collaboration between surgeons, critical care physicians, gastroenterologists, and diagnostic and interventional radiologists. Perforation is most common in the distal esophagus and associated typically with therapeutic procedures and/or patients with distal esophageal diseases or neoplasms. Common sites of perforation in the upper (cervical) esophagus are related to natural points of narrowing, including the pyriform sinus and at the cricopharyngeal muscle. The presence of an unrecognized Zenker's diverticulum may increase the risk of cervical esophageal perforation during upper endoscopy, especially when a blind technique is utilized to enter the esophagus [2, 3]. Management of esophageal perforation depends on the location as well as the mechanism of perforation and any possible underlying disease.

Presentation of patients may be varied and may include symptoms of pain (most commonly), fever, pneumothorax, pleural effusion, and/or subcutaneous emphysema. The symptoms of vomiting, chest pain, and subcutaneous emphysema (Mackler triad) are not always present [4]. An upper gastrointestinal contrast study with water soluble contrast and/or a computed tomography (CT) scan should be performed if there is suspicion for perforation. Management of these patients is largely related to the location of perforation, whether or not

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_35

the perforation is contained, and whether the patient has a systemic inflammatory response. One of the most important factors in treatment of esophageal perforation is in time to treatment as mortality increases substantially with delays in treatment beyond 24 h. Patients with perforations in the cervical esophagus tend to have better outcomes [5].

Generally, most patients with cervical perforations can be managed with conservative therapy. Surgical management is generally reserved for those with evidence of uncontained perforation or with signs of a systemic inflammatory response. Generally, wide drainage with or without primary closure is sufficient [3].

Classically, the treatment of intra thoracic or intra-abdominal esophageal perforation has relied on the principles of immediate operation for source control, primary repair with or without muscle flap and wide drainage, possible proximal diversion, and durable feeding access. For small perforations that are contained in a patient without systemic signs of illness, conservative nonoperative management including broad spectrum antibiotics is reasonable. Adjuncts such as endoscopic clips, stents, and/or suturing platforms may be of value, especially when perforation is recognized at the time of endoscopy [6] (Fig. 35.1). In patients being operated on for uncontained perforation, intraoperative endoscopy may be helpful in localizing a difficult to find perforation; in certain cases, myotomy may be necessary to fully define the injury [7].

There are important points to consider in the management of perforation in patients with pre-existing esophageal pathology. Patients who present with perforation after endoscopic therapy for achalasia (typically dilation) represent one such unique group. The majority of perforations are near the hiatus. Contained, small perforations may be treated conservatively. With uncontained perforations, the majority of these can be approached from the abdomen and potentially with laparoscopy depending on available expertise. Operative principles include takedown of the short gastric vessels, hiatal dissection, esophageal mobilization, primary esophageal repair (mucosa/submucosa layer), myotomy, and partial fundoplication [8]. The use of esophageal stents or endoscopic clips has been described in small case series in the management of small perforations in patients with achalasia. The utility of these techniques is likely in those patients in which perforation is recognized at the time of dilation [9].

Perforations in patients undergoing endoscopy for esophageal malignancy pose another challenge in management. In the case of localized disease, esophagectomy may be considered [5]. Other instances in which esophagectomy may be

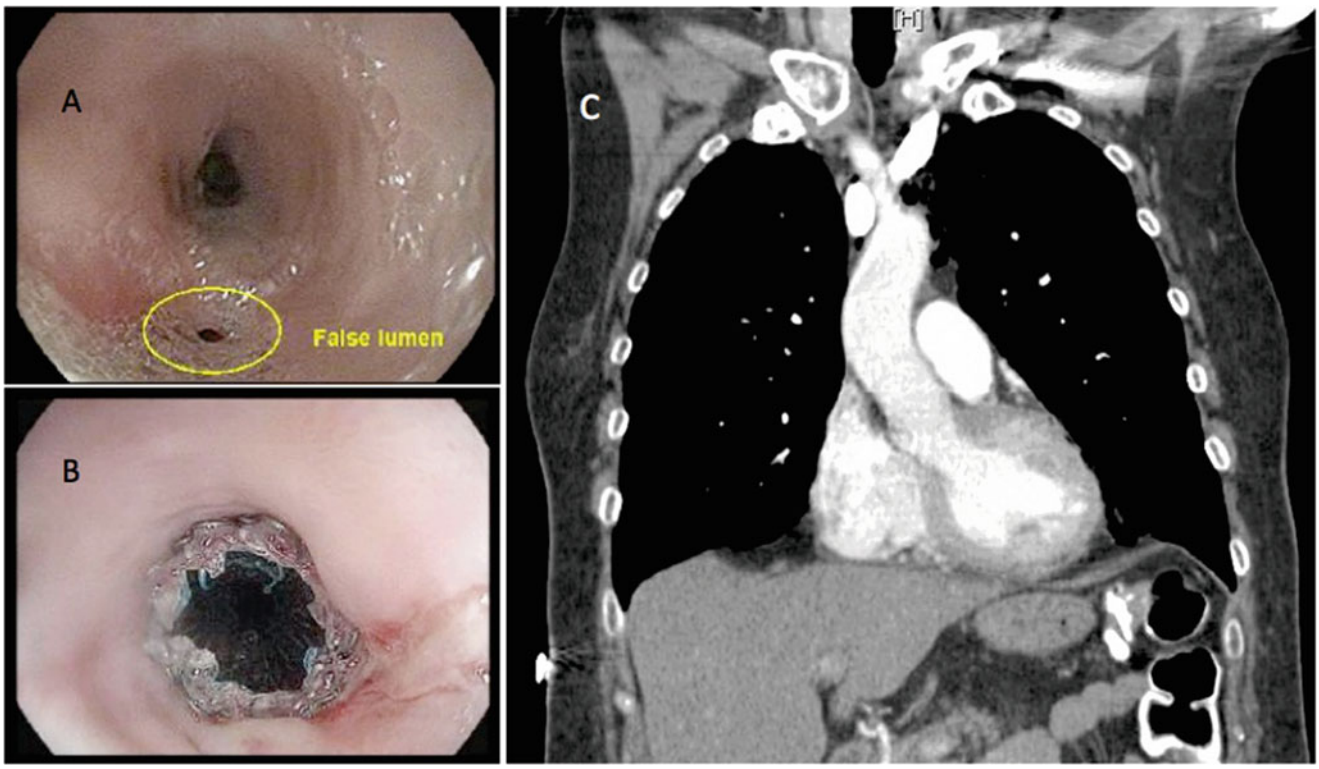

Fig. 35.1 Perforation after EGD/dilation. A 64-year-old female with a long-standing history of peptic ulcer disease and smoking underwent diagnostic EGD for dysphagia and was noted to have esophageal narrowing at the proximal esophagus. A diagnostic gastroscope (9.8 mm) was advanced through the esophageal stricture with moderate resistance and subsequently a false lumen was noted. She was transferred to our institution for higher level of care. CT scan of the chest revealed mediastinal free air (**b**). Repeat endoscopy with an ultraslim (4.9 mm) endoscope revealed a false lumen (site of esophageal perforation) (**a**) which was then treated by endoscopic placement of fully covered metal stent (**c**)

considered include patients with scleroderma, certain esophageal strictures (such as those caused by caustic burns), and failure of primary repair. In patients with inoperable malignancy, palliation with esophageal stents and other adjuncts including drainage should be considered [7].

Perforation may be noted during endoscopy for removal of esophageal and gastric foreign bodies. Use of an overtube during removal of sharp foreign bodies may help to minimize the risk of injury during removal [10]. Risk factors for complications during foreign body removal include delay in endoscopic therapy [11]. The management of perforation due to foreign bodies is similar to that described above [3].

Bleeding

Significant bleeding is extremely uncommon during/after upper endoscopy. The risk of bleeding is thought to be higher in patients undergoing hot biopsy, snare resection, or biopsy of the stomach after gastric operations (such as with Billroth 1 or 2 reconstruction). It is associated rarely with cold forceps biopsy [12]. Principles of management are similar to other etiologies of gastrointestinal bleeding and may include endoscopic therapy (clips, energy, or endoscopic suturing platforms) as well as angiography with embolization and/or surgical management for intractable bleeding. Management of coagulopathy is vital. In patients with a history of use of newer oral anticoagulation agents, such as direct thrombin (dabigatran and desirudin) or direct Factor Xa (rivaroxaban, apixaban, and fondaparinux) inhibitors, an aggressive approach is required due to the difficulty with as well as lack of specific reversal agents for uncontrolled bleeding [13].

Mallory Weiss tears can be a rare complication of EGD. Typically, significant retching during the endoscopic procedure is reported. Most patients have a benign course; refractory bleeding can be treated generally with endoscopic therapies. Rarely, embolization or surgical therapy (oversewing) is necessary [3].

Complications of Percutaneous Endoscopic Gastrostomy (PEG)

Feeding tubes, specifically PEG tubes, are placed for a variety of reasons, including neurologic diseases. It is often a preferred mode of long term enteral access in part due to its ease of placement, relatively low cost, general ease of removal, and avoidance of general anesthesia. Care should generally be taken not to place PEG tubes in patients with severe ascites, patients who have had significant gastric surgery including gastric bypass, infection of the abdominal wall at the site of planned placement, severe gastric motility disorders, patients with esophageal or gastric cancer, as well as severe coagulopathy. In patients who have had previous open abdominal operations, it is important to confirm a direct tract from the skin to the stomach to avoid placement through small or large bowel. Strategies include trans-illumination, visualization of indentation of the stomach with external pressure over the abdominal wall, as well as endoscopic visualization of a needle placed through the abdominal wall into the stomach [14–16].

Complications of PEG placement are similar to other endoscopic procedures and may include bleeding complications, aspiration, and injury to adjacent organs including small or large intestine or solid organs (typically liver or spleen). Fistulas between the colon, stomach, and skin (gastro-colo-cutaneous) have been described if colon is inadvertently interposed between the stomach and abdominal wall. This usually presents in delayed fashion and may manifest as significant diarrhea soon after tube feed administration (Fig. 35.2). Contrast studies are helpful for diagnosis and removal of the PEG tube may allow for spontaneous closure of the fistulous tract. Evidence of peritonitis or systemic signs of illness generally mandates laparotomy [14, 15, 17].

Significant infection of the abdominal wall including necrotizing soft tissue infection has been reported after PEG placement and requires immediate source control with

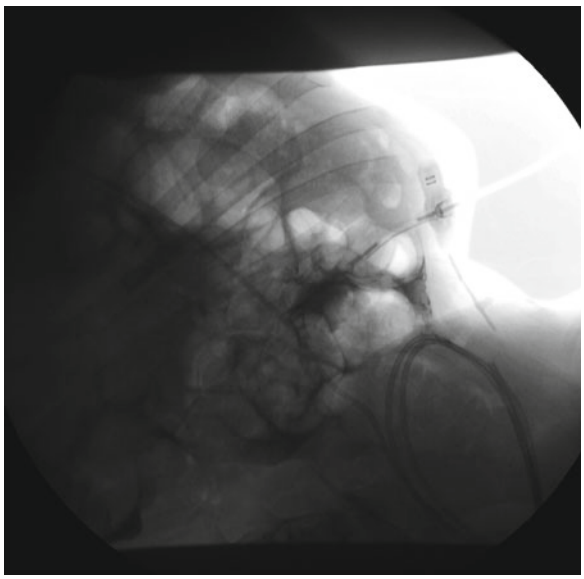

Fig. 35.2 Complications of PEG placement—gastro-colo-cutaneous fistula. Contrast study done after replacement of a feeding gastrostomy tube. Demonstrated is contrast surrounding loops of small bowel, suggesting malposition of the replaced gastrostomy tube. Secondary to signs of peritonitis, the patient was taken to the operating room in which a defect was seen in the colon. The patient was thought to have likely had a gastro-colo-cutaneous fistula. Damage control with colorrhaphy was performed followed by placement of a new gastrostomy tube at a subsequent operation. Upon questioning, a history of significant diarrhea soon after initiation of gastrostomy feeds was elicited, clinically suggestive of a gastro-colo-cutaneous fistula

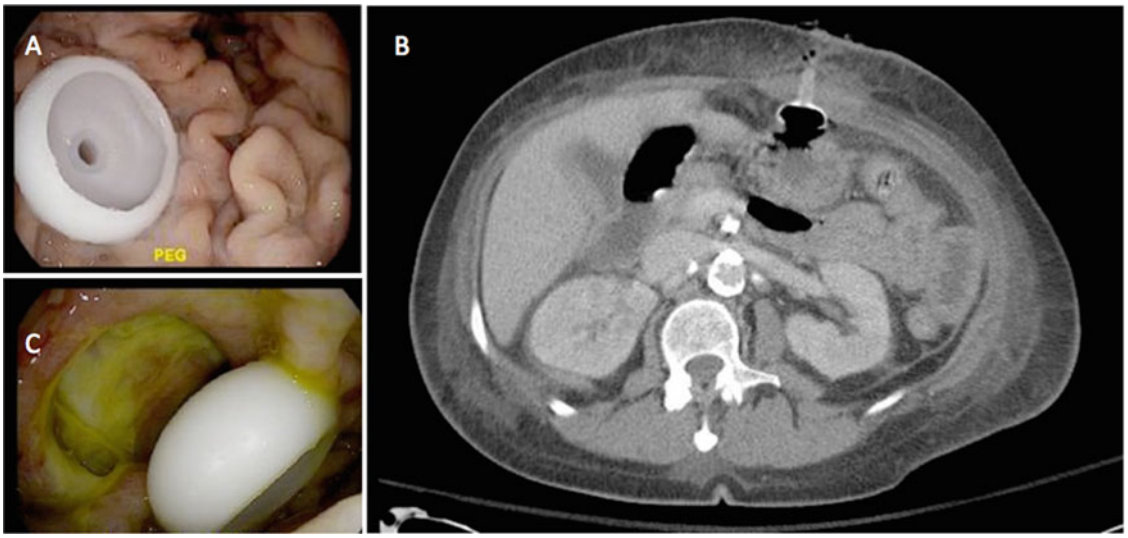

Fig. 35.3 Complications of PEG placement—buried bumper syndrome. A 69-year-old lady with hypertension, diabetes, and left subclavian artery stenosis s/p stenting presented to the hospital with left sided weakness and falls. MRI of her brain showed a new right anterior cerebellar stroke. She underwent uneventful PEG tube placement (**a**) but on postoperative day 8, she was noted to have fevers, chills, and foul smelling drainage from around the PEG tube site. CT scan (**b**) suggested displacement of PEG tube with the internal bumper having been displaced through the anterior wall of the stomach with free air. On repeat endoscopy, she was noted to have a full thickness defect in the anterior wall of stomach (**c**) requiring emergent surgery

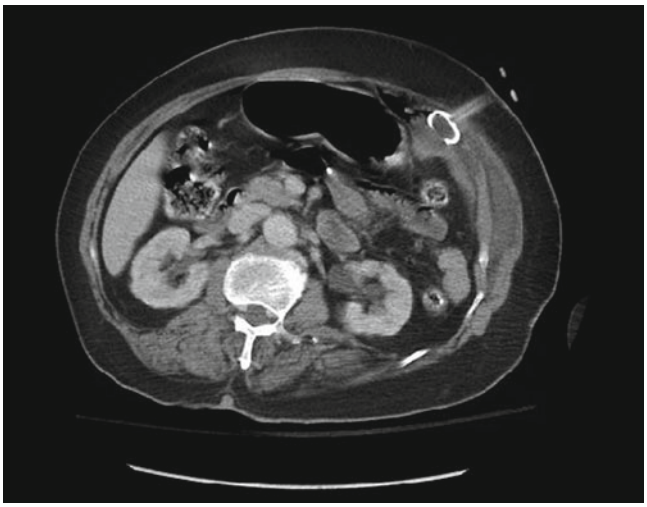

Fig. 35.4 Complications of PEG placement—buried bumper syndrome. CT demonstrating buried bumper syndrome. Note the internal bumper of the PEG tube is extraperitoneal. This occurred approximately 3 months after uncomplicated PEG tube insertion. This patient developed a large preperitoneal abscess after PEG removal requiring surgical incision/drainage and drain placement

debridement and broad spectrum antibiotics. Significant pressure on the abdominal wall has been thought to contribute to this complication. It is important to ensure secure placement of PEG tubes, however excess pressure or tightness between the internal and external bumpers can cause ischemia and necrosis of the stomach leading the erosion of the tube out of the stomach and into the abdominal wall (buried bumper syndrome) (Figs. 35.3 and 35.4). The PEG should be able to freely rotate and excess tension should be avoided by keeping the external bumper loosely approximated to the abdominal wall. Seeding of tumor can be seen along the PEG tract in patients with malignancy, specifically head and neck cancer. Other local wound complications can be seen, including development of granulation tissue around the PEG tube (treated with local therapy including silver nitrate cauterization), wound infection (erythema or redness around the external PEG site is fairly common due to local irritation), and leakage around the PEG tube. Preprocedure administration of antibiotics has been shown to reduce wound infection rate substantially [14, 15, 17].

Gastric outlet obstruction can be rarely seen if the tube migrates into the stomach and gastric outlet. This is treated with tube repositioning. It is not uncommon to see extra luminal (free) air in the immediate post procedure period after PEG placement. For extraluminal air that persists after 72 h or if there are other signs of peritonitis or systemic illness, consideration should be given for evaluation for a hollow viscus injury. When PEG tubes are inadvertently removed, they can be replaced either by placing a new tube into a well formed tract (if the tube has been in for sufficient time) or via repeat endoscopy or interventional radiology. When the tube is replaced at the bedside, a contrast study should be performed if there is any question about intraluminal placement. Aspiration of gastric contents can also be a secondary marker for successful intraluminal placement. If the tract has closed somewhat, pediatric feeding tubes can be utilized to access the tract and keep it open. Serial dilation with sequentially larger tubes can be done at bedside, in the operating room, or via interventional radiology to place an appropriately sized tube [14].

Endoscopic Retrograde Cholangiopancreatography (ERCP)

Common complications of ERCP that may require surgical management include pancreatitis, hemorrhage/bleeding, and perforation. Other rare complications reported include, amongst others, infection (cholangitis, liver abscesses, cholecystitis), infection of pancreatic pseudocysts, and duodenal hematoma [18]. We focus on post ERCP pancreatitis, perforation, and hemorrhage.

Pancreatitis is the most common adverse event seen after ERCP. Factors identified to increase the risk of post ERCP pancreatitis include pancreatic duct injection, pancreatic sphincterotomy, sphincter of Oddi dysfunction, young age, normal bilirubin, previous history of post ERCP pancreatitis, balloon dilation of biliary sphincter, and precut sphincterotomy. Factors that may help reduce the risk of pancreatitis after ERCP include use of magnetic resonance cholangiopancreatography (MRCP) especially in high risk patients in which MRCP may prevent a purely diagnostic ERCP. Placement of pancreatic duct stents in patients at high risk and wire guided cannulation of the bile duct may also help reduce the risk of post ERCP pancreatitis [18].

Bleeding complications during ERCP are typically related to sphincterotomy. Severe bleeding after ERCP is rare, and is estimated to occur in about 0.2 % of cases. Control of bleeding may be difficult, and endoscopy for control of bleeding (clips, injection therapy, and/or thermal therapy) and aggressive correction of any associated coagulopathy should be the initial step. Angiography and/or surgical exploration, generally through a duodenotomy, may be required in selected cases [18, 19].

Perforation after ERCP is managed best by collaboration between surgeons and therapeutic gastroenterologists. Increased risk of ERCP related gastrointestinal tract perforations may be noted in patients with altered anatomy [20]. The spectrum of clinical presentation can be varied. Perforations can be categorized into several general categories including perforation due to guidewires, periampullary perforations (Fig. 35.5), or remote (duodenal/gastric) perforations [18]. Conservative management, including bowel rest, broad spectrum antibiotics, and nasogastric/nasoduodenal decompression, may be attempted for contained perforations, especially with contained periampullary perforations given the difficulty in identifying these surgically given their location and generally small size. The use of internal biliary drainage via stents, nasobiliary tubes, or external biliary drainage via percutaneous transhepatic catheters is advocated by some for the conservative treatment of periampullary perforations. Bile duct perforations are generally managed best by endoscopic therapy (drainage) given the usual small size. Small luminal perforations noted at the time of endoscopy can sometimes be managed by application of clips [21, 22].

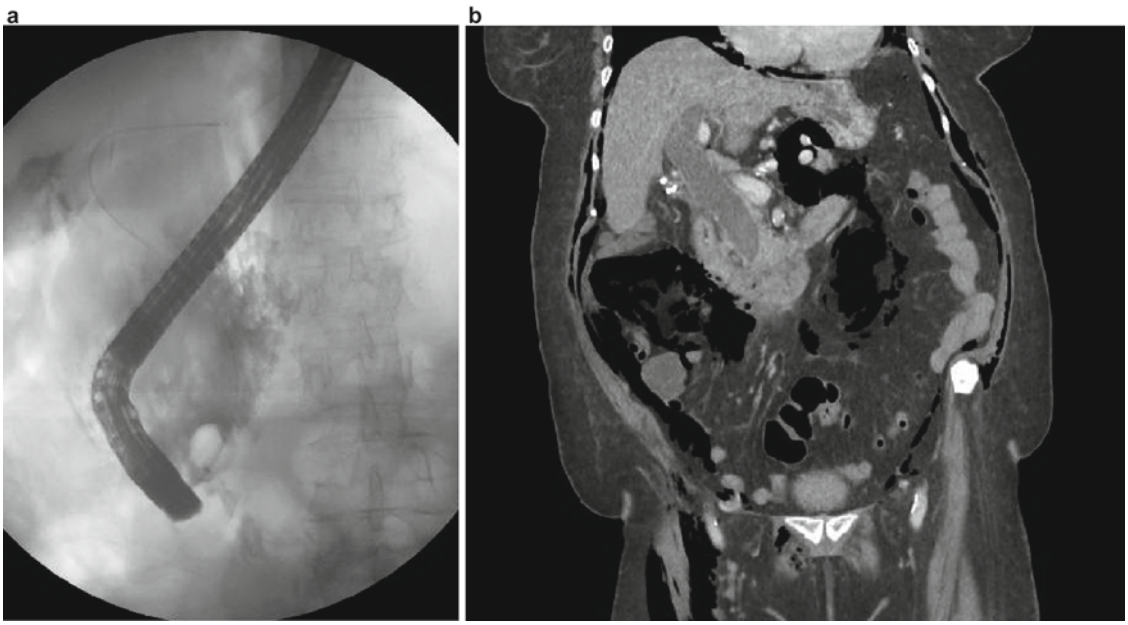

Fig. 35.5 Periampullary perforation after ERCP. Extraluminal air noted after ERCP with difficult stent placement attempt. Initial cholangiogram demonstrated contrast outside of the bile duct. (**a**) Periampullary perforation was suspected. The patient was stable without signs of systemic illness. CT scan done for abdominal pain about 6 h after ERCP demonstrated large volume of extraluminal air but minimal fluid. (**b**) Patient was treated with bowel rest, NG decompression, and broad spectrum antibiotics with a good response. Patient did not require surgery. Periampullary perforations in patients without systemic signs of sepsis or uncontrolled leakage can be treated often successfully with nonoperative management

Evidence of uncontained perforation, systemic signs of illness, or large luminal perforations should prompt urgent surgical exploration. Surgical principles include wide drainage as well as repair with or without diversion. Debridement of tissue to viable tissue followed by transverse single or double layered closure to prevent luminal narrowing is usually done for small perforations. Occasionally, despite meticulous examination, a site of perforation is not identified. Consideration should be made for wide drainage of the area if the site of leak is not identified. For larger or more complex perforations, a jejunal serosal (Thal) patch or duodenojejunostomy may be utilized. For patients at very high risk for leak or breakdown of a surgical repair, including those with delayed presentation and/or treatment, duodenal diversion may be performed. Although a number of techniques have been described, pyloric exclusion is usually the recommended procedure and arises out of the experience of treatment of traumatic duodenal injuries [22, 23].

Endoscopic Ultrasound (EUS)

One of the most significant increases in endoscopic procedures being performed in the United States (US) is EUS based procedures. This technology is being increasingly used for staging of malignancies including esophageal, gastric, pancreatic, and rectal malignancies as well as for biopsy (fine needle aspiration), difficult bile and pancreatic duct access, as well as a variety of therapeutic maneuvers (endoscopic cyst gastrostomy and celiac plexus block, for instance). Complications related to EUS are similar to other endoscopic procedures and include perforation, infection, pancreatitis, bleeding, bile peritonitis, pneumothorax, pneumoperitoneum, and malignant seeding [24]. While the principles surrounding management of these complications are generally the same as with other endoscopic procedures, several points deserve mention.

Passage of EUS scopes into the esophagus is performed generally without direct visualization and may increase the risk of perforation in the upper/cervical esophagus. The tip of the EUS scope is larger and more rigid than that of standard flexible upper scopes. Risk factors for perforation include endoscopist experience with EUS, patient age (older than 65), previous difficulty with esophageal intubation, luminal stenosis, presence of a duodenal diverticulum, and pre-EUS stricture dilation. Perforations of the stomach and rectum are extremely uncommon [24, 25] (Fig. 35.6).

Bleeding is uncommon and mild bleeding is reported in about 4 % of procedures and most resolve with conservative management [25]. Pancreatitis is rarely reported in patients undergoing FNA of pancreatic lesions or the pancreatic duct. Most cases respond to conservative management. The risk of pancreatic duct leak after EUS FNA is extremely rare but has been reported; most resolve with conservative treatment including stenting and percutaneous drainage [24, 25].

Enteroscopy/Small Bowel Endoscopy

Single, double balloon, and spiral enteroscopy are being increasingly utilized for evaluation and therapy of mid gastrointestinal tract pathology, including obscure gastrointestinal bleeding, polyposis syndromes (Peutz-Jeghers syndrome), inflammatory bowel diseases, small bowel tumors, foreign body extraction, as well as examination of the biliary tract in patients with altered anatomy (i.e., after roux-en-Y gastric bypass). Complications of this procedure include abdominal pain (most often), pancreatitis (likely related to mechanical stress during push pull maneuvers or compression of the ampulla with the balloon), perforation, and bleeding. Previous abdominal surgery and altered gastrointestinal tract anatomy increase risk of complications, particularly with perforation [26, 27]. Endoscopic tattooing techniques, especially at sites of intervention or concern may aid the surgeon when complications arise.

Capsule endoscopy can be utilized for identification of small bowel pathology; however it does not allow for therapeutic interventions. One of the most often reported adverse events is capsule retention, which is defined when the capsule does not pass within 2 weeks. If asymptomatic, this can be treated with endoscopic or surgical retrieval methods or medical therapy aimed at the underlying disease. When symptomatic, it may result in obstruction and/or perforation. Treatment options depend on the clinical status of the patient and may involve surgery, endoscopy or enteroscopy to retrieve the capsule [28].

Endoluminal Stent Related Complications

Stenting in the gastrointestinal tract is used frequently for the treatment of benign and malignant strictures, including in the esophagus, biliary tract, and colon. Potential complications generally include bleeding, migration, obstruction, and perforation. Depending on the indication for stenting, endoscopic therapies can often be utilized to manage these complications. The care of patients with complications from endoluminal stents requires close collaboration with surgeons and/or therapeutic gastroenterologists familiar with stent placement and management.

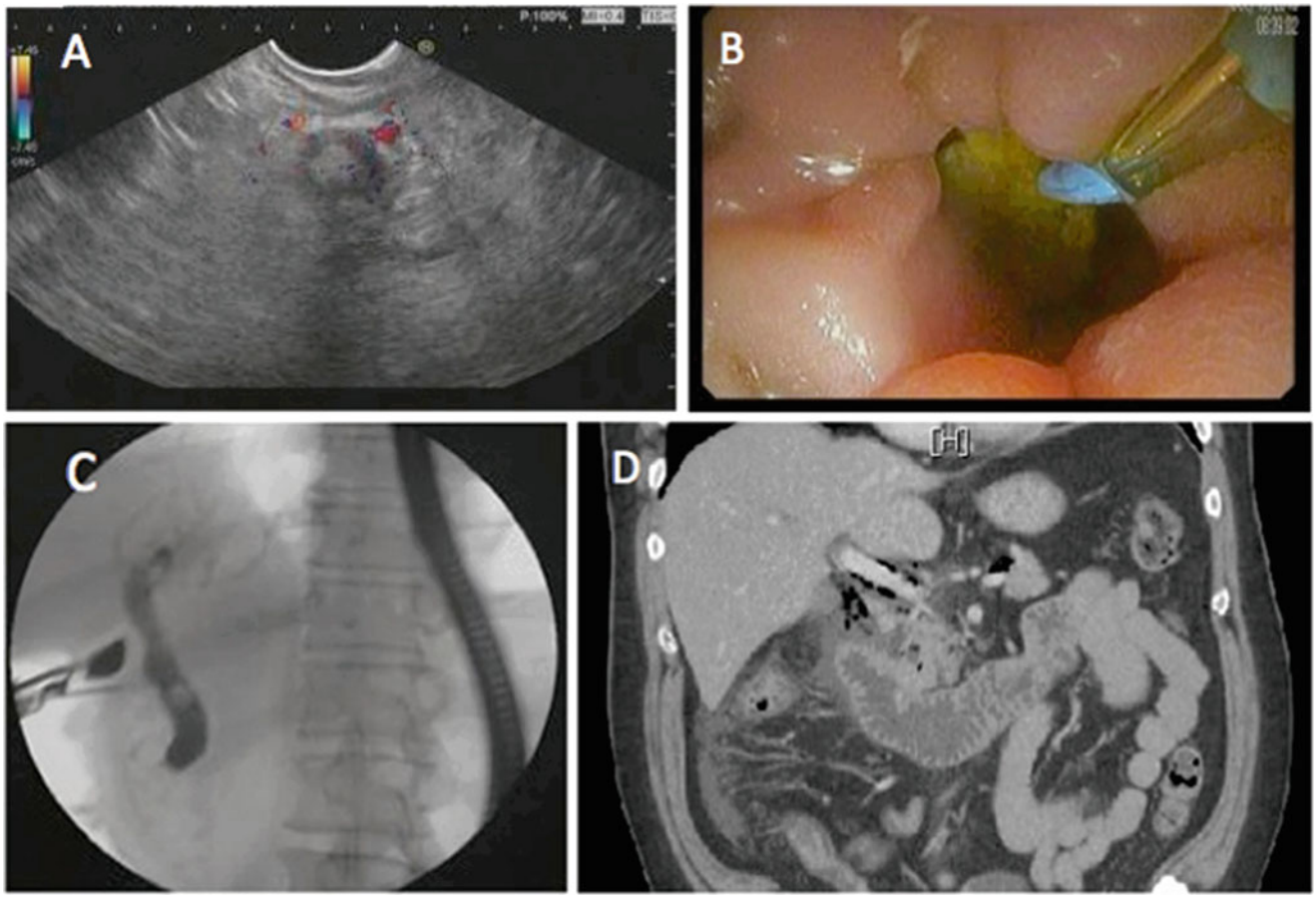

Fig. 35.6 Perforation after EUS/ERCP. A 59-year-old man underwent outpatient EUS and ERCP for elevated LFTs. EUS revealed choledocholithiasis marked by hyperechoic material with acoustic shadowing within the extrahepatic bile duct (**a**). On ERCP, the ampulla could not be identified and he was noted to have a large duodenal diverticulum at the expected location of the ampulla (**b**). EUS guided cholangiogram was then obtained showing a large filling defect within the CBD and possible distal CBD stricture at ampulla and no passage of contrast into the duodenum (**c**). Despite EUS guided cholangiogram, bile duct could not be cannulated on a subsequent ERCP attempt under fluoroscopic guidance and the procedure was terminated. Patient developed abdominal pain post procedure and CT scan revealed an air fluid level in retroperitoneum concerning for duodenal diverticular perforation (**d**). Patient then underwent surgery with hepaticojejunostomy and cholecystectomy

Esophageal/Gastric/Duodenal Stents

Massive bleeding after palliative placement of esophageal stents for malignancy is reported as a rare, serious, and often lethal complication. A large study identified the presence of an esophageal fistula or a tracheal stent as risks factors for massive bleeding. Etiology is thought to be related to pressure, especially near the aortic arch, causing ischemia and necrosis, or secondary to tumor involvement with the aorta [29, 30].

Perforation is a risk of esophageal stent placement. Given that the majority of these stents are placed for palliation, there are often limited options for treatment. Perforation may be associated with previous chemotherapy or radiation therapy. Placement of a covered stent along with conservative management including broad spectrum antibiotics is central to management of this complication [30]. Uncontained perforations in patients with inoperable tumors are typically associated with poor prognosis.

Obstruction related to tumor can be seen, particularly with uncovered stents. This is generally treated best with re-stenting with a covered stent or endoscopic tumor ablation [30].

Migration of stents may be seen, particularly with plastic or covered stents. In patients with altered anatomy, such as gastric bypass, stents may migrate into the distal bowel. Endoscopy or surgery may be required to remove the stents depending on the location and/or symptoms of obstruction and/or perforation [31].

Biliary Stents

Obstruction is generally the most common issue seen with biliary stents, particularly when used for malignant strictures. The use of metallic stents may help maintain patency longer than with plastic stents. Migration of biliary stents has been reported to cause perforation of the gastrointestinal tract. This may be precipitated by intra-abdominal adhesions preventing passage of a large stent, diverticular disease (small or large intestine), or incarcerated abdominal wall hernias. Depending on patient presentation and location of the stent, endoscopic or surgical means may be required to remove the stent [32].

Colonic Stents

Colonic stents may be used for the palliation of malignant strictures, either as an attempt at definitive therapy in poor operative candidates or as bridge therapy to potentially allow for a single stage operation without the need for a stoma. Common complications of colonic stent placement include perforation, migration, and obstruction [33]. The risk of perforation with colonic stent placement is approximately 7 % and may be associated with stent type, benign nature of the stricture, and use of bevacizumab based chemotherapy. Some studies suggest that predilation of strictures prior to stent placement may increase the risk of perforation, however that has not been uniformly shown [34]. Migration of colonic stents is generally asymptomatic unless the patient re-obstructs. Obstruction may be seen also when stents are used long term for palliation of inoperable malignant obstruction. Similar to palliation of esophageal malignancies, endoscopic ablation therapies or re-stenting is typically utilized for palliation.

Endoscopic Interventions for Weight Loss

The field of endoluminal weight loss procedures is rapidly expanding with the introduction of gastric balloons as well as a widely available full thickness flexible endoscopic suturing platform (OverStitch™ Endoscopic Suturing System, Apollo Endosurgery, Austin, TX). Currently, the most widely performed endoscopic weight loss procedures include revision of dilated gastric pouch and/or gastrojejunostomy for weight regain after gastric bypass [35] or primary endoluminal sleeve gastroplasty [36]. Gastric balloons, utilized widely in Europe, have recently been introduced into the US market and are temporary saline and methylene blue filled single or double balloons that remain in the stomach for 6 months prior to scheduled endoscopic removal. Rupture of the balloon is usually indicated by change in urine color (given the methylene blue) and should prompt endoscopic removal. With the European experience, complications including bowel obstruction and perforation have been reported and if widely adopted may be seen by acute care surgeons [37–39].

Lower Endoscopy

Possible complications of colonoscopy are similar to other endoscopic procedures and include bleeding, perforation, and infection. In addition, splenic injury can rarely be seen after colonoscopy. There are several important issues to consider regarding the surgical management of complications of lower gastrointestinal endoscopy.

The risk of perforation during colonoscopy is approximately 0.2–0.4 % and the most common region of perforation is in the rectosigmoid region. Perforation may result from mechanical pressure, passing a scope through a diverticulum, pressure from a loop created by the endoscope, aggressive insufflation, or at the site of polypectomy. Although traditionally, perforation after colonoscopy mandated urgent operative exploration, management depends on the mechanism as well as the clinical state of the patient. In a patient without signs of a systemic response or peritonitis and evidence of a contained perforation, conservative management with bowel rest, serial abdominal exams, broad spectrum antibiotics, and intravenous fluids is often sufficient for treatment and may be associated with better outcomes (Figs. 35.7 and 35.8). Evidence of an uncontained perforation or worsening clinical condition should prompt urgent operative exploration [2]. With early intervention and lack of significant contamination, primary closure without diversion may be sufficient. Typically, delay in intervention as well as larger perforations typically requires diversion secondary to significant contamination. When expertise is available, laparoscopy should be considered as the initial approach [40].

In settings with surgeons or gastroenterologists familiar with endoscopic clips or endoscopic suturing platforms, certain small series have demonstrated the utility of these adjuncts in the closure of iatrogenic perforations, especially when recognized at the time of initial endoscopy [41].

Bleeding after colonoscopy is managed in a similar manner to that in other parts of the gastrointestinal tract. Delayed bleeding can be seen after therapeutic procedures, and tend to be associated with resuming anticoagulation after polyp removal and increasing size of polyp [42]. Resuscitation along with correction of coagulopathy is paramount. Failure to respond to resuscitation or evidence of continued bleeding may prompt repeat endoscopy for identification and control of bleeding. If the source is unable to be located, a tagged red blood cell scan or angiography may be of value. Failure

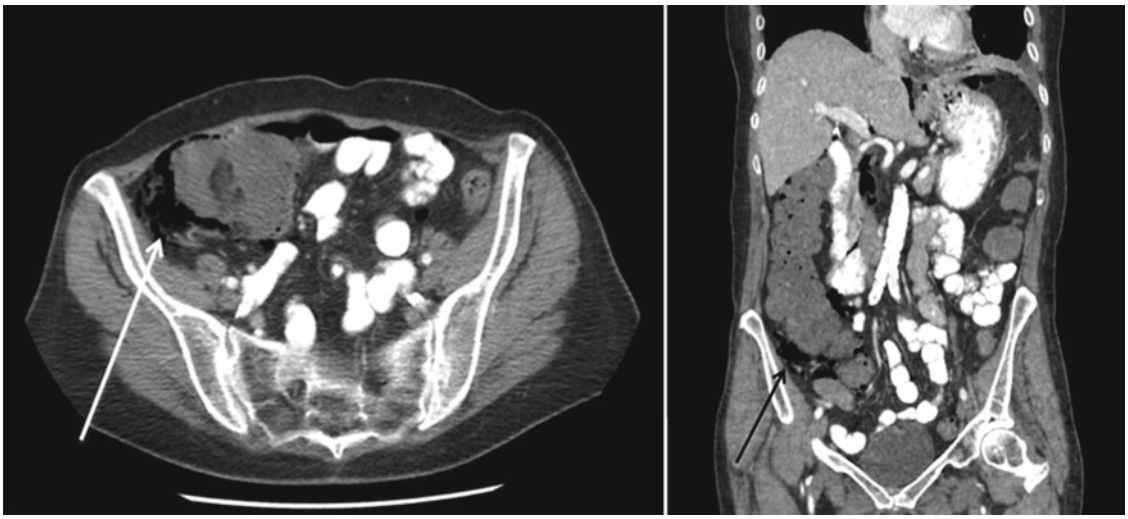

Fig. 35.7 Perforation after therapeutic colonoscopy. Extraluminal air seen after argon plasma coagulation (APC) of a bleeding right colon arteriovenous (AV) malformation. On CT, there was no evidence of free fluid suggesting a small localized perforation. The patient had localized pain on exam and responded to bowel rest and IV antibiotics without need for surgery

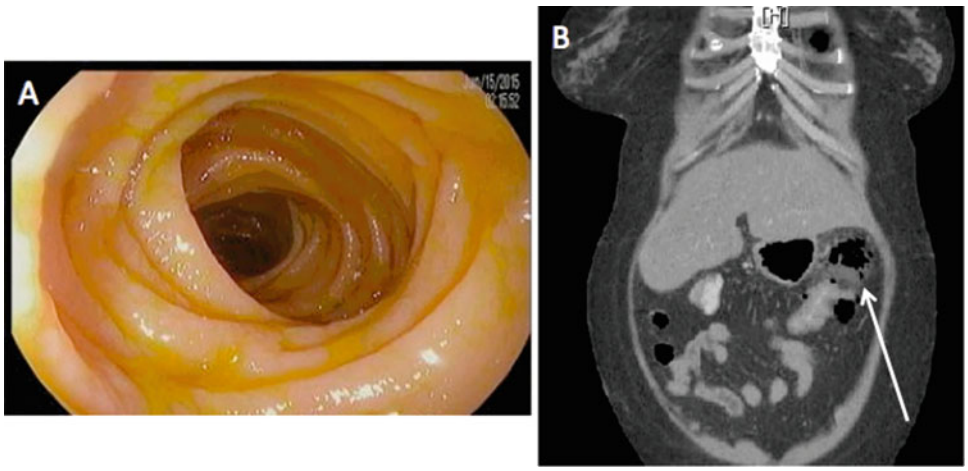

Fig. 35.8 Perforation after diagnostic colonoscopy. A 59-year-old female underwent colonoscopy (**a**) with random biopsies for workup of chronic diarrhea. She presented to the ER 6 h after the procedure with severe abdominal pain. CT scan revealed thickening of the wall of the colon at the splenic flexure along with an air fluid level suggesting colon perforation (**b**). She was managed with IV antibiotics and bowel rest and recovered well without requiring surgery

requires surgical management, which often requires resection. Inability to localize a colonic source of bleeding may require total abdominal colectomy [2].

Injuries to the spleen during colonoscopy are rarely reported (Fig. 35.9). It is often secondary to direct trauma from the endoscope causing traction on the splenocolic ligament and avulsion of the splenic capsule. Risk factors that may be associated with splenic injury include technically difficult procedure, prior surgery, splenomegaly, as well as anticoagulation. It also appears to be more common in women. Diagnosis is often delayed and is often found incidentally when imaging is performed for unexplained post colonoscopy abdominal pain. Referred left shoulder pain may provide a diagnostic clue. Treatment is as per the guidelines for management of blunt splenic trauma [2, 43, 44].

Per Oral Endoscopic Myotomy for Achalasia

The technique of per oral endoscopic myotomy (POEM) is gaining increasing traction as an effective trans oral treatment for patients with achalasia. The worldwide experience currently is limited to several thousand cases and to certain centers around the USA and world; however, the popularity of this procedure continues to grow. It requires endoscopists with an advanced therapeutic skill set and briefly consists of a mucosal lift followed by mucosotomy, entry into the submucosal space, creation of a submucosal tunnel, identification of the esophagogastric junction, circular muscle myotomy, and closure of the mucosotomy with clips or an endoluminal suturing platform [45].

The major post procedure complication of worry is a leak, which surprisingly is rare in published reports.

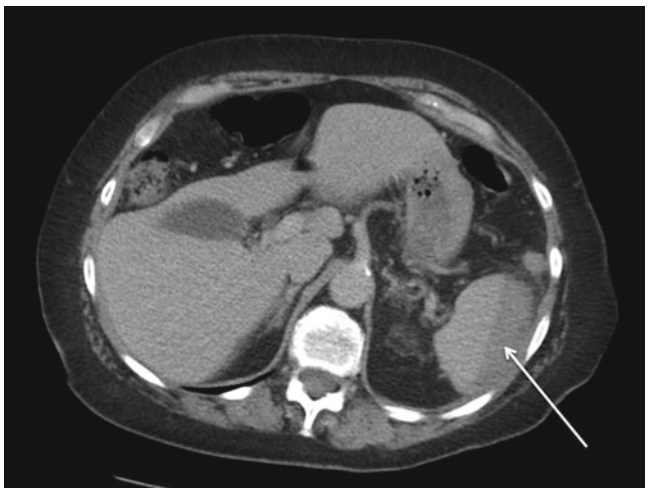

Fig. 35.9 Splenic hematoma (subcapsular) seen after colonoscopy. This patient presented after a difficult colonoscopy after an episode of diverticulitis. Abdominal pain prompted her return to the ER. She was found to have a subcapsular hematoma of the spleen. She had no evidence of active bleeding and responded to conservative treatment

Complications including subcutaneous emphysema, pneumoperitoneum, pneumomediastinum, and pneumothorax (requires chest tube if symptomatic) have been reported. These may be minimized by the use of carbon dioxide insufflation for the procedure. Pleural effusions have been reported and typically treated with drainage. Hemorrhage is rarely reported and typically can be addressed with endoscopic options [46].

Endoscopic Mucosal Resection and Endoscopic Submucosal Dissection

Endoscopic mucosal resection (EMR) and endoscopic submucosal dissection (ESD) techniques are utilized by certain centers for various indications including the excision of carefully selected premalignant and well differentiated early stage malignancies as well as submucosal lesions of the gastrointestinal tract. Certain centers are utilizing the technique for endoscopic full thickness resection with concurrent endoscopic or laparoscopic closure. Bleeding and perforation are the most common complications seen; bleeding is typically controlled with endoscopic adjuncts. Perforation, when small and recognized, can be addressed with endoscopic clips or endoscopic suturing platforms. When endoscopic measures fail, or there is development of a systemic inflammatory response or peritonitis, standard surgical principles apply for treatment. Stricture or stenosis is seen late, and typically addressed with endoscopic dilation [47].

Conclusions

The number of endoscopic procedures performed annually continues to increase. With the continued evolution in endoscopic technology, the indications for endoscopic approaches to the diagnosis and treatment of gastrointestinal diseases continue to expand. Whether surgeons perform diagnostic and/or therapeutic endoscopy as part of their practice, it is imperative for those who take care of acute care surgical issues to understand the potential complications of flexible endoscopic procedures and the subsequent endoscopic and surgical management. A close working relationship between surgeons and gastroenterologists assures best care practices and outcomes for this subset of patients.

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Complications of Morbid Obesity Surgery

36

Christian Perez, Peter A. Walker, and Shinil K. Shah

The number of weight loss procedures being performed annually continues to increase. Therefore, it is important for the acute care surgeon to be familiar with the complications of common bariatric procedures including adjustable gastric banding, sleeve gastrectomy, and roux-en-y gastric bypass. The following chapter summarizes the complications of different bariatric surgical procedures and highlights the initial evaluation and management [1].

Laparoscopic Adjustable Gastric Band

Since its introduction in 1993, the laparoscopic adjustable gastric band (LAGB) gained popularity because of its reversibility, relatively minimal alteration of gastric anatomy, ability to be performed with laparoscopy, and short learning curve. Its popularity has declined in recent years, from 42.3 % of all weight loss surgery procedures in 2008 to 17.8 % in 2011. This is in part secondary to multiple factors including a 40–50 % reoperation rate secondary to device complications, weight loss failure, and significant readmission rates (reported to be over 10 %) [1, 2].

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Intraoperative Complications

Refinements in operative techniques, such as dissection through the pars flaccida and routine gastro-gastric plication, have decreased the incidence of previously common complications such as immediate posterior band slippage. Additional intraoperative complications that have been described are gastric and esophageal perforation and splenic injury with associated bleeding. Overall the procedure is extremely safe with a <1 % incidence of intraoperative complications.

Band Slip

Band slip is the most common complication seen after LAGB placement. According to some reports, it occurs in nearly 40 % of patients. Slippage of the band can result in dilation of the gastric pouch as well as esophageal dilation [1]. Band slips were much more common before adoption of the pars flaccida technique of placement as well as the placement of gastro-gastric plication sutures over the band.

Slippage is caused by prolapse of the gastric wall, which causes a clockwise or counterclockwise rotation of the band. The clinical picture is characterized by nausea, reflux, vomiting, dysphagia, and/or epigastric pain.

The diagnosis is made with radiographs, with slip being suggested by loss of the appropriate angulation between the band and the vertebral bodies. Contrast (swallow) studies will demonstrate pooling of the contrast in the upper gastric pouch without passage through the band. Normally, when viewed in the anteroposterior projection, a gastric band will be inclined along its longitudinal axis at an angle from 4 to 58° to the vertebral column (phi angle) and be positioned about 5 cm below the left hemidiaphragm [3] (Figs. 36.1 and 36.2). When slippage presents, this angle is lost. Since the introduction of the pars flaccida technique, the majority of gastric band slips are anterior. Endoscopy demonstrates an enlarged gastric pouch above the level of the band.

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_36

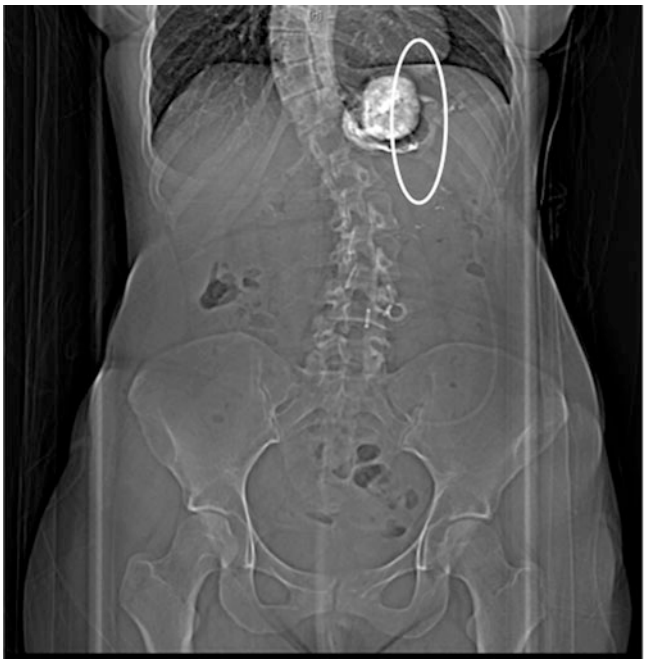

Fig. 36.1 Slipped gastric band. Plain film demonstrates retained contrast in the gastric pouch above the level of the band as well as the band (*white circle*) almost parallel to the vertebral column. This is consistent with a gastric band slip

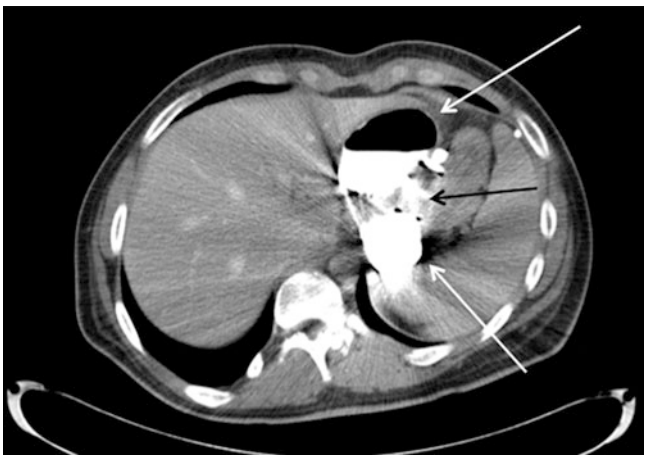

Fig. 36.2 Slipped gastric band. Computed tomography (CT) scan of the abdomen demonstrates a "muffin top" appearance of the stomach, indicating a significant gastric band slip. There is significant stomach (*white arrows*) above the level of the band (*black arrow*) with contrast retained in the pouch

The treatment for band slippage is immediate deflation of the band; if symptoms persist, removal of the band may be needed. There have been some reports of gastric ischemia and necrosis secondary to delayed treatment of a gastric band slip. If there are any clinical signs or indications of ischemia, the patient should immediately proceed to the operating room for gastric band removal.

Port, Tubing, and Reservoir Complications

The incidence of complications related to the mechanical device is reported to be between 4.3 and 24 % and includes port-tubing disconnection, port infection, port rotation and flips, and leaks within the tubing system [2]. Port disconnections can be diagnosed with fluoroscopy. When contrast is injected into the port, the band will not fill and extravasation will be noted. Tubing and reservoir leaks are often difficult to diagnose. They are usually suspected when patients frequently visit the clinic for band fills with poor weight loss or restriction after fills. The diagnosis is also usually confirmed with fluoroscopy and contrast injection.

Other complications related to the device include infection, flipping of the subcutaneous port, or a chronic sinus tract. It is important to remember that a port or tubing infection should be thought to represent band erosion until proven otherwise. This can be a serious complication and will be discussed in detail later in this chapter.

Erosion of tubing into other organs has been described as has been internal hernias and/or bowel obstructions from gastric band tubing. In patients with LAGBs who present with bowel obstruction, the band tubing should be evaluated as a potential cause. Standard surgical principles apply for treatment of the bowel obstruction; if band related tubing is found to be causing a bowel obstruction, the band does not necessarily have to be removed; however, some recommend shortening of intra-abdominal band tubing, plication of the band tubing to the anterior abdominal wall, and/or placing excess tubing over the right or left upper quadrant [4].

Retained band tubing has been reported rarely after band removal due to unrecognized erosion at a metallic connector that is present in the tubing connecting the subcutaneous port to the tubing attached to the gastric band device in some older generations of LAGBs [5].

The treatment for device related complications may require replacement of the affected parts of the system. This may require a local procedure (subcutaneous port related complications) or a laparoscopic intervention.

Reflux Esophagitis

Exacerbation or de-novo esophageal reflux has been described after band placement. This may be secondary to an over-tightened band and treatment is usually removing fluid from the band. This can be frustrating for patients who may then not see the expected restriction and results with their bands. New reflux symptoms should prompt evaluation for a gastric band slip.

A preoperative endoscopy is recommended on patient with gastroesophageal reflux disease (GERD) symptoms before placing a band to identify significant reflux esophagitis

or hiatal hernia, which may lead to recommendation for another procedure. Laparoscopic roux-en-Y gastric bypass (LRYGB) is usually considered the procedure of choice for patients with severe reflux symptoms and morbid obesity.

Pouch Dilation

This complication usually indicates a prolapse/slip of the band but it has been described in patients with normal positioning of their bands. The treatment for pure pouch dilation is deflation of the band. Usually, with time, this leads to regression. In a patient with isolated minor pouch dilation without a slip or other symptoms, band removal is usually not needed.

Esophageal Dysfunction

A spectrum of esophageal dysfunction is seen in patients with LAGBs with reflux representing the most common complaint. Pseudo-achalasia has also been reported in patients with gastric bands (Fig. 36.3). A significant percentage of patients with esophageal dysfunction/dilation improve with deflation of the band. Severe or persistent dilation should prompt band removal. Patients with LAGBs who present with recurrent episodes of aspiration pneumonia should be evaluated for esophageal dilation or pseudo-achalasia symptomatology.

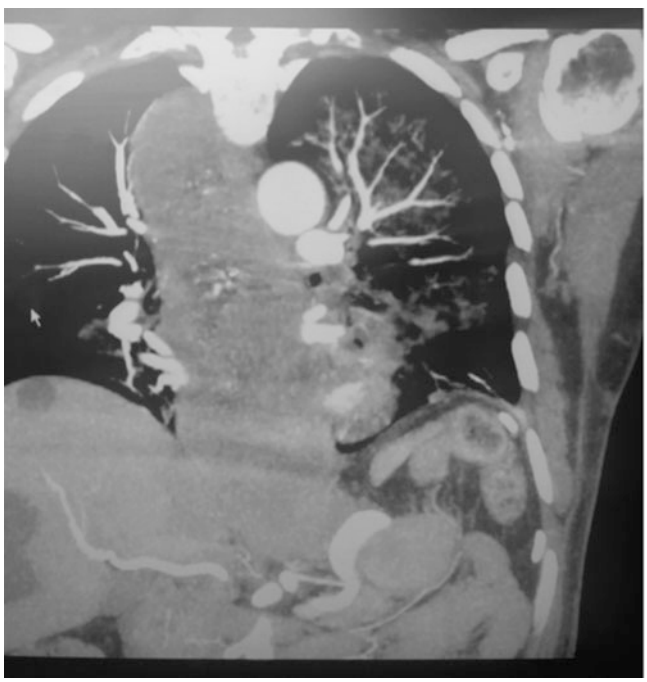

Fig. 36.3 Significant esophageal dilation in patient with gastric band. A chronically over-tightened band and/or untreated slip with obstruction can result in impressive esophageal dilation, resulting in a pseudo-achalasia type picture. In mild cases, band deflation usually leads to resolution. Severe cases should prompt band removal. This is sometimes diagnosed by atypical symptoms including recurrent aspiration pneumonia or significant uncontrolled reflux

Band Erosion

Band erosion is generally considered the most serious complication of LAGB aside from gastric band slip with ischemia/necrosis. Incidence is reported to be as high as 3.9–5.8 % [1, 2]. However, the rate of erosion has decreased with the current generation of gastric bands, which are larger and exert pressure on the stomach over a wider surface area.

Erosion is by definition an intra-gastric migration of the band. This complication usually presents late and may present months or years after the initial band placement. It is usually related to gastric wall ischemia secondary to extrinsic pressure from an over distended band, infection or chronic inflammation of the band [6].

The most common presentation is loss of satiety and weight regain. Other presentations of band erosion include spontaneous infection (Fig. 36.4), extrusion or tenderness at the subcutaneous port site, atypical of atypical fluid (or loss of fluid) in the LAGB system, acute abdominal pain, intra-abdominal fluid collection, empyema, chest pain, small bowel obstruction, and/or vomiting [6].

The diagnosis can be suspected with a change in band position over time on X-rays. On fluoroscopic evaluation, extravasation of contrast around the gastric band and/or an open band indicates full thickness erosion. On computed tomography (CT) of the abdomen, eccentric gastric wall

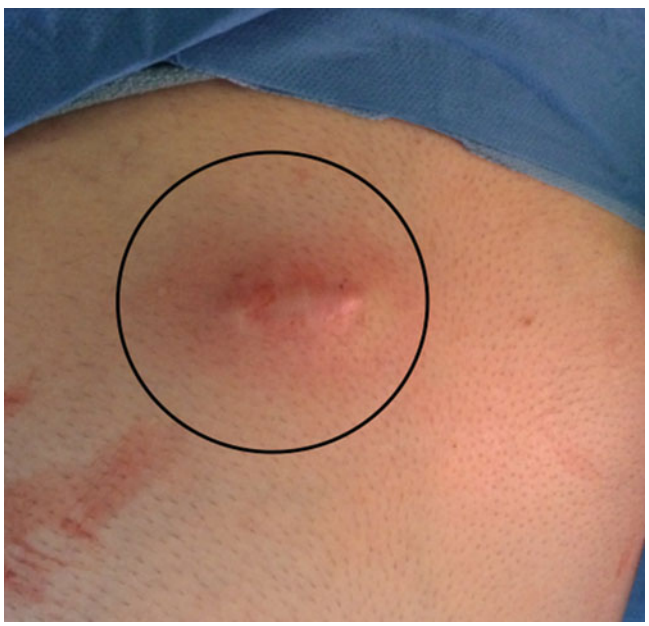

Fig. 36.4 Eroded gastric band. Physical exam of a patient with an eroded gastric band. Port site infection should be thought of as gastric band erosion until proven otherwise

thickening adjacent to the band or intraluminal migration can be seen. Endoscopic evaluation will make the final diagnosis with direct visualization of the eroded band [6].

The treatment of eroded band is generally surgical. The goal is to remove the band and repair the gastric wall. This can be safely achieved with a laparoscopic approach. A minimal dissection technique should be utilized. The perforation site is not always easily identified especially with erosion of only a small portion of the band. If a site is not identified and there is no leak of fluid or air on intraoperative leak testing, aggressive dissection to identify the site of perforation should be avoided. Some groups have described endoluminal techniques for removal of eroded gastric bands. If the buckle of the gastric band is intraluminal, this technique should be considered, especially if there is available expertise.

The general recommendation is to postpone any further additional weight loss procedures until the stomach has healed but some groups have described the immediate replacement of the band [7]. This should not be viewed as standard practice.

Laparoscopic Sleeve Gastrectomy

Laparoscopic sleeve gastrectomy (LSG) was originally performed as the restrictive component of the duodenal switch procedure. Substantial weight loss occurred with sleeve gastrectomy alone. In the last 10–15 years, the LSG has been used as a stand-alone procedure for weight loss with good results. It continues to gain popularity and in some centers is the primary procedure performed for weight loss in the appropriate patient population [8–11]. The increasing popularity of this procedure is secondary to the associated weight loss, lower long-term risk profile as well as the relative simplicity of the procedure [9, 10]. There are several complications or issues that are seen in patients after sleeve gastrectomy.

Reflux

The association between LSG and reflux is controversial. The majority of published studies have reported increases in reflux symptoms after LSG. The incidence of reflux after LSG in large series has been reported to be present in up to 20 % of patients [8, 12]. Four technical errors have been identified during the procedure that predispose patients to reflux including relative narrowing at the junction of the vertical and horizontal parts of the sleeve (angularis incisura), dilation of the fundus, twisting of the sleeve, and persistence of a significant hiatal hernia or a patulous cardia [13, 14]. Repair of a moderate or large hiatal hernia if present at the time of LSG may be a factor to prevent postoperative reflux [14].

Bleeding

Bleeding has been reported in up to 13.7 % of patients after LSG. The source of bleeding during this procedure can come from the staple line, the omentum, the short gastric vessels, the abdominal wall, and the spleen. Persistent bleeding from short gastric vessels or the spleen will usually require that the patient be brought back to the operating room [15].

Multiple steps should be taken to decrease the risk of bleeding during this procedure. Appropriate perioperative management of anticoagulation is imperative. Technically it is important to visualize port insertion sites to avoid injuring blood vessels. During division of the short gastric vessels while approaching the spleen, it is important to stay close to the serosa of the stomach to avoid injuring the spleen. It is important to avoid excessive traction during division of these vessels. When approaching the left crus and dissecting the phreno-esophageal ligament, careful identification of the phrenic vein should be achieved to avoid injury. Use of the appropriate height gastrointestinal stapler will also improve hemostasis along the staple line [16].

Use of buttress material along the staple line and suturing of the staple line of the sleeve have demonstrated in certain studies to reduce bleeding. Hemostatic agents have shown controversial results.

The treatment of minor bleeding is usually conservative with close monitoring and transfusion when needed. Significant transfusion requirements or lack of response to transfusion should prompt serious consideration for reoperation. Bleeding from the spleen and/or short gastric vessels will usually require prompt surgical intervention including washout, identification, and control of bleeding. This can often be accomplished laparoscopically.

Gastrobronchial Fistula

This is a rare surgical complication that can happen after gastric and esophageal surgery. A systematic review was recently published showing that the majority of the cases associated with bariatric procedures are related to sleeve gastrectomy, which is the reason for including this complication in this chapter. The initial event is usually a gastric leak, perisleeve fluid collection, and/or postoperative hemorrhage that lead to pulmonary abscess and subsequent gastrobronchial fistula. Multiple cases were reported after drain placement, and some speculate the possible relation of a small puncture though the diaphragm with drain placement as a possible event that could facilitate the occurrence of the fistula. The symptoms are productive cough, fever, chest pain, recurrent pneumonia, vomiting, dyspnea, wheezing, hypoxemia, abdominal pain, expectoration of food residues or surgical endoclips, and hemoptysis. The diagnosis is difficult and a

high index of suspicion is needed. The diagnosis is made with computed tomography, contrast films, endoscopy, and bronchoscopy [17, 18].

The management is a combination of multiple therapies, including endoscopy with stent placement and at times associated procedures to improve drainage of the sleeve, such as dilation. Abdominal and pleural drainage is warranted in these cases. Supportive treatment with total parenteral nutrition (TPN), antibiotics, and medications to decrease GI secretions (proton pump inhibitors) should be administered. Surgical treatment is needed in more complex and/or chronic cases and usually involves a gastrectomy with esophagojejunostomy. and at times a thoracotomy with lobectomy and debridement of the diaphragm with closure. The management of these patients requires multiple specialties including thoracic surgery to assist with the management [17, 18].

Leak

Postoperative leaks are one of the most concerning complications after sleeve gastrectomy and probably one of the most common complications of LSG the acute care surgeon will see and manage.

The leak rate has been described to be between 0 and 7 % with a mean reported rate of approximately 2 %. The majority of the leaks have been described in the proximal stomach. Patients with body mass index (BMI) >50 have shown in multiple series to have higher leak rates. The stomach after sleeve gastrectomy is considered to be a high-pressure system. Leaks have been associated with distal strictures that perpetuate the leak secondary to poor distal drainage of the gastric contents [9].

High index of suspicious is required. Tachycardia, fevers, abdominal pain, and persistent hiccups after the procedure should trigger further workup to rule out this feared complication.

Some centers use routine postoperative upper gastrointestinal contrast studies before starting a diet on patients but this has not been shown to have any benefits in preventing leaks. Intraoperative endoscopy has also been used to visualize the shape of the sleeve and perform an air leak test. Routine drain placement with measurement of drain amylase levels (levels around 1000 will indicate saliva) has been used by other groups. Most do not routinely place drains after sleeve gastrectomy and most patients who present with leaks will generally have negative air leak tests intraoperatively or negative early postoperative contrast studies.

Once a diagnosis of a staple line leak is suspected, upper gastrointestinal swallow/contrast studies or contrasted CT scan is used for diagnosis. CT scan will provide information about the anatomy, fluid collections, and their potential accessibility for image guided drainage. This tends to be one of the initial preferred studies.

Leaks are classified according to the time of their presentation. They can be acute (within 7 days), early (within 1–6 weeks), late (after 6 weeks), or chronic (after 12 weeks) [11]. The majority of leaks will present 7–10 days after surgery. This timing is important in the decision making process regarding treatment. During this time of maximal inflammatory response, primary repair of the leak is usually not successfully given inflamed, friable, and poor quality tissue. Key to the treatment of leaks includes source control, nutrition, management of gastrointestinal secretions, and relief of potential obstruction.

The management will depend on the time of presentation. Acute leaks can be treated at times with oversewing of the leak and coverage with an omental patch. Wide drainage should be performed. This can usually be achieved laparoscopically [11, 19]. In early leaks, appropriate drainage with or without endoscopic stenting of the leak represents the main goals of the treatment. Drainage can be achieved with image guidance if they are small and contained. Source control must be achieved. The role of laparoscopy is important to achieve debridement and drainage of the affected area. Rare cases require formal laparotomy. Adequate nutrition, cessation of oral intake (especially if a stent is not placed), nutrition (TPN), and antibiotics (including antifungal coverage) are required. Stents are generally placed endoscopically making sure complete coverage of the defect is achieved. This frequently requires esophageal overlap, which can cause significant symptoms, including pain and reflux. Stents are left in place usually for several weeks if the patient tolerates [10, 11, 19]. Early placement of a stent has been shown by some studies to lead to better closure rates of the leak [20]. It is important to note that the primary goal of stent placement is to help control persistent leakage of gastrointestinal contents. In some cases when distal stricture is suspected, dilation (particularly at the angularis incisura), seromyotomy, or stricturoplasty may be necessary [17].

Late and chronic leaks that persist after adequate drainage and attempted endoluminal treatment may require gastric resection with esophagojejunostomy, jejunal patch, omental patch, bringing a jejunal loop to the leak site to create an anastomosis to drain the leak, or conversion to a gastric bypass. For leaks that persist after 30 days, the likelihood of a leak to seal by exclusion using a stent is very low. Surgeon should generally wait at least for 12 weeks before attempting any reoperation to perform the above-mentioned procedures [10, 11, 19].

Principles to prevent leaks have been described extensively. It is important to assure good staple line formation by allowing time for tissue compression. Avoid creating a stricture by not stapling too close to the incisura. Avoid stapling to close to the esophago-gastric junction or having the staple line on esophagus. Buttressing material, oversewing of the staple line, and fibrin glue have all been used with unclear results in preventing post operative leaks [10]. There are multiple recommendations about the size of staples used to

create the sleeve and the size of the bougie used for sizing the sleeve that are not part of the focus of this review but should be followed when performing a sleeve gastrectomy [11].

Stricture

This complication presents in 0.5 % of patients who undergo sleeve gastrectomy [9].

Early stricture presents in the first 6 weeks after surgery [11]. The most common site of luminal narrowing is at the incisura. This problem is not always a true mucosal or luminal stricture but usually an angulation or kinking of the stomach. The clinical picture is persistent dysphagia, nausea, vomiting. Upper gastrointestinal contrast studies and endoscopy make the diagnosis. Treatment consists of symptom control, nutritional support, and endoscopic balloon dilation [11, 21]. Laparoscopic seromyotomy has been used for long strictures. This is a technique similar to a Heller myotomy [22]. When all procedures fail, conversion to a gastric bypass should be considered [11, 21].

Gastric Bypass

This procedure is considered by many to be the "gold standard" and the procedure to which to compare the rest of the bariatric surgery procedures. Gastric bypass is considered to be one of the more advanced complex laparoscopic operations. In 2007, approximately 200,000 bariatric procedures were performed, with the majority being gastric bypass. This number gives an idea of the number of patients who have undergone this procedure for treatment of morbid obesity and associated comorbidities [23]. It is imperative to recognize the complications of this procedure and the initial management. When available, a surgeon with expertise in weight loss operations should be involved in the care of these patients. However, the acute care surgeon is often faced with the initial management of these complications.

Marginal Ulcer

Marginal ulcers presents in 1–16 % of patients who have undergone gastric bypass. They occur usually between 1 month and 6 years after gastric bypass but can appear at any time point [23, 24].

The presence of a marginal ulcer has been attributed to different causes. Surgical technique in early presentation has been well documented as a cause. Tension and ischemia at the anastomotic site as well as the use of non-absorbable suture material are usually the principal technical causes [23, 24].

Ulcers that present later have been related to Helicobacter pylori (H. pylori), use of nonsteroidal anti-inflammatory drug (NSAIDs), smoking, use of steroids, larger gastric pouches that have present more parietal cells increasing acid production and diabetes [23, 24]. Gastro-gastric fistula should be ruled out as a cause of persistent ulcers.

Patients will present with chronic abdominal pain, reflux, and nausea. The main concerns with marginal ulcers are that they can cause considerable upper gastrointestinal bleeding and occasionally perforation.

The diagnosis is made with endoscopy. The ulcer is usually located on the intestinal side of the gastrojejunostomy. CT scan should be performed to rule out gastro-gastric fistula in patients with persistent ulcers or that present with other symptoms of gastro-gastric fistula like weight regain or sudden worsening of diabetes. This diagnosis is suggested by air in the gastric remnant or proximal duodenum.

The initial treatment of patients that do not present with signs of bleeding or perforation is elimination of the contributing factor (cessation of smoking, stopping use of NSAIDS, and/or H pylori eradication) and proton pump inhibitors alone or in combination with sucralfate [23–25]. The majority of patients (68–80 %) respond to this treatment regimen. This should be continued for 3–4 months. If a gastro-gastric fistula is demonstrated, surgical management will be required. A follow-up endoscopy should be performed to confirm the resolution of the ulcer.

In patients that do not respond to medical treatment, revision may be needed. Endoscopic suturing for oversewing of the ulcer has been described with good results but an experienced surgeon or gastroenterologist that is familiar with this technique is required. There is also little data on this technique for the treatment of marginal ulcers [26].

Some patients with marginal ulcers will present with acute bleeding or perforation. Both of these conditions can be life threatening. The management for bleeding includes management of coagulopathy, hemodynamic support, and endoscopy with control of the bleeding. Perforation should be treated with adequate drainage and primary closure with an omental patch, similar to treatment for perforated gastric or duodenal ulcers. This is generally performed laparoscopically.

Rarely, ulcers can develop in the remnant or bypassed stomach. This may be suggested by melena or evidence of upper gastrointestinal bleeding with negative upper endoscopy or imaging showing hyperdense fluid in the gastric remnant (Fig. 36.5). Diagnosis requires a high degree of suspicion and generally balloon endoscopy for retrograde examination of the bypassed gastric remnant.

Internal Hernia

Internal hernias are one of the major causes of morbidity and mortality in postoperative gastric bypass patients [27]. The incidence of internal hernia has been reported from 0 to 6.9 % [28].

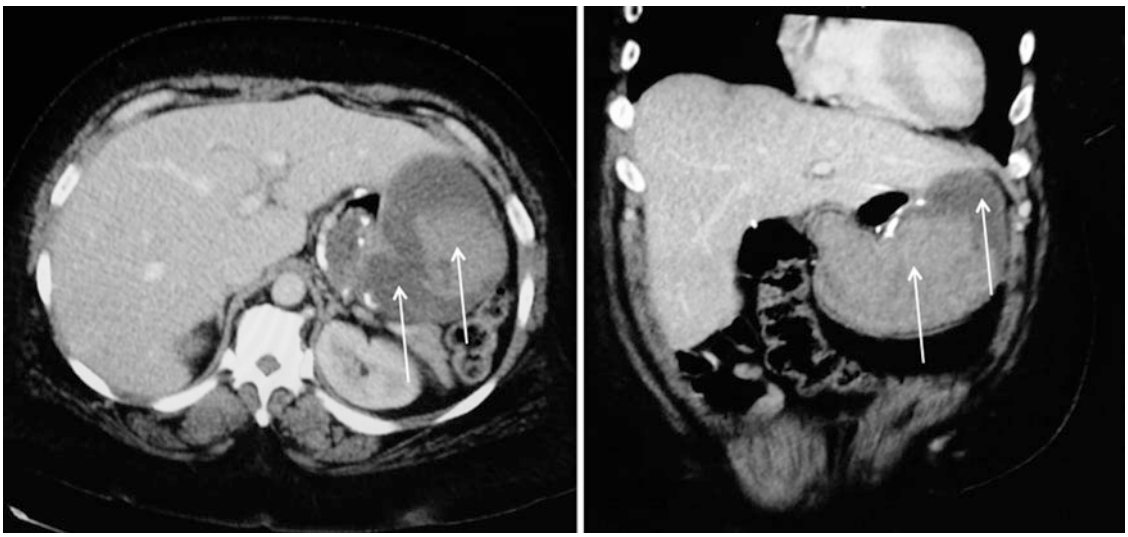

Fig. 36.5 Remnant gastric ulcer. Layered density in the remnant stomach in a patient with signs of an upper gastrointestinal bleed with negative upper endoscopy should prompt investigation of the remnant stomach (potentially ulcers) as a potential source of bleeding

Internal hernias can be localized at Petersen's defect (space between the mesentery of the roux limb and the mesentery of the transverse colon with an antecolic gastrojejunostomy), at the jejunojejunostomy defect, beneath the mesentery of the Roux limb, and when performed in retrocolic fashion, at the mesocolon defect.

Internal hernias usually present after the patient has lost a significant amount of weight with the associated loss of intra-abdominal and mesenteric fat. They have also been described more often with laparoscopic procedures, most probably related to less adhesion formation with the minimally invasive technique.

The clinical picture of patients with internal hernia includes abdominal pain, nausea, and occasionally vomiting. Patients with a history of gastric bypass and these symptoms should be worked up for internal hernia.

The study of choice to make the diagnosis is CT of the abdomen with contrast. The most classic and obvious sign is swirling of the mesentery (Fig. 36.6). This may not always be present. Other more subtle signs include a large amount of small bowel in the left upper quadrant and/or dilation of the gastric remnant or biliopancreatic limb suggesting a distal obstruction (Fig. 36.7). Occasionally an experienced radiologist with expertise in bariatric surgery imaging is required; the "new anatomy" by itself makes the CT scan harder to read. There are some studies showing that multiple scans read as normal on patients with an internal hernia actually had signs of internal hernia on imaging when the scan was read by a radiologist experienced with post gastric bypass anatomy.

The main complication of delay in diagnosis of internal hernia or misdiagnosis is obstruction and/or ischemic bowel that will require intestinal resection and anastomosis.

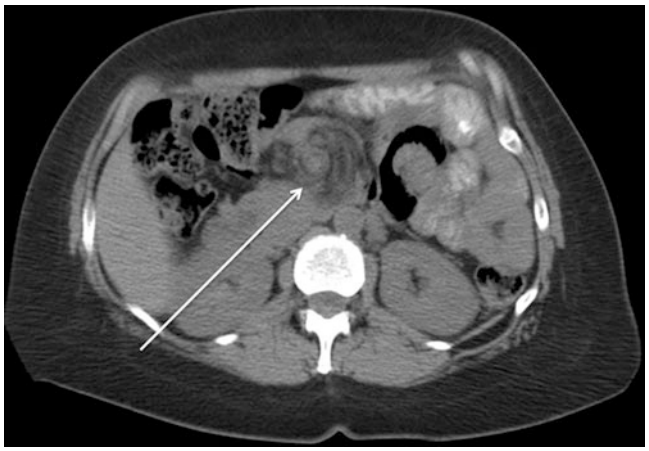

Fig. 36.6 Internal hernia. Demonstrated is the classic mesenteric swirl seen with internal hernia

Negative imaging should not delay intervention with the appropriate clinical signs and symptoms of internal hernia.

The treatment for internal hernia is reduction of the hernia with subsequent closure of the involved space [23, 27, 28]. There has not been clear data that supports the notion that routine closure of Petersen's space decreases the incidence of internal hernia [23]. With significant obstruction, a gastrostomy should be placed into the remnant stomach to help with postoperative intestinal decompression as well as potential feeding access. While waiting for the operating room, nasogastric decompression has little to no role in the treatment of patients with obstruction after gastric bypass as patients tend to decompress into the remnant stomach, not the gastric pouch.

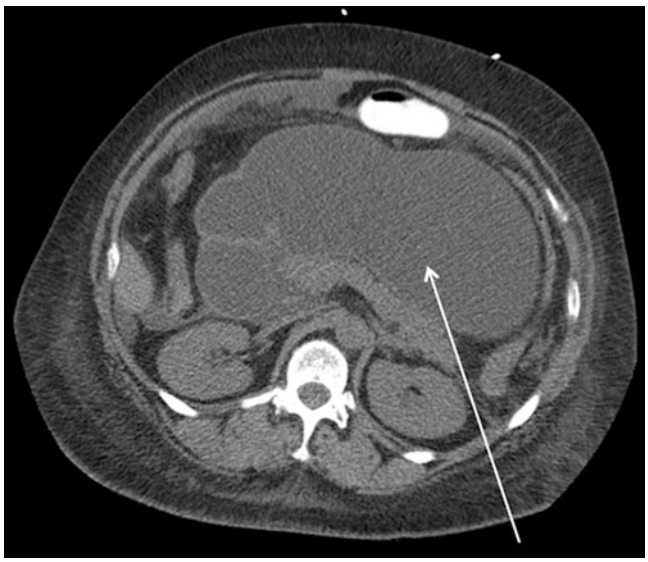

Fig. 36.7 Internal hernia. Oftentimes, the classic mesenteric swirl may not be present. Other signs including dilation of the remnant stomach and biliopancreatic limb suggest obstruction potentially from an internal hernia. *White arrow* demonstrates obvious dilation of the remnant stomach. When there is significant dilation of the remnant stomach in a patient with internal hernia, a gastrostomy in the remnant/bypassed stomach should be placed at the time of operation for decompression as well as feeding access

Obstruction

Just like any other surgical procedure, patients can develop bowel obstruction after gastric bypass secondary to adhesions or other technical problems that may precipitate the need for emergency surgery [23]. The most important aspect when managing this problem is to be familiar with the anatomy of a roux-en-Y gastric bypass. Whenever possible, surgeons experienced with weight loss procedures should be available to perform more definitive treatments if revision of the bypass is required.

Intussusception, particularly at the jejunojejunostomy, has been described as another cause of obstruction. There is no standard approach to the treatment of this issue. There is some evidence that reduction of the intussusception with or without imbrication of the anastomosis may be adequate as long as there are no clinical signs of ischemia. Recurrent episodes may require a bowel resection with anastomosis. An underlying mass contributing to intussusception may require resection [29].

Stricture

Anastomotic strictures (typically at the gastrojejunostomy) have been described in 5–27 % of patients after gastric bypass. Multiple factors have been discussed as possible etiologies, including ischemia and tension at the anastomotic site. It has been shown that the use of a smaller 21 mm circular stapler does have a higher incidence of stricture. Some studies demonstrate a lower incidence of stricture with a hand-sewn anastomosis (30 % rate with circular stapler versus 3 % rate with hand-sewn technique) [30]. A history of chronic non-healing marginal ulcers can predispose patients to late strictures.

The diagnosis is suspected in patients with progressive dysphagia. Oftentimes, and especially with early postoperative strictures, patients present with symptoms when progressing from a liquid to a more solid diet. The diagnosis is confirmed with contrast studies and endoscopy. Endoscopy has the advantage of being diagnostic and therapeutic. Endoscopic balloon dilation is the initial treatment of choice. Multiple dilations may be required. Occasionally dilation will not be successful and revision will be needed.

Strictures can also rarely present at the jejunojejunostomy; this is usually secondary to a technical issue when creating the anastomosis and may present as an early partial bowel obstruction.

Gastrointestinal Leak

Leaks after gastric bypass have been reported in 0–5.6 % of patients. They usually occur 7–10 days post procedure. Early leaks are usually related to technical problems.

Leaks can occur at different sites, including at the gastrojejunostomy, at the staple line of the gastric pouch, at the gastric remnant staple line, at the jejunojejunostomy, and at the different staple lines of the small bowel.

A high index of suspicion is required. In patients that present with persistent tachycardia, fever, pain, and signs of a systemic inflammatory response, a gastrointestinal leak must be ruled out.

Along with clinical suspicion, CT of the abdomen with oral and intravenous contrast is the gold standard for diagnosis of a postoperative leak. Upper gastrointestinal contrast series can also help with the diagnosis. Findings of extravasation of the contrast and free air and fluid are the most common findings. However, it should be pointed out a leak will not always be seen on imaging. It is important to pay attention to secondary imaging signs of leak (fluid and/or extraluminal air).

The treatment required depends on the presentation at the time of diagnosis. Cessation of oral intake, nutritional support, and broad spectrum antibiotics are the mainstays of initial treatment.

Conservative treatment is successful in patients that do not present with hemodynamic instability. Appropriate image guided drainage of fluid collections is required. In patients with a clinical picture of sepsis or hemodynamic instability, surgical intervention should be considered to appropriately drain fluid collections and washout the abdominal cavity

from gross contamination. These patients should be closely monitored in an intensive care unit.

Feeding access for long-term nutrition should be obtained when possible. Gastrostomy placement into the gastric remnant is a good option when dealing with gastrojejunostomy leaks. Generally, gastrostomy tubes should not be placed into the gastric pouch and feeding jejunostomy tubes should be used with extreme caution and after consultation with a surgeon experienced with weight loss surgery.

In certain patients, leaks will "self drain" into the remnant or bypassed stomach, which over time creates a gastrogastric fistula. This usually prevents the patient from getting septic but may cause issues with long-term weight loss and reversal of medical comorbidities.

Other Bariatric Surgical Procedures

Occasionally, patients with older or less common weight loss surgical procedures will present with gastrointestinal issues. These operations may include vertical banded gastroplasty (VBG), gastric plication with or without gastric band placement, and fixed gastric band placement (Molina bands). Most of these complications are chronic in nature, and management of these patients should be done in concert with a surgeon experienced in the management of these complications.

Duodenal switch with biliopancreatic diversion is a malabsorptive and restrictive procedure. Common acute complications seen include those seen after sleeve gastrectomy and/or gastric bypass and can include leak, internal hernias, and significant nutritional deficiencies. Generalized enteritis in these patients should prompt aggressive nutritional workup. The management of leaks and internal hernias follows the same principles as of those with gastric bypass.

Other General Complications

Patients who undergo weight loss procedures can present with general post surgical complications such as deep vein thrombosis and pulmonary emboli. Morbid obesity is a significant risk factor. The basis of treatment is anticoagulation, and occasionally thrombolysis or surgery in more advanced and extreme cases. Guidelines on the management of thromboembolic events have been widely published [31].

Late complications related to these procedures may include malnutrition and vitamin deficiencies. High levels of suspicion are required to make these diagnoses. Particular attention should be paid to iron, Vitamins B1 (thiamine), B12, folate, Vitamin A, and Vitamin D [32]. An experienced multidisciplinary team of surgeons, medical weight loss specialists, psychologists, and nutritionists is often required to successfully manage these complications. All patients with history of bariatric procedures should be closely monitored with nutritional laboratories according to institutional protocols. Early treatment of vitamin deficiencies prevent the occurrence of permanent chronic conditions such as beriberi and Wernicke's encephalopathy that can be irreversible.

Conclusion

As the number of weight loss procedures being performed continues to increase, the number of patients who will present with complications from such procedures will continue to rise. It is important for acute care surgeons to have a clear understanding of the anatomical changes associated with bariatric surgery as well as the common complications and treatment algorithms. Optimal care requires identification and stabilization of patients with complications followed by consultation by surgeons experienced with weight loss procedures. Early recognition of complications and prompt treatment can prevent potentially disastrous complications.

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Abdominal Wall Hernias: Emergency Ventral Hernia Repair

37

Julie L. Holihan and Mike K. Liang

Ventral hernia repair is one of the most common operations performed by general surgeons [1]. Approximately 10 % of ventral hernia repairs are performed emergently, and this rate is rising [2, 3]. The increasing prevalence of emergency ventral hernia repair may be partially related to the growing comorbid population (e.g., obesity, smoking, aging, sedentary lifestyle), improving understanding of the impact of comorbidities on outcomes, and evolving selection criteria among surgeons [4–6]. This has left a large population of comorbid patients with ventral hernias managed non-operatively and at risk for presenting acutely and requiring emergent repair [7, 8].

Compared to elective ventral hernia repair, emergency repair is associated with increased complication rates including infections, mortalities, reoperations, and readmissions [2]. This may be partially attributed to the fact that patients presenting acutely more frequently have significant comorbidities (e.g., diabetes or obesity) and more advanced comorbidities (e.g., poorly controlled diabetes and morbid obesity) [3, 9]. Exacerbating these cases are an acute inflammatory process, metabolic and volume derangements, and off-hour presentation (i.e., potential systems issues). Contamination due to the presence of inflammation, organ ischemia, or organ necrosis is an additional and frequent challenge. These patients require a different treatment paradigm compared to elective ventral hernia repair. For example, using advanced techniques (such as component separation) in a sub-optimal setting may not only be less effective and complicate an inevitable future surgery, but also be associated with a higher wound infection and wound complication rate [10, 11]. In assessing the best option for a given clinical setting, clinicians must assess what the primary purpose of the current surgery is, consider future surgical plans, and balance the risks and benefits.

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Presentation and Preoperative Preparation

Among patients with ventral hernias managed non-operatively, the risk of acute presentation/year is reported to be 2.6 % (range 0–20 %) per year [12–19]. Acute presentation is more likely in two patient populations: (1) patients more likely to be managed non-operatively due to medical risk or poor access to healthcare and (2) patients with concerning mechanical hernia features (Table 37.1) [2, 3, 9, 20–22]. Older, higher risk (i.e., greater and more severe comorbidities), and lower socioeconomic status (i.e., uninsured) individuals are less likely to undergo elective surgery, while younger, healthier patients, with health insurance are more likely to undergo repair [2, 3, 9, 20]. Often, elective surgery for patients with ventral hernias is delayed or deferred due to modifiable comorbidities such as obesity or smoking. The traditional teaching that "small hernias" are more likely to incarcerate may be due to the fact that there are more small hernias than large hernias. When adjusted for prevalence, ventral hernias of any size can present acutely [2].

Acute presentation can be due to bowel incarceration (pain, nausea, vomiting, distension, skin changes), incarceration of non-bowel contents (e.g., preperitoneal fat or omentum), skin erosion with ascites leak, acute pain, or any combination of these signs and symptoms. The acuity of each setting is variable and may affect whether a surgeon pursues elective (discharge and scheduling of surgery as an outpatient), urgent/expedited (prior to discharge), or emergent (to be done immediately) repair. This decision is made based upon the risk, likelihood, and potential for major complications such as bowel ischemia or another acute presentation.

An incarcerated hernia is a hernia that cannot be reduced, or returned to its original compartment [23]. The contents incarcerated can be preperitoneal fat, omentum, bowel, or any other intra-abdominal organ. Hernias can be chronically incarcerated, acutely incarcerated or both (acute on chronic incarceration). Hernias containing acutely incarcerated bowel can lead to bowel obstruction, strangulation, and/or

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_37

Table 37.1 Features that influence acute presentation due to a ventral hernia

More likely to present acutely		
Due to non-operative management	Due to mechanical physiology of the hernia	Less likely to present acutely
• Older age [2, 20] • Poor socioeconomic status [20] • High-risk patient (e.g., cirrhotic, chronic obstructive pulmonary disease, congestive heart failure) [9]	• Obesity • Cirrhotic • Incarcerated with bowel • Prior emergency room presentation	• Parastomal [21] • Lumbar [22] • Incarcerated with fat

ischemia/necrosis. These patients may present with abdominal pain, nausea, vomiting, inability to pass flatus/bowel movements, distension, or skin changes. Physical exam may reveal abdominal tenderness and possibly tense skin overlying the hernia. If on physical examination an acutely incarcerated hernia with bowel involvement is identified, the patient should be prepared for urgent or emergent surgical repair. Further imaging such as CT scan is only indicated in settings where the diagnosis is unclear (e.g., morbidly obese), there is little concern for bowel involvement (e.g., umbilical hernia with incarcerated preperitoneal fat or omentum), or when the CT scan may provide valuable information for the current surgery (e.g., multiple prior surgeries or ventral hernia repairs). Otherwise, additional imaging may delay treatment and place the patient at risk for additional complications (such as aspiration of contrast due to bowel obstruction, nausea, and vomiting). If it is decided to order advanced imaging, computed tomography (CT) is the test of choice in this setting; but ultrasound can also be used, particularly among surgeons facile in using this technology themselves [24]. In the case of an incarcerated hernia, CT may show a bowel containing hernia sac with surrounding fat stranding (Figs. 37.1 and 37.2) [24]. If obstructed, the CT will show distended bowel within the hernia sac and decompressed distal loops of small bowel (Figs. 37.3 and 37.4). A Richter's hernia, where only one side of the bowel wall is trapped in the hernia, may not demonstrate signs of bowel obstruction but is still at risk for strangulation [24]. Incarcerated hernias at risk for causing bowel compromise should be repaired urgently. Preoperative resuscitation should include intravenous (IV) fluid and nasogastric tube decompression.

An incarcerated hernia can lead to strangulation of the hernia contents when the blood supply to the contents of the hernia is compromised. With strangulation, venous congestion leads to tissue edema, which further compromises circulation and can block arterial flow [25, 26]. It has been estimated that hernias acutely incarcerated are at risk for ischemia and necrosis after 8–12 h [26]. These patients often present with severe abdominal pain. On physical exam, patients typically have a tender, distended abdomen. The skin overlying the hernia sac may be tense, possibly with a color change (i.e., erythema over hernia site). There may be signs of systemic inflammatory response syndrome (SIRS), including tachycardia, leukocytosis, and acidosis. However, not all patients who have strangulation will present

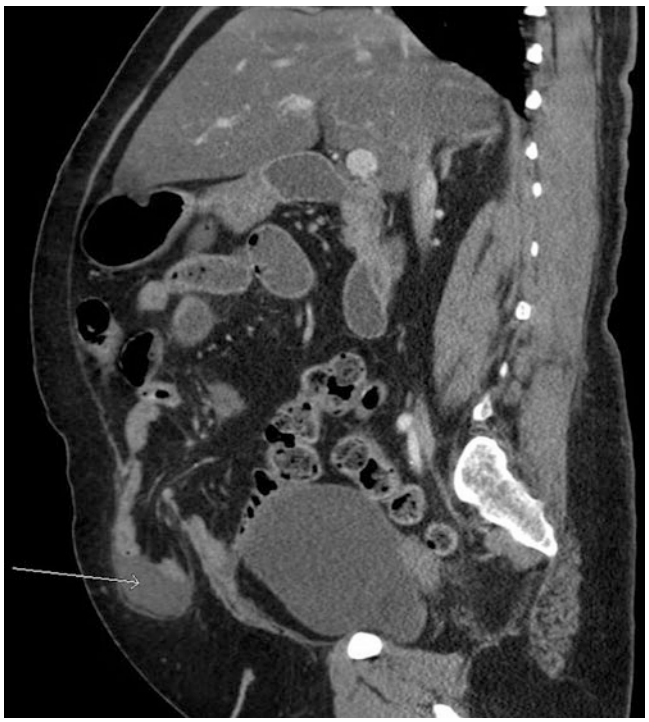

Fig. 37.1 Ventral hernia with distal ileum with stranding and free fluid (*arrow*) concerning for strangulation

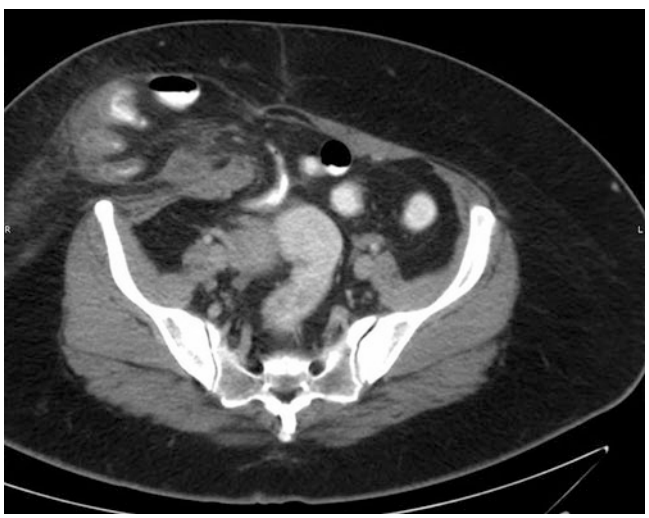

Fig. 37.2 Right ventral wall hernia continuing multiple small bowel loops with stranding in subcutaneous tissue surrounding the hernia

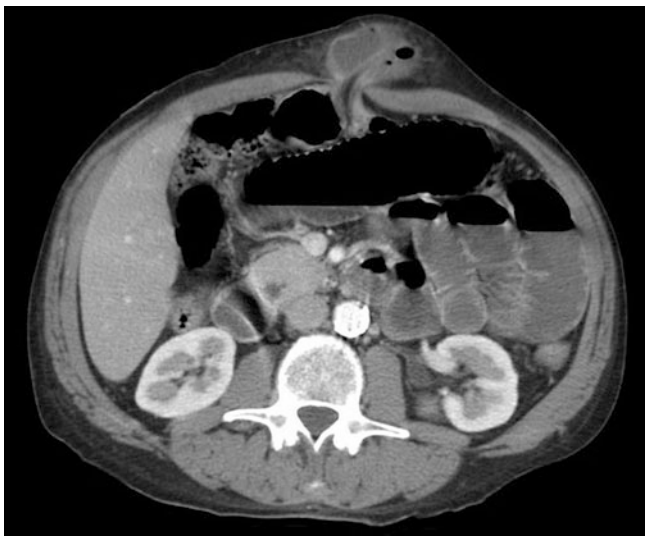

Fig. 37.3 Ventral hernia causing a high grade small bowel obstruction with inflammatory changes around hernia

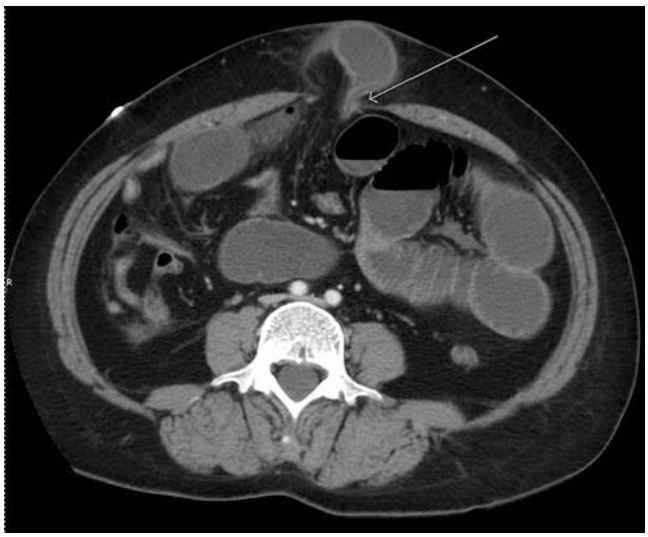

Fig. 37.4 Paraumbilical hernia containing a loop of small bowel with focal dilation of the herniated bowel loop, adjacent fat stranding and interloop free fluid, and transition point (*arrow*) within the hernia sac

with these concerning and advanced signs and symptoms. In particular, some patients may not demonstrate these findings until the hernia is reduced because the obstructed vascular outflow of the incarcerated, ischemic bowel is preventing acid, toxins, and bacteria from being released into the systemic circulation. If reduced the patient may experience a rapidly worsening SIRS, acidosis, and peritonitis. For this reason, patients with hernias acutely incarcerated for >6 h, signs of peritonitis (even focally at the hernia), or skin changes should not be reduced at the bedside [26]. These patients require emergent surgical repair. Preoperative resuscitation should be performed with IV hydration and bowel decompression with a nasogastric tube.

Cirrhotic patients can experience another hernia complication: skin rupture of an umbilical hernia [27]. Umbilical hernias are seen in approximately 20% of patients with cirrhosis and ascites. This is due to a supraumbilical fascial defect formed by recanalization of the umbilical vein, increased intra-abdominal pressure from ascites, malnutrition, and muscle wasting [28]. These patients are generally poor surgical candidates at high risk of surgical complication, and often they will not have their hernias repaired electively. In these patients, skin overlying an umbilical hernia can become ischemic and ulcerated which can lead to an ascites leak. Treatment should include medical optimization of the cirrhosis and ascites (fluid management), nutritional optimization (due to high risk of protein losses and poor nutrition among these patients), infection control to prevent or treat any infected peritonitis, management of any portal hypertension (i.e., transjugular intrahepatic portosystemic shunting or TIPS), local wound care to protect the skin, and possible surgical treatment of the hernia. In our practice, we treat these cirrhotic patients with leaking ascites with judicious fluid management (initially albumin followed by fluid restriction), antibiotics until the ascitic leak is controlled, negative pressure wound therapy with a barrier dressing to control the wound, and management of portal hypertension. Often, the above combination can stop the ascitic leak, and the patient can undergo an elective or semi-elective (urgent) ventral hernia repair.

Goals of Repair

The goals of acute repair of a ventral hernia may differ from those of elective repair. In elective repair, the main goal is to definitively fix the hernia. In the emergent or urgent setting, the main goal is to fix the acute problem caused by the hernia (e.g., obstruction, bowel compromise, leaking ascites), and definitive hernia repair may or may not be a secondary objective. Depending on the degree of contamination, patient stability, volume status, future surgical plans, and hernia complexity, less may be better.

In certain patients, a limited repair strategy should be considered. Patients who are unstable or acutely ill should spend limited time in the operating room. In addition, patients with significant contamination may benefit from limited repair. This includes patients with significant inflammation (wound class III), skin ulceration (wound class IV), or bowel necrosis (wound class IV). In contrast, patients with clean cases who are stable may benefit from definitive repair of their hernias to avoid the need for future surgery. In assessing the best option for a given clinical situation, the clinician must balance the risks and benefits of each surgical option for a given setting.

Another consideration in acute ventral hernia repair is the utility of a planned second operation 24–48 h following the initial surgery [29–32]. This second operation is aimed at

re-assessing bowel when there is any suspicion of bowel compromise, to decrease the amount and severity of contamination, or to prevent abdominal compartment syndrome. Although the pathophysiology of bowel necrosis due to an incarcerated hernia is different from mesenteric ischemia due to vascular compromise (emboli, thrombosis, low flow) and reduction of the incarcerated hernia should resolve the mechanism of ischemia, in certain situations, a second look may be considered. Among patients with ischemic but not frankly necrotic bowel and no bowel resection is performed or among patients with hypotension and/or on pressor agents, a second look to verify that none of the bowel has become necrotic may have an important role [33, 34]. If there is any concern for potential progression of bowel compromise or marginal bowel that is not resected, a second look should be considered [35]. Although multiple anecdotal reports exist on the role of decontamination and drainage with an open abdomen followed by subsequent abdominal closure, high-quality evidence does not support this practice [36]. Treatment of contamination with an open abdomen has been demonstrated to be associated with a higher rate of mortality and morbidity with no decrease in the rate infection compared to abdominal closure at the initial operation. Finally, the role of second look for abdominal compartment syndrome is discussed further below in surgical techniques. In brief, the best opportunity to close the abdomen is at the initial operation or within 24 h [31]. Delaying primary fascial closure has a low likelihood to improve the ability to close the abdomen due to the inevitable progression of edema, inflammation, and lateral retraction of the abdominal wall [31].

Surgical Techniques

Open Ventral Hernia Repair

When the Fascia Can Be Safely Reapproximated

The abdominal wall is a dynamic and functional structure that is under constant motion and tension. A ventral hernia adversely impacts abdominal wall function. The concept of "tension-free," derived from inguinal hernia literature, when misapplied to ventral hernias with "bridged repairs" has resulted in poor clinical and patient-reported outcomes [37, 38]. Bridged repairs are repairs where fascia is not reapproximated, and instead, mesh is used to span the gap. Primary fascial closure under physiologic tension should be achieved whenever safe and feasible [37, 38].

With primary fascial closure, the abdominal wall and incision can be reinforced with mesh or remain as a suture-only closure. Randomized controlled trials have shown that mesh reinforcement is superior to suture-only repairs to reduce hernia recurrence [39]. However, studies supporting the use of mesh are based on uncomplicated, elective ventral hernias with no contamination, and the safety and effectiveness of mesh placement in acute cases remain poorly understood. Placement of prosthetic material in acute settings where there may be contamination increases the risk of surgical site infection (SSI) due to inability to clear contamination from the prosthetic material, creating a potential space for infection, or causing mesh erosion and fistula formation [40, 41]. A large nationwide database study suggests that mesh reinforcement of contaminated ventral hernia repairs compared to suture repair increases rates of SSI and 30-day complications (OR for SSI 1.2, 95% CI 0.6–2.4) [41]. Overall, most studies demonstrate that suture repair is associated with a lower risk of infection but has a substantially increased rate of recurrence [42]. In our practice, where there is no violation of bowel, reinforcement with mid-density polypropylene mesh that provides at least 5 cm of mesh overlap on each side is routinely utilized. In the setting of contamination or infection, each case is individually assessed for the risks and benefits of suture-only closure or mesh reinforcement based upon tissue edema, degree of contamination, long-term factors such as need for future abdominal surgeries or presence of metastatic cancer, and patient factors such as age, and hernia defect size. Typically, these cases are evenly divided between suture-only closure and biologic mesh reinforcement.

If mesh reinforcement is planned, the prosthesis can be placed in multiple locations: underlay in the intra-peritoneal space, sublay in the preperitoneal or retrorectus spaces, or onlay repair overlying the fascia. Increasingly, surgeons are utilizing a sublay repair, although the data supporting this choice remains limited [43]. In theory, sublay mesh repair may allow decreased rates of infection and recurrence because the prosthetic is placed adjacent to two load-bearing tissue planes (posterior fascia and anterior rectus/fascia) and is protected from intra-peritoneal contamination or superficial infection (Fig. 37.5) [43]. However, these benefits may not be realized in acute settings. The additional dissection, acute inflammation, and contamination may obviate these theoretical benefits. In addition, violating this space for a hernia repair with a high probability of failure or complication can make future surgical decisions more complicated. Alternatively, utilizing an underlay repair where no further dissection or violation of potential spaces is needed may provide a reasonable alternative to sublay repair. Meta-analyses suggest that underlay repair in the elective setting offers similar short-term and long-term outcomes compared to sublay repair in elective repair [37]. Synthetic mesh should not be used in the underlay position when there is contamination. In our current practice, when mesh is used, sublay repair remains our preferred location for mesh placement even in acute cases. However, underlay is a safe and reasonable alternative.

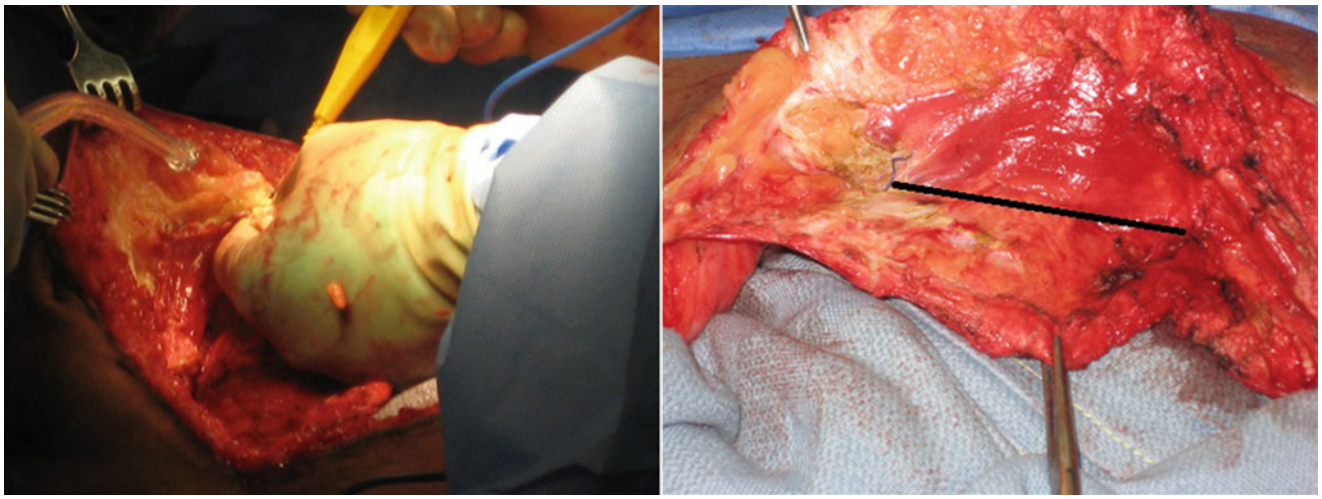

Fig. 37.5 Entering the retrorectus space (*left*). Exposed retrorectus space (*right*) with semilunar line (*black line*)

When the Fascia Cannot Be Safely Reapproximated

In some settings, the fascial defect cannot be closed without putting the patient at high risk for abdominal compartment syndrome unless another approach is utilized. This may be a common challenge with large hernia defects, extensive bowel dilation due to bowel obstruction or ileus, or in patients treated previously with an open abdomen. A rapid method to assess the feasibility of closing the fascia is to lay a moist laparotomy pad between the abdominal wall and abdominal contents, place Kocher clamps at the midpoint of the fascia on either side, and pull the tips together (Fig. 37.6). If this cannot be done without increasing the airway pressure or causing the bowel to eviscerate, primary fascial closure may be difficult to achieve. Options for these patients may include (1) skin closure alone, (2) temporizing dressing with subsequent skin-grafting, (3) bridged mesh underlay, or (4) component separation with primary fascial closure (Table 37.2).

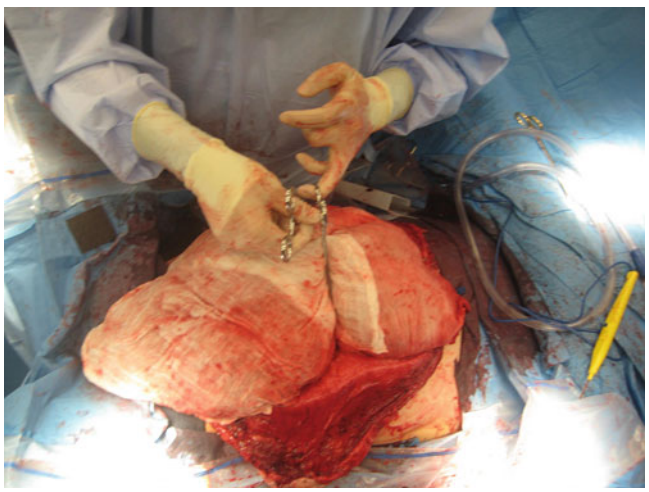

Fig. 37.6 Testing the ability to close the abdominal wall demonstrating loss of domain and inability to safely achieve primary fascial closure

Skin closure alone is easy to perform but not always feasible due to the bowel distension or edema. The advantages of skin closure alone are that it provides an inexpensive, low cost, low risk intervention to close the patient's abdomen in challenging settings. The disadvantage is that patients are relegated to a ventral incisional hernia that may become larger and more complex and likely necessitate a repair in the future. With no medial traction on the rectus complex, hernia defects become progressively larger due to unopposed oblique contraction. In addition, the raw surface of the cut fascial edges and subcutaneous tissue may create more complex adhesions prone to enterotomy and longer operative duration in the future. Finally, treatment of skin infections may become challenging as opening the wound will expose bowel.

Another option includes utilization of temporizing dressings such as a negative pressure wound therapy or moist dressings with subsequent skin-grafting to the granulation bed. This is a common technique adopted from the era of widespread use of open abdomen. However, it is a costly, high-risk approach due to multiple operative takebacks, risk of enterocutaneous fistula, need for skin-grafting, and unreliable timeframe for a granulation bed to develop. This approach faces the same challenges of a skin-only closure with a potentially larger, more complex ventral incisional hernia that will likely require surgery in the future.

Placement of a biologic prosthetic as a wide bridged underlay provides another option (Fig. 37.7). This procedure is more complex than the above two interventions, can be expensive, and has a high rate of hernia recurrence and eventration/bulging. In addition, these repairs fail to reconstruct a functional abdominal wall leaving a significant portion inert [44]. However, this technique can close the abdomen quickly, may result in hernia defects that are smaller and less complex

Table 37.2 Closure options when the fascia cannot be safely reapproximated

	Potential risks	Potential benefits
Skin closure alone	Hernia enlargement More complicated hernia Enterocutaneous fistula	No planned future surgery Low cost, low effort
Temporizing dressing	Hernia enlargement More complicated hernia Enterocutaneous fistula Frequent reoperations Skin graft site	Low effort for current surgery
Bridged underlay	Moderate effort Expensive prosthetic Enterocutaneous fistula Eventration/bulge	No planned future surgery Hernia is potentially treated
Component separation	High effort Hernia recurrence Lateral hernia Inability to close fascia even with component separation Wound complications	Primary fascial closure No planned future surgery

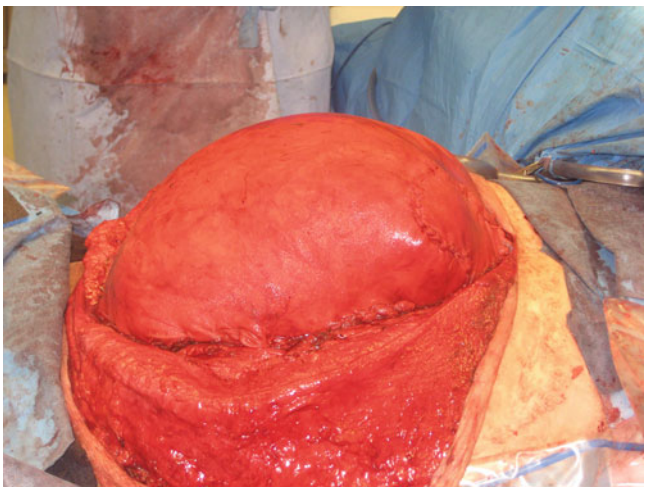

Fig. 37.7 Bridged mesh underlay repair

or potentially even create an acceptable abdominal wall that requires no further surgery.

Finally, primary fascial closure can be achieved through component separation or flap creation. In the elective setting, utilizing component separation to reapproximate the fascial and muscular layers under physiologic tension is a powerful and safe tool that can recreate a functional abdomen [45]. However, the use of component separation in the acute setting is under-investigated and among the available published data there is substantial risk for bias [2]. Component separation may be less effective in the face of extensive tissue edema and acute inflammation which both reduce abdominal wall compliance. In this setting, component separations may not be able to achieve the same amount and quality of release as in elective settings. In addition, recurrence rates, infection rates, and complication rates are likely higher. There are concerns of "burning a bridge" in what may end up being a temporary repair. For a procedure with an already high complication rate in combination with the additional challenges posed with emergency ventral hernia repair, surgeons should be cautious in attempting component separation in the acute setting.

In our practice, we utilize skin closure alone or bridged biologic mesh underlay in high-risk cases where the fascia cannot be safely reapproximated without advanced techniques. Only in rare, "optimal" settings do we utilize component separation in acute cases. In these rare situations, our preference is to utilize either a perforator-sparing or posterior component separation.

Laparoscopic Ventral Hernia Repair

Laparoscopy in the acute ventral hernia poses significant challenges including bowel distension and contamination. However, laparoscopy remains a powerful diagnostic tool and has been widely shown to decrease rates of SSI during clean, elective ventral hernia repair [46].

Care must be taken when entering the abdomen, particularly where there is evidence of bowel obstruction. Limited view entry (such as the veress needle or optical ports) risks injuring dilated, fragile bowel. Instead, an open entry at the right or left subcostal margin at the mid-clavicular line (i.e., Palmer's point on the left) may be a safe alternative. When there is distended bowel, minimal handling is recommended. Instead, running only the decompressed loops of bowel or reducing bowel with external palpation under direct visualization provides the safest options.

If there is no bowel necrosis and minimal bowel ischemia, completing the laparoscopic ventral hernia repair with coated synthetic mesh (i.e., adhesion barrier) is safe. However, in the face of contamination or bowel necrosis, synthetic mesh should not be placed in the intra-peritoneal position. Options include conversion to open (see above) or a hybrid repair. In a hybrid repair, a limited incision is made over the hernia defect, bowel is examined and resected if necessary, the hernia sac and devitalized skin are resected, a piece of biologic mesh (at least 8–10 cm larger than the hernia defect in each dimension, i.e. 4–5 cm of mesh overlap) is placed into the intra-peritoneal cavity, and fascia is approximated with running slow-absorbing sutures (Fig. 37.8). Subsequently, the abdomen is reinsufflated and the mesh is secured utilizing a laparoscopic technique. While data is needed to support the use of this technique, it has the potential and theoretical benefits of minimizing incision size, achieving primary fascial closure, allowing wide mesh overlap (particularly for smaller defects), and fixation under direct visualization.

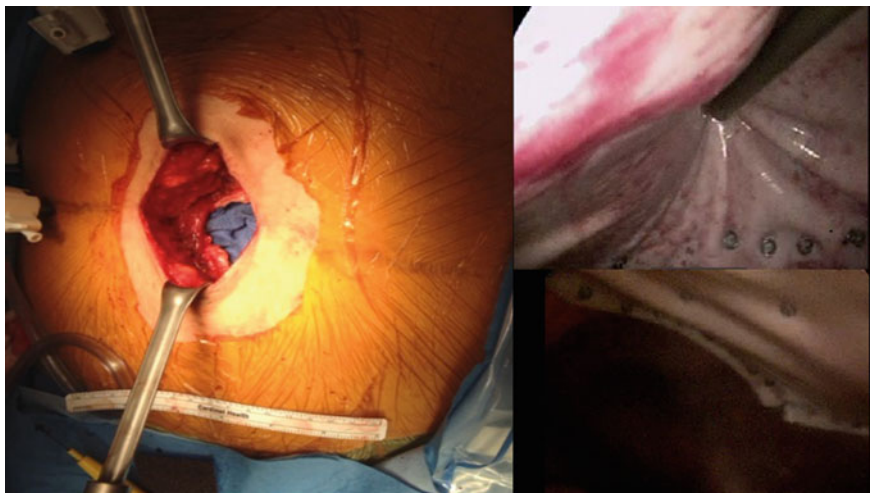

Fig. 37.8 Hybrid repair showing excision of hernia sac (*left*), securing biologic mesh laparoscopically (*top right*), and mesh after it has been secured (*bottom right*)

Many patients presenting with an acute ventral hernia can benefit from laparoscopy. These cases are typically directed towards surgeons experienced in laparoscopic surgery. When there is only preperitoneal fat, omentum, or viable bowel incarcerated, we perform a standard laparoscopic ventral hernia repair utilizing a coated mid-density polypropylene or polyester. We routinely close the fascial defect for patients where abdominal wall function is an important priority (young or active patients) [38]. We prefer to begin with an open approach in patients who are unstable, where laparoscopy is unlikely to be successful (i.e., substantial bowel distension or complicated surgical history), evidence of bowel necrosis/ischemia, or large defects >10 cm in width.

Additional Challenging Settings

Ventral hernias in cirrhotic patients can be particularly challenging. Non-operative management of hernias in cirrhotic patients has a lower rate of success compared to the non-cirrhotic population (rate of emergent surgery 58.9 % cirrhotic vs. 29.5 % non-cirrhotic; $P<0.001$) [47]. Among cirrhotics with umbilical hernias managed non-operatively, approximately half required emergency hernia repair due to a complication [18]. Not only are patients with end-stage liver disease at increased risk for incarceration and strangulation, but they are also at risk for "ruptured hernia" and leaking ascites. The morbidity and mortality of emergent hernia repair is high among cirrhotics when compared to non-cirrhotics (morbidity: 17.3 % vs. 14.5 %, $P=0.04$; mortality 3.8 % vs. 0.5 %, $P<0.01$), although elective surgical morbidity in carefully selected cirrhotics is no different when compared to non-cirrhotics (15.6 % vs. 13.5 %; $P=0.18$) [47].

Cirrhotic patients presenting with an acute ventral hernia complication should be counseled regarding the high likelihood of complications. Utilizing a surgical risk-calculator, such as the National Surgical Quality Improvement Project calculator (http://riskcalculator.facs.org) or Model for End-Stage Liver Disease (MELD) score can provide a starting point for patient and family counseling. Patients presenting with advanced cirrhosis or MELD score >15 have a poor surgical prognosis [48–50]. In our practice, we commonly encounter three scenarios of patients with advanced cirrhosis and an acute ventral hernia complication: leaking ascites from an umbilical hernia, incarcerated hernia with necrotic bowel, or incarcerated hernia that is easily reducible. In all three settings, we begin with a multi-disciplinary approach (internal medicine, hepatology, and surgery), establish realistic expectations with patients and families, and institute aggressive medical optimization.

Patients with leaking ascites from an umbilical hernia are initially treated with medical optimization (including initial resuscitation followed by fluid restriction, diuretics, and management of portal hypertension), negative pressure wound therapy with a barrier dressing to control output and protect the skin, and antibiotics to treat/prevent bacterial peritonitis. Following medical optimization, the patient is taken to the operating room for an umbilical hernia repair under local anesthesia with either suture-only or preperitoneal mesh placement [51]. We continue to utilize negative pressure wound therapy with a barrier dressing to the closed incision for up to 1 week following surgery [52].

Among patients with necrotic bowel and advanced cirrhosis, outcomes are extremely poor. Patient and family counseling to establish realistic expectations and potentially limited medical interventions can be considered depending on the severity of the cirrhosis. If surgery is pursued, judiciously utilizing an ostomy, limiting the amount of dissection of the abdominal wall particularly when the risk of bleeding is high due to portal hypertension and/or coagulopathy, and aggressive medical management of the cirrhosis and portal hypertension should be integrated in the care process. Short-term (up to 1 month) and longer-term (>1 month) outcomes are poor, and care of these patients is resource intensive [48–50].

In current practice, cirrhotic patients presenting with acute pain and incarceration of a hernia without concern for bowel ischemia or necrosis are often reduced and discharged. However, as previously stated, these patients are at high risk for re-incarceration and possible strangulation. Medical optimization and carefully planned early elective repair or repair prior to discharge may represent one good option for these patients [53]. There is limited high-quality evidence to guide care in these patients, and further study is needed. However, it is clear that emergency surgery in cirrhotic patients typically has much worse outcomes compared to elective surgery [48–50]. Making this decision should be based upon the local system and resources, patient wishes, and surgeon expertise. In our practice, we routinely admit, optimize, and repair cirrhotic patients with umbilical and inguinal hernias who present acutely to the emergency room but can be safely reduced with manual palpation.

Another challenging patient population is pregnant patients. Indications for emergent repair in pregnant patients are no different than those for other patients. Because nausea and vomiting can be common in pregnancy, the diagnosis of an incarcerated ventral hernia may be difficult to make. Imaging should be limited to ultrasonography whenever possible to limit radiation to the developing fetus. There is limited data on the outcomes of emergent ventral hernia repair during pregnancy [54]. Case reports with limited follow-up describe both suture and mesh repair of acutely incarcerated ventral hernias during pregnancy. In 12 case reports, there were no reported maternal postoperative complications and a fetal complication of spontaneous abortion that occurred 4 weeks following surgery [55]. However, this data is limited in quality, and conclusions reached should be interpreted and integrated cautiously. We treat pregnant patients with a ventral hernia like all other patients. Elective repair is delayed until following delivery and emergency repair is performed when there is risk for bowel injury. During emergency repair, operative duration and potential for irritation of the uterus should be minimized to prevent spontaneous labor. This may mean suture-only repair despite the higher recurrence rates. Laparoscopy and laparoscopic ventral hernia is considered safe during pregnancy; however, the benefits of laparoscopy need to be balanced with the potentially increased risk for preterm labor. In addition, adjustments to minimize the potential for injury or irritation of the uterus should be addressed during port placement, gas insufflation (consider lowering the peak setting and rate of insufflation), and inserting of instruments [56–58]. Evidence-based guidelines are utilized to help manage these patients in the perioperative period [59].

Fascial dehiscence following abdominal surgery is not uncommon [4, 60]. Among patients with limited fascial dehiscence and no evisceration, non-operative management with local wound care, binder, and careful monitoring may provide the least morbid option. These patients should be counseled regarding potential risk for evisceration and the high likelihood of needing a ventral incisional hernia repair in the future. In patients with early postoperative dehiscence, extensive dehiscence, or evisceration, reoperation may be needed. Whether the dehiscence was due to an intra-abdominal infection versus a mechanical issue should be elucidated. Anastomotic leak and organ space SSI is a common cause of fascial dehiscence. In this setting, controlling the underlying source, drainage, suture-only closure, and meticulous wound care may provide the safest option. Utilizing mesh reinforcement in this setting is risky due to the infection and contamination. Alternatively, dehiscence due to mechanical issues (obesity, chronic cough, technical failure) may benefit from mesh reinforcement. Often, a second chance of closing the fascia with sutures-only is limited due to the devitalized margins and persistent mechanical challenges (obesity or smoking). In this setting, a limited underlay with biologic mesh reinforcement of the closure may represent one reasonable option.

A final challenge in acute ventral hernia repair is management of an open abdomen. The abdomen may be left open for a number of reasons, including for a second look, to avoid or treat abdominal compartment syndrome, and limiting time in the operating room. An open abdomen may pose a number of challenges including degree of contamination (by definition, an open abdomen is at least clean contaminated), increased intra-abdominal pressure, edema and inflammation, and retraction of the fascial margins. There is inadequate high-quality data to make best practices recommendations in closure of the open abdomen [61–63]. In our practice, whenever feasible, we utilize suture-only repair to achieve primary fascial closure. Gaps or defects that cannot be safely closed are managed with a bridged underlay of biologic mesh, drain placement, skin closure, and application of a negative pressure wound therapy with a barrier dressing to the closed incision.

Postoperative Management

There are several practices that may improve outcomes after surgery, but there is limited data to support these practices. Surgical drains are often left in place following ventral hernia repair if there is concern for seroma development. The decision on which type of drains to use and when to remove the drains has little evidence for guidance. A recent Cochrane review of wound drains after incisional hernia repair revealed data too sparse to reach any conclusions on the best drain management [64]. In our practice, we utilize drains with any skin flap or biologic mesh. Drains are left in until there is less than 30 ml of output for 2 days in a row.

Other practices, like early feeding and pain control, have been studied in other types of surgery. In particular, the Enhanced Recovery After Surgery (ERAS) pathway has been studied in colorectal surgery. This pathway includes limiting fluids, early feeding, and multi-modal pain control with an emphasis on non-narcotic medications [65]. It is based on the principle that reducing the body's stress response after surgery will reduce the time needed to recuperate [65]. Early feeding has been demonstrated to be beneficial by reducing infectious complications and length of hospital stay [66]. The use of epidural analgesic has been shown to reduce time for return of bowel function and to improve pain scores, although it does not affect length of hospital stay [67]. While these interventions may have some benefit in abdominal wall surgery, they have not been adequately investigated to draw definitive conclusions. Furthermore, the applicability of these interventions in the acute setting is unknown, as these interventions have largely been evaluated only in the elective setting [68, 69]. In the acute setting, volume resuscitation is often needed to replace losses in preparation for surgery and following surgery due to hemodynamic challenges. While limiting fluids in the stable patient is recommended, the effectiveness of this practice in acute, hypotensive patients remains to be evaluated. In our practice, the amount and volume of fluid utilized have reduced over time, including for acute cases. Patients routinely receive multi-modal pain management; however, many interventions are challenging or cannot be utilized in the acute setting. Post-operatively, once signs of bowel obstruction have resolved, early feeding is routinely initiated.

Finally, abdominal binders are frequently prescribed by hernia surgeons for their patients to reduce pain and seroma formation. A recent systematic review demonstrated that while abdominal binders may reduce postoperative psychological distress, they have no effect on postoperative pain or seroma formation [70]. In our practice, we routinely utilize binders loosely applied. Patients report comfort with coughing with the use of binders; however, this is anecdotal in nature.

Conclusions

Acute ventral hernia repair presents a unique set of challenges. Surgeons must decide if a limited or definitive repair is warranted on an individual patient basis. Repair technique chosen must balance risks and benefits of each strategy. Randomized controlled trials of acute ventral hernia repairs are unlikely given the nature and frequency of the disease, so observational studies may provide the best available evidence on this topic.

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Damage Control Surgery and the Open Abdomen

38

Clay Cothren Burlew

Management of the open abdomen incorporates tenants of intensive care unit and operative care of the critically ill patient. While several etiologies may result in the requirement for an open abdomen, goals of care are similar to all: temporary coverage of the viscera, appropriate critical care to include fluid resuscitation and nutrition support, treatment of the underlying etiology, attempts at fascial coverage and prevention or treatment of complications. This article will discuss each of these core components of open abdomen management in turn.

Etiologies of the Open Abdomen

The most common scenarios that lead to a patient requiring an open abdomen include abdominal compartment syndrome (ACS) and damage control surgery (DCS) [1–4]. Primary abdominal compartment syndrome is typified by intraabdominal hypertension (IAH) due to an intraabdominal injury or disease process; some examples include solid organ injuries, ruptured vasculature, and postoperative hemorrhage. Secondary ACS occurs following a large volume resuscitation involving both crystalloid and blood products. Patients may also have a combination of primary and secondary ACS in cases such as severe acute pancreatitis. Regardless of the underlying process, once end organ sequelae are identified with IAH, decompression of the ACS is necessary. The final potential scenario is the role of the open abdomen in preventing the development of ACS. In some cases, at the end of an operation, closure of the abdomen may precipitate IAH. In this scenario, leaving the abdomen open to prevent the progression of IAH to ACS, particularly in patients that are predicted to need further resuscitation volumes, is wise.

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Open abdomen management is also a necessary component of DCS. In DCS techniques, the goal is to limit the operation to key components: control of hemorrhage, re-establishing all essential vascular conduits, and limiting enteric contamination. In patients who are dying due to the lethal triad of hypothermia, coagulopathy, and acidosis, this abbreviated laparotomy permits physiologic restoration in the surgical intensive care unit (SICU). Resuscitation of the critically ill and injured patient, as DCS can be performed for both trauma and emergency general surgery cases, occurs concurrently with management of the patient's open abdomen.

Techniques of Temporary Closure

For patients relegated to an open abdomen, temporary coverage of the abdominal viscera is critical. Historically, temporary closure of the abdomen was performed with "towel clipping." This process entails placing penetrating towel clips through the skin only, 2–3 cm apart, down the length of the midline laparotomy incision. While this is a rapid abdominal closure technique, patients often develop ACS during the ensuing resuscitation. Also of historical interest is Bogota bag closure of the abdomen. A silo approach to contain the protruding bowel is constructed using either a sterile 3 L irrigation bag or a sterile X-ray cassette cover which is sewn to the skin; Jackson-Pratt (JP) drains are positioned along the external edges of the suture and an occlusive Ioban covering is placed over the entire abdominal wall.

Currently the most commonly used techniques of temporary abdominal closure are adaptations of the "homemade vacpack" or commercially available negative pressure wound therapy (NPWT) systems [5, 6]. The author's preferred method of temporary closure at initial laparotomy is an adaptation of Barker's technique termed the "10-10 drape and Ioban closure." The bowel is covered with a fenestrated 1010 steri-drape (3M Health Care, St. Paul, MN) that is then placed circumferentially under the fascia of the midline laparotomy

L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_38

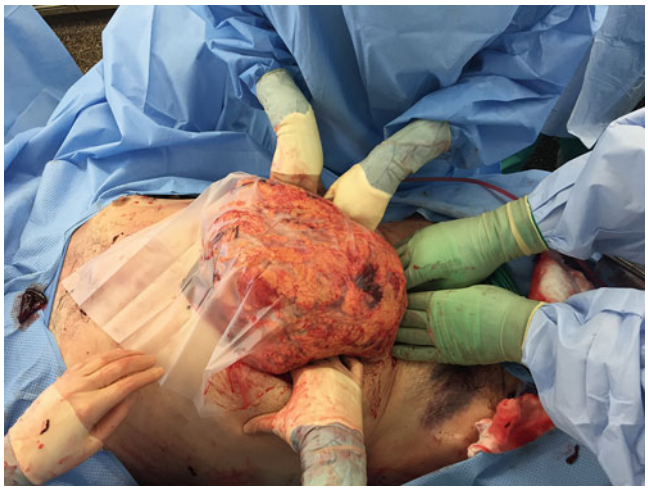

Fig. 38.1 Temporary closure at initial laparotomy is performed using the "10-10 drape and Ioban closure." The first step is covering the viscera with a fenestrated 1010 steri-drape that is placed circumferentially under the abdominal wall

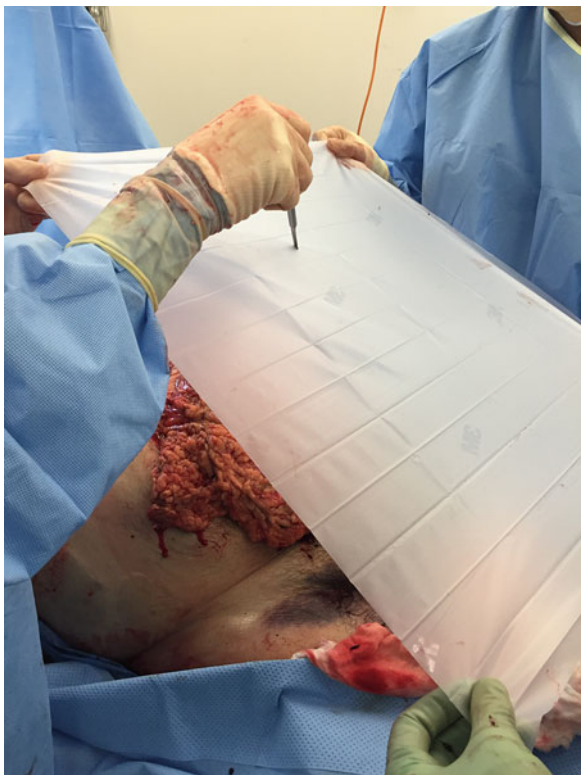

Fig. 38.2 A scalpel is used to create small slits in the plastic drape

incision (Fig. 38.1). The fenestrations in the plastic drape are made with a scalpel blade to create small slits rather than large apertures (Fig. 38.2). This permits intraabdominal fluid and blood to pass through the plastic while preventing the Ioban from sticking to the bowel. Occasionally, two drapes must be used in an overlapping technique to protect and contain all of the protruding intestines.

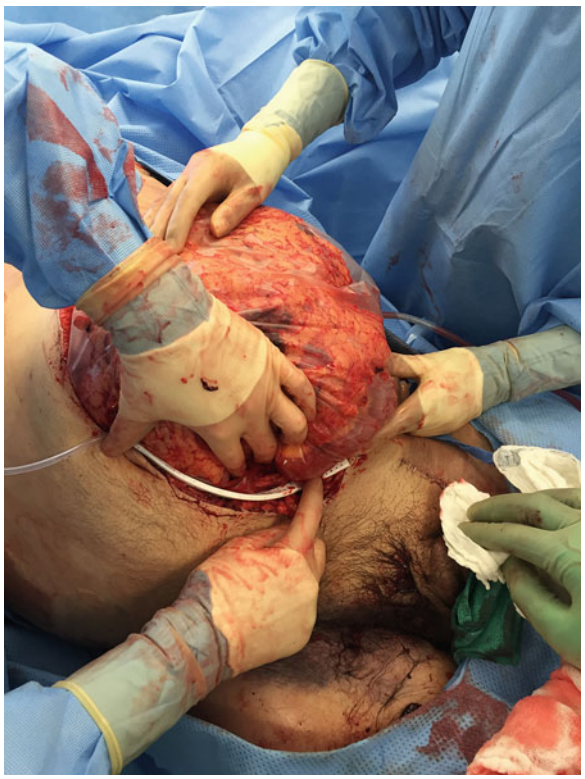

Fig. 38.3 JP drains are placed along the fascial edges in the subcutaneous space

Two JP drains are placed on top of the plastic 1010 drape, in the subcutaneous space of the midline incision, just above the fascial edges (Fig. 38.3); the drains control the egress of reperfusion-related ascitic fluid. Management of the drains is best done by running the drain tubing cephalad from the midline wound (Fig. 38.4); once the Ioban covering is placed, this tube location provides a more effective closed suction system. Once the 1010 drape and JP drains are in place, an Ioban covers everything including the adjacent abdominal wall (Fig. 38.5). When placing this temporary dressing, one should anticipate bowel swelling secondary ongoing resuscitation and therefore leave adequate space. Ensuring the plastic drape is redundant rather than pulled tight over the abdominal contents is important. Likewise, when applying the Ioban occlusive dressing, leaving some expansion room by not pulling the Ioban taut is critical.

There are multiple advantages to the "10-10 drape and Ioban closure" technique. First, it affords bowel coverage while allowing egress of the abdominal contents and effective decompression. Second, it can be accomplished quite rapidly. Third, without placement of a sponge, blue towel, or laparotomy pad over the 1010 plastic drape, one can directly visualize the bowel and can identify early ischemia or bleeding. Fourth, should the patient require angiography, this temporary closure is compatible with fluoroscopy. And finally, the components of the closure technique are readily

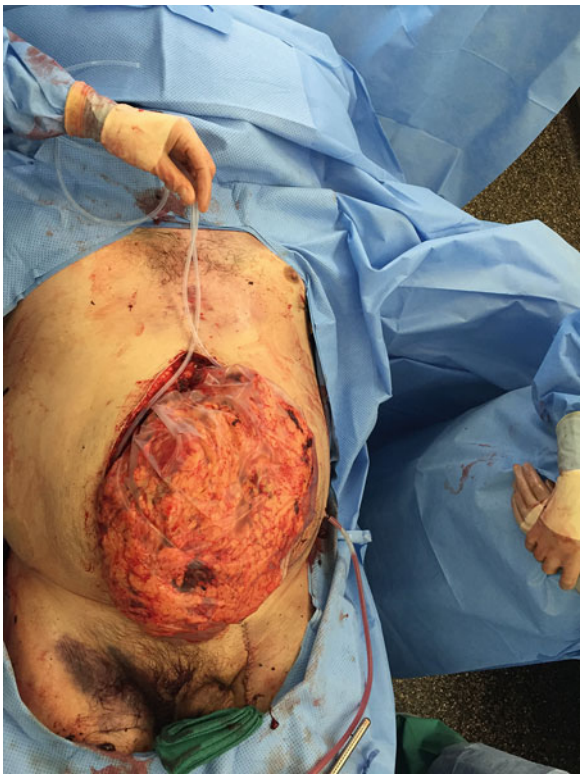

Fig. 38.4 The JP drain tubing is run cephalad from the midline wound for a more effective closed suction system once the Ioban is placed

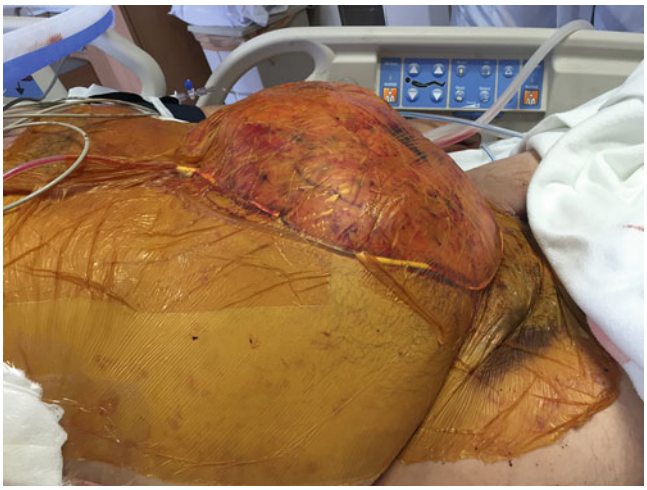

Fig. 38.5 An Ioban covers the 1010 drape, JP drains, and the adjacent abdominal wall

available in all operating rooms and comparatively inexpensive. Commercially available NPWT systems may also be utilized for temporary closure. There are a variety of sponge options and occlusion devices that are available. While NPWT plays a crucial role for patients who require an open abdomen past the initial 24 h [7], early utilization of these techniques is not mandatory.

ICU Management of the Open Abdomen Patient

Following decompressive laparotomy for ACS or abbreviated laparotomy for DCS, the patient is transported to the intensive care unit (ICU) for physiologic restoration. The guiding principles of critical care management such as rewarming techniques, correction of coagulopathy and acidosis, lung protective ventilation, prevention of ventilator associated pneumonia, treatment of adrenal suppression, and management of hyperglycemia predominate. There are, however, some specific management concerns that pertain to the open abdomen patient worth addressing.

During the early resuscitation of the patient, careful fluid balance is crucial. The well-meaning clinician may attempt to optimize the patient's hemodynamics with initial volume loading to attain adequate preload. However, an understanding of the sequelae of crystalloid resuscitation in patients with an open abdomen is paramount. Attempts at volume loading may only lead to further visceral edema and development of ascitic fluid [8]. Judicious use of inotropic agents or vasopressors should be encouraged [9]. Balancing cardiac performance versus generating retroperitoneal edema and intestinal swelling is one of the most challenging aspects in optimizing patients' fluid administration. Although early colloid administration with albumin may be appealing, evidence to date does not support this concept. Finally, the role of gentle diuresis in patients with a persistent open abdomen, 24 h following their completed resuscitation may be entertained [10] but earlier reports question its utility [11].

One pitfall to avoid in the ICU management of these patients is the presumption that a patient with a widely open abdomen cannot have IAH and subsequent hemodynamic compromise. Monitoring bladder pressures, an easy bedside metric of IAH, should be performed in open abdomen patients, particularly if they are unstable or have a low urine output.

One of the newer modalities in the management of the open abdomen patient that has shown promise is the use of direct peritoneal resuscitation [12]. In this technique, catheters (either 19F round Blake drains or Davol drains) are placed along the retroperitoneum to infuse hypertonic dialysate into the abdomen (Fig. 38.6). The dialysate then bathes the abdominal contents and is removed through the JP drains located next to the abdominal wall fascia just under the temporary closure dressings. This continuous infusion of dialysate causes the edematous bowel to shrink over 24–48 h. The specific protocol is infusion of a 2.5 % hypertonic glucose-based peritoneal dialysis solution (Delflex; Fresenuis USA) at a rate of 1.5 mL/kg/h. Early reports demonstrate an increase in fascial closure rates, with a faster time to closure and fewer abdominal complications [13]. One caveat for those performing this technique: standard wound VAC sponges, particularly the white sponge that may be used on

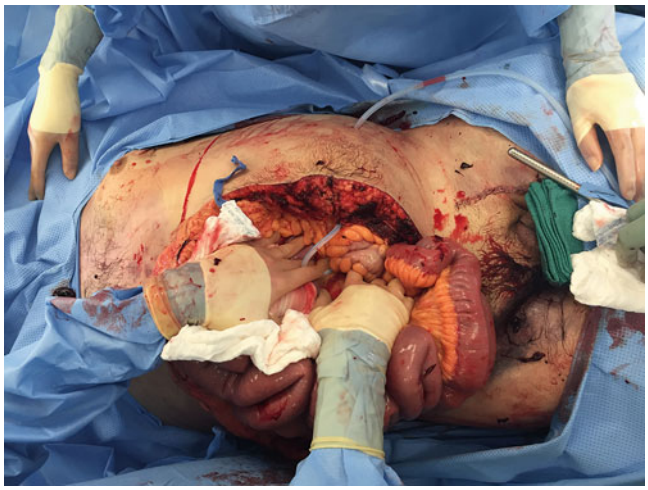

Fig. 38.6 For direct peritoneal resuscitation, a 19 Fr round Blake drains is placed through a separate stab incision in the abdominal wall and positioned along the retroperitoneum at the root of the mesentery to infuse hypertonic dialysate into the abdomen

exposed viscera, do not permit the dialysate to be suctioned out of the abdomen, and hence should not be used; temporary closure with the "10-10 drape and Ioban closure" of the abdomen or a homemade vacpack is advocated. The role of direct peritoneal resuscitation in patients with bowel repairs, enteric anastomoses, significant liver injuries, or vascular grafts has not been elucidated, but anecdotally appears to be safe.

Nutritional support is one of the cornerstones of ICU management of critically ill patients. There may be hesitation in starting enteral nutrition for those patients with an open abdomen or marked visceral edema. However, multiple studies support the use of EN in the open abdomen patient once deranged physiology is corrected [14–17]. In the largest study population to date, performed by the Western Trauma Association multicenter trials group, EN was associated with a higher abdominal closure rates (albeit with a longer time until closure) and a reduction in mortality compared to those patients who were kept *nil-per-os* [14]. The optimal EN formulation, necessary quantity, and location of delivery (stomach versus duodenum/jejunum) remain areas of active investigation. One consideration suggested by a single institution's experience is quantification of protein loss related to the open abdomen [18]; direct measurement of the albumin rich ascitic fluid that is removed from the abdomen suggests the addition of up to 2 g of nitrogen to the patient's daily protein requirement for every liter of abdominal fluid output. The effect of additional protein supplementation and its impact on patient outcome has not been studied to date.

Additional adjuncts that impact outcomes or alter management in the open abdomen patient population have been reported in single-study publications. Hypertonic saline (3 % sodium chloride) administered at a rate of 30 mL/h as maintenance fluid is associated with increased fascial closure rates compared to standard crystalloid maintenance fluids [19]. Vasopressor use has been implicated in cases of anastomotic failure following damage control surgery [20]. Damage control resuscitation, although initiated in the trauma bay, has important implications during the first 24 h of the patients management; higher plasma to red cell ratios impacts fascial closure rates and should not be abandoned during the ICU phase of resuscitation [21]. Finally, patients with an open abdomen do not require mechanical ventilation unless they have associated respiratory failure; small patient series suggest extubation in patients with an open abdomen, even in the acute phase of management, is feasible [22].

Considerations at Repeat Laparotomy

Following normalization of physiologic parameters, typically after 12–24 h in the ICU, the patient is returned to the operating room for definitive repair and attempts at fascial closure. There are some key questions that should be entertained prior to the operation: (1) If there is a bowel injury or the bowel is in discontinuity, should this be managed with an anastomosis or a stoma, (2) if a bowel anastomosis or repair is performed, can the suture line be "hidden" in the abdomen, (3) what type of enteral access should be placed, (4) if the fascia cannot be closed at this operation, what is the plan to definitively close the patient's abdomen?

Regarding the first question, should one perform an intestinal anastomosis versus a stoma, there are some guiding principles. First, the location of the injury or resection may be the deciding factor. Patients with a proximal small bowel injury should undergo anastomosis if technically possible; the morbidity and fluid balance challenges of a proximal stoma are too great. Distal ileal lesions and colonic injuries, however, provide more of a critical decision point, with either anastomosis or stoma being technically feasible. Although the largest study of penetrating colon injuries to date supports primary anastomosis in all patients [23], this study did not specifically analyze patients requiring an open abdomen. Five studies have specially addressed the question of primary repair/anastomosis versus stoma creation in a delayed fashion in patients requiring an open abdomen [24–28]. All but one of these studies are single-institution analyses of a small population of patients [25–28]. The Western Trauma Association multicenter trials study is the largest report to date, with over 200 patients with enteric injuries requiring a post-injury open abdomen [24]. In reviewing this literature cohort, the minority of patients suffer abdominal complications. In general, bowel repair in patients with the post-injury open abdomen appears safe, with similar anastomotic leak rates and abscess rates between patients undergoing immediate anastomosis, delayed anastomosis, and stoma formation. Two of the five published reports do, however, issue a cautionary note in relation to colonic wounds, particularly as one progresses along the colon toward the left

side [24, 27]. For patients undergoing primary repair/anastomosis, there is a reported increase in leak rate as one progresses toward the left colon, with a 3 % leak rate on the right, 20 % leak rate in the transverse, and 45 % leak rate with left colon/sigmoid repairs.

The timing of abdominal closure may also impact the decision to perform even a diverting stoma. There appears to be an increasing leak rate based upon time to fascial closure. The Western Trauma Association study demonstrated that patients with fascial closure beyond day 5 sustained a leak rate 4 times that of those already closed [24]. Two additional studies demonstrated a similar relationship between delayed timing of abdominal closure and significantly higher complications including anastomotic leak [29, 30]. Therefore, repair or anastomosis of identified injuries should be considered in all patients—however in those patients with left colon injuries or marked delay in abdominal closure, colostomy should be considered.

The next concern is question number 2, where to hide a newly fashioned anastomosis. With prolonged exposure to the atmosphere, the bowel in the open abdomen patient becomes more friable and adherent. Manipulation of the viscera, even simply the repeated placement and removal of temporary abdominal dressings, can result in a breakdown of an anastomosis and a resultant enteroatmospheric (EA) fistula. Therefore, enteric repairs or anastomoses should be placed deep within the pelvis or central abdomen under multiple loops of bowel, or out laterally under the abdominal wall.

Additionally, at repeat laparotomy, the abdomen does not need to be thoroughly re-explored nor the bowel eviscerated. The integrity of the suture lines and anastomoses do not need to be investigated at each repeat operation unless the patient has clinical evidence of an intraabdominal complication.

Placement of feeding tubes for enteral nutrition access is the third question one must consider upon return to the operating room. Early enteral nutrition, whether the abdomen is open or recently closed, is crucial in the critically ill patient. Options for enteral access include nasogastric tubes, Dobhoff tubes placed into the duodenum, nasojejunal tubes placed via endoscopy, and operatively placed gastrostomy and jejunostomy tubes. There may be hesitancy to place operative jejunostomy tubes through the edematous bowel wall; however, this can be safely performed [31]. In patients with a persistent open abdomen requiring multiple repeat laparotomies, however, manipulation or marked movement of enteral access sites (i.e., gastrostomy and jejunostomy tubes) can cause injury with leakage, tube dislodgement, or fistula formation. For this reason, gastrostomy and jejunostomy tubes should not be placed until closure of the fascia is well underway. Alternatively, nasogastric, nasoduodenal, or nasojejunal access is a viable option for early enteral nutrition and does not create an additional enterotomy with potential for leakage or complication.

Abdominal Closure

The final, and perhaps most critical step in the management of the open abdomen patient is closure of the abdomen. Leaving bowel exposed to the atmosphere for a prolonged time will result in EA fistulas which are notoriously difficult to manage. The ideal coverage for the bowel is native fascia, so primary closure is the goal. At the first return to the operating room, the majority of patients can achieve fascial closure of their abdomen [32]. If there is a question of success, towel clipping the abdomen closed can demonstrate effective closure prior to placement of fascial sutures. Monitoring airway pressures while re-approximating the fascia temporarily may assist in the determination of successful closure without creating significant IAH.

If early complete fascial closure of the abdomen is not possible, there are several options. Currently, sequential fascial closure techniques are the most attractive [33]. There are multiple published techniques but the majority involve three key components: (1) fascial tension toward the midline to prevent lateral retraction and loss of abdominal domain, (2) vacuum-assisted control of abdominal effluent and reduction of abdominal viscera within the abdominal cavity, and (3) methodic return to the operating room every 24–48 h for attempts at further fascial closure [33, 34]. Options to provide midline traction of the fascia include simple sutures (over the top of the sponges used in the vacuum-assisted closure) or commercially available bridging devices such as the Wittman patch (Starsurgical, Inc, Burlington, WI) [35, 36].

Other options for bowel coverage include prosthetic fascial closure with either mesh or biologics. Closure of the subcutaneous tissue and skin over top of these prosthetics often prevents desiccation and evisceration should the prosthetic fail. If one questions the use of prosthetics, a skin-only closure with planned hernia is always an option. In patients truly relegated to the open abdomen, in which no closure can be accomplished, a final option for bowel coverage is skin graft placement directly onto the granulating intestines [37]. Skin grafting can be surprisingly successful in this location with subsequent healing. Delayed abdominal wall reconstruction with component separation is performed once the skin graft has separated from the underlying bowel, approximately 9–12 months later.

Complications of the Open Abdomen

Some of the most common complications observed in patients with an open abdomen are ubiquitous to any patient undergoing a laparotomy: abscess, anastomotic leak, and enterocutaneous (EC) fistula. In general, these complications are treated using the similar approaches. One caveat in this population of open abdomen patients is the opportunity to

identify an anastomotic leak while the abdomen is still open; according to one published report, the majority of patients with an anastomotic leak were identified while the abdomen was still open, facilitating diversion and drainage [26].

One of the most vexing complications of the open abdomen is an EA fistula. The optimal management technique is prevention through a combination of careful manipulation of the bowel and aggressive abdominal closure techniques. For those that develop an EA fistula, most commonly seen in a "frozen abdomen," spontaneous sealing seen commonly in EC fistulas will not occur due to the lack of soft tissue covering the tract. If one can mobilize the adjacent soft tissue (abdominal wall or even just skin), the fistula tract can be intubated and then covered to promote a drainage tract and permit healing. For those that cannot obtain coverage, other options for EA fistula control have been suggested. Attempts at sealing the fistula aperture with fibrin glue and biologic dressing (acellular dermal matrix or cadaveric skin) can be attempted [38, 39]. A "fistula patch" made of a flexible silica gel lamellar which can be placed inside the lumen of the bowel through the EA fistula site has also been described [40]. If there is ongoing peritoneal contamination due to the EA fistula, control may be obtained using a "floating stoma" [41]. NPWT appears to have the greatest success in management of EA fistulas. A variety of techniques have been suggested with a variety of modification in either suction, control of fistula effluent, or composition of sponges [42–46].

Summary

In summary, understanding the management of the open abdomen is necessary for any clinician treating patients with either the ACS or following DCS. Considerations of fluid resuscitation, enteral nutrition, and supportive care continue to evolve. Management of the bowel incorporates several basic techniques and thoughts: appropriate temporary covering, a consideration of bowel repair in the majority of patients, placement of the anastomosis within the abdomen with both minimal manipulation and atmospheric exposure, and consideration of enteral access for initiation of nutrition support while the abdomen is still open. Early aggressive attempts at fascial closure remain pivotal to prevent the myriad of complications that can develop.

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Abdominal Compartment Syndrome

39

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Abdominal compartment syndrome (ACS) is defined as an abnormally elevated intra-abdominal pressure (IAP) associated with organ dysfunction. Traditionally, the term compartment syndrome was used to describe increased subfasical pressures in extremities. An intra-abdominal syndrome gained wide recognition in the Acute Care Surgery literature during the 1990s, when aggressive crystalloid resuscitation was common [1, 2]. Significant resources were then spent attempting to identify causes, risk factors, methods of diagnosis, and treatment. This culminated in the creation of the World Society of the Abdominal Compartment Syndrome (WSACS), a working group that has published consensus definitions and treatment algorithms (www.wsacs.org).

Etiology

There are many potential causes of intra-abdominal hypertension (IAH) and ACS. In general, the etiology of IAH and ACS results in one or more of the three following phsyiologic changes: (1) decreased abdominal wall compliance, (2) increased volume of intra-abdominal contents, and (3) capillary leakage [3].

A decrease in abdominal wall compliance can be seen in obese patients, in patients with abdominal burns and eschar, the presence of auto-PEEP, prone positioning, rectus sheath hematomas, and following massive ventral hernia repair.

An increase in intra-abdominal contents can be the sequelae of severe, acute pancreatitis, intra-abdominal or retroperitoneal mass lesions (e.g., tumors, pregnancy), hemo- or pneumoperitoneum, cirrhosis with ascites, ileus, or abdominal packing following trauma.

Capillary leak, concomitant fluid resuscitation, and resulting edema can be seen with acidosis and/or high volume crystalloid administration following trauma, burns, or sepsis. This also can be seen as a result of massive trauma requiring large volume blood product resuscitation. Cases of IAH following cardiac surgery have also been reported [4].

Despite the presence of a multitude of causes, the WSACS developed a standard classification system. Although a high degree of suspicion is necessary to make one begin to consider the diagnosis of ACS, once the diagnosis is made, this classification system allows for straightforward grading of severity and need for medical or surgical management.

Definitions of IAH and ACS

Intra-abdominal hypertension (IAH) is defined as the sustained, pathological elevation of IAP ≥12 mmHg. IAH is further subdivided by degree into one of four grades (Table 39.1). Grade I IAH is IAP 12–15 mmHg, grade II IAH is IAP 16–20 mmHg, grade III is IAP 21–25 mmHg, and Grade IV is >25 mmHg [5].

ACS is sustained IAP >20 mmHg associated with new organ dysfunction. However, a reduction in blood flow and the initial development of ACS can occur with IAP as low as 10–15 mmHg. Thus, early recognition is vital. If the IAH at this stage is not identified and treated, progression to ACS and its associated organ dysfunction can occur.

Classification

IAH and ACS are further classified by etiology into primary and secondary. Primary IAH or ACS is more common than secondary and is due to an injury or disease in the abdomen or pelvis. In trauma, this may be due to massive blood loss, ischemia/reperfusion gastrointestinal injury, resultant capillary leak, and bowel edema from massive crystalloid resuscitation. Despite a decrease in the incidence of ACS in the era of dam-

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_39

Table 39.1 Definitions

Intra-abdominal hypertension (IAH)	IAP ≥12 mmHg
Grade I IAH	IAP 12–15 mmHg
Grade II IAH	IAP 16–20 mmHg
Grade III IAH	IAP 21–25 mmHg
Grade IV IAH	IAP >25 mmHg

age control resuscitation (DCR—limitation of crystalloid, high ratios of RBC:FFP, permissive hypotension until hemorrhage is controlled), it still occurs in the severely injured patient population and requires an even greater degree of suspicion [6]. In the emergency general surgery population, ACS can still be seen in patients with sepsis requiring massive crystalloid resuscitation or with severe acute pancreatitis.

Secondary IAH or ACS is the result of an injury, disease, or process that does not originate from the abdomen and pelvis [7]. In the past, secondary IAH or ACS would be seen in patients with significant non-abdominal trauma who were resuscitated into ACS. This is more rare in the era of DCR, but may still be observed in massively transfused patients. A more common presentation of secondary ACS is the resuscitation of major burn patients, as they often require large volumes of crystalloid resuscitation. Interestingly, the addition of fresh frozen plasma to the resuscitation algorithm of large burn patients appears to decrease the IAP by decreasing the volume of crystalloid required [8].

Diagnosis

Again, the diagnosis of IAH and ACS begins with a high index of suspicion in a patient with one or multiple risk factors. The measurement of bladder pressure has become the most common technique for estimating IAP as it is non-invasive and simple. Clinical examination alone has been shown to be a poor predictor of IAH and ACS [9, 10]. Additionally, the use of peak inspiratory pressure, plateau pressure, and mean airway pressures as a surrogate for IAP, especially during abdominal fascial closure, is also not accurate [11].

IAP can be quickly and accurately measured by obtaining a bladder pressure measurement, considered by most to be the gold standard diagnostic test [12]. After complete drainage of the bladder, 50–100 cc of saline is instilled into the patient's urinary catheter and column of fluid is created that neither distends the bladder nor causes it to contract. With the pressure transducer zeroed at the level of the pubic symphysis, the intra-vesicular pressure closely reflects the IAP [13]. Initially, this required taking a closed system (the urinary Foley catheter and attached bag) and pening it, potentially increasing the risk of hospital-acquired urinary tract infections in this severely injured group. closed systems have been created and are widely available.

When measuring bladder pressures in attempts to estimate IAP, there are a number of considerations. First, the position of the patient matters greatly [14]. IAP should be measured with the patient in the supine position. Additionally, the use of greater than 100 cc can lead to overestimation of IAP in patients with a non-compliant bladder or may result in bladder contractions which may falsely elevate the IAP.

Pathophysiology

As IAP increases, multiple pathophysiological changes occur in the body. As the IAP increases, intrathoracic and systemic afterload increases while preload decreases. Once the IAP reaches critical threshold, blood flow to the intra-abdominal organs and lower extremities decreases. These changes lead to alterations in numerous body systems (Table 39.2).

Cardiovascular System

Systemic arterial blood pressure may not be affected during the early stages of IAH or ACS. As the IAP increases, stroke volume decreases due to the reduced preload from decreased blood return from the inferior vena cava [15]. Stroke volume is further aggravated by increased after load from increased intrathoracic pressure and IAP. At lower IAP and intrathoracic pressures, the heart can compensate for the decreased stroke volume by increasing its rate. But at some threshold, this compensation fails and a resultant drop in cardiac output occurs. CVP and pulmonary artery wedge pressure are elevated due to the high intrathoracic pressure and are not accurate measures of volume status.

Respiratory System

Increasing IAP is transmitted to the thoracic cavity via cephalad bulging of the diaphragm. This results in decreased pulmonary and chest wall compliance, increased peak inspiratory pressure, and decreased pulmonary compliance [16]. In pressure regulated volume control ventilation, the actual tidal volumes delivered will become smaller and smaller as the airway pressures rise. In pressure control ventilation, the increasing airway pressures from decreased chest wall compliance results in lower and lower tidal volumes at the same inspiratory pressure. In both situations, the resulting increased airway pressures decrease ventilation and result in hypercarbia. Eventually, unimpeded and progressive ACS will result in higher ventilator settings (especially PEEP) that exacerbate the already elevated airway pressure. In later phases of ACS, oxygenation will also become more difficult.

Table 39.2 Body system manifestations of ACS

Body system	Pathophysiology	Clinical manifestation
Cardiovascular system	↓ stroke volume, cardiac output ↑ systemic vascular resistance	↑ CVP and PAWP falsely Hypotension
Respiratory system	↑ peak inspiratory pressure ↓ chest wall compliance (which leads to ↓ pulmonary compliance)	↓ tidal volumes at same ventilator settings Hypercarbia Hypoxia
Renal system	↓ renal vein blood flow ↑ renal parenchymal pressure ↓ renal artery blood flow ↓ glomerular filtration rate	Oliguria Anuria Acute renal failure
Gastrointestinal system	↓ splanchnic venous outflow ↓ splanchnic arterial inflow ↑ splanchnic vascular resistance ↓ hepatic artery, portal vein flow ↓ hepatic microcirculatory blood flow	Intestinal ischemia Shock liver

Renal System

Increasing IAP results in a reduction in glomerular filtration rate (GFR) via multiple mechanisms. The increased IAP decreases renal vein blood flow. This results in interstitial edema and a rise in the intracapsular pressure of the kidneys. Additionally, increased IAP increases renal vascular resistance and decreased renal artery blood flow leads to lower renal artery blood flow [17]. The combination of these insults results in decreased urine output at low levels of IAP, anuria at higher levels of IAP, and, if uncorrected, acute renal failure.

Gastrointestinal System

Increasing IAP reduces mesenteric blood flow secondary to decreased cardiac output and increased mesenteric vascular resistance [18]. Unabated, this can lead to intestinal ischemia. A very late diagnosis and intervention for ACS can lead to pan-enteric ischemia, an ultimately fatal outcome.

The increased IAP also leads to decreased hepatic arterial blood flow, portal venous blood flow, and hepatic microcirculatory blood flow [19]. While it is reasonable to ascribe acute hepatic failure to the decreased blood flow into the liver, this connection has not been established in animal or human models.

Treatment

A major strategy for the prevention of ACS is the limitation of crystalloid resuscitation in both trauma and emergency general surgery. The utilization of DCR in trauma likely decreases the incidence of ACS by three mechanisms: (1) decreased resuscitation-induced edema, (2) decreased capillary permeability [20], and (3) overall lower volumes of resuscitation [21] In the emergency general surgery population, it is important to remember that early goal directed therapy (though now controversial) calls for an initial fluid resuscitation to raise CVP to 8–12 mmHg followed by the initiation of vasopressor support [22]. The desire to resuscitate patients with crystalloid beyond reasonable volumes errorin an effort to wean the vasopressor support is an error. While patients in septic shock are initially hypovolemic and require resuscitation, they also suffer low systemic vascular resistance, the treatment for which is vasopressor support and resolution of the infectious process.

Once a patient has been diagnosed with IAH, some medical therapies may be attempted to manage the IAH. Some medical therapies, however, are unproven and may actually aggravate the IAH, but are unproven and may aggravate the IAH. If the IAH is secondary to increased intraluminal contents, nasogastric decompression and stopping enteric feeding may improve the IAP. If there is a mass effect from an intra-abdominal or retroperitoneal lesion, evacuating the collection or surgical excision may decrease IAP. Abdominal wall compliance may be improved by adequate analgesia and sedation, removing constricting dressings, and the Trendelenburg position [23].

If the IAP continues to increase and the IAH worsens, the pathological changes often result in medical therapies that worsen the IAH. Increased intrathoracic pressure resulting in increased airway pressures requires higher ventilator support which worsens the intrathoracic pressure and IAP. Decreasing urine output leads to volume resuscitation which aggravates gut and renal edema further increasing IAP.

The gold standard therapy for ACS and for preventing the progression of IAH to ACS is decompressive laparotomy. Prior to and during decompression, the patients should be volume loaded as decompression may result in hypotension from hypovolemia and ischemia-reperfusion reaction from the washout of acidotic products of metabolism in underperfused organs.

After decompression, the abdomen should be left open with the temporary abdominal closure (TAC) of choice. No prospective randomized control trials support the use of one product, so the choice of TAC is left to surgeon preference and institutional availability. It is important to note that patients with an open abdomen and TAC, recurrent ACS is possible and IAP should be closely monitored following decompression.

Conclusion

The diagnosis of IAH and ACS requires a high index of suspicion in critically ill patients. At risk patients should undergo routing bladder pressure monitoring in an intensive care unit. Low grade IAH should undergo prompt medical management. Any progress to high grade IAP or ACS requires immediate surgical decompression via laparotomy.

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Necrotizing Soft Tissue Infections

40

Krislynn M. Mueck and Lillian S. Kao

Necrotizing soft tissue infections (NSTIs) are a group of rare but fulminant complicated skin and soft tissue infection. The United States (US) Food and Drug Administration differentiates complicated from uncomplicated skin and soft tissue infections based on several criteria including the need for surgical intervention [1]. These infections are typically characterized by advancing tissue necrosis and are known colloquially as being caused by "flesh-eating bacteria." Other terms that are used to describe NSTIs include: gas gangrene, streptococcal gangrene, gangrenous cellulitis, necrotizing cellulitis or erysipelas, bacterial synergistic gangrene, Meleney ulcer or gangrene, and Clostridial myonecrosis. NSTIs of the perineum are referred to as Fournier's gangrene. Although NSTI is often used synonymously to mean necrotizing fasciitis, coined by Dr. Wilson in 1952, NSTIs have now come to represent a spectrum of diseases that range from necrotizing cellulitis to myonecrosis (Fig. 40.1).

Epidemiology

Incidence

The incidence of NSTIs in the USA has been increasing since the 1980s [2, 3]. Whether the increase represents a true rise in the number of infections or simply better identification and reporting of NSTIs is unclear. The incidence ranges from 3800 to 5800 cases annually [4]. Furthermore, the gross incidence of NSTIs more than doubled between 1999 and 2007, and the population-adjusted incidence rate has increased by 91 % [5]. Although NSTIs are still considered rare, it is estimated that clinicians, regardless of specialty, will encounter at least one NSTI patient in their lifetime [6].

Classification

There are several methods for describing NSTIs, although there is no standard classification system. NSTIs can be described by their depth of invasion (Fig. 40.1); necrotizing fasciitis is characterized by pathological findings at the level of the subcutaneous fat (i.e., thrombosed vessels) and deep fascia (i.e., necrosis). NSTIs can also be classified by their anatomic location (i.e., Fournier's gangrene for NSTIs of the perineum).

Another method for describing NSTIs is based on their microbiology: Type I, II, and III. Type I NSTIs are the most common type, accounting for 55–75 % of infections. They are polymicrobial and include organisms such as gram-positive cocci, gram-negative bacilli, and anaerobes. They have been associated with multiple predisposing factors including surgical procedures, diabetes, and peripheral vascular disease. Type II NSTIs are caused by Group A beta-hemolytic *Streptococci* with or without *Staphylococcus aureus*. These infections are less common than Type I infections and can occur in young, healthy individuals. Type III NSTIs have been attributed to *Vibrio* species by some authors and to *Clostridium* species by other authors.

An alternative classification system was proposed by Bakleh et al. based on histopathologic findings [7]. They proposed three stages based on combinations of inflammatory response and gram-stain results. Grades of the inflammatory response were characterized by the degree of neutrophilic infiltration and presence of necrosis or microabscesses. The histopathologic stages correlated with mortality, although only unadjusted analyses were performed due to small sample size.

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_40

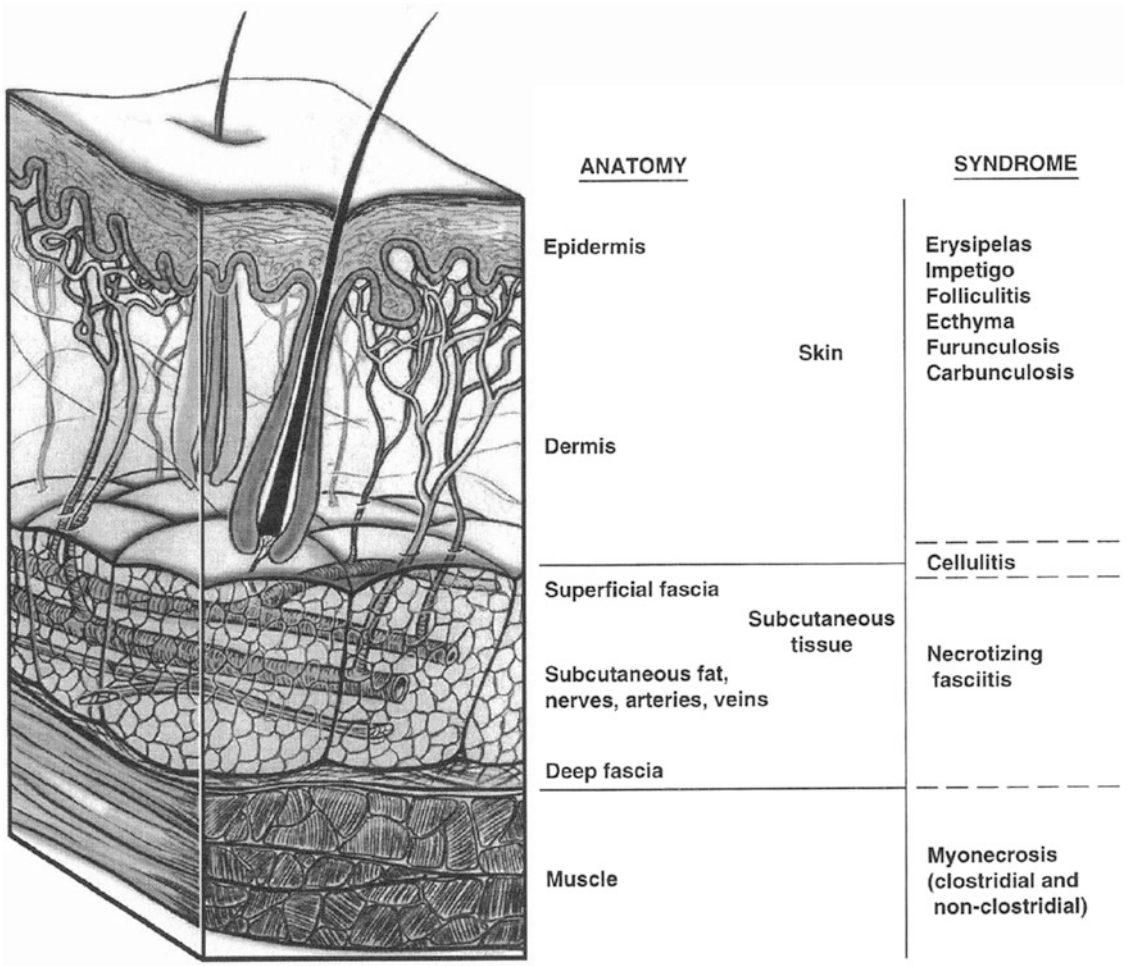

Fig. 40.1 Anatomy of skin and soft tissue and infectious processes associated with each layer. Reproduced with permission from the American College of Chest Physicians. (From Green R, Dafoe D, Raffin T. Necrotizing fasciitis. *Chest*. 1996;110:219–229, with permission)

Risk Factors

Although there are multiple risk factors, NSTIs often develop in young, healthy hosts. Comorbidities that have been associated with NSTIs include diabetes mellitus, peripheral vascular disease, obesity, chronic renal failure, cirrhosis, heart disease, acquired immunodeficiency syndrome (AIDS), and immunosuppression. Injection drug use and alcoholism are associated with NSTIs as well. Infections may develop as a result of insect bites, abscesses, recent trauma, or surgery [2, 8].

Microbiology

As previously described, NSTIs may be polymicrobial or monomicrobial depending upon the patient's comorbidities, risk factors, and clinical setting. Cultures may identify gram-positive and gram-negative bacteria, aerobic and anaerobic bacteria, and fungi. Historically, monomicrobial NSTIs were attributed to *Group A Streptococcus* (GAS), *Clostridium* species, and *Vibrio* species, but as described as follows, any number of microorganisms may cause monomicrobial NSTIs. Table 40.1 details many of the virulence factors of the causative organisms of NSTIs.

The two most common gram-positive cocci isolated from patients with NSTIs are *Staphylococci* and *Streptococci* [1, 9]. *S. aureus* is the most common pathogen present in serious soft tissue infections in North America, Latin America, and Europe [10]. Over time, its virulence and resistance has changed; there has been a concomitant decrease in infections caused by methicillin-sensitive *Staphylococcus aureus* (MSSA) and an increase in infections caused by methicillin-resistant *Staphylococcus aureus* (MRSA) [11]. Furthermore, there has been an increase in the prevalence of community-acquired MRSA (CA-MRSA), which was first described in the 1990s [10]. Initially CA-MRSA infections were primarily present only in specific sub-populations such as prisoners or sports participants, but now CA-MRSA is on its way to becoming the predominant strain of MRSA in hospitals [12]

Table 40.1 Causative microorganisms of NSTIs and their virulence factors

Microorganism	Virulence factors
Gram-positive bacteria	
CA-MRSA	Panton-Valentine Leukocidin gene, encoding a potent exotoxin
GAS (*S. pyogenes)*	M protein, superantigens, degradative enzymes, associated with Streptococcal Toxic Shock Syndrome
Gram-negative bacteria	
Klebsiella spp.	Carbapenemase, K1 genotype with increased ability to spread hematogenously resulting in distant abscesses
Aeromonas	Potent exotoxins
Fungi	
Aspergillus	Mycotoxins
Cryptococcus spp.	Polysaccharide capsule, superoxide dismutase, proteases

and is increasingly identified in patients with NSTIs [13]. In 2005, Miller et al. described 14 patients with NSTIs and positive cultures for CA-MRSA, 12 of who had monomicrobial infections [13]. These patients had risk factors such as diabetes and hepatitis, history of injection drug use, homelessness, and prior MRSA infection. All of the infections were due to the USA300 clone and had similar genotypes including the presence of the Panton-Valentine leukocidin (pvl) gene, which encodes an exotoxin that causes leukocyte destruction. There is a suggestion that mortality may not be as high in patients with CA-MRSA, but because of its increasing prevalence, empiric coverage should be started in patients with suspected NSTIs [13–16].

Streptococcus pyogenes is a type of Group A beta-hemolytic *Streptococcus* (GAS) that can cause a spectrum of diseases from bacterial pharyngitis to necrotizing fasciitis and myositis to toxic shock syndrome. In a European population-based study, the crude rate of *S. pyogenes* infection was 2.79 per 100,000 population [17]. Eight percent (308 patients) of all of the cases were diagnosed with necrotizing fasciitis, of which 50 % were associated with toxic shock syndrome (TSS). Streptococcal TSS has been reported to be an independent predictor of mortality [18]. Risk factors for GAS infections include comorbidities such as liver disease or underlying malignancy and behaviors such as injection drug use, but these infections can also occur in healthy immunocompetent patients [19]. GAS NSTIs have a predisposition for the lower extremities and tend to spread rapidly.

Several gram-negative rods have been associated with NSTIs, including *Klebsiella* species, *Enterobacter* species, *Pseudomonas* and *Aeromonas*, *Vibrio* species, *Acinetobacter* species, *Eikenella corrodens*, and *Citrobacter freundii* [1, 9]. Liver disease is a risk factor for NSTIs caused by gram-negative rods, particularly *Vibrio*, *Klebsiella*, and *Aeromonas* [20]. Furthermore, these gram-negative rod NSTIs appear to have a higher prevalence in Asian countries [18]. *Vibrio* infections occur in immunocompromised hosts such as those with cirrhosis, diabetes mellitus, adrenal insufficiency, and chronic renal insufficiency; they are associated with contact with seawater or ingestion of raw seafood [20–22]. These infections may have an atypical presentation; increased level of suspicion should occur in these patients, particularly when hemorrhagic bullae are present given an increased associated mortality. *Klebsiella* NSTIs are also more common in Asia, but have been reported as nosocomial infections in patients with underlying malignancy as well as after liver transplantation in the Western hemisphere [23, 24]. *Klebsiella* NSTIs, specifically the virulent K1 genotype, manifest a higher component of hematogenous spread than do other NSTIs and are associated with concomitant distant abscesses, most commonly found in the liver or brain [25]. Furthermore, cases involving carbapenem-resistant species are associated with increased mortality due to fewer antimicrobial options for treatment [23, 24]. *Aeromonas* species are facultative anaerobic gram-negative bacilli which are typically found in fresh or brackish water and sewage, with species *hydrophila, caviae,* and *sobria* responsible for the majority of associated NSTIs [26]. Their history and clinical presentation is similar to that of *Vibrio* infections, and they produce a potent exotoxin which results in myonecrosis and gas production, as in clostridial infections. Like *Vibrio* and *Klebsiella* NSTIs, *Aeromonas* infections are rare in immunocompetent patients, though a few cases have been reported after traumatic inoculation in heavily contaminated environments [27].

Clostridum is a genus of gram-positive bacteria that are obligate anaerobes. Multiple species including *Clostridium perfringens* have been identified in NSTIs. Clostridial infections may cluster in areas with heavy injection drug use. For example, King County, Washington, has a high prevalence of drug users who inject heroin. In a review of 10 years of autopsies of patients who died due to NSTIs, clostridial infections were identified as being significantly associated with injection drug use of black tar heroin [28, 29]. A retrospective review of patients treated in Seattle, Washington, identified a significant association between clostridial infections and an increase in mortality and limb loss [28]. NSTIs caused by *Clostridium septicum* are often associated with an underlying colonic malignancy [30, 31].

Fungi (i.e., *Candida* species) may also be found in both polymicrobial and monomicrobial NSTIs. There have been case reports of monomicrobial NSTIs due to *Aspergillus* [32, 33]. Zygomycotic NSTIs from *Apophysomyces* have been reported in trauma patients and in immunocompetent hosts [34–36]. Cryptococcocal NSTIs have also been reported, largely in immunocompromised patients [37, 38].

Pathophysiology

Spread of pathogens that cause NSTIs occurs through the production of a variety of endotoxins and exotoxins, many of which have already been mentioned. Toxins may cause tissue destruction, ischemia, and necrosis; endothelial damage, which results in increased tissue edema and impaired capillary blood flow; increased escape from host defenses such as phagocytosis and neutrophil infiltration at the site of infection; and activation of the coagulation cascade, which may cause vascular thrombosis and worsened tissue ischemia [2].

Clinical Presentation

NSTIs can be difficult to distinguish from other non-necrotizing infections. Early manifestations may include swelling, erythema, and warmth, which are nonspecific findings that are also present in patients with cellulitis (Fig. 40.2). Pain out of proportion to physical exam may be present. By the time NSTIs become clinically apparent and patients manifest "hard signs," the associated morbidity and mortality are increased because of the delay in diagnosis [40–42]. Hard signs include late skin manifestations such as bullae, crepitus, or skin necrosis (Figs. 40.3 and 40.4). Wang et al. performed an observational study of patients and developed a staging system based on the time course of symptoms and signs (Table 40.2) [39]; such hard signs are classified as Stage III or late findings. Furthermore, NSTI patients may present with hemodynamic instability and organ failure; the number of dysfunctional organ systems at admission is predictive of mortality [43].

Diagnosis

Multiple studies have demonstrated an association between a delay in diagnosis and worsened outcome from NSTIs [40–42]. The diagnosis may be obvious in the setting of the hard signs described above such as hemodynamic instability and late skin manifestations. However, these findings are only present in a small percentage of NSTI patients; in a matched case–control series, necrotic skin and hypotension each occurred in only 5 % of patients and no patients had crepitance [44]. Furthermore, as described previously, by the time bullae, crepitus, or skin necrosis are apparent on physical examination, the NSTI has already progressed to an intermediate or late stage.

Compounding the difficulties in diagnosis are the similarities in presentation between early stage NSTIs and cellulitis such as fever, pain, swelling, tenderness, erythema, and warmth. In a matched case–control study, Wall et al. compared physical examination findings, laboratory values, and radiologic findings in patients with necrotizing fasciitis to those with a non-necrotizing soft tissue infection [44]. They found that the parameters with the highest sensitivity for necrotizing fasciitis were white blood cell count greater than 14×10^9/L, sodium less than 135 mmol/L, and blood

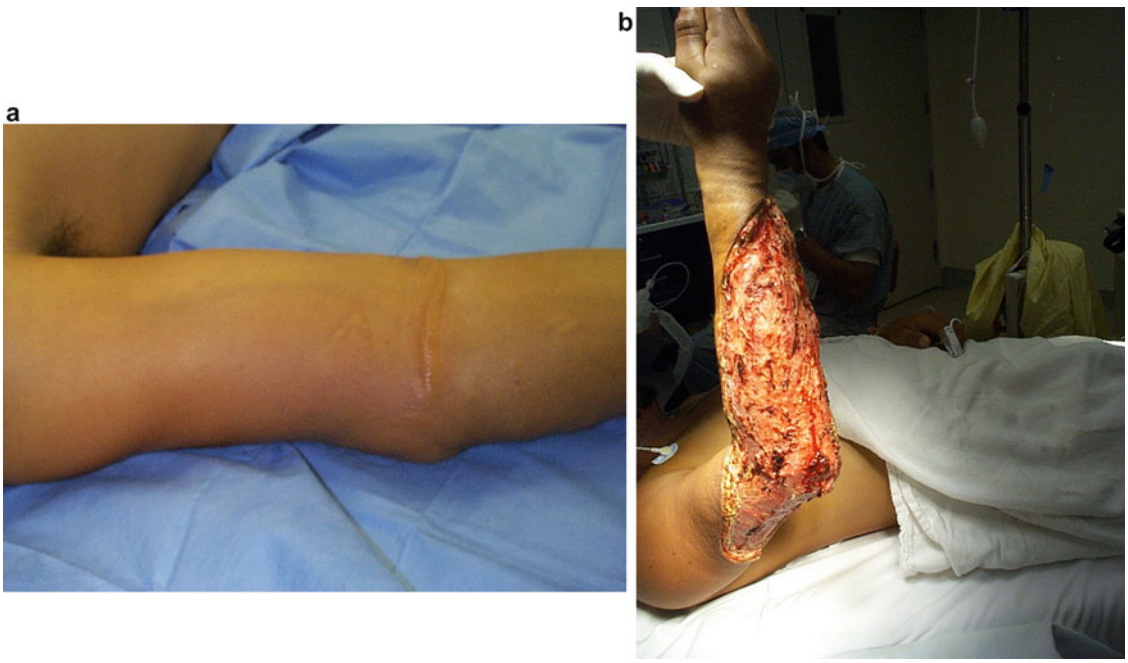

Fig. 40.2 (**a**) This patient has minimal skin manifestations of NSTI other than erythema and swelling, characteristic of Stage I or early NSTI as proposed by Wang et al. [43]. (**b**) The same patient after debridement of necrotic infected tissue

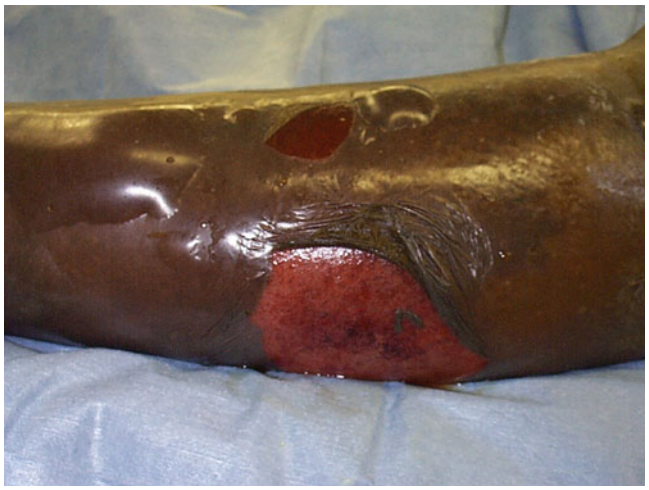

Fig. 40.3 This patient has multiple blisters filled with serous fluid, characteristic of Stage II

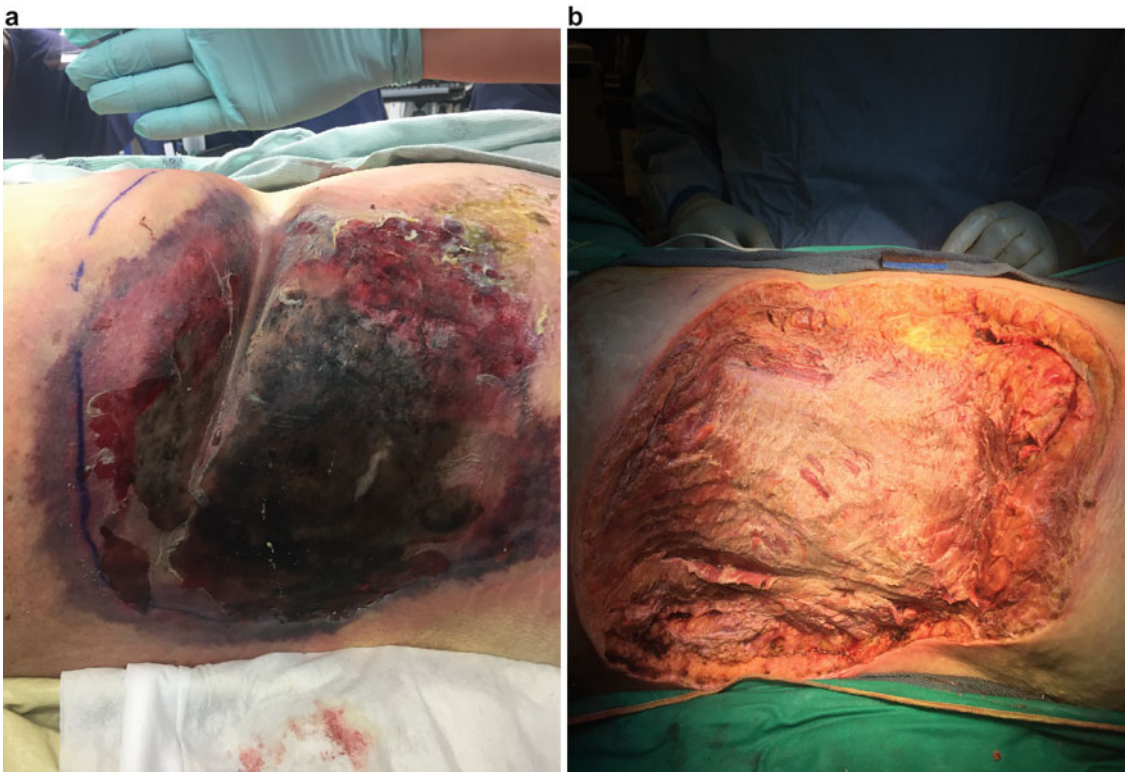

Fig. 40.4 (**a**) This patient had skin necrosis and crepitus of the flank characteristic of Stage III. (**b**) The same patient after debridement of necrotic infected tissue. (Courtesy of Bryan A. Cotton MD, MPH)

Table 40.2 Stages of evolving necrotizing soft tissue infection based on cutaneous changes [39]

Stage	Time course	Symptoms and signs
Stage I	Early	Tenderness to palpation (extending beyond the apparent area of skin involvement)
		Erythema
		Swelling
		Warmth
Stage II	Intermediate	Blister or bullae formation (serous fluid)
Stage III	Late	Crepitus
		Skin anesthesia
		Skin necrosis with dusky discoloration

From Wang YS, Wong CH, Tay YK. Staging of necrotizing fasciitis based on the evolving cutaneous features. *Int J Dermatol*. 2007;46(10):1036–1041, with permission

urea nitrogen greater than 15 mg/dL. The parameters with the highest specificity (100 % for all) were tense edema, bullae, sodium less than 135 mmol/L, and chloride less than 95 mmol/L. Based on these findings, Wall et al. developed a simple model to assist in diagnosing NSTIs [45]. A corrected serum sodium (for glucose) of less than 135 mmol/L or a white blood cell count of greater than 14.3 $\times 10^9$/L had a 90 % sensitivity and a 76 % specificity for necrotizing fasciitis. This model correctly classified 18/19 (95 %) of patients who had no "hard signs."

Another commonly used model for diagnosing an NSTI is the Laboratory Risk Indicator for NECrotizing fasciitis (LRINEC) score [46]. Six laboratory parameters are included in the score and are weighted from 1 to 4 points for a total possible score of 13 (Table 40.3). The probability of necrotizing infections was less than 50 % with a cutoff score of less than or equal to 5, but increased to greater than 75 % with a cutoff score of greater than or equal to 8. A cutoff score of 6 had a positive predictive value (PPV) of 92 % and a negative predictive value (NPV) of 96 % in the original validation dataset. The LRINEC score has not been validated across other patient populations and settings [47, 48], although one study suggested that it may function as both a diagnostic and prognostic tool [49]. Thus, the LRINEC score may be useful in select patient populations in increasing the suspicion for a necrotizing infection, but further studies are required. As with all diagnostic tools, the predictive values are dependent on the incidence of the disease in the population, and the utility of a test in changing management depends on the level of suspicion for the disease (or the pretest probability).

Table 40.3 Laboratory Risk Indicator for Necrotizing Fasciitis (LRINEC) score; a cutoff six points had a 92 % positive predictive value and a 96 % negative predictive value [46]

Variable (units)	Score
C-reactive protein (mg/dL)	
<150	0
≥150	4
Total white cell count (per mm^3)	
<15	0
15–25	1
>25	2
Hemoglobin (g/dL)	
>13.5	0
11–13.5	1
<11	2
Sodium (mmol/L)	
≥135	0
<135	2
Creatinine (μmol/L)	
≤141	0
>141	2
Glucose (mmol/L)	
≤10	0
>10	1

From Wong C-H, Khin L-W, Heng K-S, Tan K-C, Low C-O. The LRINEC (Laboratory Risk Indicator for Necrotizing Fasciitis) score: a tool for distinguishing necrotizing fasciitis from other soft tissue infections. *Crit Care Med*. 2004;32(7):1535–1541, with permission

Several recent studies have advocated for the addition of serum lactate level as a diagnostic tool. Schwartz et al. found that only arterial lactate was predictive of both mortality and limb loss. In addition, while using the well-defined parameters of decreased serum sodium and elevated WBC served as an adequate screening tool, the addition of serum lactate level greater than or equal to 6 mmol/L had both a sensitivity and NPV of 100 % [50].

Radiographic imaging may be helpful in improving diagnostic efficiency. In the case–control study by Wall et al., 39 % of patients with necrotizing fasciitis had gas on plain film versus 5 % of patients with a non-necrotizing infection [45]. However, gas on X-ray only had a sensitivity of 39 %. Ultrasonography has been increasingly used as an adjunct in the diagnosis of NSTIs [51–55]. Ultrasound has the advantage of being rapidly performed at bedside, unlike computed tomography (CT) and magnetic resonance imaging (MRI), and it may be helpful in differentiating simple cellulitis from necrotizing fasciitis in a timely fashion. In a prospective observational study of 62 patients with clinically suspected NSTI, Yen et al. found that ultrasound had a sensitivity of 88.2 %, specificity of 93.3 %, PPV of 95.4 %, NPV of 95.4 %, and diagnostic accuracy of 91.9 % for NSTI, as confirmed by subsequent surgical exploration [52]. Sonographic findings consistent with necrotizing fasciitis include subcutaneous thickening, air, and fascial fluid, which may be recalled using the mnemonic "STAFF" [55]. While ultrasonography has become increasingly available, its utility is limited by variability in operator training and expertise. Thus, currently there is insufficient evidence to recommend routine use of ultrasound in the diagnosis of NSTIs.

Traditionally, although CT and MRI have been reported to be useful adjuncts in the diagnosis of NSTIs, there has been a hesitation to recommend their routine use due to potential delays in obtaining the studies. However, as technology continues to evolve, these studies may become more feasibly and efficiently obtained. In a study of 67 patients without indication for immediate surgical exploration for NSTI, CT scans had 100 % sensitivity and 81 % specificity for diagnosing NSTIs [56–58]. Three out of eight patients with a false-positive CT scan had fluid collections identified that ultimately were diagnosed as abscesses associated with pyomyositis [58]. Another study by McGillicuddy et al. reported that 305/715 (43 %) of NSTI patients diagnosed over a 10-year period at a single center underwent CT scan. They developed a scoring system of five CT findings to aid in the diagnosis of NSTIs (Table 40.4). A score of greater than 6 had 86 % sensitivity,

Table 40.4 Computed tomography (CT) NSTI Scoring System: a score of >6 points had an 86 % sensitivity and a 92 % specificity for the diagnosis of NSTI [59]

Variable	Points
Fascial air	5
Muscle/fascial edema	4
Fluid tracking	3
Lymphadenopathy	2
Subcutaneous edema	1

From McGillicuddy EA, Lischuk AW, Schuster KM et al. Development of a computed tomography-based scoring system for necrotizing soft-tissue infections. *J Trauma*. 2011;70(4):894–899, with permission

92 % specificity, 64 % positive predictive value (PPV), and 86 % negative predictive value (NPV) [59]. Further prospective validation studies are planned.

MRI has been used to diagnose NSTIs, but like CT has a high sensitivity but a low specificity [2]. Findings on T2-weighted images have included: gas or low signal intensity in the deep fascia [60, 61], abnormal deep fascial thickening with or without contrast enhancement [60, 62, 63], peripheral high signal intensity in muscles [60, 64], extensive involvement of the deep fascia [60], and involvement of three or more compartments in one extremity [60]. However, several authors have noted that MRI tends to overestimate the extent of deep fascial involvement [54, 65]. Concerns about availability, potential delay in diagnosis and subsequent intervention, and lack of well-defined criteria for distinguishing NSTIs from non-necrotizing infections still limit the widespread use of MRIs for this purpose.

Fluid and tissue sampling have also been suggested for diagnosing NSTIs. A 22-gauge needle with a 10-mL syringe has been used to aspirate fluid in the setting of soft tissue infections [66]. In a study of 50 patients in whom aspiration biopsy was performed, cultures were positive in 81 % of patients not on antimicrobial therapy, but the percentage dropped to 30 % in patients receiving antimicrobial treatment. Growth of an organism on aspirate was not specific as the cultures were taken from patients with cellulitis, ulcers, chronic osteomyelitis, and infected surgical wounds. Furthermore, although the organisms on aspirate were similar to those in surgical specimens among patients who were subsequently debrided, there was often a delay to growth of an organism in the aspiration fluid (up to 72 h) [66]. There is inadequate evidence to recommend the routine use of aspiration biopsy to diagnose NSTIs.

Ultimately, the diagnosis of an NSTI is confirmed by surgical exploration, either at the bedside (if the patient is clinically unstable) or in the operating room. Typical gross findings include loss of tissue resistance to blunt dissection, thrombosis of subcutaneous vessels, presence of foul-smelling and/or dishwater fluid, and grayish appearance of fascia with or without obvious tissue necrosis. These findings are sufficient to confirm the diagnosis, but if the surgeon is still uncertain, frozen-section biopsy can be performed. Frozen-section biopsy for rapid and early diagnosis of necrotizing fasciitis was advocated by Stamenkovic and Lew in 1984 [67]. They recommended obtaining at least a 10×7×7 mm incisional biopsy of soft tissue under local anesthetic. Histologic samples from patients who did not undergo frozen-section biopsy demonstrated further extension of the necrosis representative of progressive disease. Use of frozen-section biopsy, however, is limited by the availability of a pathologist to read the samples, and NSTIs are usually associated with obvious findings such as those described previously.

Management

The mainstay of treatment for NSTIs is administration of broad spectrum antibiotics and prompt and aggressive surgical debridement of infected tissues (Fig. 40.5). Randomized trials of adjunctive treatments are lacking, and synthesis of observational studies is hampered by: (1) a lack of standardized terminology and (2) heterogeneity in patient populations, bacteriology, and management strategies.

Surgical Management

Recognizing the lack of randomized trials to guide management, the Surgical Infection Society (SIS) and the Infectious Diseases Society of America (IDSA) Guidelines for the Treatment of Complicated Skin and Soft Tissue Infections strongly recommend timely and adequate surgical debridement to improve outcome [1, 68]. General caveats for operative debridement include complete resection of necrotic tissues and drainage of fluid collections. Non-viability of tissues is often marked by easy separation from surrounding structures, thrombosis of blood vessels and lack of arterial bleeding, and lack of muscle contraction. Tissue should be cultured to guide postoperative antibiotic management.

Source control may require aggressive surgical management. Ten to 25 % of patients required amputations in several cases series [15, 28, 40, 69], and approximately a quarter of patients with extremity involvement required amputation in two series [15, 28]. Guillotine or through-joint amputations can be done expeditiously at the initial operation if the patient is hemodynamically unstable and/or the level of involvement is not clearly defined. SIS guidelines recommend frequent reevaluation or return to the operating room within 24 h of the initial debridement to determine the adequacy of source control and to verify the lack of progression [1]. Repeat operative exploration is continued until source control has been achieved and no more tissue requires debridement. In order to more conclusively determine the

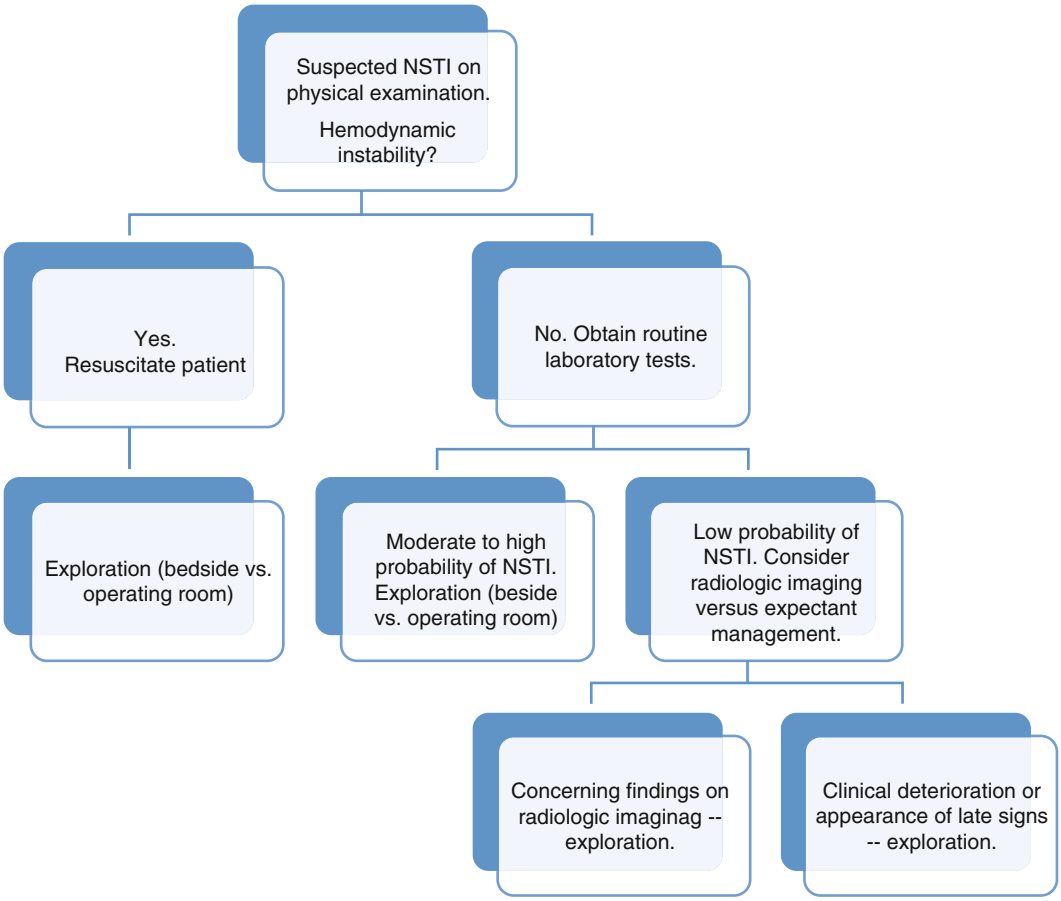

Fig. 40.5 Algorithm for management of a patient with a suspected NSTI

success of surgical debridement, Friederichs et al. found that the procalcitonin ratio from postoperative day 1 to day 2 following major surgical procedures for NSTIs identified persistent infection [70]. They found that a ratio of 1.14 had a sensitivity of 83.3 %, specificity of 71.4 %, PPV of 75.8 %, and NPV of 80 % for successful treatment. In the clinical setting, a ratio below the cutoff should raise suspicion for persistence of the infectious focus and suggests a need for more radical reoperation or an earlier life-saving amputation.

Management of open wounds associated with aggressive surgical debridement has traditionally been to employ wet-to-dry dressings, but there have been increasing reports of negative pressure wound therapy usage [71]. Some of the clinical benefits of negative pressure wound therapy include reduction of wound area secondary to enhanced wound retraction, promotion of granulation tissue formation in an optimally moist wound milieu, continuation of effective wound cleansing with removal of small tissue debris by suction after adequate primary surgical debridement, and continuous removal of wound exudate within a closed hygienic system [72]. However, additional research and quantitative assessment is needed prior to comprehensive recommendations for use in NSTIs. Ultimately, large wounds that do not heal by secondary intent may require coverage with split thickness skin grafts or musculocutaneous flaps.

Antibiotic Therapy

Early, empiric, broad spectrum antibiotics are strongly recommended for the treatment of NSTIs. Antibiotic coverage should include activity against aerobic and anaerobic gram-positive and gram-negative organisms. The SIS Guidelines recommend several effective single-agent regimens including carbapenems (i.e., ertapenem), other beta-lactam antibiotics (i.e., piperacillin/tazobactam), and glycylcyclines that are similar to tetracyclines (i.e., tigecycline) [1]. However, antibiotic combinations with the same coverage can also be used. If Group A streptococcal infections are suspected, penicillin is the drug of choice with or without a protein synthesis-inhibitory agent [1]. If clostridial infections are suspected, a protein synthesis inhibitor is again recommended to prevent production of exotoxins that contribute to the organism's rapid spread. If *Vibrio* infections

are suspected, tetracyclines (i.e., doxycycline), quinolones (i.e., ciprofloxacin), and third-generation cephalosporins or carbapenems can be used. In severe cases with rapidly progressive infections, combination therapy with cell-wall-active agents and a tetracycline should be used. There are no evidence-based guidelines regarding the length of antibiotic therapy—whether a set duration should be predetermined or whether clinical criteria should be used such as 3 days after the resolution of signs of systemic toxicity and local infection have resolved [73–75].

Supportive Care

While the mainstays of therapy are rapid and aggressive surgical debridement and antibiotic therapy, supportive care is important as well given that these patients are at high risk of death. Perioperative resuscitation of patients with septic shock and severe sepsis should be performed using evidence-based guidelines [76]. Postoperative care should include supplemental nutrition, preferentially enteral, given the increase in predicted energy requirements of NSTI patients [73].

Adjunctive Therapies

There are a number of adjunctive therapies that have been suggested but there is a paucity of high quality evidence to support their use. Hyperbaric oxygen therapy (HBOT) has been proposed to improve outcome—the resultant increased partial pressure of oxygen in infected tissues may improve polymorphonuclear leukocyte function and wound healing [77]. In animal studies, HBOT has been shown at the tissue level to reduce edema, stimulate fibroblast growth, increase the killing ability of leukocytes by augmenting the oxidative burst, have independent cytotoxic effects on some anaerobes, inhibit bacterial toxin elaboration and release, and enhance antibiotic efficacy [78]. Retrospective studies have conflicting results as to whether or not HBOT confers a mortality benefit in NSTI patients [79–81]. These uncontrolled studies may have an inherent selection bias in that hemodynamically stable patients may be more likely to be able to be safely transported to the hyperbaric chamber and therefore have improved outcomes. Furthermore, it is unknown whether there is a potential harm in transporting these patients or whether use of HBOT may delay definitive surgical therapy. The largest available study to date included over 1500 patients from 14 centers. When stratified for severity of illness, HBOT was only identified to convey a morbidity and mortality benefit in the most severely ill patients [82]. The SIS guidelines conclude that there is insufficient evidence to make a recommendation regarding HBOT for treating NSTIs [1].

Intravenous immunoglobulin (IVIG) has been suggested in patients with severe Group A streptococcal or staphylococcal infections or TSS. The proposed mechanisms of action include binding of bacterial toxins and inhibition of binding of bacterial superantigens to T-cell receptors with resultant down-regulation of the inflammatory response. Despite the biological plausibility, data are limited to case reports and expert opinion. The only randomized trial of IVIG in streptococcal toxic shock syndrome was terminated early due to slow recruitment and was underpowered to identify either a mortality benefit or harms from adverse effects [83]. The SIS guidelines gave only a weak recommendation based on low or very low quality evidence for the use of IVIG in patients with TSS due to staphylococcal or streptococcal NSTIs [1].

Plasmapheresis has also been suggested as an adjunctive therapy for NSTI patients, but evidence specific to this patient population is limited to a single case report [84]. Plasmapheresis has been studied in the treatment of septic shock and severe sepsis. The biological rationale is that separation of the cellular and plasma components of circulating blood allows circulating inflammatory mediators or toxins to be removed. One small single-center trial of plasmapheresis in severe sepsis and septic shock demonstrated a reduction in 28-day all-cause mortality [85], but confirmatory multicenter effectiveness trials are lacking. The SIS guidelines determined that there was insufficient evidence to make a recommendation regarding plasmapheresis or other extracorporeal treatments for NSTIs [1].

Immunomodulation is a promising therapy for improving outcomes after NSTIs by limiting the overwhelming host response to bacterial superantigens. In a typical immune response, a small proportion of T cells interact with antigens to generate a limited but tailored response to infection. However, bacterial superantigens cause a nonspecific expansion and release of proinflammatory cytokines, ultimately resulting in septic shock and multiple organ failure [86]. AB103 is a novel synthetic CD28 mimetic octapeptide which selectively inhibits the direct binding of superantigen exotoxins to the CD28 costimulatory receptor on T helper lymphocytes [86]. In murine models, Ramachandran et al. demonstrated that administration of a single dose of AB103 increased survival when given up to 5 h after infection, reduced inflammatory cytokine expression and bacterial burden at the site of infection, and improved muscle inflammation in a dose-dependent manner, without compromising cellular or humoral immunity [87]. AB103 has a dual mechanism of action—modulating the innate immune response to exotoxins and endotoxins in gram-positive infections and attenuating CD28 signaling independent of superantigens in gram-negative infections [86]. A recent prospective randomized, placebo controlled multicenter trial reported that AB103 resulted in an improvement in the Sequential Organ

Failure Assessment (SOFA) Score as compared to placebo, but found no statistically significant difference in the number of debridements, intensive care unit-free and ventilator-free days, or plasma and tissue cytokine levels [86]. This phase 2a trial suggests that immunomodulation may be a safe and promising strategy for treating NSTIs.

Mortality

The acute mortality of NSTIs had been reported to be unchanging for many decades, ranging from 25 to 35 % [2]. Several case series between 2000 and 2009 have reported lower mortality rates between 10 and 20 % [15, 21, 88–90]. Mortality in an analysis of more than 10,000 hospitalized patients with NSTIs was 10.9 % [88]. This apparent recent reduction in mortality may be due to a true improvement in the diagnosis and management of NSTIs or to changing patient populations, inconsistency in the definition of NSTIs, or differences in the virulence of bacterial strains causing NSTIs.

There are multiple predictors of mortality reported in the literature including advanced age, presence of comorbidities, and severity of disease on admission [28, 41, 68]. Furthermore, delay in intervention has also been associated with increased mortality [40, 41, 68]. Other authors have proposed weighted scoring systems for predicting mortality. As previously mentioned, the LRINEC score greater than 6 has been associated with increased mortality [49]. Anaya et al. developed a scoring system that assigned points based on six variables: heart rate >110 beats per minute, temperature <36 °F, creatinine >1.5 mg/dL, age >50 years, white blood cell count greater than 40,000/mm^3, and hematocrit greater than 50 % [90]. This model was 87 % accurate in predicting mortality in a validation set derived from two different patient populations but needs to be validated in larger multicenter studies. More recently, Faraklas et al. developed and validated a 30-day postoperative mortality risk calculator for patients with NSTI using National Surgical Quality Improvement Project (NSQIP) data collected between 2005 and 2010 [91]. In 1392 patients, 30-day mortality was found to be 13 %, and seven independent variables were identified that correlated with mortality including: age older than 60 years, functional status (defined as partially or totally dependent), dialysis requirement, American Society of Anesthesiologists physical status classification of four or higher, need for emergent surgery, presence of septic shock, and low platelet count (defined as <150 K/uL). This predictive model was used to develop an interactive risk calculator for the probability of dying. Unlike prior scoring systems which focus primarily on diagnosis or need for operative intervention, this calculator allows clinicians to have better informed discussions with patients and families about mortality risk in this particular set of complex critically ill patients.

Morbidity

There is a paucity of studies evaluating morbidity among NSTI survivors. Amputations are common amongst patients with extremity involvement. Two series reported that approximately a quarter of patients with extremity involvement require an amputation [15, 28]. Pham et al. reported that 30 % of patients had mild to severe physical limitation at hospital discharge [92]. On multivariate analysis, extremity involvement, independent of amputation status, was associated with a higher functional limitation class [28].

Compared with population norms, NSTI patients have been found to have a higher incidence of functional and psychological impairments and significant difficulties with return to pre-injury employment [93, 94]. The severity of the disease and the aggressive treatment are associated with significant disfigurement, loss of function, and psychological sequelae. Multidisciplinary care, which extends from early wound care through reconstruction and long-term rehabilitation, is of paramount importance to attaining the best long-term functional and quality of life outcomes [94]. In a qualitative study of NSTI survivors and their spouses or partners, survivors had decreased health related quality of life (HRQOL) and significant impairments in physical, emotional, and social functioning [93]. Furthermore, an increased prevalence of post-traumatic stress disorder (PTSD) was noted in both the patients and their partners. Factors independently associated with lower HRQOL included upper extremity amputation, greater than five debridements, greater than ten intensive care unit days, renal failure without return of function before discharge, and involvement of the hand and face. Wound coverage procedures, less than three debridements, and involvement of the trunk or perineum were independently associated with higher HRQOL. This work illustrates the multidimensional nature of recovery for patients with NSTIs, and that this recovery occurs in the broader psychosocial context of the survivors, their family, friends, and society, the nature of which we are only beginning to understand.

Follow-up

In addition to an acute mortality risk, NSTI patients have an increased risk of long-term mortality and morbidity. Light et al. performed a study of 345 NSTI survivors followed for 15 years; the estimated median age of death was significantly younger than that for population-based controls [95]. In particular, there was a significantly increased risk of subsequent death due to infectious causes in NSTI survivors (14 % versus 2.9 %). The authors recommended the following: counseling patients regarding the increased mortality risk; broadening indications for immunizations; and pursuing aggressive modification of other risk factors for death such

as obesity, diabetes, smoking, and atherosclerotic disease. They also identified a need for further research into the genetic and social determinants of this excess mortality risk.

Conclusion

NSTIs are associated with significant morbidity and mortality. Despite advances in critical care, the mainstays of therapy have remained largely unchanged over the last several decades: prompt recognition, early and aggressive debridement, and broad spectrum antibiotics. Diagnosis remains challenging given the lack of specificity of many of the early signs and symptoms, but advances in imaging may prove to be helpful. Further studies are required to identify adjunctive therapies and to determine their benefit in treating NSTIs.

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Acute Compartment Syndrome

41

Joshua L. Gary and Gregory E. Catlett Jr.

History

Compartment syndrome is a condition that exists when the pressure within a closed fascial compartment rises to a point that it exceeds the perfusion pressure of the local tissues resulting in decreased tissue oxygenation and ultimately cell death. Development of compartment syndrome alone has been shown to have a significantly negative impact on patient outcomes [1], increase length of hospital stay, and poses a large economic impact on our healthcare system [2]. The consequences of a missed compartment syndrome can be devastating, often resulting in chronic pain, dysfunction, renal failure, and even death. The first written account of compartment syndrome is credited to Dr. Richard von Volkmann in the late nineteenth century where he described a resultant flexion contracture of the hand and forearm after the application of splints or bandages to the upper extremity. Volkmann believed an ischemic process caused by decreased arterial blood flow and resultant muscle death led to significant functional impairment. It was described as a process occurring prior to a period of initial paralysis and was noted to result in a progressive deformity with increasing rigidity as more scar tissue was formed [3]. Jepsen was the first to reproduce Volkman's findings in an animal model [4]. He found that fractures of the extremity resulted in increased compartmental pressures creating the same environment and effects of constrictive bandages or casts. He theorized that the extravasation of blood and serum into the extracellular spaces causing compression of the local vasculature prohibiting blood flow and oxygen exchange to the tissue. Additionally, he found that drainage of the accumulated fluids lessened or prevented the formation of such contractures. Jepsen went on to correctly conclude that early decompression, or fasciotomies, may be of value in restoring blood flow to the affected areas and yielded improved results in affected individuals.

Our understanding of this potentially devastating process evolved through the twentieth century, yet our diagnostic techniques are still imperfect and missed compartment syndromes continue to cause long-term morbidity. Acute compartment syndrome is a true medical emergency, where a relatively simple surgery, correctly timed, prevents life-changing sequelae. All medical providers should learn prompt recognition and have a low threshold for surgical consultation when compartment syndrome is suspected [5, 6].

Epidemiology

Compartment syndrome may result from various medical conditions or insults and certain clues in the medical history should raise suspicion for any provider. While traumatic injuries to the legs are the most common cause and most closely associated with compartment syndrome, compartment syndrome may occur in any fascial compartment including the arms, forearms, hands, thighs, feet, abdomen, and almost any area of the body that has little or no capacity for tissue expansion such as the paraspinal muscles [7]. While most associate compartment syndromes with fractures, the lack of bony injury does not exclude the diagnosis (Fig. 41.1a–c). A myriad of other factors that increase swelling and the inflammatory response such as burns, soft tissue crush injuries, vascular insults, and reperfusion of an ischemic limb are all potential causes of compartment syndrome [8].

Electronic supplementary material: The online version of this chapter (doi:10.1007/978-3-319-42792-8_41) contains supplementary material, which is available to authorized users. Videos can also be accessed at http://link.springer.com/chapter/10.1007/978-3-319-42792-8_41

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_41

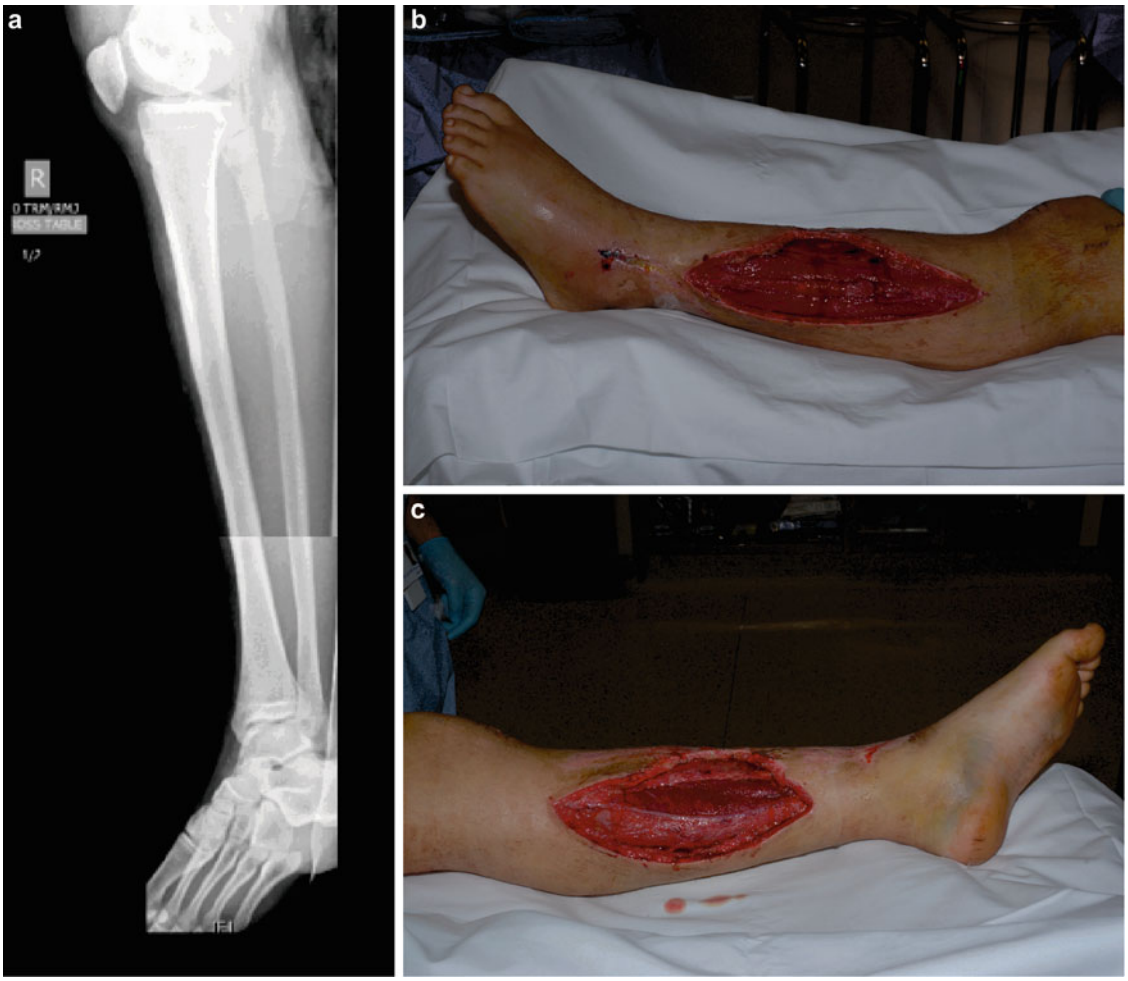

Fig. 41.1 A 17-year-old male sustained a left distal third femoral shaft fracture and crush injury to his left leg with associated compartment syndrome after an ATV rollover accident. (**a**) Oblique view of leg with no tibia or fibula fracture present. Clinical photographs of lateral (**b**) and medial (**c**) wound on leg after four-compartment fasciotomies

True incidence and epidemiological data are difficult to determine since precise diagnostic techniques do not exist, and treatment with fasciotomies creates a positive diagnosis, whether or not a true compartment syndrome was present. Rates of diagnosis of "compartment syndrome" in patients with tibia fractures have been shown to vary, by provider, between 2 and 24 % at a single trauma hospital with multiple orthopedic traumatologists taking call [9]. A Scottish study of 164 consecutive patients diagnosed with compartment syndrome found the annual incidence in males to be 7.3 per 100,000 (average age of 32 years), much higher than the annual incidence in females of 0.7 per 100,000. They found the most common cause of compartment syndrome was fracture (69 %), with diaphyseal tibial fractures the most common (36 %) followed by fractures of the distal radius (9.8 %) [10].

Compartment syndrome occurring in patients in the absence of fracture has been found to occur in older individuals, individuals with more medical comorbidities and result in a significant delay in diagnosis and increased muscle necrosis when compared to patients with compartment syndrome with an underlying fracture [11].

Vascular injuries that limit blood flow to the extremities are at particular risk of compartment syndrome and require fasciotomies in half of cases [12]. Reperfusion of an extremity after prolonged ischemia markedly increases swelling and compartment pressures and the treating surgeon should have an extremely low threshold to perform prophylactic fasciotomies after revascularization and reperfusion of a dysvascular extremity. Increasing time of ischemia directly correlates with increasing risk of compartment syndrome after restoration of blood flow and reperfusion of soft tissues [13].

Elderly patients "found down" with a history of several hours of immobility on a hard surface and extremity swelling or diminished neurovascular function of an extremity should raise immediate suspicion for compartment syndrome.

Pathophysiology

Compartment syndrome exists when the pressure within a confined fascial compartmental space increases to a point that exceeds local tissue perfusion pressure leading to an anoxic environment and resultant cell death. While the exact pathophysiology is incompletely understood, there is agreement that the pathologoical response to the increase in pressure by the small vessels (arterioles, capillary beds) and venous system play an important role. Compartment syndrome can develop from either intra-compartmental swelling or external compression. Both of these processes result in elevated tissue pressures.

As the intra-compartmental pressure increases, local blood flow to muscle decreases due to decreases in transmural pressures, defined as the difference between intraluminal and extraluminal pressures.

Elevation in interstitial, or extraluminal, pressure within a fascial compartment may be due to intrinsic or extrinsic factors, or even a combination of both. When fluid enters a compartment with a fixed volume, for example bleeding from a tibial shaft fracture or arterial injury, both the tissue and venous pressure increase. Decreases in arterial radius and arteriovenous gradient further contribute to decreased blood flow into the extraluminal space. Cell hypoxia ensues related to diminished arteriolar flow and venous obstruction, and a decreased arteriovenous gradient. If the extraluminal pressure exceeds the capillary pressure, capillary collapse occurs and cellular hypoxia increases, leading to increased soft tissue swelling. A positive feedback loop is established with increase of interstitial pressures with hypoxia and decreased cellular perfusion.

Extrinisic compression may also cause a similar reduction in the perfusion presure when the compartment size decrases due to a tight bandage or splint; intra-compartmental pressure can increase to a point that it exceeeds arteriolare pressure and local perfusion decreased, again establishing a positive feedback loop that eventually results in cell death.

Diagnosis

Physical Exam

Historically, the diagnosis of compartment syndrome has been largely based on clinical exam. The 5 P's: pain with passive stretch, pulselessness, pallor, poikilothermia, paresthesias, and paralysis are often described as the hallmark symptoms of compartment syndrome. Pain with passive stretch or that out of proportion to that expected for a given injury is felt by many as the most reliable physical exam finding in the early stages of a compartment syndrome. The reliability of the other 4 "P's" is poor as they are often late findings and only become apparent once irreversible cell damage has occurred.

The first step in examining a patient with suspected compartment syndrome is the visual inspection of the patient and extremity. Circumferential dressing or splints should be taken down or loosened for examination. Extremities with impending or active compartment syndrome are often swollen and shiny compared to the uninjured extremity. An awake and alert patient with a compartment syndrome should not be peaceful or comfortable and should be in excruciating pain.

Great caution should be taken in an obtunded patient or any patient with neuromuscular blockade. A thorough neurovascular exam should follow, assessing pulses, sensation, and motor function with comparison to the contralateral extremity. Documentation must be thorough and systematic.

While a thorough physical exam is crucial to any work-up of suspected compartment syndrome, its reliability in the detection of compartment syndrome has been called into question. Clinical exam has been found to have a low sensitivity and positive predictive value in the diagnosis of compartment syndrome, and some believe clinical exam is most useful in excluding a diagnosis when clinical findings are absent [14]. Skills in diagnosis of compartment syndrome with physical exam improve with repetition and experience, much like technical operative skills, and trainees with relatively little experience are intuitively more likely to miss subtle early signs of compartment syndrome than senior attending surgeons.

Still, there are many instances when a detailed physical exam is not possible and other means of diagnosis must be considered. Such examples include the polytraumatized patient with distracting injuries, obtunded, intubated, and/or sedated patients, pediatric patients, and patients with neuromuscular blockade, either from neurologic injury or from iatrogenic intervention. In these patients, other means of diagnosis should be considered. The authors also recommend that regional neuromuscular blockade never be performed in a patient where compartment syndrome is suspected or may develop as it clouds the exam and limits the physician's diagnostic abilities.

Direct Tissue Measurement Techniques

Whitesides et al. first reported on direct tissue measurement using a needle manometer to diagnose acute compartment syndrome [15]. Intra-compartmental pressures are indirect attempt to quantify compartment syndrome, as they do not provide a direct measurement of soft tissue perfusion and oxygenation.

The time required for complete block of nerve conduction has been shown to be inversely proportional to intra-compartmental pressure [16]. With continuous intra-compartmental pressures of 120 mmHg, a completed block in nerve conduction occurred in less than 2 h. A partial conduction block was observed in 6–8 h when intra-compartmental pressures were continuously 30–40 mmHg. No conduction block ever developed when intra-compartmental pressures

were 20 mmHg or less. This led them to conclude that 30 mmHg is the critical pressure and 6–8 h is the critical duration at which decompression should be performed in patients with compartment syndrome [16]. A canine model of induced compartment syndrome demonstrated no irreversible muscle cell changes when a difference greater than 30 mmHg between the compartment pressure and diastolic blood pressure (ΔP) was maintained [17]; they also found absolute pressures of 59 mmHg were tolerated without permanent cell injury for 8 h as long as adequate perfusion was maintained. Pressure measurements taken in alert patients with tibia fractures who were not felt to have compartment syndrome by physical exam were found to have false positive rates of 35 % and 21 %, when using ΔP values $\leq$30 and 20 mmHg, respectively [18].

The technique of pressure measurement requires great attention to detail. Slit catheters or side-port needle devices can be used. A recent study found only 31 % of providers used proper technique in a simulated cadaveric model, and that even when proper technique was used, only 60 % of the measurements were within 5 mmHg of the actual pressure [19].

Continuous compartment pressure monitoring can be performed using an arterial line setup with a slit catheter in a single compartment. Earlier diagnosis and treatment with continuous monitoring of the anterior compartment in patients with tibia fractures have been shown to decrease long-term complications [20].

The authors believe compartment pressure measurements are best used when no physical exam is possible or the results are unclear, even though traditional diagnostic criteria with pressure measurements appear to be unreliable and an imperfect means of diagnosing acute compartment syndrome.

Applied Surgical Anatomy

Compartment syndrome may occur in any fascial compartment of the body. Knowledge of extremity anatomy and the ability to make an incision with a scalpel are all one needs to perform fasciotomies. Surgeons who claim they cannot perform a fasciotomy either lack knowledge of anatomy or the ability to make an incision.

The most common locations within the extremities are the leg and the forearm and a brief review of their pertinent anatomy is below.

The Leg

The leg is made of up of the tibia and fibula and a connecting interosseous membrane with four surrounding myofascial compartments, subcutaneous tissues, and skin. Muscles of the leg taper from proximal to distal and generally transition into tendons in its distal third.

The anterior compartment musculature includes the tibialis anterior, extensor hallicus longus, and extensor digitorum longus muscle which originate from the proximal tibia, proximal fibular and interosseous membrane. The anterior tibial vascular system enters the anterior compartment via an aperture in the most proximal portion of the interosseous membrane just distal to the proximal tibiofibular joint. A recurrent branch of this artery travels proximally toward the tibial tubercle. The deep peroneal nerve enters the anterior compartment from lateral just distal to the fibular head. It approximates the anterior tibial artery in the proximal third of the leg and both travel distally to the foot as a neurovascular bundle between the tibialis anterior and extensor hallicus longus muscle bellies.

The lateral compartment includes the peroneus longus and peroneus brevis muscles, which originate from the fibula and interosseous membrane. The superficial peroneal nerve enters the compartment from posterior moving wrapping around the fibular head and proceeding towards the fascial border between the anterior and lateral compartments. It becomes extrafascial near the junction of the middle and distal thirds of the leg and proceeds to the foot.

The superficial posterior compartment included the medial and lateral heads of the gastrocnemius and soleus muscles. The heads of the gastrocnemius muscle originate above the knee from posterior aspect of the medial and lateral femoral condyles and the soleus muscle originates from the posterior aspect of the proximal tibia and fibula. The muscle bellies coalesce near the junction of the middle and distal thirds of the leg to form the Achilles tendon. The plantaris tendon also travels between the medial head of the gastrocnemius and soleus muscle bellies. The medial sural nerve is a branch from the tibial nerve, lies between the heads of the gastrocnemi in the proximal third of the leg. The lateral sural nerve branches from the common peroneal nerve above the knee and remains extrafascial as it travels to provide sensation to the lateral aspect of the foot.

The deep posterior compartment contains the tibialis posterior, flexor hallicus longus, and flexor digitorum longus muscles. The tibialis posterior originates from the proximal tibia, fibula, and interosseous membrane. The flexor hallicus longus originates from the posterior aspect of the fibular and the flexor digitorum longus muscle originates from the posterior aspect of the tibia. The tibioperoneal begins when the anterior tibial artery divides from the popliteal artery. This trunk quickly divides into the posterior tibial and peroneal arteries, with the posterior tibial artery running with the tibial nerve between the tibialis posterior and flexor digitorum longus muscle bellies. The peroneal artery runs laterally along the posterior aspect of the interosseous membrane between flexor hallicus longus and tibialis posterior muscle bellies.

The Forearm

The forearm is similar to the leg as two long bones, the radius and ulna, are connected by an interosseous membrane. The three compartments of the forearm are the volar compartment, the dorsal compartment, and the mobile wad of Henry. Flexors of the wrist and digits originate from the medial aspect of the elbow and volar aspects of the radius and ulna. The extensors of the wrist and digits originate from the lateral aspect of the elbow and dorsal aspects of the radius and ulna.

The volar compartment of the forearm contains flexors of the wrist and digits. The pronators of the forearm, including the pronator teres and prontator quadratus, also reside in this compartment. The medial epicondyle of the distal humerus serves as an origin for the majority of musculature via the common flexor tendon. Portions of the flexor digitorum superficialis originate from the proximal and volar ulna, interosseous membrane, and radius. The flexor digitorum profundus originates from the proximal and volar ulna and the flexor pollicis longus originates from the proximal and volar radius. The majority of major neurovascular structures also reside in the volar compartment. The radial artery runs medial to the brachioradialis tendon near the superficial branch of the radial nerve. The ulnar artery and nerve lie between the flexor carpi profundus and flexor carpi ulnaris. The median nerve and its branch, the anterior interosseous nerve also run in the volar compartment between the flexor digitorum superficialis and profundus. The median nerve, along with the eight tendons of the flexor digitorum superficialis and profundus and flexor pollicis longus, comprises the contents of the carpal tunnel.

The dorsal compartment and the mobile wad of Henry contain extensors of the wrist and hand, the supinator muscle, and the anconeus. The mobile wad is comprised of the brachioradialis muscle, extensor carpi radialis longus (ERCL), and extensor carpi radialis brevis (ECRB), which originate from the lateral aspect of the distal humerus and lateral epicondyle. These muscles are innervated by the radial nerve prior to its division into the superficial radial nerve and posterior interosseous nerve and form a third compartment. The anconeus is a vestigial muscle in the proximal forearm innervated by the radial nerve. The common extensor tendon arises from the lateral epicondyle and includes the ERCB, extensor digitorum comminus (EDC), extensor digitorum minimi (EDM), and extensor carpi ulnaris (ECU). Proximally, the supinator lies just volar to the common extensor tendon and originated from the proximal and lateral ulna and inserts on the volar aspect of the proximal radius. The posterior interosseous nerve enters the volar muscle belly of the supinator at the Arcade of Frohse and passes through the muscle before exiting dorsal and innervating all muscles other than anconeus outside of the mobile wad. The deep musculature of the forearm includes the abductor pollicis longus, extensor pollicis longus and brevis, and extensor indicis; these all originate on the dorsal aspect of the ulna. The only named dorsal artery is the posterior interosseous artery, a branch of the ulnar artery that pierces the interosseous membrane proximally and runs between the superficial and deep extensor masses.

Treatment of Acute Compartment Syndrome

Treatment of compartment syndrome, unlike its diagnosis, is simple. Once the diagnosis of compartment syndrome is made, emergent fasciotomies should be performed. External bandages or casts must immediately be removed or loosened. Casts or splints can be removed even at the risk of loss of reduction. If scar tissue of burn eschar is the cause, escharotomy must be performed. If the ischemic process is the result of intrinsic factors, immediate action must be taken to release the pressure and restore blood flow. With compressive hematoma, immediate exploration and evacuation must be performed.

Upper Arm

The upper arm has two well-formed fascial compartments: the anterior compartment containing the biceps brachialis and the brachialis and the posterior compartment containing the triceps. Once the diagnosis of compartment syndrome of the upper arm is confirmed, decompression is carried out through a long laterally based incision. The skin incision is carried from the lateral insertion of the deltoid to the lateral epicondyle. Once the fascia and the lateral intermuscular septum are identified, two longitudinal incisions in the fascia overlying the anterior and posterior compartments are made. The radial nerve must be identified and protected as it pierces through the lateral intermuscular septum approximately 12 cm above the lateral epicondyle in adult patients [21].

Forearm

Three main compartments exist in the forearm: volar, dorsal, and the mobile wad. Forearm compartment syndrome is typically addressed through a two-incision approach. A curvilinear volar incision is made from the antecubital fossa distally toward the mid-palm. Through this incision decompression of the volar compartment as well as the mobile wad is performed. Additionally, the incision is carried further distally and the carpal tunnel is released as well (Fig. 41.2). Next one must reassess the state of the dorsal compartment, as often decompression of the volar compartment is sufficient. Decompression of the dorsal compartment is performed by making a dorsal based skin incision beginning just distal to

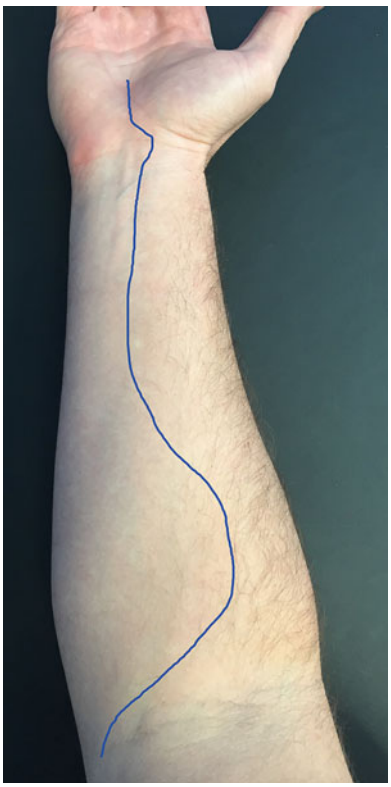

Fig. 41.2 Clinical photo of forearm with volar fasciotomy skin incision highlighted. The incision starts proximal and medial for access to the brachial artery if needed. It curves laterally to allow decompression of the mobile wad of Henry and then proceeds distally in the midline of the forearm. The carpal tunnel is released. Angles to the skin incisions are made when crossing the volar flexion creases at the wrist. The volar flexion crease of the elbow is avoided

the lateral epicondyle and continuing distally down the center of the dorsal aspect o the forearm, stopping proximal to the center of the wrist, typically about 10 cm in length. Through this incision, the entire dorsal compartment may be decompressed and muscle viability may then be assessed.

Hand

Ten defined myofascial compartments exist in the hand: hypothenar, thenar, adductor pollicis, four dorsal interosseous, three volar interosseous. Typically a four-incision approach is used to ensure adequate decompression of these compartments. One incision is placed on the radial aspect of the 1st metacarpal, this allows decompression of the thenar compartment. A second incision is made over the dorsal aspect of the 2nd metacarpal, allowing for decompression of the first and second dorsal interossei as well as the 1st volar interossei and adductor pollicis. A third incision is made over the dorsal aspect of the 4th metacarpal allowing for release of the third and fourth dorsal interossei as well as the second and third volar interossei. Finally, a fourth incision is placed over the ulnar aspect of the 5th metacarpal to allow for release of the hypothenar compartment (Fig. 41.3a, b).

Thigh

Three well-defined compartments exist in the thigh: anterior, posterior, adductor. A single incision is usually sufficient as the adductor compartment is rarely involved in the pathologic process. A long, direct lateral incision is made spanning the entire length of the thigh. Once the fascia lata is incised in line with its fibers, decompression of the anterior compartment is obtained. Using blunt dissection, the vastus lateralis can be elevated off the lateral intermuscular septum. Once exposed the lateral intermuscular septum is incised allowing for decompression of the posterior compartment. Once decompression of the anterior and posterior compartments is obtained, decompression of the medial compartment, if necessary can be obtained with a separate medial incision made over the medial aspect of the thigh.

Leg

The four compartments of the leg may be released with either a single incision or a two-incision technique. The single incision is laterally based and made directly over the fibula with the anterior and lateral compartments released by elevating a skin flap anteriorly and the superficial and deep posterior compartments accessed by elevating a posterior flap [22].

Two-incision fasciotomies are more commonly used (Video 41.1). The medial incision is placed 2–3 cm posterior to the posteromedial border of the tibia with release of the superficial and deep posterior compartments (Fig. 41.4a). The lateral incision is centered between the tibial crest and fibular shaft for release of the anterior and lateral compartments and care must be taken to prevent iatrogenic injury to the superficial peroneal nerve (Fig. 41.4b). To ensure release of both compartments, the intermuscular septum between the anterior and lateral compartments must be identified (Fig. 41.4c).

Foot

Foot compartment syndrome remains controversial, both in terms of the number of defined myofascial compartments and in regard to treatment. The long-term sequelae of "curly toes" versus the morbidity of fasciotomies and possible skin grafts causes many surgeons to avoid surgical release. When fasciotomies are performed, a three-incision technique is employed with two dorsal incisions and a single medial incision. The dorsal incisions are made over the second and

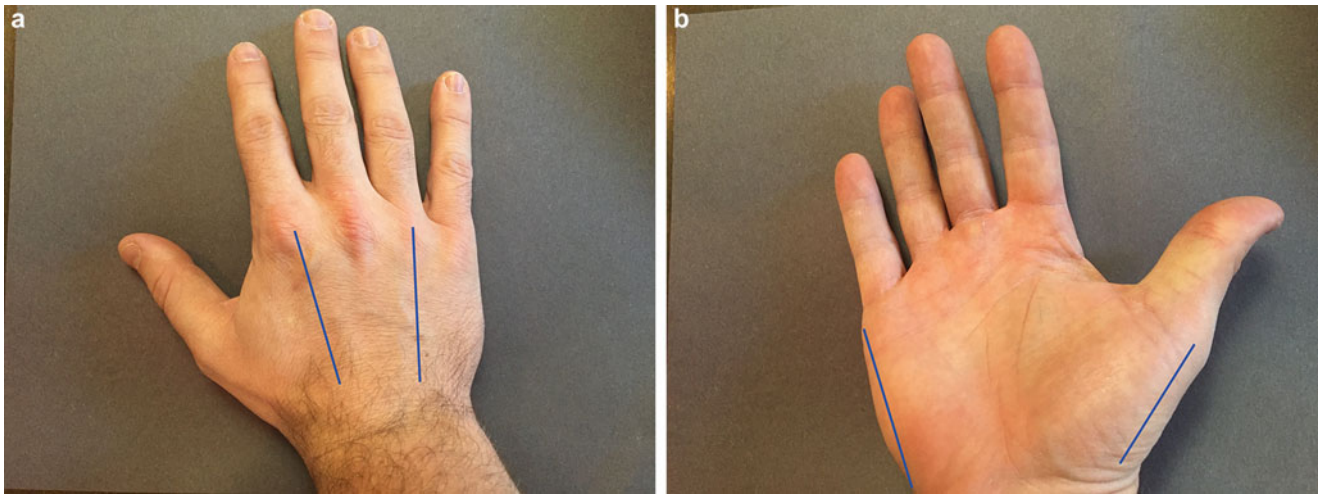

Fig. 41.3 Clinical photo of the hand with four-incision fasciotomies highlighted. (**a**) Dorsal incisions are made over the 2nd and 4th metacarpals to release dorsal and volar interossei muscles between each of the rays. (**b**) Volar hand with incisions just volar to the 1st metacarpal to release the thenar musculature and volar to the 5th metacarpal to release the hypothenar musculature

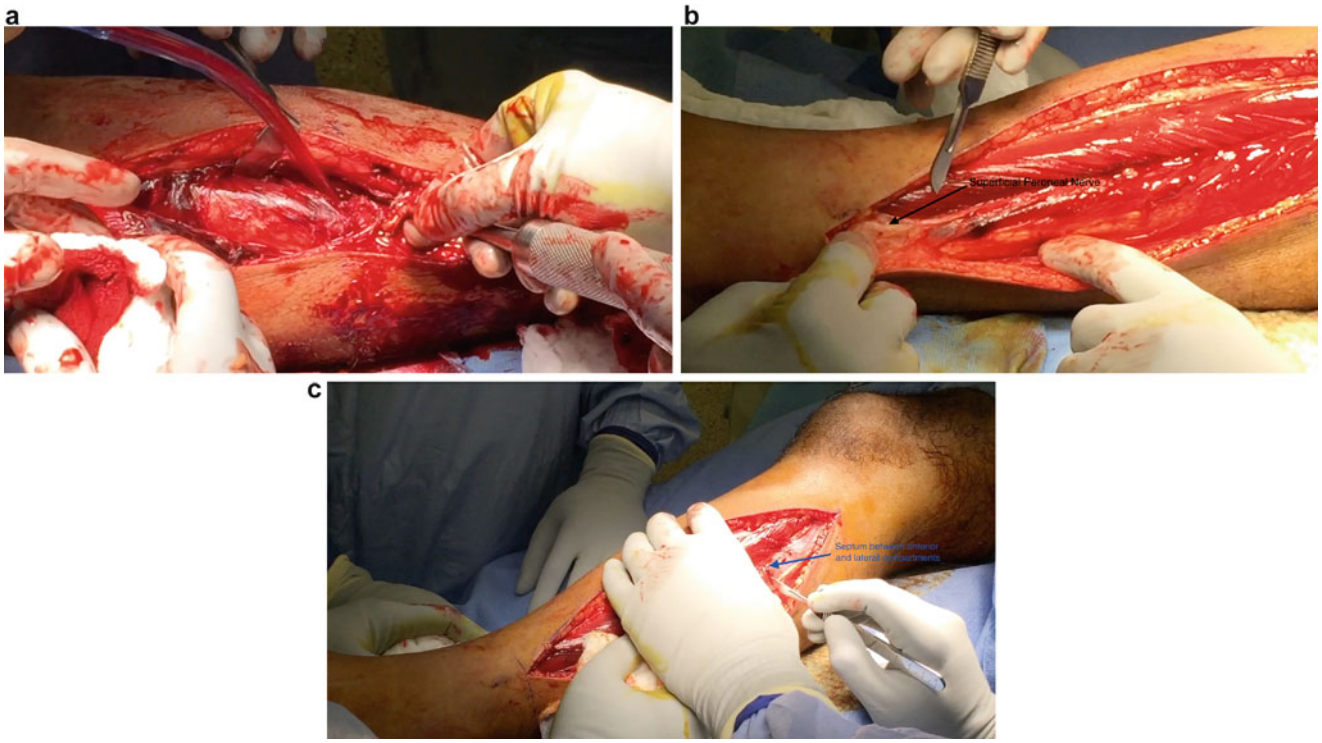

Fig. 41.4 (**a**) A Cobb elevator is passed along the posterior surface of the tibia from the soleal ridge to the metaphyseal flare of the distal tibia to ensure release of the deep posterior compartment. (**b**) The superficial peroneal nerve pierces the intermuscular septum between the anterior and lateral compartments in the distal third of the leg. (**c**) The intermuscular septum between the anterior and lateral compartments is identified proximally to ensure both compartments are released with fascial incisions anterior and posterior to the septum. A transverse incision proximally is helpful for its identification

fourth metatarsals allowing for decompression of the interossei as well as the central, medial, and lateral compartments. A third incision is made on the medial aspect of the foot, inferior to the 1st metatarsal. This allows for more extensive decompression of the central compartment and abductor hallucis longus.

Complications of Acute Compartment Syndrome

The consequences of a delayed in diagnosis or missed case of compartment syndrome can be devastating. The only way to mitigate the deleterious and potentially deadly consequences is prompt diagnosis and expedient treatment as this may help prevent permanent disability, amputation or death [23]. Unfortunately, if compartment syndrome is diagnosed after irreversible tissue ischemia occur, often after 8 h of ischemia time, treatment is not so straightforward and patient outcomes are inferior to those treated in a timely fashion [24]. Finklestein et al. examined five patients who underwent a total of nine fasciotomies that were delayed more than 35 h after their initial injury. One patient died from multi-organ failure secondary to septicemia, the remaining patients required limb amputation due to local infection of the involved limb and resulting sepsis [25].

Legal Implications

Failure to recognize and appropriately treat compartment syndrome is one of the most common causes of successful litigation amongst orthopedic surgeons [26]. Prompt diagnosis and emergent treatment with fasciotomies mitigate future disability, while a delay in either diagnosis or treatment leads to preventable and irreversible soft tissue loss. As of 2004, the average indemnity payment for a missed compartment syndrome was $426,000 with the average cost of defending a case of missed compartment syndrome $29,500 [27].

Improper and/or incomplete documentation is a common mistake made by physicians when caring for patients with compartment syndrome and is usually recognized retrospectively. In 30 consecutive patients undergoing fasciotomy for compartment syndrome, medical records were examined and 70 % of the cases lacked complete and appropriate documentation [28]. The most common errors included consents that were not properly filled out, illegible notes, incomplete documentation of physical exam findings, and inadequate documentation of compartment pressures and/or diastolic blood pressure [28].

The importance of documentation extends beyond medicolegal protection of the physician. Accurate documentation of physical examination is critical to create an accurate record of the physical exam at a given point in time to allow other healthcare providers to compare their findings to prior exams. In the era of "shift-work" and transition of care between providers, this is even more critical. The authors recommend a bedside "hand-off" between providers to ensure accurate understanding of the physical exam when a patient is being actively monitored for compartment syndrome.

Conclusions

Acute compartment syndrome is a pathological process that leads to decreased perfusion of soft tissues and irreversible soft tissue loss if timely decompressive fasciotomies are not performed. Diagnosis remains challenging and serial physical examination by a single experienced provider is best based upon our current technology. Once diagnosed, emergently fasciotomies limit morbidity and permanent loss of function.

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Part III

Ethics, Legal, and Administrative Considerations

Palliative Care in the Acute Care Surgery Setting

42

Bridget N. Fahy

Palliative Care Defined

Palliative care is based upon the Latin word *palliare*, to cloak. Based upon this Latin root, it follows that palliative care is focused on providing cover or protection to patients. In its purest sense, palliative care is intended to shield or protect patients from suffering.

According to the current World Health Organization (WHO) definition [1], palliative care is "an approach that improves the quality of life of patients and their families facing the problem associated with life-threatening illness, through the prevention and relief of suffering by means of early identification and impeccable assessment and treatment of pain and other problems, physical, psychosocial and spiritual." Furthermore, the following are considered essential elements of palliative care services:

- Provides relief from pain and other distressing symptoms
- Will enhance quality of life and may also positively influence the course of illness
- Is applicable early in the course of illness, in conjunction with other therapies that are intended to prolong life
- Includes those investigations needed to better understand and manage distressing clinical complications
- Integrates the psychological and spiritual aspects of patient care
- Offers a support system to help patients live as actively as possible until death
- Affirms life and regards dying as a normal process
- Intends neither to hasten or to postpone death
- Offers a support system to help the family cope during the patient's illness and in their own bereavement
- Uses a team approach to address the needs of patients and their families, including bereavement counseling, if indicated

Based upon this definition and the associated key elements, palliative care is ideally suited to the care of the acute care surgical patient given its focus on pain and other distressing symptoms, its holistic approach to the patient and their family, the emphasis on a team approach to both the patient and his/her family, and its applicability in conjunction with other therapies intended to prolong life. Notably absent from the WHO definition provided above is a proscription about who can provide palliative care or what specific interventions or treatments may be considered palliative. The definition above leaves open a role for *all* healthcare providers to utilize any and all tools available which will meet the needs of their patients and families as they face serious, life-threatening, and/or debilitating illness.

An important corollary to the essential components of palliative care is an understanding of what palliative care is not. Perhaps most importantly, palliative care is not synonymous with hospice care. Hospice is a program of services designed to provide care to patients and families when a patient's life expectancy is six months or less. In contrast, palliative care is appropriate for patients with potentially curable diseases or conditions for which a complete recovery may be expected. Given this distinction, palliative care is sometimes referred to as Supportive Care in order to avoid confusion with patients considered to have terminal conditions. According to the "modern" conception of palliative care, palliative care can be provided in conjunction with curative treatment and at any point during a disease: from diagnosis through end of life care (Fig. 42.1).

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_42

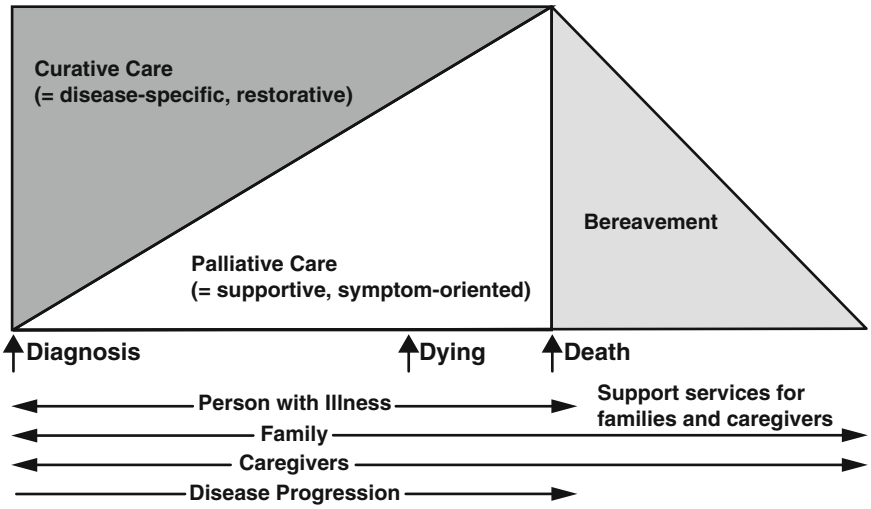

Fig. 42.1 Palliative care model. (Reprinted with permission from United States Department of Health and Human Services)

Surgeons' Role in Palliative Care

Prior to the start of the hospice movement in the 1960s with the pioneering work of Dame Cicely Saunders, surgeons have long played a central role in the care of the seriously ill. This is aptly illustrated by the work of surgeons who provided burn care during World War II. Burn care begins with pain control and progresses through the acute phase of wound healing into an ongoing process of interdisciplinary care designed to restore function and quality of life. Furthermore, many operations currently or previously used to effect a surgical "cure" were originally introduced to alleviate symptoms. Perhaps the best example of such a procedure is the radical mastectomy, first used in 1881 by William S. Halstead to treat pain from locally advanced and ulcerated breast cancers and later accepted as standard curative treatment for breast cancer.

The circumstances which have led surgeons to play a central role in palliative care were well described by Dunn and Milch [2] as follows: "The widening spectrum of disease and life expectancy encountered in palliative care led to the inevitable arrival of the concept at the doorstep of many specialties, including surgery. With their significant presence in the setting of advanced and incurable illness, surgeons could not indefinitely avoid the social, psychological, and spiritual challenges encountered there."

The routine incorporation of palliative care into the daily practice of Acute Care Surgery falls under von Gunten's definition of primary palliative care [3]. Primary palliative care refers to the basic skills and competencies required of all healthcare providers to relieve pain and other distressing symptoms. The application of basic palliative care principles to surgery is a fundamental component of good surgical clinical care. Surgeons can and should be expected to relieve suffering and maintain quality of life for all of their patients, not just those at the end of their life. Consequently, surgeons must be able to provide palliative in conjunction with curative treatment and furthermore, must possess the skills to transition from curative to purely palliative as dictated by both the patient's disease and their goals. Unlike few other medical specialties, surgeons are frequently at the forefront of providing pain and symptom control for their patients. Furthermore, surgeons from all specialties are routinely called upon to provide palliation. The central role of surgeons as "palliativists" is perhaps best illustrated through the work of the Acute Care Surgeon charged with "manning" the front lines against acute surgical disease. In this way, palliative surgery and by extension palliative surgeons are not restricted by surgical sub-specialty or procedure but by the intent of the surgical intervention offered—that is, to relieve pain or other distressing symptoms.

Despite the introduction of the term "Palliative Care" by Balfour Mount, a Canadian urologist, in 1975, it was not until 1998 that the Board of Regents of the American College of Surgeons approved the "Principles Guiding Care at the End of Life [4] and identified key palliative care concepts for surgeons." Of the 10 principles outlined, those most germane to the current discussion include the following:

- Be sensitive to and respectful of the patient's and family's wishes
- Ensure alleviation of pain and management of other physical symptoms
- Recognize, assess, and address psychological, social, and spiritual problems
- Provide access to therapies that may realistically be expected to improve the patient's quality of life
- Provide access to appropriate palliative care and hospice care.
- Recognize the physician's responsibility to forego treatments that are futile

Notable among these principles is the focus on provision of care consistent with patient and family wishes, interventions designed to improve quality of life, and an appreciation of all symptoms—physical, emotional, psychosocial.

In 2003, the American College of Surgeons published the core competencies for surgical palliative care [5]. Structured according to the Accreditation Council for Graduate Medical Education six core competencies, the Surgeons Palliative Care Workgroup of the American College of Surgeons established core competencies in two basic elements of palliative care—pain management and communication skills—to be essential for all surgeons. Additionally, for surgeons who care for dying patients more frequently, additional skills in end-of-life care were felt to be important. While a complete review of the surgical palliative care core competencies is beyond the scope of this chapter, the competencies, as delineated by the Workgroup are fundamental to the complete care of the surgical patient, regardless of diagnosis or specialty of the surgeon providing care. Furthermore, while a surgical intervention may be a component of palliative care, this is not the only palliative intervention in which a surgeon must be facile. As noted above, pain management (procedural and/or medical) and communication skills are required of all surgeons.

Application of Palliative Care to the Acute Care Surgery Patient

Recognizing the Acute Care Surgical Patient in Need of Palliative Care

Given that palliative care is appropriate for any patient facing a serious or life-threatening illness, many patients presenting with acute surgical illness will benefit from palliative care. Furthermore, virtually all patients with acute surgical disease are all symptomatic. Symptoms commonly seen in the acute care surgical patient include: right upper quadrant pain from acute cholecystitis, right lower quadrant abdominal pain from appendicitis, left lower quadrant pain from diverticulitis, nausea and vomiting due to a small bowel obstruction, anorectal pain caused by a perirectal abscess. While many of these diseases will not be life-threatening or produce long-term debility, a significant percentage of patients with these common acute surgical problems are at risk for disease and/or treatment-related morbidity and mortality which may result in long-lasting symptoms or debility. A recent study by Moore et al. [6] found that emergency colon operations were associated with a 28 % mortality rate even in the hands of experienced acute care surgeons. Ingraham et al. [7] examined the morbidity and mortality associated with emergency appendectomy, cholecystectomy, or colon resection in the National Surgical Quality Improvement Program database and reported a 15 % complication rate across these three procedures. The morbidity rate was highest for colorectal resection (47 %), followed by cholecystectomy (9 %) and appendectomy (6 %).

The first challenge facing the acute care surgeon is the identification of a patient who will benefit from palliative care. In other words, "what are the characteristics of a prospective palliative care surgical patient?" An acute care surgical patient appropriate for palliative care will typically meet the following criteria: 1) serious or life-threatening condition, 2) disease potentially responsive to surgical intervention, and/or 3) patient's premorbid health conditions do not preclude consideration for a surgical intervention. Taken together, these criteria reflect the basic tenets of surgical decision-making. As Winchester noted [8], "It is judgment that matters in this profession. Otherwise the surgeon is no more than a man (or woman) with a knife, and a license to mutilate."

Prompt identification of acute care surgical patients who may benefit from a palliative care approach involves an appreciation that any surgical disease, no matter how limited or seemingly uncomplicated, may become serious or life-threatening under certain circumstances (e.g. incarcerated ventral hernia in a patient three months following an acute myocardial infarction). The more obvious cases for which palliative care is beneficial involve either patients with common surgical problems in the setting of advanced underlying disease such as cancer or end stage organ dysfunction *or* advanced surgical disease in an otherwise healthy patient.

Common Surgical Problem in Patient with Advanced Underlying Disease

In these cases, it is imperative that the acute care surgeon consider the status of the underlying disease and its associated prognosis as well as considering the surgical disease-related complications or procedure-specific risks. To illustrate this point, consider the following case of Ms. O, a 57-year-old woman with Stage IIIC ovarian cancer whose disease has progressed on second-line chemotherapy. She presents to the emergency department with severe anorectal pain. On physical examination, you determine that she has a perirectal abscess.

A surgical palliative care approach to Ms. O will include the following steps:

1. Global assessment of Ms. O's health, including a discussion with her oncologist regarding the status of her cancer, recent treatments and their impact on wound healing, additional cancer-related treatment options.
2. Discussion with Ms. O regarding the anticipated outcomes following the proposed surgical procedure. The specific outcomes to be discussed include the likelihood that the proposed procedure will alleviate her symptom (anorectal pain), perioperative risks of the procedure con-

sidering her premorbid and treatment-related risk factors (i.e., neutropenia, thrombocytopenia, etc.), and impact of the procedure on future treatment options (i.e., potential delay in additional cancer treatment).
3. Articulation of alternate non-operative treatment options and how this may interfere or promote her goals of treatment.

Advanced Surgical Disease in Otherwise Healthy Patients

The other group of acute care surgical patients who may benefit from a surgical palliative care approach are those with advanced surgical disease but are otherwise without significant comorbidities or serious underlying disease. The case of Mr. A illustrates the vital role of communication in the setting of acute surgical disease. Mr. A is a healthy 73-year-old man recently diagnosed with atrial fibrillation during an annual physical examination. He was started on digoxin and his heart rate is well controlled. He presents to the emergency department with acute onset of abdominal pain which woke him from sleep. His work-up in the emergency department shows that he is in atrial fibrillation with a heart rate of 125 and a blood pressure of 102/58. When you examine his abdomen, you do not hear any bowel sounds, his abdomen is soft, non-tender, and non-distended. He complains of severe abdominal pain out of proportion to his physical examination. You diagnose him with mesenteric ischemia and take him to the operating room for urgent exploration. At laparotomy, his entire small bowel is ischemic but not necrotic and he has an embolus in his superior mesenteric artery for which you perform an embolectomy. You transfer him to the surgical intensive care unit intubated with a temporary abdominal closure and plan to examine his bowel again in 24 hours.

A surgical palliative care approach to Mr. A will include the following steps:

1. Discussion of the intraoperative findings with Mr. A's family, including the possible outcomes from re-exploration: complete necrosis of his small intestine representing a non-survivable injury, large amount of non-viable bowel requiring a massive small bowel resection and short-gut, or little to no bowel ischemia with the prospect of full recovery.
2. Determine if Mr. A has completed an Advance Directive and/or a Medical Power of Attorney to assist with medical decision-making.
3. Make referrals to a hospital social worker and/or chaplain as needed to provide support to Mr. A's family.
4. Arrange for a family meeting to follow Mr. A's re-exploration to update his family and begin planning for his next phase of care.

Palliative Care Competencies for the Acute Care Surgeon

Perioperative Pain Management

Inherent in both of the cases described above, perioperative pain control is required as part of the patient's routine surgical care. Patients with chronic preexisting pain conditions and those with prior addiction histories are among the most challenging surgical patients. In these cases, early consultation with the patient's chronic pain provider or referral to an addiction specialist is often required. For the routine surgical patient without these complex preexisting conditions, the acute care surgeon must be competent in basic acute pain management.

The first step in effective acute pain management is the ability to perform an accurate pain assessment. Assessing the efficacy of an intervention begins with a thorough understanding of the patient's pain. A simple technique to assess a patient's pain is using PQRST to ask about the key aspects of their pain:

P = Provocation / Palliation: what makes it better? What makes it worse?
Q = Quality: what does it feel like? E.g. sharp, dull, throbbing, twisting
R = Region/Radiation: where is pain located? Does it radiate or move around?
S = Severity: how severe is the pain on a scale of 0 to 10? How bad is it at its worst?
T = Timing: When did the pain start? How long did it last? How often does it occur?

Once a pain assessment has been performed, the next step is intervention. The WHO "pain ladder" was originally developed to guide management of cancer pain but is now widely used for the management of all types of pain. The ladder includes a three-tier approach to pain control (Fig. 42.2). A graduated approach to pain management is illustrated. Specific medications used are summarized in Table 42.1. When prescribing any pain medication, but particularly the strong opioids, it is critical to understand the basic pharmacology of these agents: relative potency, onset of action, half-life of the drug, and ability to convert between oral and intravenous routes of administration. Equianalgesic dosing tables are readily available on most hospital pharmacy sites as well as on the internet and some are available as applications for smart phones. Some general rules of thumb for opioid prescribing:

Use PRN orders only for truly episodic pain and when a patient on long-acting opioids needs a short-acting opioid for breakthrough pain.

- Do not order more than one PRN opioid or opioid-nonopioid combination product at a time.

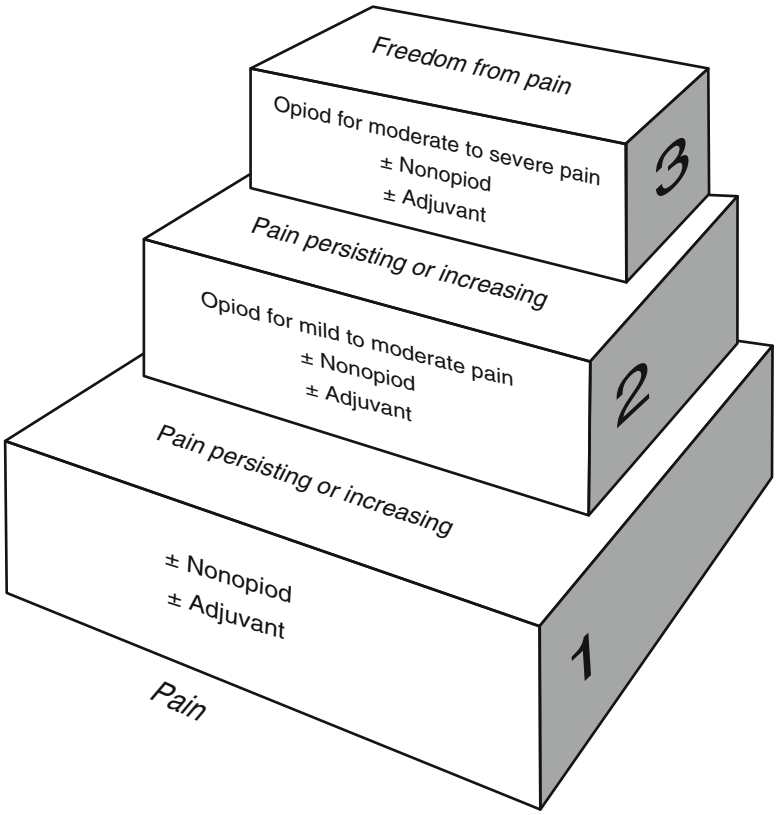

Fig. 42.2 World Health Organization Pain Ladder. (Courtesy of the World Health Organization http://www.who.int/cancer/palliative/painladder/en/)

Table 42.1 Medications utilized in WHO pain ladder by level

Level 1: Mild pain	Level 2: Moderate pain	Level 3: Severe pain
Acetaminophen	Weak opioid: codeine, hydrocodone-acetaminophen	Strong opioid: morphine, oxycodone, hydromorphone, fentanyl
Non-steroidal anti-inflammatory drugs	Tramadol	Non-steroidal anti-inflammatory drugs
Cyclooxygenase-2 inhibitors	Non-steroidal anti-inflammatory drugs	Adjuvants: e.g., gabapentin, amitriptyline, steroids
Adjuvants: e.g., gabapentin, amitriptyline, steroids	Adjuvants: e.g., gabapentin, amitriptyline, steroids	

- Use a long-acting opioid (e.g., fentanyl patch or extended-release opioid) for continuous pain.
- Use equianalgesic tables to calculate doses when changing drug or route of administration
- As noted in the WHO pain ladder, adjuvant therapies can be included at any tier of the ladder.

Commonly used adjuvants include antidepressants (both tricyclic antidepressants and serotonin-norepinephrine reuptake inhibitors), anticonvulsants (e.g., gabapentin, pregabalin), corticosteroids, intravenous lidocaine, topical local anesthetics, and ketamine. Consultation with a pharmacist, palliative care providers, or pain specialist can be helpful to learn how to dose and effectively use adjuvant analgesics.

Communication Skills

Informed Consent and Shared Decision-Making

The case of Mr. A above emphasizes the importance of prompt, clear, and direct communication when caring for a patient with serious and potentially life-threatening surgical disease. As patients or their surrogates consider surgical intervention in an emergency setting, the importance of the consent process can be overstated. Although issues related to informed consent are addressed elsewhere in this book, it is instructive to briefly consider the informed consent process

as a critical communication event. As Robert Veatch [9] notes in his remarks regarding informed consent: "Telling the patient everything about a procedure is an impossible task. All that is being called for is adequate information." The standards used to determine adequate information include the professional standard, the reasonable person standard, and the subjective standard. According to the subjective standard, the surgeon gives the patient the information he or she would personally find meaningful. The information shared should fit with the life plan and interests of the individual patient.

A recent study by Wilkinson et al. [10] studied patient preferences for information and for participation in decision-making among 152 consecutive acute medical inpatients. They found that 61 % of patients favored a passive approach to decision-making (physician makes the final decision). In contrast, 66 % of patients sought "very extensive" or "a lot" of information about their condition. Importantly, there was no relationship between patient preferences for involvement in decision-making and for information about their medical condition. A study by Mazur and Hickam [11] of 467 Veteran patients studied the level of involvement patients want in decision-making related to invasive medical interventions. The vast majority of patients (93 %) preferred that their physician disclose risk information to them and two-thirds of patients preferred shared decision-making compared to only 21 % who preferred physician-based decision-making. The use of simple consent, informed consent, and shared decision-making was the subject of an article by Whitney [12]. They diagrammed patient decision-making into four quadrants based upon the number of available treatment choices (i.e., one clear best choice versus two or more alternatives) and the risk of the intervention. They indicate that simple consent is appropriate for situations where there is one clear treatment choice and the risk of the intervention is low. Surgical decision-making in the acute care setting more often involves situations where multiple possible interventions are possible and/or the risk of the intervention is high. In these cases, a shared decision-making strategy is preferred which includes an assessment of the available treatment options in the context of a patient's goals and concerns. Taken together, these studies confirm that patients want to participate in their healthcare decisions and desire the necessary information needed to make these decisions.

Prognostication

Willingness and ability to accurately prognosticate is another key component of the communication skills needed by acute care surgeons. Although prognostication has traditionally been listed as the third of the three great clinical skills—behind diagnosis and treatment—it may be considered second behind diagnosis when caring for the acute care surgical patient in need of palliative care. When performed accurately, prognostication allows patients and their families to participate in their healthcare decision-making in a way that ensures their autonomy through a process of informed consent. Despite the well-intentioned efforts of some surgeons to avoid giving bad news out of fear of robbing hope, there is little evidence to support this position. In his book entitled "The Dying Patient," Simpson asserts that "Hope is based on knowledge, not ignorance." [13] It is more likely that misguided avoidance of difficult information, or worse, blatant dishonesty about prognosis, may add to a patient or family's distress, cause them to seek treatment which they might not otherwise pursue, and rob them of precious time better spent engaged in activities that promote peace and dignity.

Unlike prognostication in other medical specialties, surgical palliative care is unique in that surgeons are called upon to incorporate knowledge of the surgical disease, any relevant underlying diseases (e.g., end stage organ dysfunction), as well as the anticipated surgical outcome, when providing prognostic information to a patient and their family. Various factors have been used to formulate estimates of prognosis: clinician estimate of survival, performance status scales (e.g., Karnofsky performance status), biological parameters (e.g., preoperative albumin levels, Acute Physiology and Chronic Health Evaluation II score). The Palliative Prognostic (PaP) Score [14] was created by a group of Italian investigators who combined laboratory values, symptoms, clinician estimates, and performance status into a survival prognostication tool that can be readily calculable at the bedside. In their study of 451 terminally ill cancer patients, the PaP score was able to subdivide patients into 3 distinct risk groups with median survival of 14, 32, and 76 days in three groups.

The Palliative Performance Scale (PPS) is another validated prognostic tool used to estimate the survival of patients with life-threatening illness [15, 16]. The PPS provides a functional assessment of ambulation, activity level, evidence of disease, self-care, oral intake, and level of consciousness. The scale consists of 11 categories yielding a score from 0 % (death) to 100 % (ambulatory and healthy). A PPS score of 50 % is associated with a patient who is non-ambulatory (mainly sits or lies), requires a significant amount of assistance, and has normal to reduced oral intake. At a score of 50 %, extensive disease is evident, and the estimated life expectancy ranges from 2 to 4 weeks. The PPS was recently used to assess survival in an inpatient population at a university teaching [17]. A total of 310 adult inpatients with advanced cancer (60 %) and other advanced (life-limiting) diseases were included in the study cohort. Three distinct survival groups were identified based upon PPS: 10–20, 30–40, and ≥50. The median survival for patients with PPS 10–20 was approximately 10 days, while that for 30–40 was

approximately 40 days, and for patients with PPS of ≥50 it was not reached by 150 days. A 10 % decrement in PPS was associated with a 1.65-fold increased risk of death.

Formulating a prognosis in other serious diseases such as congestive heart failure, chronic obstructive pulmonary disease, and various forms of dementia can be more difficult than it is in the case of malignancy due to the difference in disease trajectories. Despite these challenges, guidelines do exist to assist in determining the prognosis of patients with non-cancer diagnoses [18]. A thorough review of the guidelines for each disease is beyond the scope of this chapter but is nicely summarized in a review article by Lynn [19].

Family Meetings: the Surgical Palliative Care Procedure

Family meetings are a crucial tool for effective communication in palliative care. Optimal palliative decision-making is facilitated through effective interactions among the patient, family members, and the surgeon through a dynamic relationship described as the "Palliative Triangle" [20]. The "Palliative Triangle" is a model designed to aid in complex surgical decision-making when palliative surgical procedures are being considered. The three arms of the triangle include the patient, family, and surgeon and the goals that each member of the triangle brings when palliative surgical procedures are considered. The patient's concerns, values, and emotional support are considered against existing medical and surgical alternatives. The process of aligning the concerns and interests of the three parties involved can moderate against the unrealistic expectations that each party may bring to the decision-making process. A study by Miner et al. [21] utilized the "Palliative Triangle" technique in 227 patients with incurable metastatic or advanced cancer considered for a palliative procedure. A palliative procedure was performed in 47 % of patients while 53 % were not selected for a palliative operation. The indications for the palliative procedures included gastrointestinal obstruction in 36 %, local control of tumor-related symptoms (e.g., bleeding, pain, or malodor, 25.5 %), jaundice in 10 % and other symptoms in 28 %. Patient-reported symptom improvement or resolution was noted following 91 % of procedures. Patients who experienced symptom relief did so within 30 days of the operation. It is noteworthy that prior to the palliative procedures being performed, one or two meetings between the patient, family, and surgeons occurred before a final treatment decision was reached. While there may be cases in which time for such meetings are not possible, this opportunity does exist for a significant proportion of acute care surgical patients. In the end, the highly satisfactory results published by Miner et al. [21] reflect the essential combination of appropriate patient selection, excellent surgical technique, and effective communication among the arms of the "Palliative Triangle." As Buckman noted, "Communication is often the most important component of palliative care, and effective symptom control is virtually impossible without effective communication" [22].

Palliative Surgery

Conspicuously absent from the discussion above about palliative care competencies for acute care surgeons was a discussion of palliative surgical procedures. Surgical procedures performed with the intention of relieving pain or other symptoms are a part of, but not the sum of palliative care that surgeons bring to the care of acute care surgical patients. In this next section, we will specifically consider surgical procedures performed with the expressed purpose of relieving pain or a specific symptom(s).

Definition of Palliative Procedure

Agreement about what constitutes a palliative procedure is a matter of debate in the existing surgical literature. First and foremost, palliative surgical care begins with a symptomatic patient. To paraphrase Dr. Blake Cady: "It is impossible to palliate the asymptomatic patient [23]." The precise definition of palliative surgery is less clear, as illustrated by a study by McCahill et al. [24]. In this study, 419 members of the Society of Surgical Oncology were surveyed and asked to select the single best way they classified a procedure as palliative. They found that 41 % of surgeons defined a procedure as palliative based upon the preoperative intent of the procedure, 27 % defined the procedure based upon the postoperative evaluation. Surgeons in this group waited for the results of the operation to determine whether it was palliative or curative. One third of surgeons based their definition of a palliative procedure upon the patient's prognosis. If a palliative operation is defined by its outcome and not by its intention, the possibility to effectively inform and prognosticate is severely hampered. In their article on the ethics of palliative surgery in patients with advanced cancer, Hofmann et al. [25] define palliative surgery in this select group of patients as "any invasive procedure in which the main intention is to mitigate physical symptoms in patients with non-curable disease without causing premature death." Regardless of the underlying disease process, most surgeons agree that the goals of a palliative operation include symptom relief, pain relief, and maintaining patient independence and function [24]. The logical extension of any definition of palliative operation that focuses on relief of symptoms and/or improvement in quality of life is that no specific surgical intervention is automatically included or excluded as potentially palliative.

Morbidity and Mortality of Palliative Procedures

Regardless of the specific procedure performed or underlying disease process, the literature is clear regarding the high morbidity and mortality rates associated with palliative procedures. Mesa and Tefferi [26] reported a 30.5 % morbidity and 9 % operative mortality rate following splenectomy for symptom palliation from myelofibrosis with myeloid metaplasia. McCahill et al. [27] reported a 41 % complication rate among their palliative-intent procedure in patients with advanced malignancy. Similar to the findings of the City of Hope group, the Memorial Sloan-Kettering Cancer Center group [28] reported that 40 % of patients developed some postoperative complication and 11 % of patients died within 30 days following their palliative procedure. Badgwell et al. [29] and the group from the M.D. Anderson Cancer Center reviewed the records of 442 patients with advanced or incurable cancer for whom a surgical oncology consultation for palliation was requested. A total of 119 (27 %) of patients underwent a palliative surgical procedure. Sixty-seven complications occurred in 48 patients for an overall morbidity rate of 40 %. The most common complications were respiratory distress or failure in 12 %, wound infection/non-healing wounds in 11 %, with approximately 5 % of patients suffering from postoperative bowel obstructions, ileus, or bacteremia/line sepsis. The overall mortality rate was 7 %. The median survival for all patients, non-operative patients, and patients who underwent a palliative procedure was 2.9, 2.1, and 6.9 months, respectively. Compared to these older studies, there appears to be some improvement in the postoperative morbidity and mortality following palliative procedures as recently reported by Miner et al. [21]. In their study of 129 patients who underwent a palliative procedure for incurable malignancy, 20 % experienced a postoperative complication and the 30-day postoperative mortality rate was 4 %.

Palliative Outcomes Following Palliative Procedures

In addition to counseling patients and their families about the high morbidity and mortality associated with palliative procedures, surgeons are challenged with providing information about the anticipated success of the proposed procedure in alleviating the patient's symptom(s). The paucity of literature regarding palliative outcomes following palliative procedures was first described by Miner et al. [30]. The authors reviewed 348 studies published between 1990 and 1996 that studied outcomes following surgical procedures for cancer palliation. They found that the majority of these studies were retrospective in nature with the balance of the reports divided between review articles, prospective studies, and case reports. More than two-thirds of the studies reviewed reported physiologic response, survival, and morbidity and mortality data while only 17 % of the studied reported any quality of life outcomes and only 26 % reported the effect of the procedure on pain control. Furthermore, less than half of the studies that considered quality of life outcomes used a validated instrument.

Since this study by Miner et al. [30] was published, a handful of studies have specifically examined the outcomes of palliative procedures and the majority of these studies have focused on oncology patients. Among the earliest studies to prospectively examine the outcome following palliative surgical procedures was published by McCahill and the group from the City of Hope Cancer Center in 2003 [27]. They studied 59 patients who underwent major operations for advanced malignancy; 22 operations were performed for palliation, and 37 were performed with curative intent. A total of 33 patients (20 in palliative group, 13 in the curative group) were symptomatic from their tumors pre-operatively. Symptom resolution was seen in 26/33 patients (79 %). The large study was published in 2004 by the group at the Memorial Sloan-Kettering Cancer Center [28] in which they examined the outcomes following over 1000 palliative procedures performed in 823 patients with advanced cancer. The indications for the procedure were gastrointestinal obstruction in 34 %, neurologic symptoms in 23 %, pain in 12 % and dyspnea in 9 %. Eighty percent of patients experienced an improvement in their symptoms and almost half remained symptom free for a median of 135 days. Most recently, Miner et al. [21] studied the outcomes following 129 palliative procedures and found that patient-reported symptom improvement or resolution occurred following 91 % of procedures. Those patients who experienced symptoms relief did so within 30 days of the operation.

On balance, the surgical literature is severely limited regarding palliative outcomes (e.g., symptom resolution) following palliative procedures. As noted by Smith and McCahill [31], "… there are educational and research opportunities among surgeons in better defining factors associated with successful surgical palliation." Although they were referring specifically to surgical palliation of advanced malignancies, their statement is equally applicable to the acute care surgical patient without malignancy.

Patient Selection for Palliative Procedures

Given the high morbidity and mortality rates associated with palliative procedures—regardless of procedure or underlying disease process—it seems that patient selection may be the single more important factor in successful surgical palliation [20]. As Smith and McCahill [31] recently noted, "The decision to pursue a major surgical intervention

becomes more controversial when it is likely to be noncurative and instead has symptom relief as its major objective." The accuracy of surgeons' preoperative predictions following major surgery for advanced malignancy was recently studied by Smith and McCahill [31]. The authors correlated surgeons' preoperative estimation of each patient's life expectancy and likelihood of symptom palliation following surgery with patient self-reports of symptom palliation following surgery. They found that surgeons' preoperative estimates of patient survival agreed with survival outcomes. However, surgeons' preoperative estimates of the success of symptom improvement following surgery did not correlate in general with patients' self-assessments; surgeons underestimated their success in symptom resolution. This tendency to underestimate the success of symptom resolution may result in patients with advanced malignancies not receiving palliative procedures.

If surgeons' predictions of symptom relief following palliative procedures cannot accurately identify those patients most likely to benefit, what other criteria are available? McCahill et al. [27] attempted to quantitate the effectiveness of palliative surgery in symptomatic patients with advanced malignancies through a Palliative Surgery Outcome Score (PSOS). The PSOS incorporates elements of treatment success (e.g., symptom relief) and treatment failure (e.g., symptom recurrence and surgical complications) and their associated hospital days. The PSOS indicates the percentage of postoperative days for which a patient was not hospitalized, free of the symptom that the operation was intended to treat, and free of major surgical complication in the 6 months after surgery. A PSOS 70 was defined as good-excellent surgical palliation as it represented a patient who lived at least 70 % of the study period outside of the hospital, free of the symptom addressed by the procedure and without major surgical morbidity. This result was achieved in 64 % of patients. Given that only 36 % of patients who lived < 6 months achieved a PSOS of 70, the authors emphasized the significant impact of limited longevity on successful surgical palliation and stressed the importance of identifying clinical factors known to correlate with survival. In their study, preoperative serum albumin and weight loss were important predictors of survival. Similarly, the group from the Memorial Sloan-Kettering Cancer Center [28] found that poor palliative outcomes were associated with patients who had poor performance status, poor nutrition, weight loss, and no previous cancer therapy. Furthermore, a major postoperative complication reduced the probability of symptom improvement to 17. A recent examination of the National Surgical Quality Improvement Program database for outcomes following operations in patients with disseminated cancer identified the following independent risk factors for postoperative morbidity and mortality: increasing age, impaired functional status, weight loss >10 %, dyspnea, ascites, chronic steroid use, active sepsis, elevated creatinine, hypoalbuminemia, decreased serum hematocrit, acuity of the surgical procedure, impaired respiratory function, and abnormal white blood cell count [32].

Future Directions for Palliative Care in the Acute Care Surgical Patient

Expanding the Role of Surgeons as Providers of Palliative Care

Although palliative surgical care has been most consistently applied to the field of oncology, it is increasingly being applied to patients with disease processes other than oncology. Furthermore, while physicians from non-surgical specialties have traditionally dominated the ranks of Palliative Care providers, this too, is changing. Surgeons can point to Balfour Mount, Geoff Dunn, Dan Hinshaw, Karen Brasel, Anne Mosenthal, and others as early pioneers in palliative surgical care. Furthermore, beginning in 2008, the American Board of Surgery (along with nine other medical specialty boards) began offering a subspecialty certificate in Hospice and Palliative Medicine. As of December 2013, The American Board of Surgery has certified 64 Diplomats in Hospice and Palliative Medicine. There is hope that that number will continue to rise as surgeons consider completing a one-year fellowship in Hospice and Palliative Medicine. One particularly exciting potential area for inclusion of more surgeons into the field is the change in fellowship eligibility requirements effective July 1, 2015 so that surgical residents who have completed three years of clinical training are now eligible to apply for fellowship training in Hospice and Palliative Medicine during their surgical training (similar to the pathway currently available for fellowship training in Critical Care Medicine). For those surgeons not interested in obtaining sub-specialty training in palliative medicine, the need for providing primary palliative care in the two essential areas of acute pain and symptom management and communication has been thoroughly reviewed above.

Education in Surgical Palliative Care

Despite the American College of Surgeon's publication of core competencies in palliative care in 2003 [5] few surgeons receive the education and training needed to satisfy these competencies. Galante et al. [33] surveyed 70 surgeons from a variety of subspecialties who practiced in both academic and community settings about their palliative care education experience. The median number of hours of palliative care education during residency was zero; approximately 85 % of

those surveyed received no palliative care education during residency or fellowship. The palliative care training received by surgical oncology and hepatobiliary fellows was recently studied by Amini et al. [34]. They found that 98 % of fellows did not have a palliative care rotation in fellowship and almost half did not have palliative care exposure during their fellowship. These studies highlight the significant need for palliative care education for surgeons at all levels of training and in all subspecialties. Given the unique perspective surgeons bring to the specialty of palliative medicine (in contrast to our non-procedural colleagues), it is imperative that education about surgical palliative care be provided by surgeons in conjunction with the other interdisciplinary palliative care team members.

Need for Surgical Palliative Care Research

The studies cited above on the morbidity and mortality of palliative-intent procedures and the paucity of research available regarding palliative outcomes following these procedures clearly demonstrate an urgent need for research specifically focused on surgical palliative care. Some of the specific areas of surgical palliative care that warrant further study include the following:

Surgical Decision-Making

Surgeons must learn how to ask "should this operation be performed for this patient at this time?" before "can this operation be done?" Establishing basic guidelines for elements to be considered prior to undertaking a palliative procedure should be a priority. Much like the computer-aided decision support models currently available to address other clinical scenarios like abdominal sepsis [35] decision support based upon evidence (when available) should also be a goal for palliative surgical decision-making. In contrast to decision support in other situations, however, patient (and family) preferences and goals of care must play a central role as defined by the "Palliative Triangle" [20].

Intimately related to the process of surgical decision-making is the role of prognostication. Prognostication is based upon a surgeon's ability to incorporate his/her knowledge of the natural history of disease with and without treatment and expected outcomes of a procedure to arrive at an overall prognosis. Several clinical prognostic scales and indices exist (e.g., Palliative Prognostic Score [14], Palliative Performance Scale [16], Palliative Prognostic Index [36] and Good/Bad/Uncertain [37] although, to date, none of these scales has been specifically validated in a surgical population and most have been applied primarily or exclusively to oncology patients.

Patient and Family Decision-Making

Understanding patient and family preferences for treatment, specifically as they relate to accepting or rejecting surgical intervention as a means of palliation, is an essential area in need of research. A recent study by Kwok et al. [38] retrospectively examined inpatient surgical procedures in the year before death for Medicare beneficiaries aged ≥ 65 years and found that 32 % (575,596) underwent a surgical procedure in the last year of their life, 18 % had a surgical procedure in the last month of life, and 8 % had a surgical procedure in the last week of their life. The high volume of surgical procedures performed in this one cohort raises significant questions about the utility and benefit of these procedures meeting the goals of these patients and their families given their short life expectancy. An important corollary to this study would be an examination of patient and family satisfaction with the decision to proceed with surgical intervention and factors associated with their satisfaction or dissatisfaction.

Symptom Management

On a daily basis, surgeons are faced with determining whether surgical intervention is an appropriate or optimal means of relieving patient symptoms. With rare exception (e.g., malignant gastric outlet obstruction [39]), surgeons have little evidence-based guidelines upon which to make their recommendations. For common clinical scenarios (e.g., malignant bowel obstruction), prospective randomized clinical trials are needed to effectively guide surgical decision-making about the optimal method of palliation. Furthermore, such trials must also include relevant palliation-specific outcomes such as efficacy of symptom relief, duration of symptom relief, and need for re-intervention.

Summary

Palliative care provides a multidisciplinary approach to patients and families facing life-threatening illness that seeks to relieve suffering in both physical and non-physical domains. Importantly, palliative care can be initiated early in the course of disease (e.g., at the time of diagnosis) and may be provided in conjunction with therapies intended to prolong life. Palliative care principles form the basis of good surgical care and surgeons can and should be expected to possess the skills needed to provide palliative care in conjunction with/as part of their routine surgical care. The American College of Surgeons has established core competencies for surgical palliative care. Two basic elements of palliative care—pain management and communication skills—are considered core competencies for all surgeons.

The application of palliative care to the acute care surgical patient reveals a significant need in this vulnerable population. Specific needs in this setting include a prompt recognition of the acute care patient in need of surgical palliation, an accurate assessment of the patient's prognosis, and an honest and accurate discussion of prognosis with patients and their families. Essential components of the communication with the acute care surgical patient in need of palliation include a discussion of the anticipated *palliation-specific* outcomes following the proposed surgical intervention and a candid discussion of the significant morbidity and mortality associated with palliative procedures.

Although some progress has been made toward integrating palliative care principles into surgical practice, substantial challenges remain. These challenges, in turn, represent important opportunities for research. A few key areas prime for investigation include validation of existing palliative care prognostic scales in surgical populations, examination of patient and family decision-making for or against surgical intervention for palliation and satisfaction with these decisions, and prospective randomized trials designed to determine the optimal method of palliation for common clinical scenarios facing the acute care surgeon (e.g., malignant bowel obstruction).

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Common Ethical Problems in Acute Care Surgery

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Jeffrey P. Spike

Ethics in acute care surgery is to a large degree a human rather than a natural phenomenon (or a blend of the two). So at the very least we need to recognize there will be some variation between different countries and cultures, and to a lesser degree there will even be some variation between different states in the USA and even between hospitals. Nevertheless, the variation is small enough, at least within the English speaking world, that the following can be taken as guidance for ethical deliberation in any acute care surgery department in those countries.

Surgical ethics has become recognized as an important and importantly different field from medical ethics [1, 2]. Any practicing surgeon who last had ethics in medical school most likely would benefit from some continuing medical education (CME) credits specifically concerned with surgical ethics [3].

Similarly, within surgical ethics, some issues stand out as of particular importance to acute surgery. This chapter will first give a brief summary of the received view of bioethics, the standard that is taught in most medical schools in the USA and Canada. Then it will outline some of the core issues in surgical ethics in general, and acute care surgery in particular.

Biomedical Ethics: The Current Paradigm

The model of ethics in healthcare used most often is called the four principles. This was first proposed in 1977 in *The Principles of Biomedical Ethics*, by Tom Beauchamp and James Childress [4]. The four principles are respect for (patient) autonomy, beneficence, non-maleficence, and justice.

The principles have been widely adopted in hundreds of articles and textbooks, not just in medicine, but also in nursing, dentistry, and other fields. They have great utility, especially for the purpose of helping an inter-professional team reach a consensus. Various authors have proposed various additional principles, such as confidentiality. But to start with the four original principles is the single best way to make sure one is starting with a common and widely agreed upon set of grounding assumptions.

Another strength the principles approach offers is it represents the traditional values of medicine, or what some call Hippocratic ethics, in two of the principles (beneficence and non-maleficence), while the other two principles (patient autonomy and justice) represent more modern ethical values that give us freedom to question certain traditional beliefs.

The principles have also been simplified into a formula known as the four boxes, which does not differ in substance. While the four principles are more of an explanatory model, the four boxes seems closer to a description of how to operationalize the four principles.

Here is a brief summary of the four principles:

Respect for Autonomy

The surgeon ought to provide all the information patients with decision-making capacity need in order to make an informed decision. The patient is the ultimate decision-maker because the decision is as much a value judgment as a clinical judgment. (The four boxes uses the term "patient preferences.") Informed consent might be seen as the legal counterpart to the ethical principle of autonomy, both being founded on a strong concept of patient's rights.

Beneficence

The surgeon ought to do whatever is determined to be in the patient's best interest, balancing benefits and burdens. This is a very high standard. It is also altruistic, as it rules out letting one's own self-interest (e.g., ownership of a lab or imaging equipment) or third-party interests (e.g., an insurance company)

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_43

interfere with what is best for the patient. It identifies the surgeon as a fiduciary, meaning that the surgeon is exclusively devoted to the patient's interest. (The four boxes simply calls this "best interest.")

Non-maleficence, or "At Least, Do No Harm"

The surgeon must include preventing or relieving pain and other symptoms in the equation. This is a conservative or precautionary principle to avoid heroic interventions that may make things worse; it may counsel that hospice or palliative care is the best of the available choices. (The four boxes calls this "quality of life.") The justification for many decisions that a patient is not a good surgical candidate is the result of non-maleficence. Confidentiality might also be seen as a consequence of the ethical principle of non-maleficence.

Justice

Justice is the most complex and least intuitive of the four principles. It can be seen as both a positive duty requiring that we give vulnerable people (the uninsured, the homeless, as well as the mentally ill, handicapped, or drug addicted) the same care as powerful people and as a negative duty requiring that we are careful stewards of resources, so there is enough to assure access to everyone. (The four boxes calls this "contextual features," a not very descriptive catch-all term for economic factors, religious factors, etc.)

It is interesting that most ethicists would hold that a society owes every member a reasonable standard of care, regardless of income or job status. Thus, of all the fields of medicine, probably emergency medicine has the best claim to the mantle of ethical practice, thanks to EMTALA (Emergency Medicine Treatment and Active Labor Act 1986). Acute care and trauma surgery, because of their close link to the patients who are admitted through the emergency room (ER), thus would have the claim to the mantle of ethical practice within surgical specialties and subspecialties.

For an interdisciplinary team, the members might try to keep the overall balance by each advocating for one of the principles. Perhaps the surgeon would represent beneficence (the best interest of the patient from a surgical point of view), the nurse might see being a patient advocate as requiring more attention to avoiding interventions with high-risk or low-probability of success in the name of "do no harm" (nursing ethics is often called an ethics of caring), and justice might be the domain of the social worker (who often weigh financial issues, Medicaid eligibility, as well as family dynamics and cultural context). Decisions should involve the entire team plus the patient (autonomy).

Even with that interdisciplinary team model, it is important that everyone on the team be aware of the importance of all four principles, and that no case is "just" an autonomy case, or "just" a non-maleficence case. The only way to do a good job understanding a case is to carefully consider how each of the four principles applies. Each principle is considered to be relevant to every case *prima facie* (when you begin the analysis). Equally importantly, they are four independent principles, meaning they can conflict with each other. Thus, they are better thought of as helping you understand why a case is complex than as a way to simplify a case.

Lastly: Here is a humorous mnemonic that may help you to remember the names of the four principles: "*A*nywhere *B*ut *N*ew *J*ersey" (*A*utonomy, *B*eneficence, *N*on-maleficence, and *J*ustice).

Ten Essential Ethical Issues in General and Acute Care Surgery

Following are a sample of primary issues in general surgery and acute care surgery. Surgical ethics includes (at least) the following unique issues that are rarely covered in medical ethics:

1. When (if ever) should a patient be "Do not resuscitate" (DNR) during surgery? It can be appropriate, especially in cases of palliative surgery. If a patient is DNR before surgery, then there ought to be a discussion of his or her code status before proceeding with surgery—it should not be assumed that the code will be temporarily removed without the patient being informed and consenting to that. And if the patient agrees to temporarily change their DNR status, the norm should be to return to their prior status once out of post-op.
2. When (if ever) can a surgeon refuse to take a patient who might benefit from a procedure because of the risk? (Who should decide which patient is a "surgical candidate"?) This should be the result of careful weighing of the benefits and risks of surgery to the patient. And the patient has a right to know when and why they are denied surgery as too high risk. Sometimes very high risk surgery is still the best option for the patient.
3. What is the ideal relationship of the surgeon to the anesthesiologist?—Their relationship—having two attending physicians simultaneously responsible for one patient—has no parallel in medicine. It might often be best for the patient to discuss a planned surgery with both, and have them share responsibility for the case, rather than have one seen as the "captain of the ship." This might help assure that the best anesthesia method for the patient and his or her recovery from surgery is chosen, rather than what the surgeon prefers. The demarcations of role between the anesthesiologist and the surgeon is a unique

relationship in the medical world, and there is no a priori reason that one should have greater authority than the other. For example, in some countries, it is the anesthesiologist who is most often seen as "the captain of the ship" during a surgery, and the surgeon is more the technician. At the very least, there is a movement towards having both required to see the patient before surgery, and to have two separate consent processes.

4. Should informed consent include a description of morbidities that are not fully understood but are statistically significant, such as "pumphead" for patients who will require cardiopulmonary bypass? How much can be presumed by a "general surgical consent" and how much should be broken down into details? It is best to err on the side of sharing information, as you can never know in advance just what will be important information to the patient. But you can also try to judge in advance whether the patient is someone who likes as much information as possible so they can decide for themselves, or finds it overwhelming, confusing, or frightening, and would prefer you keep it to a minimum and give them a reassuring recommendation. Then tell them what you think and ask them if you're right.
5. Should informed consent include a description of your connections to companies such as medical instruments, implantable devices, biomaterials, prostheses, or other devices that you use in your surgery—including investments, consulting, board membership, stock and futures ownership, paid speaker, bonus for enrolling patients into a study, etc.? There is no doubt that disclosure is the expectation now, and can be conveyed both in person (verbally) and in writing (on consent forms, advertising, brochures, etc.) because these connections are all potential conflicts of interest that can bias your decisions and recommendations.
6. When (if ever) does the surgeon's responsibility for a patient's best interest end? In contrast to medicine, some surgeons maintain the tradition that when one takes a patient, one has so great a responsibility for their interests that one may have some say in their future medical decisions in order to achieve the best possible outcome, and patients cannot change their mind in midcourse. However, one cannot impose this on patients—better to explain your expectations in advance. And for that to be fair, then the patient should know details such as what outcomes might occur (infections at graft sites, difficulty being weaned, weeks or months of physical therapy) that you consider them to be agreeing to before going into surgery.
7. How to handle errors: Yours, colleagues', and surgeons' you have never met. Here both issues of honesty (truth-telling, veracity) and professionalism come into play, and have to face the powerful forces of denial, defense mechanisms, and fear of legal retribution. If you did it, you must explain what happened, tell how it was repaired, and apologize. If you know someone else did something, it is better for them to tell the patient. But if the responsible person does not (or refuses to) inform the patient, then you should start a review process (e.g., an incident report) so the correct person of authority (rather than you) tells that surgeon to talk to the patient, or else that person will inform the patient herself/himself. This is part of the quality assurance or improvement at most hospitals now, to prevent recurrences. Studies indicate this is also the best way to prevent lawsuits, while trying to evade responsibility is (paradoxically) the best way to invite lawsuits and increase the size of settlements. (Of course your apology must be sincere.)
8. What surgery should you do, and what should you refer out? It is always tempting to try to stretch your abilities, take on new challenges. But at the same time, experience always leads to better outcomes. So when you are a novice, you are imposing greater risks on the patient than if you referred them to a more experienced surgeon. Patients have a right to know that. Professionalism means honesty about your skill level, willingness to refer, and encouraging any patient to get a second opinion from a more experienced surgeon if they would benefit from it or they indicate an interest in it. Similarly, you should be willing to give honest second opinions when requested, and not see loyalty to the other surgeon as a limiting factor on being honest. General surgeons may be the best source of information for patients who want to know whether the benefits of a new, innovative procedure are being exaggerated (and its risks minimized).
9. When is it acceptable to try an innovative approach to surgery? There must be someone who tries something the first time, but when is it acceptable to take the risk? This is an area where physicians in medicine might be expected to design a research protocol and get IRB approval. Surgery is seldom in a position to do that, since cases are often *sui generis*. But this doesn't have to mean that there is no control over surgeons, and no source of help for them. Increasingly there is a willingness on the part of surgeons to get an ethics consult in cases like this, and some services that are highly innovative (such as fetal surgery) are developing a model of having an in-house surgical ethics board with an ethicist, members of related professions (such as genetics and neonatology), and surgeons in related fields (such as pediatric surgery). Surgeons can bring a case to the board for prior review, and the chair of the board may also choose to talk with the patient or family before making any written recommendation. The consult note is seen as an indication of an open and reasoned process of debate as well as valuable institutional support before attempting a new procedure [5–7].

10. There has been growing recognition of the importance of inter-professional ethics in all fields of medicine, including surgery [8]. Besides always working closely with anesthesiologists (discussed above), surgeons are also highly dependent on pathologists, surgical nurses, perfusionists, and many others. Surgery is, in other words, really a team sport. Using the sports analogy, success does not come from any single star, but from practicing as a unit and unselfish play. Increasingly all members of the team (as well as patients themselves) are being asked to evaluate physician-performance, and this is supported by ethics. The goal of the surgeon should be to assure that all team members feel appreciated and respected.

While these first ten issues are important in all surgical ethics, they may be more important in elective surgery than acute care surgery. This rest of chapter will focus on four additional issues that may, in contrast, be more important to discuss with regard to acute care surgery.

1. What is allowable (and what is not) in the surgical theater to maintain a sense of *esprit* or teamwork—for example, is it ever acceptable to make fun of a patient's *habitus* while they are under anesthesia?
2. What is your relationship to the police, and how does it affect your relationship to your patient?
3. Can one ever have true informed consent in acute care surgery, when most patients understand so little to begin with? In cases where time is limited and decisions are urgent, is any patient really emotionally capable of participating in informed consent? What information should be included in the consent process? How much can be presumed by a "general surgical consent"? Who can give informed consent for an incapacitated patient?
4. What is "emergency consent"? Can we ever just assume all patients want to live, and would accept our recommendations, and skip the consent process (and spare them the fear that might be caused by informed consent)?

Esprit, Tradition, or Unprofessional Behavior?

Surgeries are different from most medical encounters in the way there is a team that works in very close quarters, and must be well coordinated. The best teams tend to be ones that work together often, and get to know each well. Such intimacy can bring out the best in people, or the worst. At a psychological level it can be, one might surmise, rather like a family gathering.

There are some practices that help surgeons maintain their calm and their focus, such as playing music, which are perfectly acceptable. But there ought to be limits, based on what is acceptable interpersonal and professional behavior. Thus, for example, some popular songs have such vulgar lyrics that they might offend some members of the team. In that case, the surgeon ought to respect that person's feelings and not play such music.

Respect for the patient is equally important. Another unique aspect of surgery compared to medicine is that the patient is unconscious during much of the time one spends together. However, even if a patient is unconscious, there is no justification for making any sort of insulting comments. Such behavior may have once been more common, but fortunately it has become rare.

Referring to the size or shape of a person's body, or any part of a person's body, is never necessary to maintain a surgeon's calm or focus. These are nothing more than entertainments, and even to find them entertaining is an indication of poor character. An attending surgeon ought to think of being a role model at all times, whether it is to a medical student or resident or fellow, or as a role model of the profession to members of other professions represented in the room.

What is more, there are interesting philosophical arguments that one can harm a person without the person even knowing of it—because harms are not limited to physical injuries, but also include libel and harms to the self-esteem or reputation of a person. A person's reputation can even be harmed after they are dead. If a patient heard, from any source, that insulting things were said, they would have reason to complain to a medical board, and it could be categorized as unprofessional conduct. One occurrence might be ignored, but repeated offenses might not.

Although these have become rare occurrences, there continue to be reports of such behaviors. So it would be best for all surgeons to address them with the team up front, and also have all members of the department or practice agree to the same standards. One would never want the staff to be saying, behind one's back, that they hate to work with you and would rather be on any other service.

At its extreme, this becomes the question of the disruptive physician [9–12]. It will still happen in some places that a surgeon is overheard to swear at unconscious patients, or worse—swear at nurses during a surgery. That is never acceptable. And there should be immediate reporting and sanctions against any surgeon who throws any object in the surgical theater. This behavior poses an immediate danger.

If these issues occur more in acute care surgery, it might be because of the lack of a prior relationship to the patient; empathy may benefit from a degree of familiarity to better understand another person, and a sense of mutual respect may also be nurtured in the process.

If the question is not "what must I do?" but rather "what is best?" the answer becomes clear. Act such that it would not matter if the patient was aware of everything being said. That would be the highest possible standard of behavior.

And, in the long run, it would also lead to the best *esprit de corps*, or teamwork, and hence to the best outcomes as well.

This advice can be supported by all four principles. Autonomy, sometimes called respect for persons, can be taken to require that we treat all persons with dignity and respect. Beneficence would support the practices that lead to the best overall outcomes. Non-maleficence could argue that a patient might be harmed by libelous comments, either by the rare event of unexpected levels of consciousness and memories of surgery or by somehow hearing about what was said. And justice could hold that we ought to treat poor people as well as we treat rich people, uninsured as well as the insured, the homely as well as the beautiful, the infamous as well as the famous, and the overweight as well as the well-built.

Police and Criminal Investigations

Much of acute care surgery starts with an admission from the ER. Emergency room physicians are accustomed to the presence of police. But that does not mean they should see themselves as an arm of the law. In fact, anything that appears to be a friendly overture from the police must be taken with a grain of salt. They could be "grooming" the physician, hoping to ride the rush of excitement in an "adrenaline junkie" to get them to do things that are, in fact, professional boundary violations.

Surgeons, like physicians, are there to help patients. It is the job of the law to make their case, and decide issues of guilt and punishment. But for surgeons to get involved in judging guilt and innocence risks losing the trust patients have in doctors. It could lead to people delaying going to the hospital, a potentially lethal mistake for many situations where there is a "golden hour" for successful intervention. The best reminder for surgeons would be that a primary professional value (or virtue) in surgical providers is to be nonjudgmental—quite the opposite of the police and prosecutors. (Remember too that the legal system rests its claim to fairness on an adversarial system in which the accused has his or her own lawyer and a right to a trial of his peers). A good example of maintaining a nonjudgmental attitude in the most intense situations is the obligation for military doctors to take care of enemy combatants without bias (something they do with pride).

In general, no test should be done without the consent of the patient. If the police want something done, it should only be done with a search warrant or a court authorization. Your discussions with the patient should focus on the medical situation, not what led up to it. (This is analogous to the Miranda warning: they have the right to an attorney, and to refuse to talk until they have legal representation.) If they do tell you something material to an investigation, it should still be protected by patient confidentiality and the Health Insurance Portability and Accountability Act (HIPAA) privacy rule. And unless it is clinically relevant, there would be no reason to put it in the chart.

For surgeons this should come up less often than with ER physicians. Objects removed from bodies that might be used as evidence should be properly saved; however, notes pertaining to them should be carefully worded so as not to presume any knowledge of their provenance (e.g., speculating on whether the patient was the perpetrator or the victim).

It is also important to always be up to date with state laws requiring reporting of certain things. Physical abuse of children is required in every state, usually to Child Protective Services. Gunshot wounds and knife wounds are usually reportable to the police, as is spousal abuse (but there is variation, in some states it is not required but left to the discretion of the physician). The same with clear threats of violence to an identifiable person; it is always allowed to be reported to the police (so confidentiality can be violated without consequences to you), but in some states it is required and in others it is permissible.

In each of these rules one can see how the principles apply: autonomy would suggest doing what the patient with capacity wishes, beneficence would support helping the patient even if you find some of his or her actions reprehensible, non-maleficence would support not making his or her situation worse merely because they came to a hospital for help, and justice would suggest remaining free of bias, especially against people who may have been born with every conceivable disadvantage in life.

What Is the Purpose of Informed Consent?

While there were important precedents that led up to it, the term "informed consent" was first used in a court case in 1957 called *Salgo v. Stanford* (a case involving a cardiovascular surgeon), which asserted that this is a necessary part of medical practice, and one cannot do any procedure without first getting the approval of the patient.

The concept really originated in a 1914 court case called *Schloendorff v. New York Hospital* (also a case involving a surgeon), which stated that "Every human being of adult years and sound mind has a right to determine what shall be done with his own body; and a surgeon who performs an operation without his patient's consent commits an assault for which he is liable in damages. This is true except in cases of emergency where the patient is unconscious and where it is necessary to operate before consent can be obtained" [13]. The latter sentence is particularly helpful for those who work in acute care settings. Over 90 % of patients in acute care are not unconscious or otherwise incapacitated. Thus, the mere fact of being in an acute setting like an emergency department (ED) does not rule out the possibility of consent. The setting does not matter; informed consent is necessary in any setting

unless there is imminent risk to the patient of death or serious injury and the patient is incapacitated. (Imminent is usually defined as meaning within minutes or hours, not days.)

After Nazi doctors were found guilty of crimes against humanity, the Nuremberg court wrote up guidelines for human subject research that began "the voluntary consent of the subject is absolutely essential," which solidified international recognition of consent, even though it already had clear legal roots in the USA for 30 years. Thus, the 1957 *Salgo* decision [14] can be seen as an assertion that the same rules apply to the doctor–patient relationship as to the research subject–doctor relationship, and to US doctors as well as to German doctors.

A pair of other decisions in 1960 made clear (in case there was any doubt) that a surgeon is liable for failing to properly get the consent of the patient, even if one does the medically indicated procedure, and has a good outcome. Part of the surgeon's job, one can conclude, is to talk to the patient, explain your recommendations, answer questions, and get their understanding and agreement to your plan. Moreover, the law does not allow a surgeon to claim because a patient signed a very open-ended or vague "general consent" that everything you do can be considered "covered." If a patient feels deceived, they can always bring a complaint, and can often find a sympathetic judge or jury. If you want to do your ethical duty to the patient, and if you hope the law will back you up, you should err on the side of telling the patient everything they might want to know before they make their decision. This would include anything that might impair their function after surgery, any morbidity with more than a 5 % or 10 % risk, as well as the risk of intraoperative mortality (even if it is less than 5 %).

Some ethicists have observed that calling the process "consent' distorts the purpose by being one-sided, for one does not always fail in the job if one does not get consent. It might be a success when the patient refuses your recommendation. As long as it is the result of the educational process, that refusal can be considered a successful result. It may be that a patient does not want to take the same risks that other patients would accept. A good consent process accepts such variation as a normal result of different people having different goals of treatment, and different goals in life. There is no reason to expect extremely religious people to always agree with totally secular people about anything else, so why should they agree about medical treatments, for example? And certainly it could be rational for 45-year-olds to have different goals in life than 75-year-olds [15].

Is Informed Consent Possible in Acute Care?

Some surgeons have expressed skepticism that informed consent is really possible. The reasoning is that patients are not well enough informed to understand the medical information, and cannot be adequately educated in the brief time allowed. (Sometimes it is added it would take a patient 4 years of medical school to do it.) Other surgeons put a similar skeptical view in slightly kinder terms, saying that patients are often too frightened to make a good decision. In the latter version it is also said that modern medical ethics has made autonomy into the dominant principle, and encourages surgeons to just drop decisions into patients' laps with a nonchalant attitude, as if any decision is equally acceptable.

These are important concerns. Patients certainly do understand less than their surgeons, and one of the toughest skills for many surgeons is how to communicate clearly without bias to patients of very different educational levels. But surgeons have learned many other difficult skills, and if this is posed as another competency they must master, all surgeons would. So it is important for department and hospital policies to be clear about the importance of communication to achieve required ethical and legal responsibilities.

As to autonomy, the original theory does not place any one principle above the others. It is totally reasonable to say that beneficence means one must make recommendations, and not just lay out all of the options, especially for patients who are having difficulty making a choice for any reason. And non-maleficence could be taken to imply that one should not easily let a patient refuse an intervention with great likelihood of benefit. Nonchalance is an inappropriate attitude in both circumstances. If there is time, perhaps calling an ethics consultation could help in these cases. But an angry response, "washing your hands of it," would never be appropriate.

This reminds me of one of my favorite anecdotes. I was once in the room with a pre-op patient who was about to back out of a hernia repair. He had done the same thing once before. The surgeon came in the room, but stood by the door impatiently, very unhappy about the whole situation. He did ask the patient if he had any questions, from the doorway, and the patient asked "What will happen if I don't get the surgery?" The surgeon looked annoyed, and said in an aggrieved tone of voice "Strangulation!" Then the surgeon opened the door and left the room. As I looked at the patient's face, he looked startled. I am convinced he thought the surgeon was suggesting he just might come back and strangle him if he did not have the surgery!

Who Can Give Informed Consent? (Decision-Making Capacity, and What to Do When the Patient Is Incapacitated)

Informed consent should always be given by the patient if at all possible. To have such "decision-making capacity" requires the patient be able to understand information about what is wrong, what options are available to correct it, the likelihood of a desired outcome, and the side-effects they are likely to experience. They also must be free from coercion

(from both family members and aggressive or paternalistic surgeons), and possess sufficient clarity of mind to make a decision based on their own values. If you are uncertain, the best test of the last of those requirements is to ask his family (or family doctor) if this decision is consistent with past decisions of the patient.

If the patient is incapable of consent (incapacitated), then one must find a surrogate. State laws vary in small degrees, but generally share a similar order of people who can serve as surrogate if the patient lacks capacity. First is not any "next of kin" but a person who was named by the patient. This is in many states called the "health care proxy," but the legal term for it is "durable power of attorney for health care." This person can make the same decisions the patient could make if the patient had capacity, but only for as long as the patient lacks capacity. So if the patient regains capacity, the "proxy" no longer is empowered to make decisions.

The second person on the list is the spouse, if there is one. Next (third) is usually an adult child, or all of the adult children, or a majority of the adult children. There is considerable variation in the finer details of different state laws on this point, but in practice one usually tries to talk to all of the adult children who indicate an interest and make themselves available, and get a consensus.

Ethically, the most important thing to remember is that you are asking each person—whether the proxy, the spouse, or the adult children—to decide according to what the patient would most likely want in these circumstances, not what the surrogate wants, and their authority is based on the assumption that they know the patient well enough to represent the patient. In all states, any surrogate on the list can defer to someone lower on the list if they are not comfortable in the role of surrogate (for example, a spouse who is separated but not divorced).

In the acute care setting though, an important ethical issue is not which surrogate should make the decision, but why one has turned to surrogates when the patient is available. Talking to patients can be uncomfortable to some surgeons, making it tempting to ask the family for consent even when the patient is capable of being involved in the consent process. This is not ethically justified and can lead to ethical and legal dilemmas down the road (first, as a violation of confidentiality, as well as if the family consents to something the patient did not want).

Elements of Informed Consent

If time is limited, but the patient is awake and aware, at least tell him what is wrong, what you recommend, give an explanation of what to expect, get their agreement to the procedure, and document the discussion afterwards. Those are the essential elements.

The purpose of informed consent is to help the patient make a decision that will be best for him, not just medically, but for his life overall. Hence, full and fair disclosure is best. The question then is how much information must be included to be full and fair?

First and foremost, in an ideal setting (for example, with all elective surgery) one must tell the patient about all of the reasonable options. Thus, for example, if there are radiological or pharmacological alternatives to surgery, those should be presented. One should also include the option of choosing not to treat the condition at all (which sometimes is a good choice, justified by "at least, do no harm"). Refusing treatment is always one of the options for patients with capacity, as the side-effects of surgery or the other alternatives may not be worth it. (Close observation or watchful waiting is even becoming the recommendation for what were once considered early stage cancers, such as prostate and breast.)

With each of the reasonable options you should give patients your best estimate of the likely risks and benefits. This should include not just during the intraoperative period, but also post-op; e.g., normal expected rehabilitation time and site. Even if telling more will not change the decision, the information could still be helpful to the patient to plan their life better (e.g., to visit a loved one before having surgery or starting chemo). Besides risks, benefits, and alternatives, patients may want to know about financial costs, and about outcomes—both yours and your centers (and how they compare to others' outcomes). These questions deserve honest answers, even if it requires you to do some investigating or even if it makes you uncomfortable. (For example, you should be willing to say how many times you have done a procedure, and if there's someone nearby with more experience.) The identity and role of other people involved in the surgery is also fair game, such as residents and device representatives, and you can honestly reassure the patient about your responsibility to supervise them.

There are also some religious beliefs such as Jehovah's Witnesses and Christian Science that influence medical decisions. If an adult patient refuses transfusions, you should not deceive them. You can tell them the chance they will die as a result, you can be careful to discuss this alone with them so they do not feel pressured by a spouse or other member of the church, or you can recommend a "bloodless surgery" center.

There is then, a curious, subtle, and important asymmetry at work in this entire section: patients cannot make you do something that is not indicated, but they can stop you from doing something that is. That is referred to as the right to refuse treatment, something well supported in many important legal opinions.

Consent in Emergency Situations

Some surgeons express skepticism about the entire concept of consent by using examples drawn from emergency situations. This is a logical fallacy, called a "red herring' or a

"straw man," as most surgeries are not done in an emergency situation. The simple truth is that in those relatively rare cases where a surgery must be done immediately or the patient's life will be endangered, it is acceptable to use your best judgment. However it is equally important, ethically, to recognize that those situations should be kept to a minimum. The usual definition of an emergency is that the patient is in imminent risk of dying or suffering severe and irreversible harm without immediate action. Immanent is generally meant to mean within minutes, or at least less than an hour. If you have more than an hour, then there should be time to have members of your team prepare the surgical suite while you prepare the patient or her family by communicating and getting consent.

It is important to remember that not all interventions that occur in, or begin in the Emergency Room are truly emergent. In some hospitals the mean wait time in the ER is 5 h. Those hours provide a perfect opportunity to talk about a proposed surgery and its risks and benefits, and ascertain that the patient or her surrogate understands.

After understanding all those conditions, some people have created a concept of "emergency consent." This is not a legal doctrine, but a rule of thumb that says when it is a true life-or-death emergency, and the patient is incapacitated, you should proceed on the assumption that the patient would want you to save his life, and not delay your actions while trying to get consent. While such a situation is rare in the ER, it is the norm in many trauma bays.

Ten Pearls About Informed Consent

1. Consent that is not informed is not informed consent.
2. Consent is a process, not a piece of paper.
3. "Consenting a patient" is impossible, a contradiction in terms—it is the patient that does the consenting, not the surgeon.
4. The original purpose of informed consent was to protect the patient, not the surgeon. That hasn't changed
5. If 100 % of your patients agree with you, you may be giving biased information; in other words, an occasional refusal of your recommendation can be a sign of a fair process.
6. If you let others get your consents, they may not be as thorough as they should be. Delegation is dangerous, unless you are certain they can do it as well or better than you can. To do it well requires equal parts knowledge and communication skills, both of which require training and practice to do well.
7. If a patient does not speak English, communication can be more time consuming. But ethically the same requirements hold. One should use trained interpreters whenever possible, and phone translators and/or TTY as a fallback option. Family members are not a good option unless there is no other choice (e.g., a very rare language and little time) because of the violation of confidentiality that will inevitably result, as well as the lack of sophisticated understanding that can be expected.
8. Each patient comes from a different culture, and one must be sensitive to the variations in assumptions. It is up to the patient to decide which cultural norms to live by. The only way to discover this is by talking to the patient, not the patient's parents or the patient's adult children. There can be very large differences in cultural norms between first- and second-generation Americans.
9. All doctors come from a culture too. So every doctor–patient interaction can be thought of as trans-cultural. You might be from another country than the USA, so American patients might be a little foreign to you. Even if you are from the USA, your 10 or more years of training (including some premed years, med school, residency, and fellowships) can be thought of as entering "the culture of surgery," something you must be able to translate or interpret every time you talk to a patient.
10. Patients who do not want to know anything about their own treatment are rare. But they do exist, and have the right to defer the information and decision-making to someone else. It is then incumbent on them to identify a person, using the same criteria as any patient choosing a proxy or durable power of attorney for health care. In those cases, you may help the patient by reminding them they do not need to choose their spouse if this would be a difficult responsibility for them; they can choose whomever they think is best suited to know their wishes and most likely to carry them out. (You might even warn them to not choose someone who cannot live without them if they are contemplating the possibility of someday wishing to withdraw life-support. And decisions like that, including DNR, is a part of most hospital deaths today.)

Final Observations: Culture and Consent

The USA is one of the most diverse countries in the world. In general, this is a wonderful fact. But it can lead to some difficulties with informed consent. Here, then, are the four final pearls:

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Advance Directives

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Gary T. Marshall

Acute care surgeons are working with patients at the end of their lives with greater and greater frequency. The elderly have been the most rapidly enlarging segment of the population over the last century due to the combined effects of the "baby boom," the population growth during the 2 decades after World War II, and the increase in average life expectancy. This trend shows no signs of abating, and with the blessing of increased life span has come the burden of chronic disease and disability [1]. According to Medicare data, nearly one third of Americans underwent surgery during the last year of their life. Further, 18 % underwent procedures in the last month of life, and 8 % during the last week of life [2]. Clearly it is important for the acute care surgeon to understand the issues surrounding end-of-life care. These include Advance Directives and "Do Not Resuscitate" orders. In addition, we must have the skills needed to discuss end-of-life care with patients and their families with honesty and compassion.

This chapter will review the history of advance directives, the Do Not Resuscitate order, and the current forms these now take. Application of these orders in the operating room and the intensive care unit setting will be discussed. Attention will then be directed to working with patients and families.

History

Examination of the history of cardiopulmonary resuscitation (CPR) and the "do not resuscitate" (DNR) order is necessary to understand how medicine has arrived to where it is today. CPR by closed chest massage was developed in the early 1960s for patients experiencing arrest secondary to anesthesia. It proved to be a simple and highly successful procedure in this setting, resulting in hospital discharge rates of 70 % [3]. Following publication of initial experiences, resuscitation by closed chest massage was expanded to include nearly all hospitalized patients. Medical patients presented a sharp contrast to the initial results. In these patients receiving CPR following cardiac arrest, successful return of circulation occurred in 41 % of patients, and only 18 % were discharged from the hospital [4]. Further retrospective studies in the elderly reported even more dismal outcomes [5].

In 1976 the first hospital policies on DNR orders were developed and published in the literature. The growing body of evidence showing poor response to resuscitative efforts led to the next trend in hospitals—the "slow code." Also dubbed the "chemical code" and "show code" among other euphemisms, this involved the delivery of less than full attempts at resuscitation. At other times staff members would simply refuse to call a "code blue" in those situations they believed CPR would have no benefit. Inconsistent and institution specific methods became common, including verbal orders passed from provider to provider, and initials or markers left on patient's charts indicating that resuscitation should not be undertaken. Growing controversy developed centering on issues of inadequate advanced decision making, lack of informed consent, poor documentation of procedures, and lack of accountability for the events as they transpired [6].

It was out of this confusion and inconsistency that medical societies developed guidelines. In an effort to standardize care the American Medical Association (AMA) recommended that any decision to forego resuscitation attempts should be clearly documented and communicated. The statement went to make clear that CPR was meant for the treatment and prevention of sudden, unanticipated deaths, not for those patients expiring due to terminal and irreversible illness [7]. Following this, explicit DNR policies developed with the goal of promoting patient autonomy by allowing self-determination. Open discussion of the options for resuscitation could occur with patients and their families prior to the event, and the results of these discussions communicated directly and openly between the staff [6].

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_44

Autonomy has always been at the heart of the matter in the ethical realm, and assuring that the patient's wishes are placed ahead of the physician's wishes. In 1983 the President's Commission for the Study of Ethical Problems in Medicine published an influential report challenging many of the predominant beliefs of the time. This report concluded that CPR and resuscitation would be the appropriate and desired response for all arrests. With this CPR became the default standard of care, and all patients were presumed to have consented implicitly [8]. State statutes regarding DNR orders were first enacted in New York in 1988. Under these laws, every patient was presumed to have given informed consent for CPR. For competent patients, a physician could enter a DNR order only after obtaining the patients express consent to do so. Surrogates could consent to the DNR order on behalf of patients who had become incapacitated provided that the patient was terminally ill, in an irreversible coma or if CPR was deemed medically futile. Providers were legally protected for following these orders to withhold care, and also for providing CPR in good faith when the provider was unaware of the DNR order. Since the New York action nearly all states have followed in the development of statutes allowing for living wills, and most have enacted laws regarding the use of proxy or surrogate judgment [6].

In 1991 the Patient Self-Determination Act (PSDA) was passed. This came about for numerous reasons, most notably the perception that ethical standards in end-of life care were needed. This was based on evidence that age, sex, diagnosis, physician specialty, medical institution, and even hospital unit were all associated with variability in patterns of prescribing DNR [9]. The PSDA required that any healthcare institution receiving federal funding of any type must inform their patients about their rights in medical decision making, including the right to refuse CPR and other life sustaining care [10].

Current Advance Directives

Current advance directives serve to direct care in the event that the patient is incapable of making his or her own decisions. Initially, the three letters "DNR" were simply entered in the chart. This lacked the ability to communicate exactly which procedures were to be withheld. In addition, many times the care team confused DNR to signify that other procedures and treatments be withheld [11]. In response, procedure-specific forms were developed in hospitals. These went on to specify exactly what interventions should or should not be performed, serving to increase clarity by giving very specific direction to caregivers. This type of order is best suited for the patient on the hospital ward, where a large number of caregivers may be involved and communication may be difficult due to interruptions in the continuity of care [12]. These lists have grown to include chest compression, cardioversion, vasopressor medications, dialysis, blood and blood products, intubation, enteral nutrition, antibiotics, and others. These changes within the hospital have led to changes in the advance directives patients develop on their own and present with as they seek care. Advance directives documents usually specify which treatments the patient desires and consents to and name a surrogate decision maker. These directive documents take on numerous forms, and may range from very broad to highly specific, and may even dictate that all measures be taken in the event of cardiac arrest. When overly broad in nature, definitive guidance is rarely provided, and when too specific, the actual clinical circumstances may not be addressed [13]. Showing the confusion that can arise, a recent study of physician's interpretation of advance directives and code status was conducted, only 22% of physicians identified "full code" as the status for a typical living will, and only 36% correctly equated "full care" with a code status of DNR. These decisions were improved by the addition of context and specifying code status on all of these documents, but there is clearly a need for improving these documents to assure safety and proving the appropriate care [14]. Further adding to the confusion, patient preferences are stated with regard to a particular outcome when it is certain to occur, but fail to address situations in which the functional outcome is uncertain. Despite these drawbacks, advance directives provide benefits. They can alleviate the burden of decision making for the family, and they can lay the groundwork for end-of-life discussions between the physician and family [15].

DNR Orders in the Operating Room

There are numerous barriers to the implementation and honoring of DNR orders in the operating room (OR). These include anesthes, the OR environment and culture, physician attitudes, and legal concerns. The first area in which conflicts arise lies in the very nature of anesthesia and surgery. Endotracheal intubation is required in nearly all major cases, yet this may be excluded in some highly specific advance directives. Outside of the OR vasopressor administration may be considered heroic measures, however it is commonplace in the operative environment. It may seem logical to draw the line at CPR or electrical counter shock when limiting care, but in the OR all events are witnessed, and may carry a better prognosis than events occurring outside the OR [8]. It is easy to see how the line might be blurred in determining where routine anesthesia care ends and resuscitation begins, especially for a readily reversible condition.

Another barrier arises from the physician's own interest in providing resuscitation. Any death in the OR is generally viewed as a bad outcome, and the culture tends to assume human error to be at play. In addition, physicians and anesthesiologists bear a strong and dedicated sense of responsibility

for their patients and what transpires in the operating room. When iatrogenic complications arise due to anesthesia and surgery the physicians feel the natural response is to take all measures necessary to reverse the situation [16]. Another physician factor contributing to the problem may be the physician's lack of understanding of the patients desire to forego life sustaining therapies in the OR and perioperative period [17]. The lack of understating arises due to the differing values upon which the patient and physician base their decision. The physician gives priority to the imminent death, while on the other hand, the patient is basing decisions on their functional status and longer range outcomes [18].

Finally, legal considerations impede physician from honoring patient's advance directives to withhold resuscitation [19]. Physicians are frequently concerned with potential liability, especially when death is iatrogenic or in the operative setting. Concerns may arise over whether the family shares the patient's wishes to withhold treatment, or if they have changed their minds. These fears persist despite the fact that few cases have arisen or been successful as a result of a physician honoring an advance directive. Conversely, there have been successful legal cases in which hospitals and physicians were deemed liable for damages resulting from resuscitation against the wishes of the patient and family [20]. Case law is difficult to interpret. Cases are frequently highly specific, making generalization to broader practice difficult. In addition, case law is applicable only in the jurisdiction in which the case was decided. The best recommendations for minimizing legal issues are development of an institutional policy taking local precedent and culture into consideration, and of course careful and thorough documentation of the patient's condition, prognosis, wishes, and all conversations that occur between physicians and patients or their surrogate decision makers.

Rather than rescinding DNR orders in the OR, a policy of "required reconsideration" has developed. This entails the patient or surrogate, surgeon, and anesthesiologist discussing and reviewing the advance directive together. This was formalized by the American Society of Anesthesiologists (ASA) in 1993. Following this discussion, the DNR order could be formally rescinded with the patient's informed consent; it could be left in place, specifying the patient's goals of care; or it could be left in place with a detailed list of exactly what procedures the patient would allow [8]. The American College of Surgeons (ACS) echoed the views of the ASA. In their statement, they also stated that the automatic reversal of DNR status in the OR removed the patient from appropriate participation in the decision process, and that inappropriate management in the perioperative setting might result [12]. They ACS went on to recommend that topics should include new risks and benefits associated with the proposed procedure, the patient's treatment goals, and an approach to dealing with life-threatening problems [21].

As many as 15% of patients with DNR orders will undergo surgery, either related to their pre-existing illness or for treatment of unrelated conditions [22]. The procedures offered may prolong life, ease suffering, or improve quality of life. Many of these procedures fall within the scope of acute care surgery, and examples may include the repair of pathologic fractures, tracheostomy and feeding tube placement, treatment of bowel obstruction, vascular access, and a wide variety of others [8, 23]. A study of patients with DNR orders in place showed that the presence of the order did not affect the likelihood that patients being considered for surgery would undergo the procedure considered. In only 18% of the patients was the DNR order reversed. Half of the patients undergoing surgery with a DNR order in place were discharged from the hospital, and 44% were still living 2 months following hospital discharge [23].

A Practical Approach to Working with Patients

When preparing for a high risk surgical procedure, patients may present with advance directives already in place. These can provide a framework for discussions involving care in the event of complications and the need for prolonged care in the intensive care unit (ICU). Surgeons' attitudes to these advance directives vary. Although some benefit is perceived, surgeons have a mistrust in the documents, believing that many represent a disconnect from the true wishes of the patients. Many find the documents vague or misleading, believing the information gathered from a thoughtful conversation to be far superior in determining the patient's true wishes. Finally, surgeons express a belief that their hands might be tied by these directives limiting their ability to perform the procedure [24].

The application of advance directives extends to more than the operation itself, but to the post-operative period as well. In preparing for high risk procedures and concept of surgical "buy-in" has been described. This is the complex process whereby the surgeon and patient negotiate the commitment not only to the operation but to post-operative care as well. Surgeons expect that patients are committing to all necessary care including prolonged support in the ICU as part of a "package deal" [25]. Surgeon's will often create an informal contract with the patients describing agreed upon limitations of aggressive care, however only a small proportion will document these agreements. Many of these agreements involve a specified duration of therapy such as mechanical ventilation. Whether this represents the true goals of the patient or simple acquiescence to the surgeon has not been determined [26]. Analysis of these discussions has been performed in which the surgeon believes that surgical "buy-in" has been achieved the majority of the time.

Surgeons tend to discuss high risk operations as "big surgery" and discussed a need for commitment from both the surgeon and patient, however the use of prolonged life-supporting treatment is rarely brought up, and patient's rarely asked about these issues. This results in failure to discuss the patient's feelings about these treatments. Surgeons tend to assume that the patient has agreed to all post-operative care despite the lack of an explicit conversation [27].

The key to resolving the complexities surrounding perioperative resuscitation is communication. When discussions occur the provider may learn the patient's rationale for the DNR order. Frequently the patient is far more concerned with the quality of life after CPR, not before. When the surgeon understands the patient's goals and fears, a contingency plan may be developed and implemented. Looking into these concerns may show that the patient is afraid of a long stay in the ICU, or in losing independence and not wanted to spend the remainder of their life in a nursing home. By learning these fears, the surgeon and care team may adjust therapy to address these concerns. Surrogate decision makers and the anesthesiologist should be included in these discussions [5]. The addition of the surrogate will assist in ensuring that patient's wishes are respected, as it is not infrequent that the surrogate and the patient may not share the same decision making [28]. During these discussions three options are available: rescinding the DNR order, providing limited resuscitation with a procedure-directed DNR order, and providing resuscitation with a goal-directed order.

The first option is to rescind the DNR order and provide full resuscitation regardless of clinical circumstances. This avoids the question of determining what exactly constitutes resuscitation, which may prove difficult during anesthesia. In addition, it frees the treating team to act in the event of an easily reversible or iatrogenic arrest, such as an arrhythmia on induction of anesthesia. Chances for an acceptable quality of life are better during these witnessed arrests [29], and care may be withdrawn later if the outcome is unfavorable. Despite all of the concern for ethics, this is a viable and appropriate course of action so long as the patient is involved in the decision.

A procedure-directed DNR order may be developed by the patient and surgeon. In this type of order patients may specify which procedures and interventions they will consent for and those they refuse. This is appealing to some patients, as they prefer the control of being able to dictate exactly what procedures will, and more importantly, will not be performed. This imitates the type of orders most commonly employed on hospital wards. The patient may be presented with a list of possible interventions. Frequently included items are intubation, post-operative ventilation, CPR, defibrillation, vasoactive drugs, and placement of invasive monitoring devices. When adapting these lists and preparing for the OR environment, interventions deemed mandatory for anesthesia are discussed with the patient, as they may not be refused [12]. These procedure-specific orders are clear and easily understood, but they do not allow for the all clinical circumstances which may arise, or those that may be difficult to document and define preoperatively [30].

The final approach to DNR orders in the OR is to take a goal-directed approach. In this approach the physician is left to determine which specific procedures should be performed if cardiac arrest or instability occurs. In order to supplant his own judgment for that of the patient, the surgeon must know the patient's concerns regarding resuscitation and outcome. Are they worried about pain, neurologic damage, loss of independence, or the need for further surgery and procedures? By knowing these values, the physician is able to respond appropriately. For example, if a patient sustains an arrhythmia on induction that requires brief support with CPR, it could be administered, as outcome is likely to conform to the patient's wishes. Conversely, if the patient experiences a massive intra-operative myocardial infarction and arrest, CPR could be withheld, also supporting the patient's values. This approach to DNR is perhaps the most in line with preserving patient autonomy and allowing values held by the patient to be considered. The translation from theory to practice is not quite as easy. First, the surgeon and patient must understand each other, and this requires time that is not always present in emergency situations. In addition, the person responding to the arrest situation should be the same as the person who had the discussion with the patient. Clearly this is not the case for patients on hospital wards, but the OR, better than any other location, provides for this continuity in care. When the continuity of care cannot be preserved, or when the trust required between patient and surgeon is not present, it is best to rely on a procedure-directed approach. When the goal-directed approach is taken documentation in the medical record is essential. This will usually take the form of a descriptive narrative, detailing the conversations that have occurred, and the preferences the patient has expressed for goals of care [12, 30].

Discussing End-of-Life Care with Patients

In preparing for these conversations it is important to understand those factors that are considered important by patients, family members, and how these may differ from those of the physician. As patients consider various therapies they typically take three things into consideration: the treatment burden, the treatment outcome, and the likelihood of outcomes. When outcome is likely to be favorable, patients are typically willing to tolerate a greater treatment burden, however this willingness diminishes as outcomes show only marginal benefit. Patients cite quality of life outcomes such as prolongation of inevitable death, dependence on machinery, functional

dependence, and excessive fatigue and pain as important factors in their decisions. Other non-medical concerns, such as becoming a burden on the family or society, influence these decisions as well [31]. Preparation for death, both by the family and the patient, is valued and important to the family and patient, however, physicians tend to place less emphasis on this aspect of end-of-life care. Patients also appreciate being told the expected course of their disease, they symptoms they will experience, the time course, and what can be done for them. Additionally, a sense of life completion is desired by patients, and adequate, timely communication and preparation may allow this to mature [32, 33]. Achieving the last of these goals may be very difficult for the acute care surgeon. Our practice, by its nature, frequently encounters patients in a situation that is a clear departure from their usual state of health. While those patients receiving palliative care are aware that they are terminally ill, the patient suffering an acute catastrophic event has not had the luxury of time for preparation. Understanding the value of these aspects of the end of life will help to guide conversations and treatment planning. Specific concerns can be determined and addressed. Communication should begin early with patients once the treatment team realizes death is imminent. Despite nearly a majority of physicians realizing that death is imminent in the inpatient setting, only a small percentage will communicate this with the patient. As the patients approach death their level of consciousness varies, and delay in communication until death is a certainty denies the family and patient adequate time to prepare [34].

During the end-of-life discussions the patient or their surrogates may respond by stating that they want the physician to do "everything." This is often difficult for the physician, who frequently takes this request at face value. This may result in launching into a course of action that is burdensome to the patient and family, and unlikely to result in a positive outcome. Rather, the physician should look further into what is motivating the request. First, the clinician must discover exactly what "do everything" means to the patient. Frequently, the patient only wishes to undergo all treatments that offer a reasonable chance of benefit with a tolerable amount of treatment burden. The patient may have unspoken concerns underlying the request. Frequently patients remain fearful and anxious. They may have incomplete understanding of their condition, or simply desire reassurance that all reasonable options have been pursued. Spiritual and family concerns may also play a role. Taking time to understand the hopes, fears, and goals of the patient will allow the concerns to be addressed and a reasonable treatment plan developed. A general framework for these discussions first involves development of a philosophy of treatment, determining whether the goals are for full and aggressive intervention, or more for treatment likely to provide benefit with tolerable burden, or to limit therapy to comfort measures. The physician should recommend a plan in support of the philosophy developed. At this time recommendations setting limits on CPR can be given. Often, treatments can be continued, but DNR orders placed if the outcome is likely to be unsatisfactory. This is an emotional decision, and physicians must attend to the emotional responses and seek to resolve any disagreements. When accord cannot be reached, and the family or patient insists on full resuscitation, the physician should adopt a harm reduction strategy and continue to use good clinical judgement. CPR can be initiated, but discontinued after one cycle if it fails. Different than a "show code," this is a full attempt at resuscitation, but clinical judgement allows the code to be terminated. The family can be assured that "everything was done," while avoiding the ordeal of a futile code for both the patient and the medical staff [35]. In applying this strategy to the surgical patient, especially when preparing for a high risk emergency operation, the surgeon will often know the patient will likely not survive to hospital discharge. This is an excellent time to discuss with the patient or family exactly what doing everything will involve, and what the outcome is likely to be. If multiple operations, feeding tubes, tracheostomy, and discharge to a nursing facility or long-term care facility are the most likely outcomes, this needs to be discussed. Many times, once the family or patient knows surgery will involve a long ICU stay and ventilator dependence is the most likely outcome, they will choose to forego treatment. This often avoids the difficult and futile operation followed by withdrawal of support in the immediate post-operative period. Foregoing surgery might allow the patient and family time together and avoid suffering. As always, providers must assure all involved that not having surgery does not mean no treatment. Treating pain and anxiety becomes the focus of care.

The treatment of many acute surgical patients frequently transitions to the ICU, and it is here that questions and decisions regarding advance directives play an increasing role. Surgical technique has improved to the point where nearly all patients can survive the initial operation. Unfortunately, many remain critically ill or fail to respond to surgery as hoped. Physicians are vital in the guidance of end-of-life care. The majority of physicians still rely on the family to make decisions yet the same also acknowledge that families and surrogates are rarely in an appropriate emotional state to make these decisions. Others may rely more on the advance directive. In making these decisions, surrogate decision makers are felt to honor advance directives only a little over half of the time. Physicians tend to rank quality of life as major factor in making decisions, but rarely consider costs [36]. Patients and their families often insist on prognostic information, both in terms of length of life in terminal illness and in likelihood of death and other possible outcomes. This is a constant challenge to physicians. Multiple studies have demonstrated that physicians across all specialties tend to be

overly optimistic. The accuracy does not increase with greater patient contact [37]. It has been found that although they consistently over estimate survival physician predictions do correlate, showing that physicians are able to discriminate between those closer and further from death. Accurate predictions, both long and short term, are needed to allow patients to achieve a "good death" [38].

Clear communication is difficult to achieve, especially in acute situations. Studies have documented that physicians and patients or their caregivers frequently disagree on whether conversation included discussion of the possibility that the patient may die, or on the anticipated life expectancy. This is due to both physician and patient factors. Physicians tend to be uncomfortable with prognostication, and may withhold information, or avoid the discussion. Patients and their caregivers may be unprepared to discuss issues around death, or may simply not understand the information presented [39]. To avoid misunderstanding physicians must be very clear, avoiding euphemisms and highly technical terms. Do not avoid the words death and dying. The information should be presented during multiple encounters and repeated as needed to assure that message is delivered and received. It has been shown that allowing more time for family conferences, held in a proactive manner, and allowing the family members adequate time to talk may lessen the burden of bereavement [40].

The Family Meeting

As fewer than 5 % of ICU patients are lucid enough to take part in treatment planning, clinicians must rely on decisions made by family members and other surrogates. The first step in preparing for family discussion is to identify the surrogate. Most states in the USA have a legal order of priority. First, any court appointed guardian is given priority, followed by any named Durable Power of Attorney for Health Care, and then to family members. Usually the order is spouse, then parents, adult children, and finally siblings. In practice, the decision is usually made by all of those with close ties to the patient, and develops over several meetings. Clinicians should aim for consensus, as this can usually be reached [41].

The family meeting begins with adequate preparation. First, all data must be reviewed. This should include medical history, treatments, responses, and disease course. When sub-specialists are involved, their input should be sought after, and elements of prognosis incorporated into the planning. If any prior discussions regarding end-of-life care have taken place, or if directives were made prior to admission, these should be reviewed. Before beginning any meeting the message should be developed. Once prepared the meeting should be arranged with the family, spiritual leaders if needed, and the medical care team. While it is good to include many voices, care must be taken to not overwhelm the family. Having nurses and social work present may help, as these are often better known to the family and provide a familiar and reassuring face. The meeting goals and leader should be decided in advance, and possible sources of conflict should be identified and a response developed. Finally, a quiet place should be used, unless the patient is able to participate and the surrogate desires this [42, 43].

Once gathered, the meeting is usually begun with introductions of all involved. Assure the family that these meetings are a routine part of all patient care. Next, an attempt should be made to explore the family's understanding of the patient's illness and prognosis. Following this a clear statement of prognosis should be given. This usually follows a medical review of what has happened and where things stand now. Clinicians must take care not to give too much medical information, and make certain the message is not misleading. If death is imminent this needs to be said, explicitly. Uncertainty should be acknowledged, but the message must not be diluted. Once complete, remain silent. Allow the family to grieve, ask questions, and express themselves [44]. This last component is perhaps the most difficult for physicians. Most discussions with families involve the physician speaking nearly 70 % of the time. They frequently miss opportunities to learn about the patient, their values, and concerns. Increasing the amount of time spent listening while the family is given time to speak has been shown to increase family satisfaction [45].

Conflict may arise during family discussions and communication may break down. The leader must recognize when conflict occurs and work to meet the needs of the family. The first source of conflict is usually lack of information. This may be the result of inaccurate understanding of prognosis, inconsistent information given by various providers, confusing information, excessive information from outside sources, genuine uncertainty regarding prognosis and outcome, and finally language and cultural barriers. Confusion over the goals of care may manifest in unclear and contradictory orders such as performing CPR, but not intubating a patient. The priorities placed on the treatment of the disease and the treatment of discomfort may differ. Situations in which an acute condition, such as urosepsis, occurs in a terminal cancer patient may also confuse the goals of care. Emotions such as guilt, anger, fear, and grief lead to conflict as fell. The dynamics between the team and the family and the dynamics within the family itself may be problematic. The family may have internal conflict of decisions, be dysfunctional, or simply lack the ability to make decisions. The family may also be placed in the center of disagreements between the various consulting teams. Finally, there may be a real difference in the values held by the clinician and the family. Clearly, conflict may arise anywhere and at any time. It is important to understand these sources of conflict, identify the problem,

address the cause, and continue to bring the goals of the clinician and the family into alignment [46].

Developing trust with the patient and family is essential for the delivery of quality end-of-life care. This is challenging in the short amount of time during an acute illness and hospitalization. Suggestions for the development of a trusting rapport with patient and family include encouraging them to talk and allowing them tell you about themselves, their values, and their understanding of their disease. Take the time to recognize the patients concerns, while being sure not to insult or contradict other health care providers. All errors that are made should be acknowledged, avoiding excuses. Throughout the discourse it is important to remain humble and demonstrate respect for the patient, the family, and their wishes. Finally, attempts to force a decision are discouraged. If a decision cannot be reached, allow the family to discuss amongst themselves, process what they have heard, and simply plan for the next meeting [47].

During these meetings strong emotions are provoked, and the physician must be prepared to deal with them appropriately. Empathy from physicians helps family members and is found to be strongly supportive and is associated with family satisfaction. When strong emotions are observed, first acknowledge the emotion. Once this is done the emotion should be legitimized as appropriate and normal given the circumstances. Move on to explore more about the emotion and what specifically is causing it. Expressions of empathy are important, but should only be made if legitimate. Finally the conversation can be turned to exploring particular strengths and possible coping strategies [48].

During the course of meetings and discussions it is important the clinician make recommendations. There is a tendency for physicians to present a laundry list of options and possible outcomes as if all were equal. Family members want to know what the doctor thinks is best [43]. It is especially important when the decision is to withhold or withdraw life support. The family member should not be left feeling as if they had "pulled the plug," especially when is unlikely that any further treatment would have been of benefit [41]. As families are asked to make decisions regarding the termination of life support clinicians may ease this decision. It is important to bring the patient's desires into the discussion, and reinforce that the surrogate is not being asked what he or she wants, but rather what the patient would want if they could speak for themselves. These decisions should not be forced upon a family, especially before they have had time to prepare. This may set up an antagonistic relationship and erode trust. It is important not to argue over facts, repeating them over and over. One of the most common fears held by family members is that withdrawal of support will be withdrawal of care. It cannot be emphasized strongly enough that the patient will continue to receive the full attention of the treatment team. The goals of care will simply be comfort-oriented, and this will be the utmost priority [49]. When discussing Advanced Cardiac Life Support (ACLS) it should not be broken down into component parts, but rather treated as a package. This may avoid incongruent orders, such as the "chemical code only." Finally, at the end of any meeting the decisions and agreements reached should be repeated, questions answered, and further meetings planned. If the decision has been made to withdraw support, then the family should be educated about the process, allowed to gather all loved ones, and offered additional support if desired [41].

Time-Limited Trials

A time-limited trial of therapy may be appropriate in setting the course of medical treatment to be pursued. Time-limited trials are agreements made between the patient, surrogates, and physician to use treatments for a set amount of time and then to assess the patient's response. This allows the patient to both avoid giving up all treatment options and avoid the burden of on-going treatment should it prove unsuccessful. If improvement is noted, then disease-directed therapy may be continued. If the course deteriorates, support may be withdrawn and comfort-oriented measures initiated. In considering a time-limited trial, the conversation begins as usual by reviewing the patient's condition and prognosis, and follows with a discussion of treatment goals. A course of care is then determined and objective measures of improvement or deterioration defined as well as the time frame to be considered. Potential actions are then proposed at the end of the trial. These plans are not meant to be binding, but to allow for adaptation as the clinical picture changes. Communication amongst all caregivers is important, and continuity needed to carry these plans out. The time used may allow the family and patient to come to terms with the situation at hand, and to be assured that all reasonable efforts have been made [50].

Emergent and acute surgical procedures fit well into time-limited trials with patients. Decisions may be made to go ahead with high risk procedures, but to agree that should operative findings be so catastrophic that an acceptable quality of life not be possible the operative efforts will be terminated. At other times, the patient and family may agree to proceed with surgery, but then withdraw support if the ICU course becomes prolonged, multiple organ system failure worsens, or ventilator weaning becomes unlikely. Key markers of failure such and return trips to the OR, need for tracheostomy of feeding tube, or institution of dialysis should be defined. These are concrete events and help to make the situation clear. In addition, many patients will have discussed these specific treatments and expressed their wishes regarding them. These trials allow for the operation to proceed when a poor outcome is likely but unclear with a clear plan to change strategy if efforts prove unsuccessful.

Futility of Care

Cases will arise in which the physician and the family cannot come to agreement, and the physician may feel that all further treatment is futile. At the root of this problem may be differences in core values, and the family may be willing to accept a burdensome treatment that the physician would not want for themselves. The physician should question and determine whether the surrogate is employing substituted judgement, and speaking for the patients best interest and wishes, or inserting their own wishes and values. In most circumstances agreement can be achieved between the doctor and the surrogate with time [51]. When they cannot resolve the conflict, the physician should avoid acting unilaterally to limit care. There is a risk of legal action, and although rarely successful, law suits are expensive [52]. The legal system has failed to provide clear guidelines regarding this issue, but other options are available. Ethics committees provide an outside source of action. Most committees act in an advisory capacity, but may make decisions in some states. Texas allows ethics committees to withdraw treatment deemed futile after 10 days if no other facility or provider will assume care. Experience with this extra-judicial process has proven successful in resolving these conflicts [53]. Other resources for the family and physician include palliative care services, pastoral services, and patient advocates [54]. Most institutions have policies in place in accordance with local legal statutes, and although frustrating, the physician should remember time is an ally in these situations, and outside assistance is available. Until resolution can be achieved, treatment should continue.

Results of Advance Directives

The results of advance directives have been debated, and at times some have declared them to have had been a failure [55]. This is not the universal belief, and they have had an impact. One recent review suggested that nearly two thirds of patients that required decision making at the end of life had living wills in place. All but a small percentage of these expressed wishes for limited or comfort care, and in the vast majority of these cases these wishes were honored. When a surrogate was named the patients were less likely to die in a hospital and to receive all care possible [56]. The quality of end-of-life medical care has been improved with advance directives. Patients with advance directives are less likely to die in the hospital. They have less frequent feeding tube placement, and avoid mechanical ventilation. Despite this, patients still have concerns for unmet pain needs and emotional support for both the patient and family. Room for improvement still exists [57].

End-of-life conversations can benefit both the patient and their caregivers. When these conversations take place there has been no observed increase in depression or worry. Similar to the results of advance directives, less use of aggressive care follows, with reduced ICU admission, and reduced use of mechanical ventilation and resuscitation. When these aggressive measures are used the quality of death is perceived as worse overall. In addition, the family members of those involved with aggressive treatments have a significantly higher risk for major depressive disorder. Hospice referral, especially when early, results in better quality of death for the patient and better care-giver quality of life in follow-up after the loss of a loved one [58].

Overall medical expenses in the last year of life continue to remain high nationally, and this trend has been consistent over the last decade despite changes in the delivery of medical care [59]. There has been some improvement when end-of-life conversations occur. Having these conversations has been associated both with significantly lower health care costs at the end of life, and a higher quality of death [60]. In the intensive care unit setting the incorporation of a communication team to work with families of patients with imminent death has been shown to significantly reduce the length of stay in the ICU and the hospital, and to significantly reduce the costs of treatment [61].

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EMTALA Review

45

James J. McCarthy

The United States Congress passed Emergency Medical Treatment and Active Labor Act (EMTALA) in 1985. By doing so, it defined for the first time a standard of medical care and legislated how hospitals and physicians were required to practice medicine. With the passage of EMTALA, Congress effectively defined hospital emergency departments as a community resource and essentially created a federal right to emergency care [1].

> People have access to health care in America. After all, you just go to an emergency room.
>
> President George W. Bush [2]

This chapter describes the history of the EMTALA legislation, its change over time, its current state, and implications to physicians and hospitals providing emergency care. The subject of EMTALA could easily fill an entire book; therefore, this chapter specifically focuses on the responsibilities of the on-call physician and their obligations under EMTALA.

History

Initial Law and Intent

After being stabbed in the head, Eugene Barnes was rushed to Brookside Hospital in San Pablo, California, on January 28, 1985. The emergency physician and staff promptly attended to him, and, as part of his evaluation, a computed tomography (CT) scan of the brain was performed, which revealed an emergent neurosurgical condition requiring immediate intervention. The emergency physician caring for Mr. Barnes contacted the on-call neurosurgeon who refused to come in; a second neurosurgeon (also on staff at Brookside Hospital) was contacted. He also refused to come in, as he was not on call. Over the next several hours, attempts were made to transfer the patient to two other facilities, which both refused, finally San Francisco General Hospital agreed to accept the patient but only if the emergency physician accompanied him in transport. Upon arrival Mr. Barnes was taken immediately for emergency surgery but, unfortunately as a result of his injuries, died 3 days later. The details surrounding his death attracted national media attention [3] and, as expected, generated a public outcry. With increased scrutiny over the next several months, public outrage began to grow as multiple other stories with similar themes came to light [4].

The addition of the "active labor" language in the EMTALA statute was largely driven by the case of Sharon Ford in November of 1985. Ms. Ford, in active labor, presented to Brookside's emergency department where, prior to any medical evaluation, it was determined that she was a member of a Medicaid health maintenance organization (HMO). As a result, she was not seen or evaluated but rather referred to Samuel Merritt Hospital in Oakland (the regional Medicaid HMO contract hospital). Upon her arrival to the labor and delivery suite at Samuel Merrit, her registration information could not be located in the computerized records of those covered by the HMO—this was later determined to be due to a delay in the State of California updating its records. As a result, despite the fact that she was noted to be in "active labor," she was transferred to Highland General Hospital—the local county facility where shortly after her arrival her baby was delivered stillborn [1].

These horrific stories in the lay press coincided with increasing reports of "patient dumping" in the medical literature [5, 6]. With mounting public frustration, a legislative response was perhaps inevitable.

These events at Brookside hospital and in northern California caught the attention of local Congressman Fortney Stark who championed the initial legislative effort behind EMTALA. The initial proposed legislation was focused on

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L.J. Moore, S.R. Todd (eds.), *Common Problems in Acute Care Surgery*, DOI 10.1007/978-3-319-42792-8_45

"patient dumping" and had extremely harsh proposed penalties, with physicians found to have violated a patient's EMTALA rights being subject to felony charges. The proposed penalties for physician in violation were up to 5 years in jail and up to $250,000 in fines per occurrence. After measured discourse, this language and respective penalties were softened considerably during the legislative process [7].

In response to growing public pressure and media attention, Congress passed the Emergency Medical Treatment and Active Labor Act (EMTALA) as part of the Consolidated Omnibus Budget Reconciliation Act (COBRA). President Ronald Reagan signed it into law on April 7, 1986 [8]. Interestingly and perhaps troublingly, EMTALA was passed with very little time for public comment and with no formal hearings in either the US House or the Senate [9]. Regardless of the process, effective August 1, 1986, any person presenting to an emergency room, in a hospital that participated in Medicare, had a right to emergency medical care.

The initial intent of EMTALA was clearly to prevent "patient dumping" by creating antidiscrimination legislation to protect those without insurance who could not afford emergency care services. This new legislation required that all patients be evaluated and that those with an emergency medical condition (EMC) be "stabilized" prior to transfer or discharge. There was initially no requirement for hospitals to accept transfers. Perhaps in some part due to the very compressed legislative process, there was no consideration in the EMTALA regulations as to hospital capabilities or requirements for on-call coverage. This oversight resulted in continued medical disasters as hospitals could simply not have "call coverage" and tertiary-care hospitals (with on-call physicians) could still refuse to accept patients from hospitals lacking subspecialty coverage.

The US Congress corrected this oversight in 1989 with an amendment to EMTALA, which required hospitals to have physicians on call to stabilize emergency cases and to require "higher-level of care" facilities to accept patients in transfer when they had the ability to care for the patient [10].

The result of the 1989 revision left hospitals and physicians with several clear responsibilities under the law.

Hospitals' Obligations

1. Provide an appropriate medical screening exam (MSE) to determine if an EMC exists.
2. If an EMC is determined to exist, hospitals have a duty to either provide stabilizing medical treatment or, if they lack the capability to stabilize, transfer the patient to an appropriate facility.
3. Hospitals with specialized capabilities must accept patients requiring specialized care if they have the capacity to treat them [11].

"On-Call" Physicians' Obligations

1. Respond to the emergency department to help stabilize a patient with an identified or suspected EMC.
2. Accept appropriate transfers when transfers are requested by other facilities that are unable to address a patient's EMC.

The initial legislation also defined the penalties for hospitals and physicians. Though toned down significantly from Congressman Starks' initial proposal, the penalties still carried considerable weight.

Hospital Penalties

1. Fines between $25,000 and $50,000 ($25,000 for hospitals with fewer than 100 beds) per violation.
2. Termination of its Medicare provider agreement.

Physician Penalties

1. Fines up to $50,000 per incident.
2. Excluded from Medicare and Medicaid programs.

In addition, patients who suffered personal injury from a violation could sue the hospital and physician in civil court. Receiving facilities that suffered a financial loss as a result of a transferring facility failing its EMTALA obligation could also now pursue damages.

Changes Over Time

As one can imagine, the passage of EMTALA created significant new "stresses" on the medical establishment. Numerous questions regarding the language and the enforcement of the legislation arose from hospital and physician groups. In response to these questions and concerns EMTALA has grown significantly in scope and enforcement with multiple revisions and "clarifying statements" over the 25 years since its inception. This next section covers the major changes to the statute, the rationales behind them, and their impact to hospitals and physicians.

In response to growing questions regarding enforcement, the HCFA (Health Care Financing Administration), now known and Centers for Medicare & Medicaid Services (CMS), convened an "Anti Dumping Task Force" to review the interpretation and enforcement of EMTALA. This task force had broad representation from physician and hospital groups as well as from the insurance industry and general community. The final recommendations from the task force were presented to HCFA in January of 1997, and HCFA

incorporated their recommendations into their "interpretive guidelines," which went into effect on July 14, 1998 [12]. The guidelines resulted in a more consistent enforcement of the regulations allowing hospitals and physicians to better understand their requirements and improve their efforts to comply with the regulations.

Several items of particular note from the 1998 guidelines included:

1. The MSE was clarified to be a process, not an outcome or a correct medical diagnosis. This clarification meant that failing to correctly diagnosis could not be interpreted as failing to perform an appropriate MSE.
2. Distinct responsibilities for on-call physicians were clarified.
3. Stabilization was divided into "stable for discharge" and "stable for transfer" recognizing that "stable for transfer" may not in fact be "stabilized" [13].

In 2003, after multiple updates, clarifications, legal case, and "interpretive guidelines," CMS issued "The Final Rule" on September 9, 2003, which became effective on November 10, 2003. The intent of this "Final Rule" was to "clarif(y) policies relating to the responsibilities of Medicare-participating hospitals in treating individuals with emergency medical conditions who present to a hospital under the provisions of the Emergency Medical Treatment and Labor Act (EMTALA)."[14] This update's focus was centered chiefly around: seeking prior authorization from insurers, emergency patients presenting to "off-campus" outpatient clinics that do not routinely provide emergency care, "dedicated emergency departments," allowing exception to EMTALA for nonemergency cases cared for in the emergency department, hospital-owned ambulances, and the applicability of EMTALA to inpatients and physician responsibilities related to being "on call" [15].

The final rule added much needed clarity but was by no means the last adjustment. In 2005, Congress created the EMTALA Technical Advisory Group (TAG). This group's recommendations were incorporated into the CMS State operations Manual on May 29, 2009.

The new revisions address and define the following:

1. Non-physician providers and their role in "on-call" coverage,
2. Telemedicine,
3. Newborn protection under EMTALA,
4. "Parking" of patients presenting by ambulance,
5. "False labor,"
6. Specialty Hospital Transfers,
7. Community call for on-call specialists,
8. Inpatient transfers of unstable patients, and
9. On-call coverage rules and obligations [16].

Current EMTALA Regulations

The "Final Rule" and the TAG update of 2008 largely define the current state of EMTALA. The following section discusses EMTALA in its current form and the implications to physicians and hospitals. With all of the revisions and updates, fundamental responsibilities for hospitals and physicians under EMTALA can be broken down into three distinct groups:

1. Requirement for a medical screening exam.
2. Stabilizations for patients with an EMC.
3. Transfer requirements—for patients with an EMC not able to be stabilized and the treating facility.
4. Requirements for a call schedule and on-call physicians.

For the purposes of simplification, we focus the following discussion around these four categories.

General Principles

EMTALA applies to any individual who presents to a hospital emergency department requesting emergency care. Citizenship or insurance status has no bearing on an individual's rights under EMTALA.

Medical Screening Exam

EMTALA mandates that hospitals provide every patient who presents seeking medical care a "medical screening examination" (MSE) to determine if they have an EMC or are in "active labor." The MSE is a process rather than a discrete event. Importantly, it is not triage and must be clearly separate from the triage process. The MSE includes the available history and physical and any required testing to determine if an EMC is present. Significantly, being incorrect in the determination of whether or not a patient has an EMC is not a violation of EMTALA. The law requires that the process be done consistently but does not cover medical judgment. If a patient presents with chest pain and the physician performing the MSE determines that the pain is not cardiac in nature, and that no EMC exists and discharges the patient who 2 h later dies of an acute myocardial infarction, the physician and facility would have no exposure under EMTALA as long as the standard and routine process was followed.

Hospitals must provide an MSE and stabilizing treatment for any EMC regardless of a patient's ability to pay for the services. It is imperative that the MSE or treatment of the EMC cannot in any way be delayed to obtain financial information.

The "final rule" further defined different scenarios in which a patient may present to a hospital and provided clarifying language as to the different responsibilities of each party.

Dedicated Emergency Departments

This definition applies to all licensed emergency departments or departments that advertise "emergency service" and includes freestanding emergency departments. For specialized facilities that have separate labor and delivery units, emergency psychiatric units, or pediatric emergency departments, this definition also applies to them.

When a patient presents to a "dedicated emergency department" the hospital must: [17]

1. Provide an appropriate medical screening exam to determine if an EMC exists; and
2. If an EMC exists, the hospital must provide stabilizing treatment and/or transfer for stabilizing treatment if the hospital lacks the capacity to treat the condition.
3. Hospitals must not delay the medical screening exam, stabilizing treatment, or transfer to obtain financial information from the patient.

When a Patient Presents to Another Location on a Hospital Property (That Has a Dedicated Emergency Department)

In this instance, the EMTALA obligation as defined previously is invoked. The fact that the patient walked in the wrong door does not relieve the facility of its obligation. Over the last 10 years, there has been significant change in what constitutes hospital property and when the EMTALA obligation starts. The current regulations are as follows: If a patient presents requesting medical attention at a facility that has an emergency department, the facility has an obligation as soon as the patient is on their property. Hospital property is now defined as the entire property including all parking lots, sidewalks, and buildings. It does not apply to nonhospital buildings on the campus like doctor's offices or restaurants [18]. This supersedes the old "250-yard" rule. However, for very large hospital campuses, the 250-yard language still is in place for the range of how far on hospital property the "EMTALA" obligation extends from the main building(s).

Requirements for Call Coverage and On-Call Physicians

The final rule attempts to clarify hospital responsibilities regarding call coverage to allow "local flexibility." Hospitals are now required to maintain an on-call list of physicians to meet the needs of the hospital's patients who present with EMCs. Hospitals are also required to have written policies to handle situations where the on-call physician is unavailable. This requirement also applies to situations when a given specialist may be on call simultaneously at multiple facilities or currently operating on an elective case when an emergency presents and thus be unavailable. Both of these situations are allowable under the current regulations with some restrictions. While these activities are permitted, hospitals must still ensure that services are available to meet the needs of patients with EMCs. Hospitals must have a predefined procedure for dealing with these conflicts [19]. This may include, but is not limited to, a backup call system or transfer in more extreme cases.

In contrast to previous guidance regarding the rule of three, CMS does not specify how often physicians must be on call or have any formal requirements for a facility to provide on-call coverage for services that is performed in an elective manner. This is a clear distinction from the previous guidance that if hospitals provide a service to the public they must provide that service to patients in the emergency department [20]. It is important to note that this is not an open door to eliminate call coverage to emergency department patients. CMS has clearly stated that they will continue to monitor and take appropriate actions if the availability of call coverage, in their interpretation, is inappropriately low after considering all relevant factors including but not limited to the following:

1. The number of physicians on staff.
2. The number of physicians in the particular specialty.
3. The other demands of the physicians.
4. The frequency in which a hospital's patients require the services of on-call physicians.
5. Provisions the hospital has made for when on-call physicians are unavailable [21].

So while there is no formal guidance, CMS, in the case of a complaint/investigation, will determine retrospectively if the hospital's on-call coverage "best meets the hospital's patients" [22].

Responsibilities of the On-Call Physician

The on-call physician must respond to the emergency department when requested by the emergency physician to either: help determine if an emergency condition exists or to help stabilize a patient with an EMC. The determination of whether a physician must respond to the emergency department or if phone consultation is sufficient is solely the discretion of the emergency physician. On-call physicians are not required under EMTALA to respond in situations where patients request a "specialist" when the emergency physician has the ability to perform any required stabilizing treatment and would routinely do so. In cases of disagreement, however, CMS has stated clearly "any disagreement between the two (physicians) regarding the need

for an on-call physician to come to the hospital and examine the individual must be resolved by deferring to the medical judgment of the emergency physician who has personally examined the individual" [23].

Physician extenders and mid level providers (MLP) can be utilized to improve access to specialized care, however, the decision on whether an MLP or the physician responds must be made by the on-call physician and not the MLP [24]. Once a patient has had their EMC stabilized and they are suitable for discharge, the on-call physician's obligation under EMTALA ends. Under EMTALA, there is no requirement for the on-call physician to provide follow-up care—though hospital bylaws and state regulations may make this requirement.

Transfer Patients

EMTALA only covers emergent transfers of patients with an EMC. Stable or lateral transfers are not covered by the statute. Hospitals and physicians who have the ability and capacity to treat patients with an EMC must accept appropriate patients in transfer from facilities without the ability to treat the EMC. It is necessary to point out that hospital capacity is not necessarily determined by a specific number of beds or resources. It is determined by behavior and operations. CMS clarified its position in 2001, "whatever a hospital customarily does to accommodate patients in excess of its occupancy limits" [25]. This is an important relaxation for the previous standard of "if they've ever done it before." One important example would be the case of a critically ill patient with a surgical emergency in the emergency department requiring an operative procedure and then admission to a surgical intensive care unit (ICU). In the case where ICU beds are frequently not available and these patients are routinely taken from the emergency department to the operating room and then held for extended lengths of time (hours to days) in the recovery room waiting for ICU opening or overflowed to a nonsurgical ICU, the same standard must be applied to transfer patients.

The question of who determines if an EMC exists and if the facility requesting the transfer can "handle" the EMC is again deferred to the treating physician who is "face-to-face" with the patient. This can be extremely frustrating to on-call physicians at referral facilities, but the language is quite clear. The physician taking care of the patient makes the call.

For the purposes of accepting transfers, there is no EMTALA requirement that the on-call specialist physician personally accepts the patient—this can be delegated. It is required that a physician sign off on all transfers if a non-physician accepts them. This process must, however, be clearly outlined in hospital bylaws.

Importantly, in the situation where a physician refuses to accept an appropriate transfer the hospital is responsible for the physician's decision to "deny" a transfer if CMS should find the denial inappropriate, because for the purposes of transfers they are in this case acting as the hospital's agent.

The only acceptable reason to refuse to accept a patient with and EMC in transfer is because the requested receiving facility lacks the capability or capacity to treat the patient. Reasons of insurance status, medical instability, and hospital affiliation are all unacceptable reasons for declining to accept a transfer. The transferring facility can choose to contact any facility they wish to request a transfer. They are not obligated to honor referral patterns, hospital affiliations, or transfer agreements. One exception would be in the case where a long distance transfer has been requested—if there are closer facilities that are available to accept the patient and the extended transport time would clearly lead to deterioration in condition, the facility could refuse as inappropriate. However, if the closer facilities are not available, then the transport distance alone cannot be used as a reason to decline transport.

The transferred patient remains the responsibility of the transferring facility until they are physically present at the accepting facility [26]. As such, the sending facility is responsible for determining the method of transportation and which service will provide the transportation. Receiving facilities cannot use mode of transportation or transportation service as a criteria for accepting or refusing the transfer.

When does EMTALA end? EMTALA obligation ends when a "qualified medical person" has made the determination that

1. There is no EMC, or
2. An EMC exists and requires transfer to an appropriate facility, or
3. An EMC exists and the patient is admitted for further treatment and stabilization.

EMTALA does not, in its current form, apply to hospital inpatients.

EMTALA Violations

EMTALA has several "teeth" in its provision. The largest and biggest stick is clearly the ability to exclude hospitals and physicians from participation in Medicare. Individual fines of up to $50,000 per violation can be assessed to facilities and physicians. Importantly, these are administrative penalties and typically not covered by malpractice premiums. In addition, the law allows those who have been harmed, as a result of a physician or facility failing to meet their EMTALA obligation, to seek damages in civil court. These courts have ruled that only hospitals and not physicians are

subject to these damages—however, a hospital that is sued as a result of a physician's behavior can seek damage from the physician [27].

Common Questions/Case Scenarios

Can patients be transferred if they have not been medically stabilized?

Yes. The inability to stabilize a patient may be the reason the patient required transfer in the first place. Unstable patients can be transferred in two instances: (1) when the treating facility lacks the ability/capacity to stabilize the patient and the benefits of transfer outweigh the risks of transfer, or (2) if the patient or their representative insists on transfer to another facility after being informed of the risks of transfer and the hospital's obligation under EMTALA.

If a patient in an emergency department with an abscess requests that a surgeon be called instead of the emergency physician performing the procedure, does the on-call surgeon have an EMTALA obligation to respond?

If the abscess is such that the emergency physician would routinely manage it without requiring consultation with a surgeon, then there is no EMTALA obligation for the on-call physician. However, recognizing that physician experience, training, and ability varies, there is no "community standard" for what a given provider should be able to perform. So if the emergency physician requests consultation because they "lack the expertise" to handle the EMC, then an EMTALA obligation does exist even if 9 out of 10 emergency physicians would have performed the procedure without consultation.

If a request to transfer a patient with a surgical abdominal emergency comes at 6 p.m. on Friday evening from a hospital that reports they have no surgeon on call, even though abdominal surgical procedures are routinely performed at the Hospital, does the receiving facility have an EMTALA obligation to accept the patient?

Yes. The requesting facility may, in fact, have a very legitimate reason for not having coverage at that time. However, even if they do not, and while it is possible that the sending facility may in fact be violating its EMTALA obligation, this does not excuse the receiving facility from their obligation.

If a patient is seen in the emergency department and diagnosed with diverticulitis, and after telephone consultation the emergency physician and on-call surgeon agree that the patient is stable and decide on a treatment course of oral antibiotics with outpatient follow-up, does the surgeon have an EMTALA obligation to see the patient in follow-up at his/her office?

No. The EMTALA obligation ended when it was determined that the patient did not have an EMC was stable for discharge and physician's offices are not covered under EMTALA.

What if the patient's condition deteriorates and they represent 20 h later septic with an acute abdomen? Would the physicians and hospital be subject to an EMTALA violation for failing to provide stabilizing medical treatment during the first visit?

No. The fact that after an MSE the physicians determined that the patient was safe/stable for discharge ended their EMTALA obligation. Being incorrect in their assessment does not in and of itself imply an EMTALA violation. One important cautionary point is that there must not be anything in the treatment plan that implies that the care was in some way determined by the patient's financial status or ability to pay for services.

If an emergency physician requests an on-call physician to evaluate a patient in the emergency department, when does the physician need to see the patient?

The on-call physician must respond in a "reasonable" amount of time. The guidelines state that the expected response time in minutes should be stated in the hospital policies [28]. Additionally, if the on-call physician fails to respond in a reasonable amount of time, the emergency physician is obligated to transfer the patient and must document on the transfer form the names and addresses of any on-call physician who failed to provide stabilizing services.

If a patient with EMC is admitted to hospital and the hospital later determines that it lacks the capacity to treat the patient and requests transfer for a "higher level of care," does the receiving facility have an EMTALA obligation to accept the patient?

This is a very delicate area with court decisions favoring both sides. Most currently consider that the EMTALA obligation for an individual patient ends with admission to a hospital. Previous interpretations have suggested that while the initial hospital may no longer have an obligation, the "higher level of care" facility *does* have an obligation. In 2008, CMS proposed [29] that even though EMTALA obligations cease upon admission for the first hospital, EMTALA obligations would nevertheless continue for a receiving hospital with specialized capabilities. After the public comment period, they retreated from this stance stating that a hospital with specialized capabilities is not required under EMTALA to accept the transfer of a hospital inpatient [30].

Do state laws regarding tort reform affect EMTALA penalties or obligations?

No. EMTALA preempts any state law that directly conflicts with its requirements. State laws could affect civil penalties as a result of CMS actions related to EMTALA violations.

Legal Examples

Inspector General v. St. Anthony Hospital

A 65-year-old male was critically injured in a motor vehicle collision and taken to a small rural hospital. The emergency physician on duty, Dr. Spengler recognized the critical nature

of the patient's injuries and initiated a ground transfer to University Hospital. Prior to the transfer, Dr. Spengler noted significant deterioration and believed that the patient had an aortic injury. He arranged for aeromedical transport and re-contacted University Hospital which informed him that all ORs were busy and they lacked the capacity to handle this case. Dr. Spengler then contacted Dr. Lucas (a vascular surgeon) at St. Anthony Hospital. Dr. Lucas refused to accept the patient who was ultimately transferred to Presbyterian Hospital where an angiogram revealed an aortic injury. The patient expired 3 days later. The Office of Inspector General (OIG), noting that St. Anthony Hospital, even though not a trauma center, had specialized surgical capabilities and had the capability and capacity to treat the injuries, imposed a $50,000 fine [31]. Notable in this case was the affirmation that higher level of care does not require the receiving facility to be a teaching or research facility or have a trauma designation but simply to have the capacity to treat the patient. Dr. Lucas was not fined because there is no obligation to the on-call physician to accept the patient; the risk is born completely by the hospital.

Millard v. Corrado

Dr. Corrado was providing call coverage at Audrain Medical Center. Dr. Corrado decided to attend a conference 30 miles away without notifying the hospital. During his period of unavailability, a trauma patient presented with an EMC and, because of Dr. Corrado's unavailability, required transfer to another facility. The Missouri Court of Appeals determined that the physician on call had the obligation to respond in a reasonable amount of time or to notify the hospital in light of the anticipated unavailability [32].

Conclusion

The EMTALA requirements have evolved significantly since its creation in 1985. It is critical that all providers participating in the care of emergency patients understand the current updates and their obligations when providing call coverage. The final rule, while providing significant clarification to many issues, has opened the door to allowing "gaps" in call coverage at many facilities. This change has resulted in significant increased pressure in referral centers as smaller community facilities "opt out" of providing subspecialty emergency coverage. Further updates are of course likely. In 2011 and again in 2012 [33], CMS sought public comments on whether it should reexamine the provision that states that EMTALA obligation does not apply to hospital inpatients. Relaxation of this rule might at first seem intuitive, but from a patient-centric point of view it could easily result in massive patient "dumping" from community facilities to tertiary care facilities for every complication. We do not yet have the results of this comment period—regardless of the results we can expect further revisions and those participating in emergency care will need to keep abreast of these changes.

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Developing an Acute Care Surgery Program

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Developing an Acute Care Surgery Program

History

Surgical training has been evolving since its initiation. From the abandonment of pyramidal training programs to the current 80-h work week limitations, surgical education has been molded into a specialty-specific, focused-exposure apprenticeship, with the adjunct of independent learning [1, 2]. Factors collectively described as lifestyle, which include workload, family life, and scheduling, has led trainees to choose fellowships in more specialized fields. The discipline of surgery has become increasingly specialized due to rapid expansion of medical knowledge, advances in technologies, and patient demands [2]. This has affected every subspecialty in general surgery and has resulted in the development of more and more subspecialized divisions. Concurrent with this, training in trauma, emergency general surgery, and surgical critical care has followed suit.

Training in trauma has had a robust history. After the Vietnam and Korean wars, trauma centers were established in inner city safety net hospitals by inspirational surgeons who wanted to learn how to optimally manage shock and war-related injuries (Table 46.1). As a result, since the beginning, translational research was a core value for trauma surgeons. Most of these centers were "knife and gun" clubs and early trauma surgeons became masters in aggressive surgical intervention. From the general surgery trainee perspective, the 1980s were the "golden age" of trauma surgery. These trauma centers offered trainees exciting opportunities. They independently operated (day and night) on a wide variety of emergencies, participated in the emerging field of surgical critical care, and were immersed into robust translational research laboratories. Unfortunately, in the 1990s several negative aspects of trauma surgery unfolded. The American College of Surgeon (ACS) Committee on Trauma (COT) successfully implemented widespread trauma center designation. While this was good for patient care, the demographics of trauma care changed. Designated "trauma centers" became busy regional centers that predominantly cared for blunt trauma. To handle this increased clinical load, many trauma surgeons abandoned elective surgery and minimized involvement in research. They focused their increasingly busy practices on trauma and surgical critical care. Additionally, COT verification imposed onerous on call responsibilities such that in-hospital 24-h calls became a standard work assignment. Furthermore, trauma surgeons aggressively pursued non-operative management of blunt abdominal trauma and increasingly relied on specialty surgeons for more complex urgent cases. As a result by the late 1990s, general surgery trainees became uninterested in trauma surgery as a career option. They observed that trauma surgeons were workaholics (many were "burn outs") and "baby sitters" for the surgical specialists. The term "trauma surgeon" had become an oxymoron. Surveys of practicing trauma surgeons corroborated these views. As a result, the trauma community began a series of discussions in different forums (e.g., panels at meeting, editorials, and more surveys). These were nicely summarized in Dr. Ron Maier's 2002 Presidential address to the American Association of the Surgery of Trauma (AAST) in which he concluded that we needed to redefine our specialty and recapture desirability of trauma surgery as a career. He proposed the formation of an ad hoc committee on the future of trauma specialization and that we petition American Board of Surgery (ABS) for Advisory Council status (a necessary step in becoming a recognized specialty). In 2003, under the leadership of Dr. David Hoyt from the AAST and Dr. Wayne Meredith from the ACS COT, a consortium of interested professional groups convened (including the ABS, Residency Review Committee (RRC), Association of American Physicians and Surgeons, Western Trauma Association (WTA), Eastern Association for the Surgery of Trauma

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Table 46.1 Early trauma centers were set up in inner city safety net hospitals

Buffalo General: John Border
Ben Taub Hospital Houston: Michael E. DeBakey
Charity New Orleans: F. Carter Nance
Cook County Chicago: Robert Freemark
Denver General: Ben Eiseman
Detroit Receiving: Charlie Lucas & Anne Ledgerwood
Grady Memorial Atlanta: Harlan Stone
Hermann Hospital Houston: James "Red" Duke
King County New York: Gerald Shaftan
Parkland Dallas: G.Tom Shires
San Francisco General: William Blaisdell
Shock Trauma Baltimore: R. Adams Cowley

(EAST), Society of Critical Care Medicine (SCCM) and the American Trauma Society) to evaluate the problems facing the specialty of trauma and its future. In their deliberations they created the vision of a new specialty called "Acute Care Surgery" that would encompass trauma, emergency surgery, and surgical critical care. In 2003, the AAST formed an ad hoc committee to define the future training of this new specialty. They proposed a 2-year fellowship incorporating training in emergency general surgery, surgical critical care, and surgical exposures necessary for the care of severely injured and critically ill surgical patients. In 2004 Dr. Frank Lewis, executive director of the ABS, outlined the requirements for this new specialty including: (1) must satisfy an unmet public need, (2) must be focused on disease management, (3) must create viable/attractive lifestyles, (4) must correct present deficits (non-operative, night call), (5) must not trespass on areas defended by other boards, (6) should merge with other evolving specialties (emergency medicine, medical hospitalists), and (7) must incorporate the Accreditation Council for Graduate Medical Education (ACGME) work hours and the six core competencies. In 2005 with these principles in mind, Dr. Lewis helped usher the award by the ABS of Advisory Council status for surgical critical care, trauma, burns, and emergency surgery.

In 2007, the first piloted fellowship at Denver Health Medical Center had a fellow complete a surgical critical care fellowship followed by a second year in acute care surgical training that included rotations with thoracic, vascular, transplant and interventional radiology. In 2008, the first formal AAST approved Acute Care Surgery fellowship program began at the University of Nevada School of Medicine. Since that time, 18 additional programs have been developed and approved by the AAST for training of these fellows. Currently, there are 19 fully accredited Acute Care Surgery fellowship programs (Table 46.2). The AAST continues to evaluate the educational goals and needs of the fellows and they refined the operative case requirement in 2014 [3–5]. More than eighty Acute Care Surgery fellows have graduated from accredited programs.

Program Requirements

The AAST Board of Managers approved the original fellowship requirements in March of 2007. Since that time, two subsequent reviews have been performed, most recently in June 2014. The requirements are available on the AAST website: www.AAST.org/curriculum. Programs seeking AAST fellowship approval should be robust academic centers with a commitment to education and must comply with the institutional guidelines for fellowship training [6–9]. Acute Care Surgery fellowships are designed to follow core training in general surgery [6–9]. The Acute Care Surgery fellowship must provide the necessary education to qualify the fellow as an acute care surgical specialist in clinical, education, and research areas. The basic principles of the training paradigm are depicted in Table 46.3.

One of the most important aspects in establishing an Acute Care Surgery fellowship is the assurance that the program will not detract from the existing general surgery residents' experience [10]. Thus, support from the department chairman and the general surgery residency program director is mandatory. In an Acute Care Surgery fellowship there must be support from the institution, core service support from the trauma and emergency general surgery division, as well as the thoracic, vascular, and transplant divisions. Additionally, there must be an approved ACGME surgical critical care fellowship. The program director must be a faculty member at the sponsoring institution, certified in general surgery and surgical critical care, and a member of the AAST.

Curriculum rotation requirements and elective options during the Acute Care Surgery year are shown in Table 46.4. The program should also be able to provide opportunities to participate in research, trauma outreach, intensive care unit administration, trauma systems administration, and quality improvement projects.

Setting Up an Acute Care Surgery Fellowship

The Program Information Form (PIF) can be found at: www.aast.org/program-requirements. The form requires information regarding the program director, all participating faculty, program caseload specifications, trauma information including the number of patients seen annually, operative trauma information, and the number of emergency general surgery operative cases performed annually. Individual faculty will need to provide their caseload information, research accomplishments, publications, and participation in local or national committees. Some of the information can be obtained from the billing office and/or the trauma coordinators who monitor trauma informatics. Additionally, the PIF requires information regarding goals and objectives from each potential rotation and the means of monitoring ACGME requirements

Table 46.2 AAST approved acute care surgery fellowship programs

AAST approved Programs	Location
University of California San Francisco–Fresno	Fresno, California
University of Colorado School of Medicine	Denver, Colorado
University of Maryland/R. Adams Cowley Shock Trauma Center	Baltimore, Maryland
University of Nevada School of Medicine	Las Vegas, Nevada
University of Pittsburgh Medical Center	Pittsburgh, Pennsylvania
Massachusetts General Hospital	Boston, Massachusetts
University of Texas Health Science Center	Houston, Texas
Vanderbilt University	Nashville, Tennessee
UMDNJ–Robert Wood Johnson Medical School	New Brunswick, New Jersey
Wake Forest Baptist Medical Center	Winston-Salem, North Carolina
East Carolina University/Viadent Medical Center	Greenville, North Carolina
University of Arizona	Tucson, Arizona
Baystate Medical Center	Springfield, Massachusetts
Hartford Hospital/University of Connecticut	Hartford, Connecticut
Wright State University	Dayton, Ohio
Yale University	New Haven, Connecticut
Orlando Regional Medical Center	Orlando, Florida
University of Florida	Gainesville, Florida
Indiana University	Indianapolis, Indiana

Table 46.3 Basic principles for acute care surgery training program

1. Program is two years in length
2. The Acute Care Surgery fellowship must have an approved ACGME surgical critical care residency
3. The fellowship must include specific technical training in hepatobiliary disorders, thoracic surgery, and vascular surgery
4. The trainee should participate in acute care surgery call for at least 12 months and 52 nights of acute care surgery call that includes both trauma and emergency general surgery
5. Flexibility of rotations to optimize the fellow's training
6. Participate in general surgery to gain experience and supervise residents
7. An academic environment so that fellows are trained to teach others and conduct research

Table 46.4 AAST curriculum rotations

Required emergency and elective surgery	
Trauma/Emergency surgery	2–3 months
Thoracic	1–2 months
Transplant/Hepatobiliary/Pancreatic	1–2 months
Vascular/Interventional radiology	1–2 months
Suggested clinical rotations	
Orthopedic surgery	1 month
Neurological surgery	1 month
Electives	
Burn surgery, Pediatric surgery, Endoscopy, Plastic surgery, etc.	

such as 360° evaluation process, duty hour restrictions, and compliance with ACGME core competencies.

Once the PIF is complete and support is confirmed from the chairman, the residency program director, and the rotation faculty, the fellowship is proposed to the Graduate Medical Education (GME) office for institutional support. The Designated Institutional Officer (DIO) and the GME committee must ensure no interference with current resident education. They will also require that the institution can support the educational requirements of the fellowship.

Next, funding for the fellow salary needs to be obtained and approved. A pro forma proposal will outline a mechanism for support for this new fellowship position. Some institutions may choose to provide the salary from the Acute Care Surgery division, the department of surgery, or from the GME office. Funding options are institution specific. However, there is a requirement by the AAST that the fellow participate in a call schedule where they manage emergency general surgery patients. If feasible, this may be an opportunity to support the salary as the fellow should be general surgery board eligible or certified and may obtain privileges from the hospital to bill for patient care during these calls. There is a requirement for full faculty backup for operative trauma care throughout the fellowship year. And, the fellows are still required to adhere to ACGME duty hour restrictions.

Finally, once the PIF is complete and approved by the institution, the PIF is sent to the AAST. Once reviewed by the members of the Acute Care Surgery Committee of the AAST, two representatives are selected for a site visit. A list of specific information to be reviewed during that site visit will be provided. The representatives tour the facility and probe the faculty and the residents on the desire, feasibility, and impact of an Acute Care Surgery fellowship at that institution. The site visit is generally a 2-day process where site visitors meet with the program director, the acute care surgery division faculty, the general surgery program director, and the participating division chiefs. During the site visit, interviews are conducted of specific participating faculty,

residents, and fellows as requested by the committee members. A chart review is conducted to assess the operative caseload and the involvement of faculty, residents, and fellows in the care of the patients. After the program caseload is reviewed, educational and administrative opportunities are also reviewed. At the conclusion of the site visit, a summative interview is conducted with the program director. Following the site visit, a written assessment of the program is performed. The site visitors write an overview, program description, strengths/weaknesses, major deficiencies, and a summary with recommendations. If no major deficiencies, the senior site visitor presents the highlights to the Acute Care Surgery committee of the AAST. If approved, the AAST Board of Managers will then vote for final approval. Once approved, fellow interviews may ensue for the following year. Currently, those interested in surgical critical care followed by training in Acute Care Surgery may submit applications at http://www.safas-sccpds.fluidreview.com

The entire process generally requires 3–6 months to complete. Following approval and initiation of the program an annual review by the committee members occurs. Compliance with the AAST requirements is assessed, as well as with ACGME requirements. ACGME requires a Core Competence Committee to assess a fellow's progression through the fellowship and specific evaluation of completion of milestones determined by the committee. There is also a requirement for a biannual review of each fellow's performance, which is discussed and provided to the fellow. Evaluations of the fellow, the rotations, the faculty, and the program are required.

Training Process

Two measures of the adequacy of the Acute Care Surgery training process have been implemented. First, each Acute Care Surgery fellowship graduate must take not only the American Board of Surgery examination for certification in surgical critical care, but also the examination in Acute Care Surgery by the AAST. Second, Acute Care Surgery fellows must track their operative experience through an AAST-supported online case log system. The essential and desirable case list for the Acute Care Surgery curriculum was developed based on expert opinion. It contains complex emergency, urgent, and elective cases, some of which are infrequently encountered. Based on the previous fellow data received, a revision of the Acute Care Surgery curriculum has been completed. New requirements include specific surgical approaches performed during elective and urgent cases (Table 46.5).

Training in advanced operative techniques over the breadth of anatomic locations is unique to this specialty. Each section of the curriculum now lists specific case numbers required for surgical approaches or exposures, and addresses organ-based management. Opportunities to accomplish these requirements may be done through the American College of Surgeons

Table 46.5 Operative fellowship requirements

Head and neck	
Exposures/Incisions—essential	$N=5$
Neck exploration (collar incision, sternocleidomastoid incision, thoracic extension)	
Organ management—essential	$N=19$
Brain (ICP monitor)	5
Nose (nasal packing for hemorrhage)	2
Trachea (tracheostomy, cricothyroidotomy)	10, 2
Organ management—desired	
Brain (burr hole, craniotomy, craniectomy)	
Eye (canthotomy)	
Trachea (resection/repair)	
Esophagus (resection/repair)	
Endocrine (thyroidectomy, parathyroidectomy)	
Cervical lymphadenectomy	
Thoracic	
Exposures/Incisions—essential	
Thoracotomy	$N=10$
Thoracoscopy	$N=10$
Sternotomy	$N=10$
Pericardiotomy (includes sub-xiphoid, transdiaphragmatic, transthoracic)	$N=5$
Organ management—essential	
Lung	$N=35$
Operative evacuation of the pleural space	5
Parenchymal procedures	10
Bronchoscopy	20
Diaphragm (may include spine exposures)	$N=5$
Cardiac (include emergent or elective cases requiring suture or repair)	$N=5$
Esophagus (includes elective resection)	$N=2$
Intrathoracic great vessel injury (includes endovascular stenting)	$N=3$
Organ management—desired	
Elective or emergent tracheal procedures	
Management of chest wall injuries	
Operative management of intrathoracic great vessel injury	
Extracorporeal vascular support (includes ECMO, partial left heart bypass)	
Abdominal	
Exposures/Incisions—essential	
Endoscopy	$N=20$
Enteral access	$N=10$
Laparotomy	$N=10$
Diagnostic laparoscopy	$N=5$
Hepatic mobilization	$N=2$
Damage control techniques	$N=10$
Complex laparoscopy (includes colectomy, lysis of adhesions, common bile duct exploration, graham patch, hernia repair, enteral access)	$N=10$
Organ management—essential	
Liver	$N=5$
Management of hemorrhage	3
Reexploration of hepatic wound, hepatotomy, donor hepatectomy, transplantation, partial hepatectomy	

(continued)

Table 46.5 (continued)

Spleen (splenectomy, splenorrhaphy)	$N=2$
Kidney (exploration, partial or total nephrectomy, donor/recipient nephrectomy, renal repair, renal transplant)	$N=3$
Pancreas (drainage, resection, repair, donor pancreatectomy, pancreatic transplantation)	$N=5$
Stomach (gastrectomy, management of gastric injury and/or gastric ulcer)	$N=5$
Duodenum (management of duodenal injury and/or ulcer)	$N=2$
Small intestine (enterectomy, repair of injury, lysis of adhesions, management of volvulus, internal hernia)	$N=10$
Colon/Rectum (colectomy, colostomy reversal, management of rectal injury)	$N=10$
Appendix (appendectomy)	$N=15$
Anus (incision and drainage perirectal abscess, exam under anesthesia, fistula management)	$N=5$
Biliary System (cholecystectomy, common bile duct exploration, hepaticoenterostomy)	$N=3$
Bladder (repair, cystectomy)	$N=3$
Ureter (repair/stent)	$N=1$
Vascular	
Exposures/Incisions—essential	
Left medial visceral rotation	$N=2$
Right medial visceral rotation	$N=5$
Infrarenal aorto-pelvic exposure	$N=3$
Brachial exposure	$N=3$
Femoral	$N=5$
Popliteal	$N=2$
Retrograde balloon occlusion of aorta	$N=5$
Exposures/Incision—desired	
Trap door incision	
Cervical extension from sternotomy	
Supraclavicular incision	
Infraclavicular incision	
Organ management—essential	
Management of arterial disease for injury or occlusion	$N=10$
Open arterial bypass graft	
On-table angiography	
Thromboembolectomy	
Repair of arteriotomy or venous injury	
Amputation of extremity	$N=3$
Fasciotomy	$N=5$
Organ management—desired	
Placement of inferior vena cava filter	
Ultrasound	
Organ management—essential	
Fast and/or E-fast	$N=25$
Thoracic ultrasound to assess cardiac function	$N=15$
Thoracic ultrasound guided drainage	$N=5$
Ultrasound guided central line insertion	$N=5$
Organ management—desired	
Transesophageal echocardiography	
Percutaneous cholecystostomy	
Ultrasound guided pericardiocentesis	
Ultrasound guided inferior vena cava filter placement	

Advanced Trauma Operative Management (ATOM) or the Advanced Surgical Skills for Exposure in Trauma (ASSET) courses. Organ procurement exposures may also be used for less common surgical approaches.

Conclusion

The evolution of surgical training has led to a compartmentalization of specialties and an increase in post-graduate, discipline-specific fellowship training. Acute Care Surgery is a new specialty encompassing trauma, surgical critical care, and emergency care, with its core of general surgery. This specialty was created to address a need for expeditious access to appropriately trained surgeons. This new specialty is an efficient system for the emergency care of surgical patients. Since the initiation of the first program, the number of fellow applicants has greatly expanded and continues to do so. As this training paradigm continues to mature, ongoing reevaluation of the program will continue to improve the standards for emergency care of surgical patients.

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