Rifat Latifi
Editor

Surgery of Complex Abdominal Wall Defects

Practical Approaches

Second Edition

Springer

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Foreword to the First Edition

> A surgeon can do more for the community by operating on hernia cases and seeing that his recurrence rate is low than he can by operating on cases of malignant disease.
>
> Sir Cecil Wakeley, president of the Royal College of Surgeons, 1949–1954.

Oh, if only it were that simple! Certainly, Sir Wakeley was referring to inguinal and perhaps umbilical hernias in this well-known quotation from the middle of the last century. I wonder if at the time he could have imagined the true complexity of the problem: our limited understanding of the dynamic physiology of abdominal wall tension and the need for more refined surgical techniques to manage abdominal wall defects. Perhaps most shocking of all to Sir Wakeley might have been the ability for patients to withstand and survive catastrophic illness resulting in complex abdominal wall defects. Even as recently as 25 years ago, it was hard to believe that a patient who had lost integrity of the abdominal wall as a result of injury, abdominal sepsis, or gastrointestinal failure could even survive, let alone return to functional status. However, with the evolution of resuscitation, operation, and surgical critical care for patients with devastating abdominal injury and illness, a high survival rate is now a reality. With this, our ability to manage the attendant complications, including complex abdominal wall defects with and without intestinal fistula, has improved dramatically. This has happened because the clinical circumstances have demanded it, and our zeal to improve care is no less ardent than that of Sir Wakeley over a half century ago. The editor, Dr. Rifat Latifi, and contributors to this work have produced what I believe is the quintessential and seminal resource on this vexing and challenging topic. *Surgery of Complex Abdominal Wall Defects* is the first textbook of its kind to provide a comprehensive review of modern management of abdominal wall problems. It eloquently reviews the anatomy and physiology of the abdominal wall and the pathophysiology of abdominal wall defects. It provides a valuable history of abdominal wall repair and then systematically provides the latest approach to operative repair, including preoperative preparation, acute management of the open abdomen, the approach to the hostile abdomen in the intermediate term, critical strategies in long-term reconstruction, and the full spectrum of special circumstances that arise along the way. Nowhere will you find a more comprehensive and practical guide for the management of these patients. If nothing else, this text provides the fundamental context in which these problems will be discussed and in which future advances are made.

I commend the authors on this accomplishment, and I encourage the readers to pay close attention to the content. Herein lies the state-of-the-art surgical management for patients with complex abdominal wall defects. Sir Wakeley would be proud to know how far the art and science of the approach to these patients have come.

Michael F. Rotondo
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Foreword to the Second Edition

The world of herniology has changed dramatically in the last two decades and even markedly in the last several years. These advances have changed the way we think about and approach the repair of an abdominal wall hernia, especially incisional hernias after a laparotomy.

This book edited by Dr. Latifi, now in its second edition, offers a comprehensive approach to many of the typical and atypical patients that we all see as general and plastic surgeons who repair abdominal wall hernias. The book is complete for the practicing surgeon and concentrates on abdominal wall and incisional hernias both in the postoperative setting and after trauma, the latter being especially relevant with the recent concept of damage control and the subsequent need for management of the open abdomen. While this second edition is in some respects similar to the first edition (3 of the 27 chapters are reproductions of the last edition), I want to emphasize that there are 11 new chapters dealing with other topics not addressed in the last edition, an indication of how the field has changed over these few intervening years; the remainder of the chapters have been markedly updated to reflect the current state of the art. I should like to remind the readers that the first edition had over 17,000 downloads in the first 18 months post-publication—truly an indication of its worth and relevance to the practicing surgeon. The new chapters include chapters on very relevant topics to most general surgeons, such as the timing of takedown of an enterocutaneous fistula and when and how to repair the concurrent abdominal wall hernia, how to deal with infected mesh, and which approach is best for the patient with a flank hernia of traumatic origin or after a prior flank incision. In addition, I would like to stress the importance of three new chapters, which deal with the management of abdominal wall hernias in the transplant patient, the potential for use of tissue engineering in the future, and, what I consider to be one of if not the most common associated risk factor, the obese patient indicative of the epidemic of obesity in our country and worldwide and management of post-bariatric abdominal wall hernias.

For the reconstructive plastic surgeon, the role of tissue transfer and insightful tissue management has become of prime importance in the large and complicated abdominal wall hernia. New consideration of the importance of the perforator vessels in the abdominal wall has taken on more of a focus, as we realize why the older component separation techniques involving the development of skin/subcutaneous flaps were associated with such a high incidence of wound complications approaching 40%. The use of the newer, perforator-sparing techniques has markedly lessened the incidence of wound complications. The recognition of the importance of a close interaction between the general surgeon and the reconstructive plastic surgeon has been a major advance in the repair of complicated abdominal wall hernias by more than just placement of a prosthetic mesh with the introduction of a true abdominal wall reconstruction.

While we all read and talk about gene therapy, oncologic tour de forces involve pancreatectomy, esophagectomy, etc.; nevertheless, we as general surgeons and as reconstructive plastic surgeons see inguinal and abdominal wall hernias much more commonly; they are a staple in our practice, and many, if not most, of these hernias are complicated by other very relevant comorbidities, but require repair, in order to restore the functionality and patient mobility.

This comprehensive book will be pertinent for almost all abdominal wall hernias encountered in your practice, whether the hernias are large or small. Enjoy this state-of-the-art book.

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Preface

Complex abdominal wall defects have become the new surgical disease; thus, the number of complex abdominal wall reconstructions has increased dramatically. As a considerable number of surgical patients who have sustained major abdominal trauma or catastrophic emergency surgery are treated with the open abdomen technique, the questions of how, when, and with what tools to perform these reconstructions have become serious considerations in the surgical practice.

Most surgeons use native abdominal wall during surgical procedures whenever possible. Evidence suggests, however, that synthetic or biologic mesh needs to be added to large ventral hernia repairs and in particularly complex defects. One particular group of patients that exemplify the word "complex" are those with contaminated wounds, such as enterocutaneous fistulas (ECFs), enteroatmospheric fistulas (EAFs), and/or stoma(s), where synthetic mesh is to be avoided, if at all possible. Most recently, biologic mesh has become the standard in high-risk patients with contaminated and dirty-infected wounds. However, while biologic mesh is currently the most common tissue engineered in this field of surgery in North America, Level I evidence is needed on its indication for use and long-term outcomes. Various techniques for reconstructing the abdominal wall have been described; however, the long-term outcomes for most of these studies are rarely reported.

Complex abdominal wall hernias and complex abdominal wall defects, including stomas or the complications associated with any of the above, are common and challenging for surgeons. The lack of high-quality evidence leaves surgeons without clear guidance regarding the selection of technique or material to be used when treating these serious problems.

The first edition of *Surgery of Complex Abdominal Wall Defects*, written to provide this guidance, was received very well by readers across the world; thus, the decision was made to proceed with the publication of the second edition. As with the first edition, the second edition of this book will cover the surgical anatomy of the abdominal wall; the pathology of abdominal wall defects, such as hernias and enterocutaneous or enteroatmospheric fistulas; and indications for surgical techniques used to reconstruct the abdominal wall from the practical standpoint. In addition, through a number of illustrations, the placement of mesh in the abdominal wall reconstruction and manipulation of patient's tissue including lateral component release techniques and other tissue transfer techniques are described in detail. The text also covers reconstruction of complex contaminated abdominal wall defects in patients with complex enteric fistulas, stomas, defects created after the excision of previously placed infected prosthetic mesh, and defects associated with acute tissue loss after severe trauma or necrosis of abdominal wall such as necrotizing soft tissue infections. Complex abdominal wall defects in the pediatric population and long-term outcomes and durability of these repairs are also addressed. The second edition of *Surgery of Complex Abdominal Wall Defects* is written by experts in their respective areas from around the world and has been updated thoroughly with new chapters and new approaches. Just like the first edition, my hope is that it will continue to serve as a guide for current practicing surgeons, including general, trauma, acute care, plastic, and reconstructive surgeons.

Valhalla, NY, USA Rifat Latifi

Prologue

When I conceived the idea to put together this book, I was fully cognizant of the huge task ahead of me. This was true for the first edition, and it is true now for the second edition. One would think that the second edition is easier. No it is not. It is just as difficult as the first edition. In fact, one may argue that the second edition is more difficult. The readers expect more; you yourself expect more. Nonetheless, the biggest motive to have this book was and continues to be that this book will help us as surgeons take better care of our patients. So, finalizing this book has been a great, albeit difficult, journey. Many times during this process, I have asked myself these questions: Why another edition of book? Will this one make a significant contribution, perhaps more than the first one? Will it change patient care for the better? Do practicing surgeons need this book to take care of patients with complex surgical problems or will this book help surgical teachers educate students and residents of surgery? The answers to each of these questions became clearer as I made progress. There was a great need for such a book, and a second edition became the next goal, although there are a number of books on the subject already written by some authorities in the field.

And now, seeing it complete, I do think it will add to our knowledge and improve our practice. I hope that you, the reader, will find a positive answer to these questions as well.

Here are the main reasons that drove me to produce this book that you now hold in your hands. On the first edition, I had eight reasons why this book is in your hand. This time, I have described nine reasons. There are nine steps in abdominal wall reconstruction in patients with complex defects, so nine reasons become logical.

Reason 1: Surgeons' Need

Admittedly, a number of well-written textbooks focus on hernias, a number of great surgical textbooks touch on abdominal wall reconstruction, and a number of books deal with surgical complications. However, in all my years of taking care of seriously ill patients with complex abdominal wall defects (with or without associated fistulas, stomas, and loss of abdominal wall domain), I have not been able to find a real reference textbook that reflects the latest advances in biologic and synthetic meshes, especially when we deal with open abdomen and abdominal wall reconstruction. In my surgical practice—initially in Richmond, Virginia; then at the University of Arizona and in Doha, Qatar; and now at the Westchester Health Network in New York—I have continued to care for this group of patients, due to in large part my interest in re-operative surgery and complex surgical procedures. I have longed for such a book to keep on my desk and refer to daily, something written by actual practicing surgeons for actual practicing surgeons.

I hope that my collaborators and I have now filled this gap. This was my main motive for taking on this project. As an editor of this book, I have read every word in this book and have carefully looked over every illustration and every figure. Every line represents a patient or a group of patients, offering practical evidence of bona fide surgical opinions and treatments. Real-world know-how is the power of this book, helping us to truly help patients with complex abdominal wall defects, patients who often see us as their last chance.

Reason 2: Patients' Need

Recently a patient who had a complex abdominal defect with continuous low-output fistula and multiple comorbidities, told me that his 7-year-old daughter never saw him "normal" until we reconstructed his abdominal wall.

Another recent patient of mine with truly complex abdominal wall defect, managed by open abdomen, ileostomy, and on TPN for surgical diversion induced short gut syndrome, as we were getting ready to go to the operating room, surprised me when she pulled out a copy of the first edition and asked me to sign it. All I wrote was "Good luck" and signed. No pressure, right! She showed me a handwritten note "I need my abdomen to look like this" pointing out a figure of the patient with a large defect and ileostomy that underwent reconstruction now with normal abdominal wall.

Patients with complex abdominal wall defects are not eligible for same-day surgery; they are not among those who can undergo an operation in the morning and then go home in the afternoon—not at all. In fact, far from it. Such patients will be in the hospital for a long time postoperatively; most of them have already been with us for a long time, having survived a number of previous operations. Most of them have battled, for months or even years, the consequences of major trauma or the abdominal catastrophes, cancer, or necrotizing infections that left them without an abdominal wall (a part of the anatomy that we all take for granted until we lose it).

This monstrous defect, or set of defects, results in a foul-smelling odor most of the time; it severely limits the patients' ability to work, to exercise, to have a sex life, and even to be in public. So, the need to know how to take care of these patients is enormous; as we continue to make progress in medicine and surgery, this need will be even bigger.

Reason 3: Need to Share Knowledge and the Existing Expertise

There is no better way to share the expertise that one has than written word. For this I asked some of the best practicing surgeons in the world who deal almost daily with this problem to help me put this book together. The topic is not a simple one, just as it is not a simple endeavor to take care of patients with complex abdominal wall defects. I asked the contributors to say something new, something that they think will help other practicing surgeons care for their patients. We are not dealing with small umbilical hernias, but rather giant abdominal defects that are often associated with fistulas, stomas, obesity, and the lack of an abdominal wall. These defects pose enormous problems for patients and surgeons alike. Specific medical and physiologic expertise, complicated surgical interventions, and a well-coordinated team approach are required. In each of our chapters, we share what we have learned, with an emphasis on current principles and practices and an eye toward new strategies.

Reason 4: Increased Frequency of Abdominal Wall Defects

Currently, complex abdominal wall defects are more common than in the past: a larger number of patients are surviving serious injuries and intra-abdominal catastrophes, thus living longer with significant comorbidities. As surgeons, we have made significant progress—in terms of technology, knowledge, and skills—in caring for patients with open abdomens. Often, the end result is a patient who has survived an initial insult and now has an open abdomen, with a temporary cover, that requires delayed reconstruction of an abdominal wall defect, a giant ventral hernia, or, in the worst-case scenario, a frozen abdomen with enteric fistulas. Preventing or managing complications is of utmost importance.

Reason 5: Increased Complexity of Most Abdominal Wall Defects

When complex abdominal wall defects are associated with fistulas, the complexity increases significantly. In order to disrupt this complexity, a strategic operative plan is imperative, ideally using a multidisciplinary approach. Often, surgeons “pass on” the patient dealing with only most acute symptoms such as obstructive symptoms. We have all seen patients with thick charts that have seen many surgeons in the past, who finally need an operation in the emergent or urgent matter. By the time we see these, patients, they have larger hernia defects, often present with partial or complete intestinal obstruction, are malnourished, and/or require emergent surgery under less than optimal conditions. Those of us who treat such patients know firsthand that the more operations an individual undergoes, the more potential complications can develop. However, at some point, we as surgeons must make a decision and perform what we hope will be that individual’s “final” surgery, the one that will definitively complete the abdominal wall reconstruction and return them to normal life. The complexity and associated co-morbidities will not get better if we continue to “ignore” complex abdominal wall defects. For this we should address these surgical problems early, rather then when they become emergencies.

Reason 6: Three Principles of Surgical Care

Before definitive surgical intervention, the cornerstone goal is to prevent, or at least to treat successfully, the well-recognized characteristic sequelae of fistulas and complex abdominal defects (such as sepsis, malnutrition, and fluid and electrolyte disturbances), muscle wasting, and overall stamina. There is a need for three new treatment modalities for these complex patients: first, complete nutrition and metabolic support using TPN (total parenteral nutrition) or enteral nutrition for as long as it takes; second, application of complex surgical techniques to provide skin coverage through tissue transfer techniques and biological mesh; and third, the use, in both inpatients and outpatients, of wound VAC (vacuum-assisted closure) [1, 2]. These three modalities have now become part of our armamentarium for caring for patients with complex abdominal wall defects, including those with stomas or fistulas.

Reason 7: New Technologies

The explosion in new proposed strategies and meshes, because of recent strides in technology and biomedical research, has made choices available for today’s surgeons that were unheard of in previous generations. Sometimes, though, all these choices are confusing, if not overwhelming. As surgeons, we need to evaluate each new technological “miracle” painstakingly in the light of the research presented, much of it in the form of case series rather than large, randomized, double-blind studies that yield Level I evidence.

In particular, one type of industry is on the rise, namely, the business of creating biologic mesh, be it from human sources or from different animals. This industry promotes the use of novel meshes and prostheses, each company claiming that its products are better than the competitors’. Given the significant comorbidities of most patients with complex abdominal wall defects, biologic meshes are nearly their only alternative, especially when wound infections are present or probable. The ability of certain biologic prostheses to support revascularization and to become part of human tissue is a major advance, adding a new dimension to surgical repair.

Fortunately, the use of advanced surgical techniques and biologic materials may reduce the risk of recurrence of abdominal wall defects and the risk of surgical site infections. Biologic mesh that is both human and porcine in origin is especially useful in high-risk patients. Acellular dermal matrix (ADM) provides an advantage over the nonbiologic materials used as an adjunct to hernia repairs in that ADM allows implantation in infected fields. Of concern, however, is that no method of ADM use in abdominal wall reconstructions has been standardized, despite its daily use by a number of surgeons worldwide.

Reason 8: Need for a Multidisciplinary Approach

Our rule is to try to prevent major abdominal defects and to close the abdomen as early as possible. But, even when we succeed in doing so, patients then need long-term care, including abdominal wall reconstruction. In recent years, we have come to realize the importance of a multidisciplinary team as we try to prevent or control sepsis, manage any imbalance in fluids and electrolytes, provide specialized nutritional support (both parenterally or enterally), protect the skin, define the patient's individual anatomy, and plan the appropriate surgical intervention. No single surgeon, irrespective of the type of practice (whether private, academic, or group), can adequately take care of such patients alone. The surgeon is and should be the team leader, and he or she should direct the treatment, but many other clinicians also have a crucial role.

Reason 9: Continuous Changes and Need for Progress in Complex Surgery Education

The first edition of the book was accepted and praised by the readers and reviewers across the world. The reviews have been an important element in redesigning the new edition. With 17,000 downloads in the first 18 months, and almost 7000 chapters downloaded in 2015, the need for another edition of this book became obvious. As mentioned by Dr. Michael Sarr in his foreword, this book has been updated greatly to reflect the changes in the field and the need for more practical approaches to surgery of complex defects. I hope we have succeeded in this goal.

Valhalla, NY, USA Rifat Latifi
Spring 2017

Contents

Part I Preoperative Considerations

1 **Intraoperative Decision-Making Process in Complex Surgery** 3
Rifat Latifi

2 **History of Abdominal Wall Repair: In Search of New Techniques and Materials** 7
Ronald Merrell

3 **Anatomy and Physiology of the Abdominal Wall: Surgical Implications** 11
Ronald Merrell

4 **Nutritional Consideration of Patients with Open Abdomens and Fistulas** 17
Zachary M. Bauman, Bellal Joseph, and Rifat Latifi

5 **The Biology of Complex Abdominal Wall Defects: Definitions and Causes** 27
F. Turégano and A. García-Marín

6 **Perioperative Radiologic Evaluation of Patients with Difficult Abdominal Wall Defects** 37
Fahim Habib, Antonio C. Marttos Jr., Bruno Monteiro Pereira, and Mariana F.J. Moscardi

Part II Surgical Consideration: Techniques and Outcome

7 **Abdominal Wall Reconstruction in Patients with Complex Defects: A Nine-Step Treatment Strategy** 55
Rifat Latifi

8 **A Difficult Abdomen: Temporary Closure and Management of the Consequences** 77
Rifat Latifi, Guillermo Higa, and Elizabeth Tilley

9 **Timing of Definitive Reconstructive Surgery of Abdominal Wall Defects in Patients with Enterocutaneous Fistulas** 87
Jasvinder Singh and Rifat Latifi

10 **Practical Approach to Patient with a Hostile Abdomen: Clinical Scenarios** 93
Gary Lombardo, Rifat Latifi, and Ari Leppaniemi

11 **Staged Reconstructions of Abdominal Wall Defects** 101
Ari Leppaniemi

12 **Complex Abdominal Wall Reconstruction-Plastic Surgeon's Perspective** 105
Donald P. Baumann and Charles E. Butler

13 Complex Tissue Transfer in the Management of Abdominal Wall Defects 115
Shigeki Kushimoto

14 Minimally Invasive Component Separation for the Repair of Large Abdominal Wall Defects 125
E. Barbosa and F. Ferreira

15 Abdominal Wall Reconstruction in the Pediatric Population 141
Emma C. Hamilton, Richard Andrassy, and Mary T. Austin

16 Surgical Approach to Abdominal Wall Defects and Hernias in Patients with End Stage Organ Disease and Transplantation 155
Manuel I. Rodriguez-Davalos, Christopher Ibarra, Armando Salim Munoz-Abraham, Angel Flores Huidobro Martinez, and Sukru Emre

17 Management of Flank Complex Hernia 167
Fernando Carbonell Tatay, Alfredo Moreno Egea, and Rifat Latifi

18 Laparoscopic Access to the Difficult Abdomen in Patients with Large Abdominal Wall Defects 175
Orhan Veli Ozkan, Selman Uranues, and Abe Fingerhut

19 Laparoscopic Techniques in the Repair of Large Abdominal Wall Defects 179
Selman Uranues and Orhan Veli Ozkan

20 Selection of Prosthetic Materials in the Repair of Complex Abdominal Wall Defects 187
Marcos Campos Wanderley Reis, Bruno Monteiro Pereira, Bartolomeu Nascimento, and Gustavo Pereira Fraga

21 Mesh Placement in Complex Abdominal Wall Defects: Techniques and Outcomes 193
Ansab Haidar and Rifat Latifi

Part III Post-operative Complications and Reoperative Surgery

22 Abdominal Compartment Syndrome and Hypertension in Patients Undergoing Abdominal Wall Reconstruction 201
Ajai K. Malhotra

23 The Surgical Nightmare: Dealing with Infected Mesh 207
Massimo Sartelli, Federico Coccolini, Fausto Catena, Luca Ansaloni, and Rifat Latifi

24 Abdominal Plastic Surgery and Adjunctive Procedures 213
Kaveh Alizadeh, Jonathan Lee, and Ali Shayesteh

25 Short Bowel Syndrome: A Clinical Update 225
Stanley J. Dudrick, Jose M. Pimiento, and Rifat Latifi

26 Minimizing Postoperative Complications by Preoperative Optimization 243
Ruben Peralta, Ayman El-Menyar, and Rifat Latifi

27 The Final Word on a Complex Problem 249
Rifat Latifi

Index 251

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Part I

Preoperative Considerations

1 Intraoperative Decision-Making Process in Complex Surgery

Rifat Latifi

Introduction

Complex surgical procedures carry significant risks and potential for complications, whether performed alone (as single procedure) or in combination (as multiple surgical procedures). Despite the most conscientious preoperative preparations, surprising events may still occur. If the operation takes an unplanned turn, the surgeon has to make difficult decisions. Some of the most important elements of any surgical procedure are the decisions that the surgeon makes before, during, and after the surgery itself. Notewithstanding its enormous significance and regardless of the implications that this decision-making process (DMP) has on surgical outcomes, the subject has received minimal attention in the literature [1, 2]. Subsequently, there are only a few studies that investigate how these decisions are made, although DMP is of great importance both for training and patient safety purposes. How do we surgeons make intraoperative decisions under what can be inauspicious conditions? Some describe these decisions as "intuition" or "gut-level" responses. However often we surgeons have difficulty in describing exactly how we came to specific decisions during surgery. Clearly, there are many factors that affect decision-making of surgeons before and during operations. These factors are the physiologic state of the surgeon, the harmony of teamwork, external factors at work, and the surgeon's ability to adapt quickly to a changing environment, to name only a few. Yet, the question remains, how to perform an evaluation of the surgical decision and gaining a better understanding of a seemingly gut-level process, which helps surgeons combat the external factors experienced before and during surgery?

When a patient is dying from bleeding that we cannot control, when irreversible metabolic shock does not respond to anything that we do, when new problems emerge unexpectedly, when things go alarmingly wrong in such dire moments during a carefully planned operation, how do we decide what to do next? Many surgeons decide on the next step based on "a gut feeling" or "intuition" or the "gray hair effect," among other techniques. In this chapter, I review theoretical as well as objective elements that we, as surgeons, use to make intraoperative decisions. Most of the many theories and hypotheses in the literature have been created by individuals who are not surgeons. But, our collective first-hand experience as surgeons points to a combination of factors contributing to our intraoperative decision-making process, including training and education, clinical expertise, mentoring, the creativity and the excellence that comes with long practice and with strict surgical discipline.

The Anatomy of Surgeons' Intraoperative Decisions

A number of naturalistic and complex problem-solving theories have attempted to explain how high-risk professionals make decisions [3], but such theories lump surgeons with other high-risk professionals whose decisions demand superb accuracy, such as pilots, nuclear plant scientists, and others. Indeed, it has become fashionable to compare pilots with surgeons. However, there are distinct differences between these professions. Pilots have in their hands the most sophisticated machines ever created by humans, but the pilots are backed by powerful computers and, frequently, have full support from the base on the ground. Although surgeons, just like pilots, have a team with them in every operation, they themselves make the final and most important decisions; they are in charge of carrying out the procedures that may be detrimental to patient's life. This decision may be very difficult, since, once in a perfect condition, the human machine being operated on operating table may be in

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grave condition and may not respond to any intervention that the surgeon can come up with.

So, surgeons have to rely on their own experience and knowledge, on their understanding of the patient's clinical information, and, of course on their assistants' help. This is a dynamic process that changes often from minute to minute and involves monitoring and assessing the situation, taking appropriate actions, and reevaluating the patient's response [1, 2].

However, DMP model encompasses components such as intuition (also known as "recognition-primed decision-making" analytical ability), flexibility, and creativity [4]. Nowhere is this model more applicable than in complex reoperative surgical procedures, which are often associated with an array of unanticipated problems. To this end, it is essential to be continuously aware of the patient's physiologic status—including fluid status, urine output, use of blood and blood products, bleeding, use of medications used by anesthesiologist (such as vasopressors), and biochemical endpoints of resuscitation, because, even when the operation is going well, the biochemical profile of the patient may not be optimal, or even acceptable, and this may directly affect the outcome of surgery.

In my opinion, an important theoretical component that has not received sufficient attention, and is beyond surgeon's technical abilities, is the surgeon's leadership [5]. Adroitly taking charge of a calamitous, often hopeless, situation—applying proper technical skills, assigning different team members to different tasks, and communicating in a timely, effectively, clear, and calm manner—can make a significant difference. In fraught intraoperative situations, few surgeons have reported that they make decisions through analytical, rational heuristics or through trial and error [6, 7]. Rather, studies among surgeons have shown that the basis of surgical decision-making process is primarily task visualization, communication, and the mental state of the surgeon, that is, on what is called a mental model [8]. Other critical factors influencing intraoperative surgical decision making have been described [9–11]. In addition to the surgeon's training, education, leadership ability, physiologic and mental state, creativity might be the most critical element of all. Historically, surgeons have demonstrated an amazing creativity that has often changed the way we practice medicine and surgery, defying the anatomy and physiology of the body and reaching new horizons in medicine. However, for this creativity to be fruitful one has to have an open-mind, willing to change their own mind and change the status quo of the management of the disease and disease process and demonstrable flexibility. While respecting sound surgical principles, the surgeon must be ready to adapt to any new intraoperative challenge at any time. Creativity in the service of excellence does not come easily, however. It takes dedication. It takes a lifetime of continuously studying the art and science of surgery [12, 13].

This entire book is dedicated to issues to the management of complex abdominal wall defects. The origin of such defects stems from the injury or disease itself, but a lot of it has to do with surgeon's intraoperative management. In the next sections of this chapter I will discuss few important aspects of such decisions however, one has to remember that complex theoretical discussions, though intellectually and perhaps scientifically very important, need to be backed by objective data and should take priority in our analysis of the situation and decisions that we make.

Patient's Physiology as Factor of Intraoperative Decisions

Intraoperatively, patient should be resuscitated optimally to ensure adequate oxygen delivery, hemoglobin levels to maintain normal tissue perfusion, and of course adequate body temperature. Fluid status should be monitored carefully and hypotension should be avoided. Rigorous intraoperative assessment of the patient's status mandates the use of one or more global or regional endpoint of resuscitation, since standard hemodynamic parameters (blood pressure and heart rate) do not adequately reflect physiologic disturbances and do not accurately assess biochemical and cellular status. Arterial and venous lactate, arterial and venous base deficit have limitations, yet these endpoints of resuscitation can help the resuscitation process and may predict development of multiple-organ failure and should be used to guide intraoperative care and the extent of surgery. Depending on the institution's setup, other endpoints might be used, such as oxygen delivery and mixed venous oxygen saturation, tissue oxygen and transcutaneous O_2 and CO_2, and near-infrared spectroscopy. This is particularly important since despite all the preoperative planning, extensive discussion with the patient and family, signed informed consent forms, time-out, and other preventive measures that we currently take for things to go right, things can go wrong, plans can change, and surgery can take longer than expected. In summary, in terms of objective data, the most important surgical decision-making signpost is complete and continuous awareness of the patient's physiology and anatomy (or distorted anatomy, in the case of reoperations) and thus endpoints resuscitations should be monitored carefully.

For the last few decades, to treat the most severely injured and physiologically compromised patients, the concept of damage control surgery (DCS)—e.g., an abbreviated laparotomy followed later by a planned reoperation—has been accepted as a new paradigm. Damage control surgery has been increasingly used in patients with non-traumatic abdominal emergencies, such as severe hemorrhagic or infectious acute pancreatitis, peritonitis induced conditions, intestinal ischemia, abdominal compartment syndrome and other conditions. An increased intra-abdominal pressure, especially abdominal compartment syndrome, is now recognized as condition requiring active monitoring and sometimes surgical decompression. As a result, the number of patients with an open abdomen with a temporary cover over the viscera has increased. One has to recognize that open abdomen, also known as laparostomy, potentially may have severe consequences, even though it is a lifesaving intervention. Such patients often require delayed reconstruction of abdominal wall defects or of giant ventral hernias; the worst-case scenario is a frozen or hostile abdomen with enteral fistulas.

Despite potential consequences of DCS, if the patient becomes cold, coagulopathic, or acidotic, then surgery should be abbreviated and DCS performed. The patient should be resuscitated and warmed in the intensive care unit (ICU) and prepare for the definitive surgical procedure. While DCS has been popularized mostly during major trauma and other catastrophic situations of any body cavity, it can be applied in elective surgery as well. This section is not meant to be an extensive review of DCS, but an introduction to the reader as concept and process of DMP, and it can be applied in elective surgery as well.

In these instances, that is elective surgery if patient get cold, coagulopathic and acidotic, surgeons may need to consider stopping the surgery and plan on returning the next day (or even later) to complete an anastomosis or to complete the planned reconstruct the abdominal wall. However, the need for a "break" or to abbreviate the procedure such as laparotomy or other procedure might be the result of either the surgeon's or the patient's physiology. I call this (necessary) break "damage control on demand" [14, 15]. If definitive closure of the abdomen is impossible or ill advised at this time, the surgeon should implement a plan (ideally, a plan made preoperatively) for temporarily covering the viscera and temporary abdominal closure (TAC). During the interim period (until further surgery), the patient is resuscitated optimally, any coagulation problems or acidosis is be corrected, and the surgeon and surgical team can obtain some necessary rest. The surgery can be completed next day, a day later, or even worse, at a later date.

In reoperative intestinal surgery, especially if reestablishing the continuity of the GI tract is expected, surgeons should not promise patients that their families that they will not have a stoma, temporary or otherwise, or that the operation will be completed at once. If the integrity of an anastomosis is questionable, it is reasonable to revise it. Or, a proximal diverting ostomy can be created, especially with two or fewer anastomoses or with an anastomosis deep in the pelvis [16, 17]. If diversion is performed, a loop-diverting stoma is preferred to avoid entering the abdomen.

Summary

The intraoperative decision-making process is complex and can be difficult. It draws on the surgeon's education, training, clinical experience, leadership ability, mental state, physiology, and creativity, as well as objective data from the patient's physiology and anatomy. Flexibility and an open-minded approach, along with a respect for sound surgical principles, are important. Accommodating the physiology of both the patient and the surgeon is imperative. Still, most difficult intraoperative decisions are made "on the fly" and are hard to theorize, quantify, categorize, or explain. Additional work, especially from and on surgeons themselves, is needed to delineate further how we make life-changing intraoperative decisions. Nonetheless, the anatomy of such decisions is of great importance to all surgeons, including those who work with surgeons, and patients. The construct of situational awareness can be applied to these "gut feeling" evaluations. How situational awareness and decision-making are affected by factors such as sleep deprivation and alcohol consumption is also important in understanding the decision-making process. Additionally, the mechanics behind this complex decision-making process should be tested.

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2 History of Abdominal Wall Repair: In Search of New Techniques and Materials

Ronald Merrell

Introduction

The abdominal wall was not meant to be violated. An early description of defect closure came from Plutarch in his description of the suicide of Cato the Younger in 46 BCE. Cato, the stoic, had thrown in his lot with Pompeius Magnus against the imperial Caesar, and all had turned out badly for him. After the death of Pompey and the defeat of forces in Utica, Cato decided to end his life by sword to the abdomen. He was successful in opening the abdominal wall and apparently fainted. A brave physician was called, who recognized that the situation might be remedied by surgical skill and daring. "The physician put in his bowels, which were not pierced, and sewed up the wound." This was successful, but when Cato regained consciousness and realized his global failure had even extended to his own suicide, he ripped open the wound and tore out the intestine, dying promptly as he always intended but now as a surgical complication [1].

Surgeons have struggled with the daunting task of restoring the abdominal wall despite its nature, their patients' intent, and personal inadequacy. There were many attempts at laparotomy that, despite best intentions, ended in peritonitis and death. The first success was that of Ephraim McDowell in 1809. In Danville, Kentucky, he removed an ovarian tumor without benefit of anesthesia or antisepsis. He was clean in his habits, which may explain why this procedure was followed by a 33-year survival for his patient [2]. Throughout the nineteenth century, there were many bold efforts at operating in the abdomen, and the successful reports did not seem to include any problem with healing of the abdominal wound.

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Early Reports in the Annals of Surgery

The great prospect of laparotomy, with some caveats, was declared in the *Annals of Surgery* in 1886 [3]. Reports were duly made to the American Surgical Association for pistol shot [4], gunshot [5], and splenectomy [6], and all successes were reported without failure of the abdominal wall. Dixon reported concerning an appendectomy for purulent perforation and in the same issue reported a laparotomy for strangulating hernia [7, 8]. Not only could the pristine abdomen be treated but also potentially septic pathology could be managed. Reports of ventral hernia after laparotomy were slow to come. The first report in the *Annals of Surgery* was in 1901 from Eads [9]. The early problem was considered that of great difficulty, and the reports of hernia were notably lacking in the bravura of earlier reports of successful laparotomy. When the surgeon was confronted with massive protrusion of abdominal contents, which could be seen writhing in peristalsis just beneath the thin skin, there was a strong urge to repair the problem. Many of these efforts followed in the twentieth century and today.

The persistence in innovation for repair of the anterior abdominal wall strongly suggests that there is no good way to repair the problem even now. The current incidence of incisional hernia may be as high as 11% across the board. One might implicate a poor effort at the closure of the original laparotomy. However, the surgeon who undertakes to remedy the earlier mess is rewarded with a 33% likelihood of hernia recurrence. The second or third effort at repair of abdominal wall defects is associated with an even higher likelihood of recurrence [10].

The options to repair include movement of local tissue into a configuration that will restore wall integrity. This approach was the mainstay for most of the history of laparotomy. However, the inadequacy of this approach in general led to a relentless search for autologous, allogeneic biological material or prosthetic materials for over a century.

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Prosthetic Materials

In 1947, Koontz (Baltimore, MD) reported at the Southern Surgical Association on his work with tantalum gauze. Tantalum was an interesting choice based on the tragic story of the element's namesake, the mythological Tantalus, who was condemned to stand in a pool of water he could never reach to drink. Certainly, the identification of a prosthetic material to slake the knowledge thirst of frustrated surgeons did not end with this material; it continues to the present. Koontz had previously reported the use of preserved ox fascia but now moved on to a relatively inert metal that could span the defect of an abdominal hernia. Experimental repair preceded his clinical application, and he was insightful in recognizing that the strength of his experimental repair was because of the infiltration explained by the structural strength of the repair and not the mesh itself. Furthermore, he described the use of the material as a full replacement of the defect as well as an overlay for tenuous fascia approximation. He described the need to overlap the fascia and the material with generous sutures [11]. Koontz also described the desirability to divide the rectus fascia vertically to provide the abdominal fascia mobility in seeking midline union. His work followed a half century of difficult work with silver mesh. That material was not only antiseptic but also irritating, eventually dissolving.

The local tissue approach to reapproximate the anterior abdominal wall continued as an evolving challenge with a seminal development by Albanese in the 1950s and popularized by Ramirez in 1990. He described the elevation of subcutaneous flaps far lateral of the midline and the division of the external oblique fascia. This plane also became undermined, and the rectus fascia was divided just posterior to the midline to allow advancement of the rectus. This dissection and fascial division allowed advancement perhaps 10 cm to the side to provide a generous coverage of even huge hernias while relying on the redundancy of the abdominal wall layers to ensure structural integrity [12]. Regional flaps—such as tensor fascia lata, latissimus dorsi, and free flaps—have been applied for specific needs, but these are generally proposed for initial repair of large defects created in the resection of abdominal wall tumors.

Finding the Perfect Mesh

There has been great interest in finding a polymer that would approximate collagen in strength, durability, and flexibility. Such a polymer has not been found. In this search, a reasonable set of criteria was proposed by Cumberland [13] and Scales [14] in 1952 and 1953, respectively. They proposed eight characteristics for an ideal mesh; the ideal mesh should be noncarcinogenic, chemically inert, resistant to mechanical strain, suitable for sterilization, biologically inert, nonallergenic, limited foreign body tissue reaction, and amenable to production in useful form for surgery. Polypropylene was first synthesized in its crystalline isotactic form in 1954. Commercial production began in 1957, and Usher described the first use of polypropylene mesh for hernia in 1959 [15, 16]. The mesh was marvelously flexible, durable, and strong. It also harbored bacteria in its many interstices; an infection could flare many years after implantation. Undesirably, the material not only incorporated the invading fibrous tissue but also engendered adhesions to the intestine and created a prospective intestinal obstruction. Polyester has similar qualities.

Because of adhesions and infections, new expectations were placed on the ideal mesh. It would be desirable if the mesh resisted infection, presented a nonadherent face to the abdominal cavity, and could respond biologically in a manner similar to autologous tissue [17]. A review of prosthetics by Shankaran et al. was superb, timely, and scholarly.

Nonabsorbable Mesh

The polymer meshes include polypropylene (Prolene®, Ethicon, Somerville, NJ; Marlex®, C.R. Bard, Murray Hill, NJ); lightweight polypropylene (Vypro®, Ethicon; ProLite™, Atrium, Hudson, NH); polyester (Dacron, Mersilene™, Ethicon); and expanded polytetrafluoroethylene (ePTFE, GoreTex®, W.L. Gore & Associates, Newark, Delaware). They differ by pore size; ePTFE has smallest and therefore has the least likelihood to harbor bacteria. They differ in tensile strength, but all exceed the necessary strength. They are of similar thickness. They differ in varying degrees in postoperative pain syndromes, and there are varying reports of recurrence. Generally, after a mesh repair of an incisional hernia, there is a recurrence rate of 2–30% compared to open/primary repair failures of 18–62% [18–22]. None of the polymer meshes achieve the ideals listed previously. A large number of coated or composite meshes have been introduced to address needs. Mesh has been coated with bioabsorbable but initially active agents such as poliglecaprone (Ultrapro®, Ethicon); carboxymethylcellulose–Seprafilm on polypropylene (called Sepramesh™, C.R. Bard); omega-3 fatty acids (C-Qur™, Atrium); cellulose (Proceed®, Ethicon); and collagen-polyethylene-glycerol on polyester (Parietex™, Covidien, Dublin, Ireland). Each has great proponents and detractors, but a definitive advantage is not obvious. The mesh has been made double sided to address the special issue of reactivity next to the bowel on the peritoneal side. Lightweight or heavyweight polypropylene on ePTFE (Composix™, C.R. Bard) is dual sided, and there is dual-sided ePTFE with a different surface, resulting in a nonporous material (DualMesh®, W.L. Gore) as need proposed. The chemistry of the mesh occupied most of the discussion and progress in understanding and treating massive abdominal trauma in the latter part of the twentieth century. The technique regarding placement of the mesh relative to the abdominal viscera has continued to add fuel to the debate, and the truth is still out there somewhere [23–27].

Absorbable Mesh

Absorbable mesh has also been considered in order to provide a temporary matrix and strength, with subsequent replacement with natural tissue. Polyglycolic acid (Dexon™, Covidien) and polygalactin (Vicryl®, Ethicon) had been used, but problems with failure to control infection and high recurrence rates have dimmed enthusiasm except in severe circumstances of sepsis for which a temporary barrier is all that is required [28].

Laparoscopic Repair

In 1982, laparoscopy was applied to ventral hernia for the first time with internal closure of a hernia sac [29]; a full description and result were published in 1993 by Le Blanc and Booth [30]. Full anatomic reconstruction of the abdominal wall by laparoscopy has been a growing trend because of its decreased injury and quicker return to function [31]. The data have been subject to the improved database registry of the American College of Surgeons National Surgical Quality Improvement Program [32]. Despite lower overall morbidity with laparoscopic technique, this 2011 report only accounted for 17% of the procedures in a registry of over 71,000 ventral herniorrhaphies for the years 2005–2009. Laparoscopy for massive abdominal wall defects is considered difficult because of alternate entry ports, adhesions, and the disorientation of the surgeon confronted with terribly distorted anatomy. Comparison of open versus laparoscopic procedures examined ten randomized controlled trials in the Cochrane Database [33]. A general review of the dramatic progress in herniorrhaphy was published by Gray et al. in 2008 [34].

Conclusion

The next level of endeavor for the thousands of disabled patients threatened by abdominal hernia probably lies with improved skills in laparoscopy. Most likely, materials science is not going to offer the next frontier in hernia repair. The possibility of tissue engineering manufacturing a truly comparable dynamic tissue to substitute for the abdominal wall should be anticipated, however. Further improvement in results will certainly come from agreement on proper surgical indications, eliminating high-risk patients from the tally. Finally, better understanding of the biology of the marvelous structure, function, and plasticity of the abdomen may offer sound and new principles in the initial repair of this essential barrier to prevent such a prevalent and almost always iatrogenic scourge.

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Anatomy and Physiology of the Abdominal Wall: Surgical Implications

3

Ronald Merrell

Introduction

The abdominal wall forms a container filled with solid and hollow viscera. The volume is a function of pressure with a potential for vast distension in isobaric conditions or with little change in pressure. The normal pressure is less than 10 mmHg (13.6 cm H O) [1]. The pressure needs to be raised only to 15 mmHg to accommodate the entire 5 L or so needed for the distension of pneumoperitoneum in laparoscopy [2]. The cavity can distend to allow the growth of a full-term fetus with little change in pressure. Furthermore, the cavity can be distended with ascites to grotesque dimensions without organ compromise. The distensibility of the cavity is used to excellent advantage for peritoneal dialysis or to increase the tissue surface in preparation for hernia repair [3]. The tissues stretch. The hollow viscera are compressible, of course, but the noncompressible elements of solid viscera and vessels are well served by abdominal wall distensibility. Difficulties for the solid viscera and vessels are discussed in this chapter.

The abdomen is well designed to increase its volume with minimal change in wall tension. The problem for intraperitoneal physiology comes when the pressure rises rapidly and the abdominal wall cannot mitigate the pressure with volume. The first victim of pressure in the abdomen is the diaphragm, with displacement into the thorax and a rise in respiratory pressures. The next victim is the inferior vena cava, with reduction in right heart return and relative hypovolemia. Each of these can be compensated by resuscitative measures. However, the ureter and renal calices are also affected by increased intra-abdominal pressure, and resuscitative measures may not easily compensate; renal oliguria follows. The pressure in the abdominal wall is accurately reflected by pressure in the urinary bladder, which is easily measured through a urinary catheter. The problem of excess pressure caused by failure of the abdominal wall to distend is termed *abdominal compartment syndrome*, with a fall in renal function at 25 mmHg or higher [4, 5]. The problem is so urgent that drastic measures such as decompressive celiotomy or leaving the abdomen open have become standard practices in the last 30 years.

Although the abdominal wall customarily handles chronic pressure threats with distension, the wall can sustain enormous increases in pressure that are brief, such as in coughing or heavy lifting. In these circumstances, the pressure may reach 150 cm H O in reflex coughing but never at the risk of compromising the normal abdominal wall over many decades of life and many thousands of cough strains [6]. With exercise-induced strain, the pressure may reach 250 cm H O.

The container function of the abdominal wall is indispensible. Without the integrity of the abdominal wall, viscera protrude along with whatever coatings of peritoneum, subcutaneous tissue, and skin remain. This protrusion through the otherwise containing influence of the abdominal wall is a hernia. If the coatings fail, the abdominal contents under the influence of even normal intra-abdominal pressure will rush from the body as an evisceration.

Anatomical Boundaries

For the purpose of this chapter, the term *abdominal wall* refers to the anterior abdominal wall, and failings are limited to acquired failure caused by either surgical incision or ventral hernia of natural causes. No discussion of herniation through natural weaknesses and orifices is included. The anterior abdominal wall in terms of structural integrity is composed of muscle and fascia attached to the costal margin, spine, pelvic rim, and pubis (Fig. 3.1). The attachments are firm although elastic. The fascia is cleverly engineered to overlap with decussation in the midline linea alba (Fig. 3.2).

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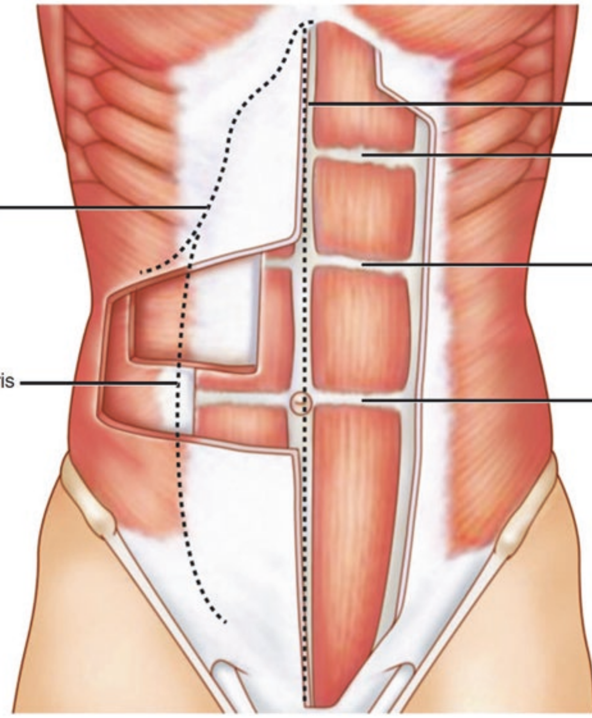

Fig. 3.1 Frontal view of the abdominal wall at the level of the fascia indicating midline, costal margin, linea semilunaris, and rectus inscriptions

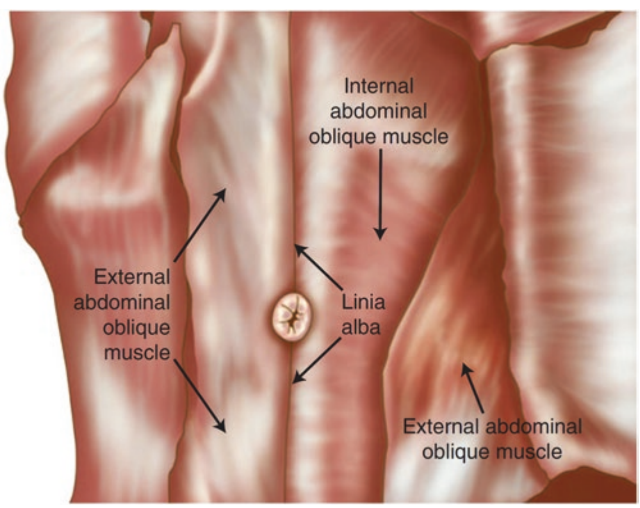

Fig. 3.2 Criss-crossing decussating fibers at the linea alba, with umbilicus

The fascia has a dominance of collagen type 1 and is dynamic rather than static, with a fairly vigorous biological turnover. The fascia in turn invests three layers of abdominal wall musculature, which are oriented not in parallel but at various angles to increase strength (Fig. 3.3a, b). The transversus abdominis is more or less oriented horizontally. The internal oblique is oriented superiorly, and the external oblique is at a right angle to this, directed essentially as hands would be thrust into the pocket. The musculofascial structure is further differentiated toward the midline. The fascia of the internal oblique splits to invest the rectus abdominis above the arcuate line, and the anterior leaflet fuses with the external oblique fascia to form the rectus fascia and the linea alba at the midline. Below the arcuate line, the fascia of the internal oblique sweeps anterior to the rectus entirely to unite with the external oblique to form something of a bulwark in the lower abdomen, where gravity would predict pressures in the wall will be somewhat greater than in the cephalad abdomen. The layers of the abdominal wall are easiest seen in cross section by computed tomographic imaging (Fig. 3.4a, b). The three layers and their relationship to the rectus abdominis are clearly visible.

The abdominal wall has neurovascular bundles coming from the back in a dermatomal distribution from T8 to T10. Crucial blood supply comes from the superior and inferior epigastric vessels along the belly of the rectus abdominis (Fig. 3.5a, b). The merger and fusion of the external and internal oblique muscles form the linea semilunaris to the lateral aspect of the rectus. Just below the umbilicus, the change in the fascia of the internal oblique from separation cephalad to invest the rectus to a unitary sweep behind the rectus forms an arch termed the arcuate line.

Abdominal Wall Distensibility

The anterior abdominal wall is strong but easily distended, which is explained by the structure. The collagen stretches, as does the muscle. The abdominal wall can be stretched quite thin without

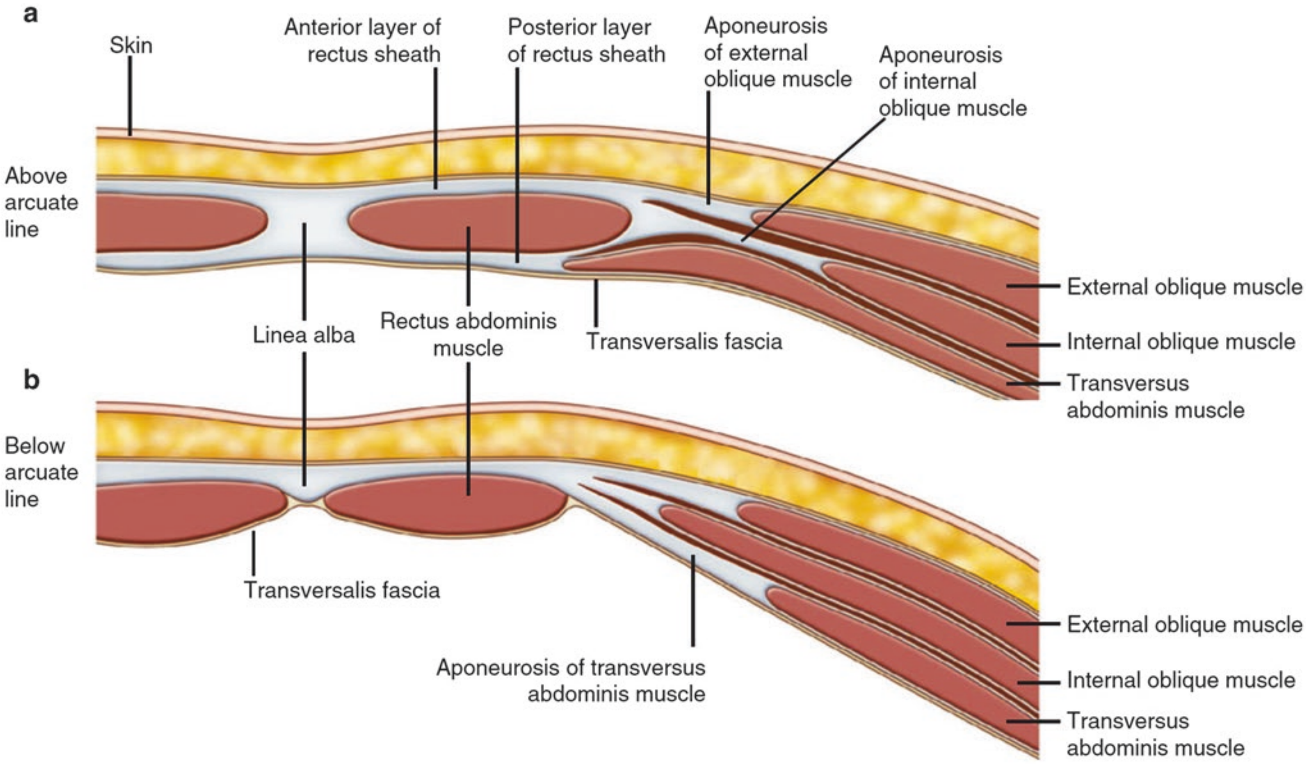

Fig. 3.3 (**a**) Cross section of the anterior abdominal wall indicating the split of the internal oblique fascia to invest the rectus above the arcuate line. (**b**) Internal oblique fascia sweeping behind the rectus below the arcuate line

losing its integrity, as in ascites. The distensibility is remarkable in that even an excess of gas in a compressible viscera such as the colon or obstructed small bowel will stretch the abdominal wall to fabulous dimensions without threatening structural integrity. Please note the contrast with the pressure and wall tension features of the cecum in obstruction. Past 14 cm distension, the integrity of the cecum is in great peril, but the anterior abdominal wall is durable. The Laplace effect is certainly applicable to the abdominal wall, but the wall tensions are not an issue for the native anatomy. The issue is only of importance when we consider the bursting strength of the altered wall, say after repair from laparotomy. The abdominal wall will fall back to its proper tension and dimension almost immediately after the obstruction is relieved. This resumption of size is also remarkable after delivery of conceptus or drainage of ascites.

The triple layering and the decussation of the linea alba create a restraining structure that is remarkable for its high bursting strength. In fact, there is no force that can breach the abdominal wall integrity except that of the well-intended surgeon, an assailant, or some other penetrating assault.

In human biology, natural function is most often studied in the context of pathology. Except for early work on anatomy with cadaver dissection, the majority of our advances in understanding the human state have been prompted by studying its shortcomings in disease. Such is the case for a thorough comprehension of the anterior abdominal wall. The abdominal wall after injury and repair has a higher representation of immature collagen type III that persists. This material lacks many of the better characteristics of collagen type I, and that difference has been used to explain the propensity of the integrity of the wall of the abdomen to fail after incision and repair [7]. Abnormal collagen has been associated with poor abdominal repair in congenital conditions such as Ehlers–Danlos syndrome [8]. Abnormal collagen in aortic aneurysms was proposed by Tilson many years ago, and an association with high hernia rates after aneurysm repair was identified [9]. Indeed, it is well recognized that the repair of the abdominal wall does not lead to restoration of its full glory, and failure of the wall through hernia has been an affliction that continues to be present despite massive efforts to reproduce what nature does so well: to create a retaining and protective wall over the abdominal cavity that allows massive excursion in strain and pressure during the extremes of human work, reproduction, athleticism, and most external physical assaults, at least those with blunt instruments.

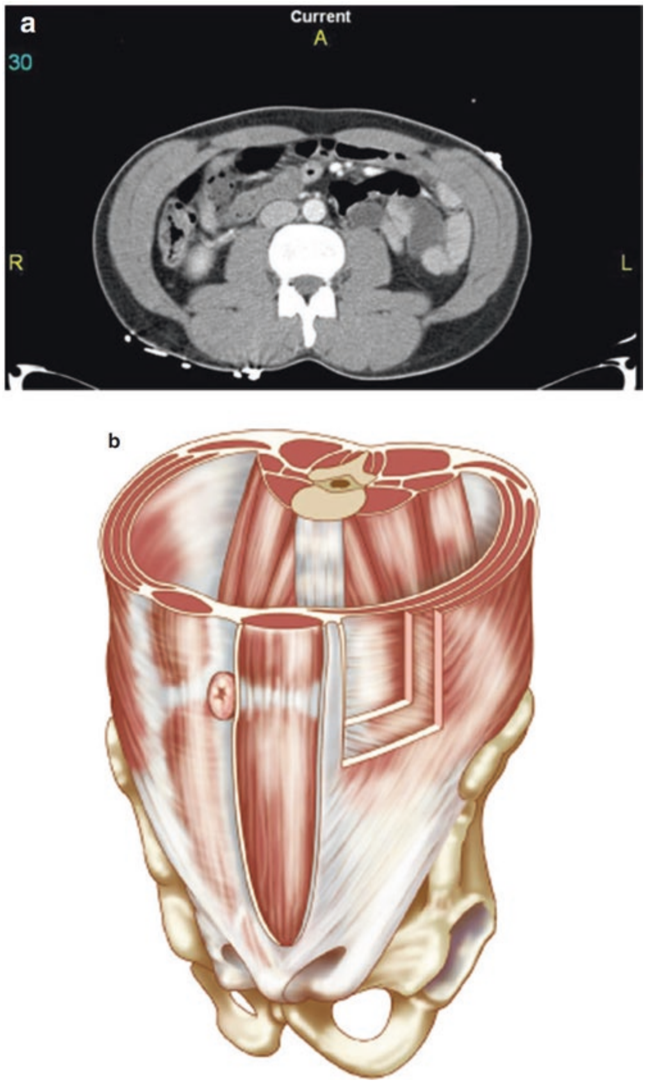

Fig. 3.4 (**a**, **b**) Layers of the abdominal wall as seen in cross-sectional computed tomography (CT) (**a**) and in illustrated form (**b**). The three layers and their relationship to the rectus abdominis are clearly seen

Surgical Implications

The anatomy and physiology of massive abdominal wall hernia deserve mention. As the abdominal contents emerge from the abdomen proper into the large sac of peritoneum, subcutaneous tissue, and skin, the pressure in the abdomen is maintained. However, with cough or strain the contents can leap from the cavity with propulsive and painful consequence. Because the hernia contents are associated with prior operation, they may obstruct because of adhesions in the sac. However, with large hernias, the likelihood of incarceration into the neck of the hernia seems to diminish. The defects may be single or multiple. There is a dictum that says "a hernia never gets smaller with the exception of the congenital umbilical hernia in the first 3 years of life." Indeed, the progress of the exodus from the cavity proper is relentless, and the hernia sac may come to hold more of the abdominal viscera than the contracted abdominal cavity. The abnormal anatomy and physiology of the herniated abdomen seem to demand restoration to normal to the extent possible with surgical intervention. However, with truly massive herniation and insufficient volume remaining in the cavity, repair of a hernia, in fact, may not be feasible. Furthermore, as repairs demand increasingly greater surgical measures, there is a balance between patient interests in the restoration versus the danger and morbidity of the repair itself. With massive hernia well compensated by nature, the obligation to repair must be considered an elective matter and not a surgical certainty.

A further remark should be reserved for prevention. Massive abdominal hernia should not be considered inevitable. With sepsis, massive distension, malnutrition, ascites leak, cancer invasion, cardiac insufficiency, hypoxia, multiple fistulae in inflammatory bowel disease, and major resection of the abdominal wall itself, perhaps some hernias are inevitable. However, as an operating principle, consideration of the hermetic closure of the violated abdomen, even if in stages, should be a large concern to the original operating surgeon. Of the over 100,000 ventral hernia repairs per year in the United States, surely most could be considered preventable [10]. How is prevention ensured?

Conclusion

Detailed knowledge of the native anatomy, physiology, physics, and biology of the abdominal wall should permit a coherent approach to the choice of closing materials and their application technique. The surgeon should strive to replicate as closely as possible normal abdominal wall anatomy.

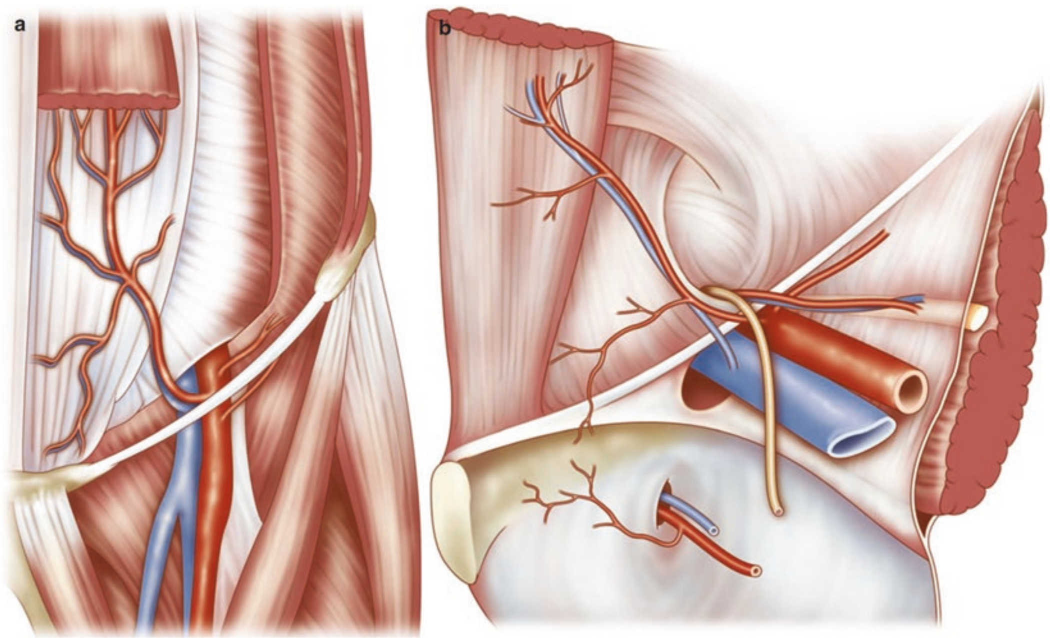

Fig. 3.5 (**a**, **b**) Posterior views of the anterior abdominal wall showing inferior epigastric vessels coming from below at external iliac and suggestion of dermatomal vessels coming from the sides. This is critical in planning a repair to have blood supply

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Nutritional Consideration of Patients with Open Abdomens and Fistulas

4

Zachary M. Bauman, Bellal Joseph, and Rifat Latifi

Introduction

Most hospitalized patients with a normal functioning gastrointestinal (GI) tract usually do not require specialized nutritional support. However, significant malnutrition defined by anthropometric, biochemical measurements and weight loss may be documented in up to 50% of surgical patients [1, 2]. This percentage may even be higher in patients admitted to the intensive care units [2]. Although many patients are malnourished at the time of hospital admission, there are many factors responsible for the development of malnutrition during hospitalization [2, 3]. These factors include the hypercatabolic states associated with sepsis, trauma, cancer, surgical interventions, and many other interacting biologic and social factors [2]. Malnutrition can present in a variety of ways and the astute surgeon needs to recognize these early, or even predict them, in order to provide the most appropriate nutritional support to allow for the best healing possible. Signs and symptoms of malnutrition include a history of unintentional or unexplained weight loss of 10 pounds or 10% body weight during the previous 2 months, serum albumin less than 3.4 g/dL, impaired immunocompetence, a total lymphocyte count less than 1200/mm^3, prior to hospitalization, or those who are likely to develop these during hospitalization as a result of stressful periods of diagnostic and therapeutic interventions [2].

Two specific surgical clinical situations that require special nutritional consideration are the open abdomen and fistula development and can be extremely challenging to manage not only from a nutritional standpoint, but also from a surgical, physiologic, and social standpoint. Although the latter are important aspects that must be considered and addressed when these disease processes develop, they are outside the scope of this chapter. For the remainder of this chapter, we will discuss the important nutritional features that should be considered and/or addressed when patients have an open abdomen or develop a fistula.

The Open Abdomen

Although there are multiple reasons for having an open abdomen, critically ill patients with an open abdomen generally fall into one of two categories; those who had developed abdominal compartment syndrome (ACS) that required surgical decompression and those undergoing damage control surgery (DCS) [4]. ACS is characterized by the presence of intra-abdominal hypertension (intra-abdominal pressures ≥12 mmHg), which occurs as a result of either a direct abdominal injury or process (*primary*—i.e., bowel perforation, obstruction, solid-organ laceration) or due to processes that require large-volume resuscitation (*secondary*—i.e., extremity trauma, pancreatitis, septic shock) [4, 5]. The definition of ACS extends further in that in addition to sustained intra-abdominal hypertension, there must be the presence of end-organ dysfunction. This includes decreased urine output, elevated peak pressures on the ventilator, decreased cardiac output due to suppressed preload or elevated intracranial pressures [4, 6]. The "classic" triad for development of ACS is the patient who sustained multiple traumatic injuries

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requiring large volume resuscitation which leads to massive bowel wall edema, retroperitoneal edema and ascites, although ACS can develop in non-trauma patients as well [4, 7]. No matter the cause of ACS, the treatment is relief of the intra-abdominal pressure via percutaneous drainage, which is gaining more popularity recently, or decompressive laparotomy, in which the abdominal fascia remains open until ACS risk factors have resolved.

Damage control surgery is the other most common etiology of the open abdomen and refers to a surgical strategy of performing only essential interventions during a laparotomy in an unstable patient, with postponement of procedures such as bowel anastomoses, that do not offer immediate steps toward survival [4]. This concept is designed to relieve or stop a process going in the abdomen that may result in death (i.e., excision of ischemic/perforated bowel, control of intra-abdominal hemorrhage) followed by the appropriate resuscitation in the ICU prior to definitive surgery. The ultimate goal with DCS is to halt the "lethal triad" of hypothermia, coagulopathy, and acidosis [4]. Although DCS surgery is not always necessary and should be avoided when possible because it is fraught with its own complications [8], it has been shown to improve survival outcomes in selective patients when necessary [9]. It is during this stabilization period that patients must be managed with an open abdomen, resulting in a variety of unique challenges, including nutritional support, for even the most experienced care providers.

Early nutritional support, within 24–48 h of intensive care unit (ICU) admission, has been shown to be greatly beneficial in surgical patients by improving wound healing, decreasing catabolic response to injury, preservation of gastrointestinal (GI) tract integrity and function as well as reduction of overall complication rates, length of ICU/hospital stay and costs [4, 10, 11]. Several studies have demonstrated lower incidences of pneumonia, abdominal infections, and catheter-related infections when early total enteral nutrition (EN) is utilized instead of total parenteral nutrition (TPN) [12, 13]. This is especially true in trauma patients, with the greatest benefits coming from a reduction in septic complications [12–15]. Although the benefits of early EN are obvious for surgical and trauma patients, how to nutritionally manage patients with an open abdomen is still a challenge for many critical care providers. Not only is nutritional management a challenge, but critical care providers are also trying to determine timing of abdominal wall closure, trying to assess volume loss and fluid replacement strategies as well as determining appropriate concomitant medications [16]. Although these management issues seem somewhat unrelated, they are clinically interwoven and must be managed collectively.

Physiology of the Open Abdomen

Patients with an open abdomen are usually among the most severely injured and critically ill patient population in the hospital. Because of this, early EN for the patients would be expected to reduce morbidity and mortality as previously discussed with patients in the ICU [4]. Unfortunately, the exposed abdominal viscera of an open abdomen leads many physicians to withhold EN due to concerns for development of a paralytic ileus, aspiration and dilation of bowel with EN further delaying or preventing closure of the abdominal wall [4]. Most patients with an open abdomen require ongoing resuscitation with blood products, crystalloid or colloid in combination with vasopressor support to maintain adequate central perfusion pressure [16]. Furthermore, many of these patients have enduring metabolic derangements, including acidosis, hypocoagulability, and significant electrolyte abnormalities [17, 18]. Many of these patients will have bowel wall edema with some requiring large or small bowel resections, where the bowel may be left in discontinuity [16, 19]. Others may have undergone extensive intra-abdominal packing for control of hemorrhage.

The exposed viscera of the open abdomen serves as a significant source for loss of protein-rich fluid, exacerbating nitrogenous losses [4, 16]. In a prospective study of 20 open abdomens following DCS, a mean loss of 2 g of nitrogen per liter of abdominal fluid was extrapolated over a 3 days, with an average of 7 L of total abdominal fluid collected [16, 20]. Furthermore, patients with an open abdomen are routinely hypermetabolic with increased circulating inflammatory cytokines [16, 21]. This can lead to worsening end-organ dysfunction, including respiratory and renal failure [21]. Finally, open abdomens without EN can lead to mucosal barrier atrophy, increased bacterial translocation, and increased risk of septic complications, which logically would exacerbate bowel edema, further impede fascial closure and increase the risk of enterocutaneous fistula formation [4, 22, 23].

Often times, the open abdomen may show signs of distension and dysfunction, causing many physicians to shy away from the use of EN. As a result, these patients will routinely go without nutrition until the abdomen is closed or total parental nutrition (TPN) will reflexively be initiated. Although withholding nutritional support during this period of an open abdomen should be avoided, one should not automatically start TPN unless patient does not tolerate optimal nutritional EN. Multiple studies have demonstrated the benefits of early EN, especially in the trauma population, when compared to TPN, including decreased ventilator days, sepsis, and multi-system organ failure [13, 15, 16]. These benefits are more likely to be seen when nutrition is started within the first 48 h following hospital admission [11].

As the continued hypermetabolic response to injury, sepsis, etc., occurs, ongoing protein catabolism heightens the risk of malnutrition [16, 24]. Furthermore, open abdomens behave like a fluid as the electrolytes and protein sump adding an additional 20–30% increase in metabolic demands following an acute injury or stress [16, 25].

Nutritional Considerations for the Open Abdomen

One of the most challenging aspects of nutritional support for the open abdomen patient is there is a lack of adequate prospective studies providing evidenced based research guiding nutritional management of these patients [26]. This often leads intensivists to provide nutritional support to these patients based off personal bias and/or individual or institutional experiences. During the remainder of this portion of the chapter, we will provide some important considerations about the nutritional support of the open abdomen in order to simplify the care of these complicated patients.

First and foremost, if the patient has undergone DCS for trauma, intra-abdominal sepsis or ACS, the initial focus period should be on that of intense resuscitation with correction of electrolyte abnormalities, resolution of the septic source, and rectification of metabolic and coagulation parameters [16]. However, once physiologic stabilization has occurred, focus needs to shift to nutritional support and an adequate assessment of the patient's caloric needs must be calculated. The predicted caloric requirements can be calculated through formulas such as the Harris–Benedict equation, Ireton-Jones equation, Penn State equation, or though indirect calorimetry if the patient is on the ventilator [27]. Although these equations often underestimate predicted caloric requirements by 10% compared to measurements obtained by indirect calorimetry [27], all these methods are likely to underestimate basal energy expenditures for a patient with an open abdomen as they do not account for the significant protein-rich fluid loss from the open abdomen itself [20, 28, 29]. Therefore, it is important to recognize these significantly elevated nutritional requirements and protein losses in the open abdomen patient and consideration for these losses must be taken into account when completing a nutritional assessment. Furthermore, standard nutritional measurements, including serum pre-albumin, albumin, transferrin, and C-reactive protein may confirm a return to an anabolic profile, but they may lag in demonstrating short-term or acute nutritional changes required, especially during the first 2–5 days following the initial insult [16]. In a recent report discussing nutritional support following DCS, it was estimated that patients with an open abdomen had a basal energy expenditure increase of 40% [16, 25]. In addition, despite TPN administration followed by EN at goal predicted caloric requirements, the pre-albumin only increased to 11.0 mg/dL from a baseline of 8.9 mg/dL 24 days after admission [25].

Although it may not seem likely, most literature thus far has confirmed that open abdomen patients can successfully reach their nutritional goals while the abdomen is open. In one retrospective review of 14 patients with DCS and an open abdomen, a total of 57% of the patients reached greater than 80% of their predicted caloric requirements via EN with the majority of intolerance coming in the form of diarrhea or gastric reflux; problems that are usually transient and fixed by increasing fiber, changing tube feeds, repositioning the feeding tube, or adding anti-reflux medication [16, 30]. Another similar study demonstrated all patients with an open abdomen were able to receive EN with 66% tolerating goal tube feed requirements to meet predicted nutritional requirements [31]. Finally, a large retrospective review of 78 patients with open abdomens showed that whether or not EN was started before or after postoperative day 4, over half the patients were able to reach their predicted nutritional goals by postoperative 6 [32]. These studies further support that unless patients are requiring ongoing resuscitation, have small bowel discontinuity or have significant bowel ischemia, EN seems to be well tolerated with achievable nutritional goals [16]. Our experience has demonstrated that post-pyloric feeding is much better tolerated than gastric feeding. The method by which this occurs, nasally versus surgically placed feeding tube, does not seem to make a difference and is at the discretion of the treating surgeon.

One of the unfortunate myths that has developed in the surgical patient population, especially those patients with the open abdomen, is that EN may actually exacerbate bowel wall edema and promote post-operative ileus further delaying definitive abdominal wall closure [16]. In fact, most literature on this matter would support just the opposite. Rodent models have demonstrated EN improves vascular flow to and from the bowel, promoting the movement of lymph, improving venous return, decreasing the overall weight of the bowel and thereby decreasing bowel wall edema [33, 34]. Further studies on trauma patients have suggested similar clinical findings. In one study, of the 43 patients with an open abdomen that were started on early EN (≤4 days) compared to the 35 patients who received late EN (≥4 days), the early EN patients had an increased rate of primary abdominal wall closure (74% vs 49%) [32]. Furthermore, another study of 100 trauma patients with open abdomens, all receiving EN, demonstrated that nearly 94% of all these patients had definitive closure of the abdominal wall fascia [35]. Of the patients in this study that were started in early EN (within 36 h of surgery), there was approximately a 2 day earlier closure compared to the late group (6.47 ± 0.83 vs 8.55 ± 0.85 days) resulting in re-establishment of normal abdominal wall anatomy and decreasing overall protein loss [35]. A large multicenter trial was completed and although time to fascial closure was longer in the EN group (9 versus 5 days), the overall abdominal closure rate was significantly higher in the EN group compared to the nil per os (NPO) group (75% vs 67%) [36]. Finally, in a small study of 23 patients with an open abdomen, 100% of these patients were able to achieve abdominal wall closure with initiation of EN while the abdomen was still open [31].

Although it is still somewhat unclear in the literature whether or not early EN administration will result in earlier definitive abdominal wall closure, it does appear that the trend is in that direction. These studies do demonstrate that EN administration in the open abdomen is safe and the preferred method. There does not appear to be a worsening of bowel wall edema, but in fact, quite the opposite, aiding in abdominal wall closure. Our recommendation is to provide EN as early as possible in these patients with an open abdominal wall as EN should be the preferred method of nutrition when possible. Furthermore, it is very important to keep in mind the frequency of operating room visits following DCS since return to the operating room is the most common reason to interrupt EN in the ICU [37]. Protocols with anesthesiology should be established so these interruptions can be avoided if at all possible to continue to provide these patients with their daily nutritional needs.

One of the most feared complications from DCS and the open abdomen is the development of an enterocutaneous fistula (ECF). The risk of ECF formation is high in patients with an open abdomen given bowel exposure, highly hemodynamically unstable patients and multiple abdominal explorations [16]. The incidence of ECF formation in patients undergoing DCS can range from 5% to 20% [38, 39]. The best measure to prevent ECF formation is abdominal wall closure as soon as possible. The formation of an ECF through bowel wall edema and distention is one of the major reasons which physicians are reluctant to start EN in patients with an open abdomen. Once again, this idea is in fact quite opposite of what current literature would suggest. In one small study, none of the patients with an open abdomen started on EN developed an ECF [31]. Another study demonstrated a significant reduction in ECF formation rate when early versus late EN was started (9% versus 26%) [32].

Although open for discussion in current literature, most studies to date would suggest complication rates such as empyema formation, bloodstream infections, wound infections, urinary tract infections, or development of ventilator-associated pneumonia are the same or less in patients receiving EN with an open abdomen compared to those kept NPO [31, 32, 35, 36]. In one study that looked at overall hospital costs, those patients receiving EN with an open abdomen had significantly lower hospital costs (mean cost $122,283) compared to those patients that did not receive EN with an open abdomen (mean cost $223,349) [32]. Most importantly, however, it has been demonstrated multiple times that patients receiving EN with an open abdomen have an overall lower mortality than those patients kept NPO [35, 36]. This was confirmed in a large multi-center trial in patients who underwent DCS for traumatic injuries. Those patients with an open abdomen receiving EN had a mortality rate of 9% compared to 17% for those open abdomen patients who were kept NPO [36]. This study further confirms the importance of EN in patients with an open abdomen to attempt to restore normal physiologic states in these critically ill patients.

One of the last aspects to consider for patients with an open abdomen is that of bowel injury. The presence of bowel injury with an open abdomen only adds to the complexity of management of these patients. Previous studies have demonstrated patients undergoing elective GI surgery with resection and anastomosis of the bowel have fewer postoperative complications and no increase in anastomotic leak rate when early EN is initiated [40]. It would therefore suggest that the bowel resection itself is not the driving force behind complication rates [4]. Unfortunately, the level of evidence in the literature is not robust enough to make generalized conclusions about bowel injury and the associated benefits or harms from EN. Only one study to date has looked at this and this multicenter trial concluded from their analysis that EN neither helped nor harmed post injury patients with an open abdomen and associated bowel injuries [36]. It would make sense, however, that patients left in discontinuity would not benefit from EN but rather TPN and should be considered in these circumstances.

Summary of Nutritional Considerations for the Open Abdomen

Although current literature about nutrition and the open abdomen is retrospective and somewhat scarce, several recommendations can be made [16]:

1. The initiation of early EN should be started if the abdomen remains open after DCS as long as there is bowel continuity and the patient has been adequately resuscitated, correcting electrolytes and metabolism, and making sure the patient is hemodynamically stable. If bowel continuity has not been re-established within 48 h, TPN should be strongly considered.
2. Caloric needs and protein balance must be correctly calculated and monitored, taking into account daily fluid losses from the open abdominal wall.
3. Enteral nutrition causing delay in fascial wall closure does not seem warranted, however, EN improving time to fascial wall closure is yet to be determined given variability in current studies.

4. Development of ECF does not appear to be increased with EN and therefore should not deter physicians from starting EN on patients with an open abdomen. Fascial closure as soon as possible and other protective measures should be taken to further prevent ECF development.
5. Enteral nutrition for patients with an open abdomen does appear to improve overall mortality rates for these patients. The verdict is still out on the association between EN and other complications such as blood stream infections, empyema formation, ventilator-associated pneumonia, etc., although the trend would seem to show there is a decrease in these complications with EN administration.

Enterocutaneous Fistulas

Enterocutaneous fistulas (ECFs) represent a catastrophic problem for patients and continue to be complex and labor-intensive problems for healthcare providers [41]. In addition to the many physiologic and mental stressors these patients must endure, the development of ECFs also put a strain on healthcare systems resulting in prolonged hospital stays, multiple readmissions, and increased resource consumption [41]. Nutritional support, fluid and electrolyte management, wound care, frequent infections, chronic pain, and depression are just a few of the healthcare issues that require a significant amount of investment when managing these patients [41]. Up to one-third of ECFs will close spontaneously when medically optimized, but for those patients whose ECF does not close spontaneously, surgery becomes necessary [42]. Unfortunately, definitive operative closure is only successful 75–85% of the time [42].

The management of ECFs has improved significantly resulting in decreased mortality rates from 50% in the 1950s to approximately 5–15% currently [43]. As many as 85% of ECFs present as a complication after abdominal surgery, providing further challenges to already compromised post-operative patients. Spontaneous fistulas usually result as a complication of inflammatory bowel disease, radiation, or cancer [43]. The general consensus is to withhold operative intervention for ECF fixation until there has been resolution of most of the related metabolic complications and the abdominal cavity has become less hostile [41].

Classification and Physiology of Enterocutaneous Fistulas

An ECF is defined as an abnormal connection between the gastrointestinal tract and the skin. Most ECFs develop as a result of one of the following conditions: extension of bowel disease to surrounding structures, extension of disease of the surrounding structures to the bowel, unrecognized bowel injury or breakdown of a gastrointestinal tract anastomosis [43]. ECFs may also form due to decreased blood supply to the bowel or from distended, weakened bowel due to delay in relieving a gastrointestinal tract obstruction [41]. Furthermore, ECFs can form after repair of a ventral hernia with permanent mesh. ECF formation has been estimated as high as 10% from erosion of mesh into surrounding bowel [43]. ECFs can further be defined as postoperative or spontaneous. Postoperative ECFs account for 75–85% of all fistulas whereas spontaneous fistulas account for 15–25% of ECF occurrence [41, 43–46]. Cancer and inflammatory bowel disease are the most common disease processes causing spontaneous ECF formation [41, 43–46].

Multiple patient factors can increase the likelihood of ECF development. These factors include infection, electrolyte abnormalities, malnutrition, anemia, hypothermia, poor oxygen delivery, and emergent procedures. For elective surgery, these factors should be optimized and tobacco use should be stopped prior to the operation. Ideally, albumin levels should be >3.3 g/dL and glucose levels should be well controlled [41]. Nutritional status should be optimized using enteral immune enhancing diets and, if needed, parenteral nutrition should be combined with enteral feeding to provide additional support [43, 46]. Cardiac output, electrolytes, and anemia should be examined and corrected [41].

Enterocutaneous fistulas are classified anatomically as external fistulas connecting a hollow viscera organ to the skin. Esophageal, duodenal stump, and jejunal fistulas with enteric defects less than 1 cm and tracts longer than 2 cm are favorable as they have high spontaneous closure rates. Gastric, lateral duodenal, ligament of Treitz and ileal fistulas are much less likely to close spontaneously. Furthermore, fistulas resulting from adjacent abscesses, complete disruption of intestinal continuity, diseased and/or strictured bowel, obstructed bowel or foreign bodies are unlikely to close spontaneously [41]. Understanding the anatomic make-up of the ECF is important in the decision making process. This information provides insight into the type and amount of intestinal fluid that will be lost from the ECF and if surgical closure will likely be required.

Enterocutaneous fistulas can also be classified based on physiologic output. Fistulas may be classified as low-output (<200 mL daily), moderate-output (200–500 mL daily), or high-output (>500 mL daily) [41, 43–46]. Thorough monitoring of fistula output helps determine appropriate nutritional support, as intestinal fluid is rich in minerals, electrolytes, and protein. Loss of intestinal fluid through the ECF results in electrolyte imbalances and malnutrition that plague these patients until ECF resolution. Fistula output is also predictive of overall mortality [44]. Mortality rates up to 54% for patients with high-output fistulas and 16–26% with low-output fistulas have been reported [41, 44, 47]. Unfortunately, the literature is still controversial on whether or not fistula output is directly related to spontaneous closure. Some studies suggest low-output fistulas are 2–3 times more likely to close spontaneously, while others lack this evidence [44, 48, 49].

Nutritional Considerations for Fistulas

Gastrointestinal fistula exudate is usually comprised of sodium, potassium, chloride, bicarbonate ions, proteins, and a variety of other components. Large volume of fluids can be lost from ECFs, which can cause major electrolyte disturbances, dehydration, and worsening metabolic acidosis [41]. The initial focus for ECF management should be that of correction of major electrolyte disturbances and infection control with appropriate resuscitation [41]. Once the patient's hemodynamics are appropriate, control of fistula output, skin care, and correction of malnutrition need to be addressed [41]. Approximately one-third of patients that develop an ECF will have spontaneous resolution of the ECF within 6 weeks of formation [41, 50]. For those that do not heal spontaneously, surgery will be the definitive cure, but patients need to be nutritionally optimized if surgery is to be successful. Many patients who develop an ECF, especially after emergent surgery, do so because they are malnourished prior to the initial operation [41]. Therefore, timing of surgery needs to be considered. It is the responsibility of the surgeon to balance the adequacy of nutritional support, likelihood of spontaneous closure, and the technical feasibility of the procedure [43, 44]. One of the biggest challenges of ECF management is patients are constantly pushing surgeons to repair the ECF before surgery can safely be tolerated [41]. Studies suggest that patients with an ECF who are reoperated on within 10 days of the initial surgery or whose reoperation is delayed 120 days have mortality rates of approximately 10%. [41, 43, 51]. Those patients who are operated on between 10–120 days of the initial surgery have mortality rates of approximately 20% [41, 43, 51]. Although mortality is decreased with early ECF operative intervention, it is wise to avoid operating during this time period. The risks of causing additional enterotomies or disrupting the previously created anastomosis are too great. Furthermore, the patient is rarely optimized at this time, specifically from a septic or nutritional standpoint [41].

With the development of sepsis and an ECF, the metabolic demands can increase substantially. Baseline nutritional needs in non-septic patients are 20 kcal/kg/d of carbohydrates and fat and 0.8 g/kg/d of protein. These requirements can increase to 30 kcal/kg/d and 2.5 g/kg/d in the setting of sepsis and high-output fistulas [41, 44, 45, 52]. Patients require a calorie-nitrogen ratio of 100:1 during severe catabolic states and when more stable, the calorie-nitrogen ratio increases to 150:1 [44, 45, 52]. It is also important to note that patients with high-output fistulas should receive 1.5–2 times their basal energy expenditure daily, otherwise it is easy for these patients to quickly become malnourished [50]. This nutritional regimen should also include twice the recommended daily allowance for vitamins and trace minerals, and up to 10 times the recommended daily allowance for vitamin C and zinc supplements [50].

Nutritional status is an important predictor for mortality in patients with ECFs [45, 46, 52]. Serum albumin is the best marker to examine overall nutritional status [41, 43, 44]. Albumin levels <2.5 g/dL have been associated with mortality rates as high as 42%, whereas those patients obtaining albumin levels ≥3.5 g/dL usually experience very small mortality rates if at all [41, 53]. Any improvement in the nutritional status of patients undergoing surgical closure of their fistula will aid by improving wound healing, enhancing the immune system and preserving lean cell mass. Serum markers such as transferrin level, retinol-binding protein, and thyroxin-binding prealbumin have also been associated with predicting mortality in ECF patients [43, 44].

Total Parenteral Versus Enteral Nutrition for Enterocutaneous Fistulas

During the initial stage of treatment, the patient who develops an ECF should be kept NPO [50]. This is to minimize the amount of output from the ECF to help with resuscitation in the early phase of the disease process. After correction of fluid, electrolyte, vitamin, blood volume, and clotting deficits, nutritional support should be initiated. Enteral feeding is the physiologically preferred nutritional support for ECF patients [41, 43, 44]. Enteral nutrition has shown to maintain bowel integrity as well as provide benefits regarding healing, repletion of nutrient stores, hepatic protein synthesis, hormonal function of the gut, and immune function [41, 47]. Occasionally, patients cannot tolerate EN due to ileus, obstruction or high fistula output [49, 52, 54]. In these situations, TPN is often required in addition to or as the sole nutritional supplement in patients who cannot tolerate EN.

Since the 1970s, the mainstay of treatment for ECFs has been supportive with the initiation of an NPO regimen and TPN [50]. The goal of this treatment was to stabilize the patient and rest the GI tract allowing natural healing of the ECF [50]. In 1967, Dubrick et al. first described the use of intravenously fed (TPN) beagle puppies that experienced normal weight gain and growth [50, 55]. This new development was eventually brought from the lab to the clinical bedside. It was demonstrated that TPN could be administered to patients with low morbidity, reducing disease severity, diminishing complications and decreasing ICU length of stay [50, 55]. The beauty of TPN is that it allows physicians the ability to fulfill patient needs of ongoing caloric, protein, vitamin, mineral, and fluid requirements when EN is not possible [50]. It is well known that 20–40% of critically ill patients exhibit some form of malnutrition and of this population, 85–90% can be treated with EN [50]. In the remaining 10–15% where EN is contraindicated, however, TPN provides the only nutritional support [50]. Often times with the development of an ECF, EN and TPN are used together to provide patients with their total nutritional requirements while still allowing oral intake. Caution should be taken when utilizing TPN, however, as it is not without its own risks and drawbacks. TPN can be very costly as it must be made special for the patient. This requires frequent lab work and long-term central venous access. If not carefully monitored, TPN can cause extreme electrolyte abnormalities, specifically hyperglycemia, and blood stream infections [41, 56].

As stated previously, EN is the preferred route of nutritional support when compared with TPN as it has few associated complications and is less expensive [41, 50]. EN formulas differ in their protein and fat content and can be classified as elemental (monomeric), semielemental (oligomeric), polymeric, or specialized. Elemental formulas contain individual amino acids and glucose polymers and are low fat, with only 2–3% of calories derived from long-chain fatty acids [50]. Semielemental formulas contain peptides of varying chain length, simple sugars, glucose polymers or starch and fat, primarily as medium-chain fatty acids [50]. Polymeric formulas contain intact proteins, complex carbohydrates, and mainly long-chain fatty acids [50]. Specialized formulas contain biologically active substances or nutrients such as glutamine, arginine, nucleotides, or essential fatty acids [50]. Elemental and semielemental formulas are widely used even though they are more expensive because they are believed to be better absorbed, less allergenic, and better tolerated in patients who are malnourished [50]. It is important to tailor the EN to the patient, what they need nutritionally and what they can tolerate. Once the patient is eating, it can still be difficult to obtain the appropriate combination of fatty acids, proteins, carbohydrates, etc. Many of the EN formulas are now available in forms that can be ingested orally with flavoring to make them taste better.

An often-overlooked aspect of artificial nutrition is the role of micronutrient supplementation [50]. Micronutrients include vitamins, minerals, and trace elements. Micronutrient deficiencies are based on inadequate or inappropriate administration during artificial nutrition or as a consequence of increased requirements or bodily losses associated with critical illness [57]. Although the exact requirements of micronutrients in critically ill patients are unknown, they do play an important role in the body's defensive and reparative processes. Because of this, the US Food and Drug Administration and American Society for Parenteral and Enteral Nutrition have made recommendations on the dosage of vitamin and trace element supplementation [58, 59]. ECFs unfortunately disrupt the anatomical sites where these micronutrients are absorbed and enhance their loss from the body [50]. Identifying the location of these ECFs through the use of fistulogram and computed tomography plays a vital role in providing the appropriate replacement of these micronutrients [41, 60].

Minimizing Enterocutaneous Fistula Output

A number of strategies have been used to decrease fistula output. Initially, patients are restricted to nothing by mouth. Liquids and food are cautiously introduced to help with nutritional and electrolyte support as long as fistula output does not substantially increase. Medications such as H_2-receptor antagonists, proton-pump inhibitors, and sucralfate have been shown to decrease the volume and acidity of gastric secretions [41, 43, 44]. Although these medications have never been shown to improve fistula closure rates, decreasing gastric acid secretion allows for better control of electrolyte and acid–base imbalances [41, 43, 44]. Historically, nasogastric tubes have been used to help decrease fistula output. Unless the patient has an obstruction or prolonged ileus, this is now considered undesirable treatment as it can lead to other complications such as sinusitis, acid reflux, or esophageal strictures. Furthermore, antidiarrheal medication and bulking agents, such as psyllium, can help to control fistula output [41].

Somatostatin and its analog, octreotide, have frequently been utilized to help slow fistula production. Somatostatin inhibits the endocrine and exocrine secretion of many gastrointestinal hormones including gastrin, cholecystokinin, secretin, insulin, glucagon, and vasoactive intestinal peptide [61]. Furthermore, somatostatin inhibits gastric acid secretion, intestinal and gallbladder motility and contractility [61]. Theoretically it makes sense somatostatin would decrease ECF output and aid in spontaneous closure of ECFs, however, multiple studies have failed to demonstrate this process [44, 62]. Occasionally, somatostatin may convert high-output fistulas to moderate or low-output fistulas, however, there has been little success using this medication to close ECFs [41]. Caution should be taken when using somatostatin as it can result in frequent hyperglycemia, a significant rebound effect when discontinued, and decreased blood supply to the gastrointestinal tract [41, 44, 62].

Summary of Nutritional Considerations for Fistula Patient

The development of an ECF can be devastating not only for the patient but also for the treating physician. A strong knowledge of the pathophysiology and risk factors for development of ECFs allows for early recognition and management [41].

Once this complication occurs, a systematic, rational management protocol should be established to provide the best outcome. Below are nutritional recommendations for patients who develop the complex problem:

1. Prevention is best! Always try to optimize patients nutritionally before elective surgery. If this not an option and an ECF develops, operating on patients within 10 days or after 120 days of the initial surgery has shown to improve overall mortality and success for closing these fistulas surgically.
2. Once an ECF develops, sepsis control and patient stabilization is the most important first step. Patients need appropriate nutritional support as one-third of ECFs will close spontaneously if the septic source is relieved and the patient can achieve adequate caloric intake.
3. Enteral nutrition is always preferred as it maintains bowel integrity, improves immunologic function, and is less expensive for the patient. However, EN may not be tolerated by the patient, therefore TPN may be necessary as the only nutritional support option.
4. Investigation of the ECF is needed to determine which micronutrients are being lost or not properly absorbed so they can be replaced to help with healing and immunity.
5. Bulking agents and medications that reduce gastric acid production can help decrease fistula output and maintain acid–base balances. Somatostatin analogs should be used with caution as they may decrease fistula output but are not without their own side effects [41].

Conclusion

Both open abdomens and enterocutaneous fistulas can be very challenging for managing physicians, especially from a nutritional standpoint. Enteral nutrition can be provided safely to both patient populations and is the preferred method. However, if these patients cannot tolerate EN for various reasons, nutritional supplementation should be provided in the form of TPN. Malnutrition is very common in these patients and therefore it essential to recognize this and manage it appropriately. Understanding the importance of nutritional supplementation, how to determine nutritional requirements and how to track the success of nutrition administration in these patient populations is extremely valuable. The best management strategy is always prevention of the open abdomen or ECF development, but when that is not obtainable, individualized nutritional plans are a must to provide the best possible outcomes for patients.

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The Biology of Complex Abdominal Wall Defects: Definitions and Causes

5

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Definition of Complex Abdominal Wall Defects

One of the following characteristics is necessary for wounds, in general, to be classified as being complex: (1) has not healed in 3 months, (2) infection is present, (3) compromised viability of superficial tissues, necrosis, or circulation impairment, and (4) association with systemic pathologies impairing normal healing. It has been estimated that complex wounds, in general, cost the healthcare system $10 billion annually in North America alone [1].

Although there is no single universally accepted definition, the term CAWD generally describes wounds that may anatomically involve several tissues, often develop after severe injuries and their surgical management, and do not heal in a timely manner or fail to heal completely. Comorbidities are common and often multiple. Prolonged periods of wound management can delay chemo-radiation treatments, represent a significant toll on patient's quality of life, compound psychological devastation on top of injury and illness, and may lead to cosmetically unacceptable results [2].

CAWDs usually require distinct and individualized, frequently interdisciplinary, interventions beyond primary repair or the simple placement of mesh. These CAWDs include recurrent hernias with multiple failed repairs, infection or other local tissue compromise, inadequate soft-tissue coverage, or multiple sites of abdominal wall defects. A subset of patients requires concomitant procedures, such as enterostomy or enterocutaneous fistula (ECF) takedown, bowel resection, or specific plastic surgical approaches, including complex wound closure, panniculectomy, and abdominoplasty [3, 4]. Some authors have suggested the following CAWD criteria to identify patients who may require special closure techniques for an abdominal wall defect: large size (>40 cm^2), absence of stable skin coverage, recurrence of defect after prior closure attempts, infected or exposed mesh, patient who is systemically compromised (e.g., intercurrent malignancy), compromised local abdominal tissues (e.g., irradiation, corticosteroid dependence), and concomitant visceral complications (e.g., ECF) [4].

The CAWDs are not all alike, and their anatomic complexity varies; the comorbidities and previous surgical history of different patients vary as well. All of this has a significant impact on the outcome [5]. These defects can be superficial, involving only some layers of the soft tissues of the abdomen (Fig. 5.1), or they can be full thickness, extending into the abdominal cavity.

Causes of Complex Abdominal Wall Defects

Full-thickness open abdominal (OA) wounds primarily are encountered in patients after acute trauma, infectious processes, or after abdominal catastrophes. In some instances, such defects represent life-threatening conditions with loss of domain, persistent infections, exposed abdominal viscera, bowel fistulas, and lateral retraction of the abdominal wall (Fig. 5.2). Furthermore, some patients are gravely ill, in poor general health, with several significant medical problems, including sepsis, compromised nutritional status, immunosuppression, and cardiopulmonary problems. Such patients will need to be managed aggressively and in a timely fashion to avoid further complications and deterioration that could affect the outcome of any future reconstructive procedure or endanger their lives.

In other patients, there is no tissue loss but simply a loss of domain with chronic and long-standing recurrent incisional

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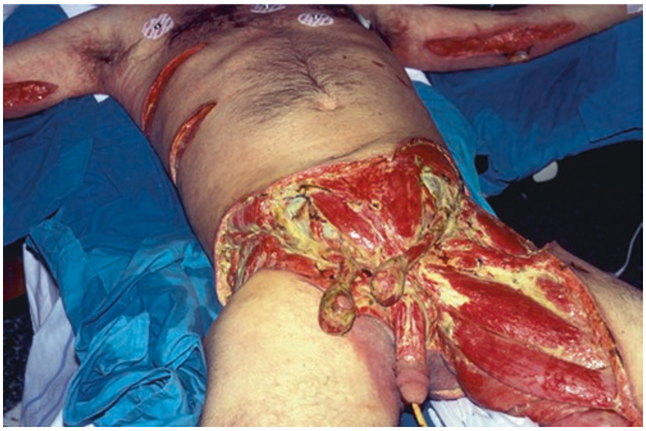

Fig. 5.1 Extensive fasciitis by *Streptococcus pyogenes* of urethral source involving the abdominal and thoracic walls and the extremities and creating a superficial complex abdominal wall defect

Fig. 5.2 Postoperative full-thickness complex abdominal wall defect with large enteroatmospheric fistula

Fig. 5.3 Loss of domain after recurrent incisional hernia

Fig. 5.4 Loss of domain after long-standing neglected right inguino-scrotal hernia

hernias (Fig. 5.3) [6]. Long-standing neglected primary abdominal wall hernias with loss of domain, which can create a complex clinical problem, are less frequent (Fig. 5.4).

In a practical and specific sense, acquired CAWDs are mainly caused by abdominal wall infections complicating surgical procedures, with resulting recurrent incisional hernias, the OA approach after damage control (DC) procedures in acute care surgical problems, or less frequently, ablative resection of primary or recurrent tumors, among other less-common conditions [6].

Abdominal Wall Infections and Recurrent Incisional Hernias

An acute wound infection is the main etiologic factor, although not the only one, behind the development of recurrent incisional hernias. These ventral hernias represent the main etiologic group within most series of CAWDs. Ghazi et al. from Emory University in Atlanta described a series of 165 patients with CAWDs treated over a 7-year period; of these individuals, 101 (61%) were recurrent ventral hernias [7].

To a lesser extent, severe and extensive abdominal wall necrotizing infections requiring surgical resection can also occasionally result in CAWDs. They occur most frequently after gastrointestinal operations, especially in the immune-compromised host with multiple comorbidities, and might be associated with fistulas of the gastrointestinal tract. Clostridial myonecrosis, although rare, is the most severe form of abdominal wall infection (Figs. 5.5 and 5.6).

Failure of biomaterials represents a significant setback in patient care. Patients might present with an array of problems ranging from wound dehiscence and infection to suture line disruptions with subsequent formation or recurrence of abdominal wall hernias, mesh extrusion, or even intra-abdominal complications such as bowel damage and fistulas. The incidence of fistula formation with various alloplastic materials has been reported to be as high as 33%. It has also been well recognized that the incidence of fistulas is increased with the use of some type of synthetic prostheses, and that fistula formation can occur even when absorbable meshes are used.

Fig. 5.5 Postoperative fulminant necrotizing fasciitis of the abdominal wall after creation of a colostomy for diverticulitis

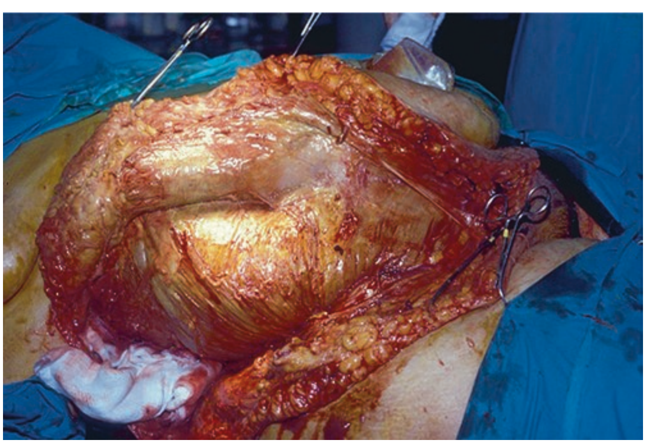

Fig. 5.6 Same patient as in Fig. 5.5 undergoing extensive debridement and resection of the infected abdominal wall tissues

Damage Control and the Open Abdomen Approach

CAWDs in this setting are the result of emergency laparotomies performed for a number of severe conditions and can pose a formidable challenge to the clinical surgeon. A damage control (DC) laparotomy in trauma and emergency surgery, with repeated reentries in the abdominal cavity, is a harbinger of a potential CAWD.

An OA is defined as an abdominal wound requiring temporary abdominal closure due to the skin and fascia not being closed after laparotomy. It is classified in four grades according to severity [8, 9]. The DC surgery and the OA approach have led to an increase in survival of the patient with severe trauma, and this has created an increased need to reconstruct complex defects thereafter (Fig. 5.7). The incidence of chronic ventral hernias is very common in this setting, with a wide range (13–80%) that depends on patient-specific factors and institutional patterns of practice (i.e., aggressive fascial repair vs. a "planned ventral hernia" approach) [10]. Because of the potentially devastating consequences of prosthetic infections, biologic meshes, both crosslinked and non-crosslinked, are currently being recommended when native tissue component repair is not possible [11–14]. These meshes, together with the vacuum-pack technique, are diminishing the rate of planned ventral hernia approaches, in favor of early primary fascial closure [15, 16], with a likely decrease in the overall morbidity and the percentage of CAWDs resulting from this DC/OA surgery [17]. Nevertheless, the data to date suggests that the majority of patients repaired with biological mesh may develop laxity of the repair resulting in a hernia 6–12 months later [18].

Surgical site infections and intra-abdominal abscesses associated with DC/OA occur in as many as 83% of cases and might also contribute to postoperative fascial dehiscence (reported in up to 25% of DC/OA patients) [19].

Fig. 5.7 Open abdomen with overlying synthetic mesh and lateral retraction of the abdominal wall

Fig. 5.8 Recurrent fatal aggressive fibromatosis of the abdominal wall in a 19-year-old woman

Fig. 5.9 Lateral view of the same patient in Fig. 5.8

Resection of Abdominal Wall Tumors

Primary malignancies of the abdominal wall are uncommon. Desmoid tumors are benign fibrous tumors that arise from the musculoaponeurotic structures of the abdominal wall. They are frequently locally invasive (aggressive fibromatosis) (Figs. 5.8 and 5.9) and local recurrence rates of 25–65% after local excision have been reported. Treatment requires wide excision followed by complex abdominal wall reconstruction in up to one-third of patients [20]. This reconstruction is usually performed immediately with synthetic materials (meshes) or myocutaneous flaps when the defect is extensive [21], and usually in collaboration with plastic and reconstructive surgeons.

Complex Recurrent Incisional Hernias and the Pathophysiology of Wound Healing of the Abdominal Wall

The abdominal cavity represents one of the most active areas of surgical activity, and surgical procedures involving the gastrointestinal tract are among the most common procedures performed. Full understanding of the pathophysiology of the healing responses after the surgical procedure remains elusive. Nevertheless, progress in this area is of great interest because complications of abdominal healing represent a significant clinical and economic burden as well as decrease in quality of life [22].

The abdominal wall is a complex region of the body; all of its components are organized in delicate balance to provide maximal protection while preserving physiologic and locomotive function. It is a laminated cylinder of muscle and fascia with an overlying, well-vascularized skin envelope. It serves as a core unit for musculoskeletal posturing, a protective barrier for the viscera, and a base for respiratory mechanics. The maintenance of a constant intra-abdominal pressure allows for support in respiration, locomotion of the trunk, as well as micturition and defecation, among other physiologic functions [22].

When the abdominal wall is in a weakened state, intra-abdominal pressure follows fluid patterns and tends to exert the greatest pressure at the weakest point as opposed to the natural state of diffuse and equal distribution [7]. Although true strangulation of hernia contents is uncommon, many patients with a recurrent incisional hernia have lifestyle limiting symptoms that necessitate operative intervention. Patients may present with chronic dull abdominal pain. They might have postural alterations, leading to lumbar lordosis and chronic back pain. A massive CAWD can also lead to paradoxical respiratory motions, which inhibit respiratory mechanics.

Biological and Mechanical Factors Involved

Modern surgical practice suggests that biologic and mechanical pathways overlap during normal acute wound healing. The cellular and molecular processes activated to repair tissue from the moment of injury are under the control of biologic and mechanical signals. Successful acute wound healing occurs when a dynamic balance is met between the loads placed across a provisional matrix and the feedback and feed-forward responses of repair cells [23].

When a midline incisional hernia develops, the normal force across the composite myofascial structure is lost, functionally resulting in passive unloading of the lateral abdominal wall. Although the adjacent rectus muscles maintain their origin and insertion, the insertion of lateral oblique muscles is lost following midline laparotomy and incisional hernia formation. The linea alba of the abdominal wall is anatomically a tendon that, when severed, should induce pathologic abdominal wall muscle changes similar to those observed in the soleus and gastrocnemius muscles when the Achilles tendon is divided [24]. In a rat model of chronic incisional hernia formation, these authors showed that internal oblique muscles in herniated abdominal walls developed pathologic fibrosis, disuse atrophy, and changes in muscle fiber-type composition. Myopathic disuse atrophic changes significantly altered the phenotype of the herniated anterior abdominal wall. Hernia defects do not enlarge simply by repetitive evisceration of peritoneal contents dilating a fascial defect. Rather, the lateral muscular components of the abdominal wall retract away from the midline fascial defect, and this has therapeutic implications.

Laparotomy wound healing is a complex process involving interplay between many different types of cells; failure with progression to hernia formation is multifactorial. This failure of healing of laparotomy wounds is promoting a considerable body of research focusing on the modulation of the major effectors of wound healing; its emphasis is to improve outcome in tissue remodeling and mesh integration [25].

Biologic factors that contribute to simple and complex abdominal wall defects are multiple [26, 27]:

1. *Inflammation*: When injuries occur, dead or dying structural cells (e.g., epithelial and endothelial cells) release inflammatory mediators that initiate an antifibrinolytic coagulation cascade, which triggers platelet aggregation, clot formation, and development of a provisional extracellular matrix (ECM). Platelet degranulation also promotes vasodilation, increased blood vessel permeability, and production of enzymes known as matrix metalloproteinases (MMPs), which temporarily disrupt the basement membrane, allowing the efficient recruitment of inflammatory cells to the site of injury. Epithelial and endothelial cells also secrete growth factors (GFs), cytokines, and chemokines, which promote the recruitment and activation of leukocytes that participate in wound repair. During this initial inflammatory phase, macrophages and neutrophils debride the wound. They also produce soluble mediators that amplify the wound-healing response by recruiting T cells and other inflammatory cells [28]. Wound strength is low during this phase and depends only on the sutures; a prolonged inflammatory response as seen with incisional foreign bodies or infections predispose to wound failure; besides, microorganism can degrade GFs and synthesize proteinases that remove ECM [26, 29]. Steroids can reduce inflammation but inhibit collagen synthesis.
2. *Fibroblasts and myofibroblasts*: Fibroblasts are one of the most abundant cell types in connective tissues, responsible for tissue homeostasis under normal physiologic conditions. Myofibroblasts are derived primarily from an extensive network of mesenchymal cells, which include fibroblasts and those cells known as pericytes due to their close relationship with the capillary wall. When tissues are injured, fibroblasts become activated and differentiate into myofibroblasts; these promote wound contraction, a process in which the edges of the wound are physically pulled toward the center. They also secrete factors that are mitogenic and chemotactic for epithelial and endothelial cells, which grow inward, forming new ECM and blood vessels as they migrate toward the center of the wound [28]. Myofibroblasts are responsible for collagen synthesis and the recovery of wound-breaking strength, and is the dominant cell type during the proliferative and remodeling phases. Little is known about defective myofibroblast function in wound failure. Some authors have suggested that the loss of abdominal wall load forces signaling as a result of fascial healing failure would select an abnormal population of repair myofibroblast (mechanotransduction pathways) similar to widely described in tendons, ligaments, and bone repair [26, 30, 31]. Recent in vitro studies suggested that early fascial separation and diminished wound tension might lead to loss of a key stimulatory mechanical signal for myofibroblast proliferation, alignment, and contraction function, resulting in the inability to heal the initial wound failure with subsequent progression to hernia formation [32].
3. *Collagen*: Collagen is the main structural protein in abdominal wall fascial layers (at least 80% of tissue dry weight). Defects are described either in its synthesis, with an increase of type III collagen and decrease of collagen I/III ratio and with thinner and less resistant fibers, or in its degradation, with an increase of MMP activity [26, 33]. Numerous studies have now associated incisional hernias with impaired collagen and tissue protease metabolism, and there is a strong correlation between MMP-1 and MMP-13 overexpression and recurrent hernia [33–35].
4. *Growth Factors*: It is not known whether delays in the appearance of GFs contribute to the development of incisional hernias. Experimental models have demonstrated that wound treatment with transforming GF beta 2 or basic fibroblast GF stimulates angiogenesis, fibroblast chemotaxis, and collagen production, increasing wound resistance and reducing the incidence of incisional hernia [29, 36, 37].

Local and General Factors Affecting Wound Healing

Local Factors

Closure Under Tension and Blood Supply

It now appears that, in load-bearing systems like the abdominal wall, a tension equilibrium point exists that maximizes repair signals to wound repair fibroblasts (mechano-transduction pathways) [34]. Nevertheless, closure under excessive tension is probably the most common reason for several complications, ranging from superficial wound dehiscence, infection, tissue necrosis and loss, to abdominal compartment syndrome (ACS) [6]. The site of an incision may disturb the blood supply to a wound. Vertical parallel incisions on the same side of the midline impair healing of the wound placed more medially and risk necrosis of the intervening skin bridge. Suturing might adversely affect the blood supply of a healing wound, especially if there is infection and edema.

Hematoma

Postoperative seromas and hematomas, if not recognized early on and appropriately managed, also might result in wound dehiscence, infection, and tissue loss [6]. A mass of blood apparently exerts a toxic effect independent of the level of bacterial contamination and of the amount of internal pressure they produce, theoretically obstructing the dermal circulation and causing necrosis [38].

Infection

It is the most common complication of wound healing. The principal biochemical abnormality in infected wounds seems to be a disturbance of fibroblast proliferation and subsequent collagen metabolism. In DC surgery, the incidence of dehiscence and abdominal wall infections is approximately 9% and 25%, respectively, and their development is multifactorial [19]. The intra-abdominal hypertension (IAH) that commonly develops in this population reduces abdominal blood flow even in the face of maintained arterial perfusion pressures, contributing to local edema and ischemia. This impairs wound healing, and the ischemic tissue provides a site for bacterial infection.

Irradiation

There are several hypotheses on the role of circulatory decrease and radiation-induced direct cellular damage. Recent advances highlight that transforming GF beta 1 is the master switch in pathogenesis of radiation fibrosis [39].

Mechanical Stress

A rise in intra-abdominal pressure by coughing or distention of intestine is a factor in abdominal wound failure. Sutures may cut through the abdominal wall or break.

Surgical Technique

Good technique and gentle handling is one of the most important factors affecting healing in surgical practice.

Tissue Type

The surface epithelium of the skin retains its power of regeneration throughout life. The bulk of tissue lost dictates whether the process of repair is primary or secondary.

General Factors

Age

Wound-healing complications (e.g., abdominal wound dehiscence) are more common in elderly persons. Age affects epithelialization and maturation of the scar as well as gain of tensile strength.

Anemia

Anemia has been linked with an increased incidence of abdominal wound dehiscence, although it is almost impossible to separate it from other factors, such as the nutritional state and the type of surgery performed.

Diabetes

Failure of wound healing, particularly related to infection, is encountered in up to 10% of diabetic patients undergoing operations. It has been known for some time that neuropathy, atherosclerosis, and propensity to infection, all frequently encountered in diabetic patients, may contribute to wound-healing failure. A large body of evidence from in vitro and in vivo studies indicates that advanced glycation end products may play a role in the pathogenesis of impaired diabetic wound healing. These products hamper fibroblasts and endothelial cells proliferation, migration, homing, secretion, and organization of a productive granulation tissue. Diabetic fibroblasts and endothelial cells may bear mitochondrial damages becoming prone to apoptosis, which impairs granulation tissue cellularity and perfusion [40, 41]. Diabetes-enhanced and prolonged expression of TNF-α, a potent proinflammatory cytokine, also contributes to impaired healing [42].

Nutrition

Undoubtedly, there is a relation between malnutrition and abdominal wound dehiscence and infection. The exuberant cellular and biochemical events that constitute the wound healing cascade require energy, amino acids, oxygen, metals, trace minerals, and vitamins for successful completion. Many nutritional deficiencies have an impact on wound healing by impeding fibroblast proliferation, collagen synthesis, and epithelialization. There are also nutrients that can enhance wound-healing responses [43].

Steroids

Experimentally, large doses of steroids depress the healing process and reduce wound strength. Nevertheless, one should be careful in assigning wound-healing problems to steroid therapy, because many patients receiving steroids are elderly, malnourished, and often suffering from malignant disease. Steroid therapy begun several days postoperatively has little effect on wound healing, and acute stress or single-dose steroids have no effect on healing.

Jaundice

Experimental evidence in abdominal incisions suggests that jaundice delays the appearance of wound fibroblasts and new blood vessels and affects collagen synthesis, although the clinical relevance of these findings is uncertain. The role of jaundice in predisposing to problems of wound healing is probably multifactorial. The baseline synthesis of type I and Type III collagen in the skin is decreased in jaundiced patients; this is partly restored by the resolution of jaundice [44].

Malignant Disease

It is difficult to conclude from clinical studies what effect malignant tumor cells or their systemic sequelae have on healing because associated local problems, such as infection and obstruction, may also be present.

Obesity

Incisional hernias are significantly associated with obesity, partly through an increased occurrence of wound hematomas and infection [45].

Temperature

Wounds heal much more slowly in low temperatures, probably through a reflex vasoconstriction.

Trauma, Hypovolemia, and Hypoxia

Posttraumatic hypovolemia and low inspired oxygen tension are associated with delayed healing, especially delayed collagen synthesis. There is also an increased susceptibility to infection, probably because of tissue hypoxia.

Uremia

Experimental evidence three decades ago showed that certain aspects of wound healing may be adversely affected by uremia, leading to considerable diminution in the bursting strength of the laparotomy wound [46]. Also, a high wound complication rate was found after abdominal operations in patients undergoing long-term peritoneal dialysis. Poor nutrition together with a high urea level was found to be significant [47]. Recently, in vitro studies have shown that uremic solutes decrease endothelial proliferation and wound repair [48].

Complex Abdominal Wound Defects from Damage Control Surgery and the Open Abdomen

The peritoneal environment is instrumental in the response to injury that occurs with DC surgery or trauma. The peritoneum is composed of mesothelial cells that respond to surgically induced tissue trauma, ischemia, and infection. The local inflammatory response within the abdomen results in a copious fluid and cellular response in the first 48 h, but will continue at a slower rate while the abdomen remains open [49]. The initial response involves migration and activation of macrophages in the peritoneum. Fibroblasts, platelets, and chemoattractants such as thrombin and plasmin are part of the cascade for healing and functional restoration. Vascular injury and subsequent endothelial cell activation result in fibrinogen accumulation and chemokine release. Mast cells recruited secondary to the peritoneal trauma release histamine and vasoactive kinins, which in turn increases capillary permeability [22].

After 48 h, the formation of fibrin within the exudate results in a gelatinous mass in which intestine and omentum are loosely held. During the next 4 or 5 days, this loose coagulum is replaced by increasingly tough adhesions as polymerization of fibrin and collagen occurs, and, by day 10, the abdomen is sealed by vascular, organizing granulation.

The practical implication of this healing process is that, beyond the first 10 days, any attempt to suture the fascial edges or dissect the bowel away from the posterior aspect of the anterior abdominal wall is likely to result in multiple enterotomies and fistulas [50]. ECF is the second most common type of abdominal complication associated with DC/OA, and they arise as a result of a leaking anastomosis, bowel ischemia, obstruction, exposure of the bowel to the air, or ill-advised dissection. The incidence varies between 5 and 19% depending on the presenting diagnosis/indication for DC/OA [10, 19]. If the fistula arises in a mobile portion of the bowel, it might slowly rise to the surface, where mucosa might be seen (enteroatmospheric fistula, which rarely closes spontaneously) (Fig. 5.2). The lack of skin surface around the fistula makes for difficult management, aggravating the already-existing abdominal wall defect. The organizing granulation may adhere to the margins of the fistula, and eventually it will be incorporated into the scar, uniting the edges of the abdominal wall. Thus, if a fistula is present after a period of 10 days in an OA, a long period of supportive treatment might be inevitable before repair and closure of the CAWD is contemplated [50].

Although the maturing adhesions are laying down increasing amounts of fibrin and collagen from the first week, a strong and sudden increase in intra-abdominal pressure, as from a strong cough, in the first 3 weeks might rupture the fragile coagulum holding the gut, omentum, and abdominal wall together, spilling intestine onto the surface of the abdomen. Such eviscerations might produce serosal tears and fistulas. Furthermore, the process of adhesion formation and maturation fixes the omentum and bowel to the edges and posterior aspects of the abdominal wall.

Because of the natural elasticity of the abdominal wall structures, wound retraction in the OA will progress during the first week, and this could produce evisceration, with the bowel losing its "right of abode" within the abdominal cavity. The practical implication for the surgeon is that evisceration should be converted as rapidly as possible to an eventration: The abdomen, though open, contains most or all of the intestines. By the end of the first 2 weeks, vascular granulation will occlude the surface of the OA, uniting the edges of the wound. Over the succeeding weeks and months, collagenization of the wound proceeds to convert this granulation into a scar. During this process, a hernia might not be visible because of the density of the scar. Over the succeeding months and up to a year, the collagen is slowly removed, the scar thins and softens, and a hernia will become apparent. If this large, granulating, OA wound is skin grafted, wound contraction and the development of collagen might be impaired, leading to the early development of large hernias with a progressive loss of abdominal abode.

Based on limited evidence, functional status in patients with a CAWD resulting from DC/OA seems to be dependent on several factors, including the size of the hernia, the presence of skin and subcutaneous tissue overlying the midline defect, and the presence of a fistula [51]. There are some reports of up to 55–78% of patients eventually returning to work after abdominal closure or reconstruction [52], although other studies of patients with large chronic ventral hernias show persistent significant impairment of activity, productivity, and quality of life [53]. The successful repair of these CAWDs might be a challenge [54], and the biology of the healing process in this OA approach must be well understood and respected by the surgeon to achieve a successful final outcome.

Summary

In summary, the definition of what constitutes a CAWD is not universally defined, but its causes are varied and well recognized by practicing surgeons all over the world. The complex mechanisms and factors intervening in wound repair at the molecular level are not fully understood to this day, but the biology of these defects and the difficulties involved in their management are better known. CAWDs are very often a real challenge to the technical abilities, patience, and wisdom of surgeons.

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Perioperative Radiologic Evaluation of Patients with Difficult Abdominal Wall Defects

6

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Introduction

The number of patients undergoing complex operative interventions for the surgical repair of abdominal wall defects has increased greatly over the last several years [1]. The basis for this near-exponential increase is the result of two key factors.

First, as a result of advancements in medical science, patients who were previously denied operative intervention because of comorbidities or severity of disease are now undergoing laparotomy. In a good portion of these patients, a damage control approach is often adopted [2, 3], with the creation of an open abdomen; many cannot be closed during the initial operation, resulting in a planned ventral hernia [4]. Even when primary closure is achieved, the proinflammatory milieu created by the severity of the underlying disease and the resultant malnutrition frequently lead to acute wound failure and the development of enterocutaneous fistulae. In addition, the use of stomas is frequent in this group.

Second, since the early 1990s, the use of more complex surgical techniques in reconstructing the abdominal wall has become increasingly popular [5–7]. Adoption of component separation techniques has allowed large defects to be closed primarily. This, coupled with the availability of a plethora of synthetic and biologic materials as adjuncts to support such complex repairs, has broadened the surgical options available for the repair of these defects [8].

The use of the appropriate radiologic imaging modality assists the surgeon in planning the surgical management of the patient with complex abdominal wall defects. Radiologic imaging can be used to establish a diagnosis, define the defect when this defect is not clinically apparent, characterize the condition of the various components of the abdominal wall, determine the presence and location of interloop intestinal fistulae, provide intraoperative guidance, detect postoperative complications, and identify recurrences.

Diagnosis

In the vast majority of patients, the diagnosis can be made with physical examination alone. Careful examination can reveal the defect, its margins, likely contents, reducibility, presence of associated fistulae or stoma, and the condition of the overlying skin. On occasion, the diagnosis might not be as readily apparent. This is most likely to be witnessed in patients with a large body habitus (Fig. 6.1a, b) and in patients with associated tenderness that precludes a thorough examination. Physical examination similarly might be inadequate in certain anatomical locations, such as the subxiphoid region, where divarication of the recti is difficult to distinguish from true herniation (Fig. 6.2). In such conditions, additional imaging modalities are warranted and include ultrasonography (US), computed tomography (CT), and, rarely, magnetic resonance imaging (MRI).

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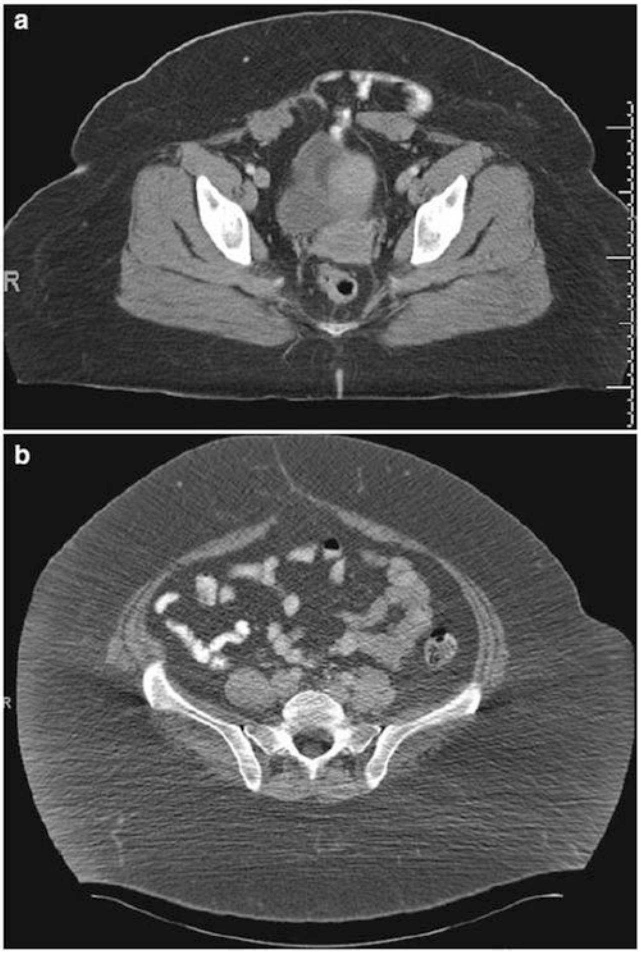

Fig. 6.1 (**a**, **b**) A small incisional hernia in patients with a large body habitus is difficult to diagnose on physical examination, but it is clearly seen on CT

Fig. 6.2 Subxiphoid defect with herniation of omentum. A posterior component separation with retrorectus placement of the mesh will allow adequate superior overlap of at least 5 cm to reduce recurrence

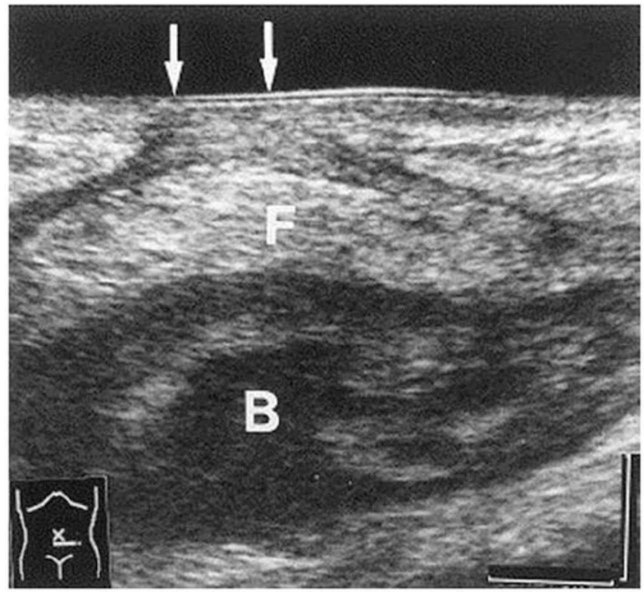

Fig. 6.3 Sonogram of an abdominal wall hernia in a postoperative patient. Transverse scanning of the lower abdomen identified a fascial defect (*arrow*), herniated bowel loop (B), and omental fat (F) along the linea alba. (Reprinted with permission of Elsevier from Ishida et al.)

Ultrasonography

Ultrasonography is a noninvasive, easily performed, readily available, and relatively inexpensive modality. Its use in the diagnosis of abdominal wall hernias was first described by Spangen [9], and it has since been well validated [10–12]. Images are acquired using grayscale imaging and a high-frequency 5 or 7-MHz transducer. Imaging is performed in the supine and standing positions, both with and without the performance of a Valsalva maneuver [13, 14].

Recent improvements in technology have resulted in notably improved images, with the dull gray abdominal wall muscles and “hyperechoic” bright fascia more easily visualized [15]. The hernia defect can be appreciated as a discontinuity in the structures of the abdominal wall, potentially with abdominal contents herniating through the defect (Fig. 6.3). Use of real-time imaging allows the dynamic visualization of the abdominal muscles with the hernia contents seen traversing through the defect [16]. The use of the Valsalva maneuver can further accentuate the herniation of contents, and it is especially useful when static imaging is equivocal and in certain anatomic locations, such as with a spigelian hernia. Imaging can assist in the detection of additional defects, the presence of which might alter the operative plan or constitute a potential cause of recurrence. US can furthermore distinguish between hernias and other abdominal wall masses, such as tumors, seromas, hematomas, and abscesses. As US is operator dependent, close communication between the surgeon and sonographer is critical.

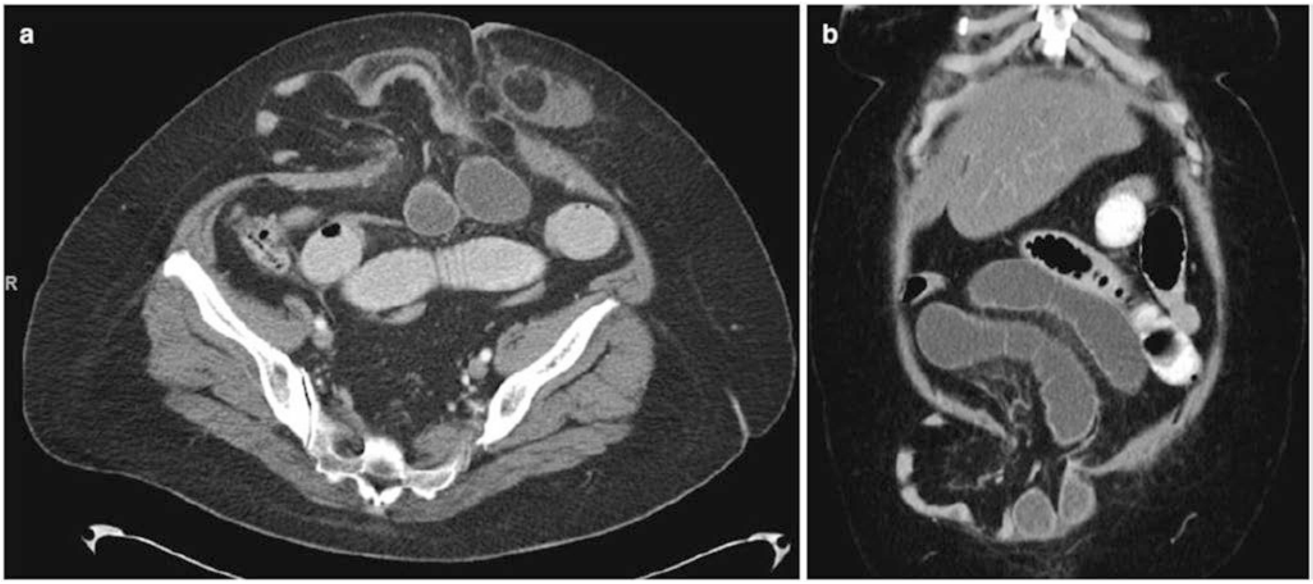

Fig. 6.4 (**a**, **b**) Differential caliber of bowel loops, which, in conjunction with inability to reduce the hernia on physical examination, indicates the presence of incarceration. Emergent operative intervention is indicated

Computerized Scan

Multidetector row CT with reformatting is currently the ideal modality for establishing the diagnosis [17–20]. Axial imaging is performed in the supine position with thin (5-mm) slices. Intravenous contrast is administered if there is need to assess the vascular supply of the hernia contents. Oral contrast helps visualize bowel loops and is routinely administered in all cases. In subtle hernias, image acquisition is performed using the Valsalva maneuver. Multiplanar reformatting allows better appreciation of the anatomy in a manner more familiar to the surgeon. CT is especially useful in identifying hernias in unusual locations, such as with lumbar [21, 22], obturator [23], sciatic [24], and perineal hernias [25]; these are challenging to detect either on physical examination or with US. CT not only identifies the presence of a hernia but also allows for the detection of complications, including bowel obstruction, incarceration, and strangulation. Bowel obstruction is identified when the transition point is located at the level of the hernia, and the bowel proximal and distal to the hernia is dilated and decompressed, respectively. Although incarceration is a clinical diagnosis, the hernia contents have bearing on the timing of the operation. The presence of bowel in the incarcerated hernia mandates immediate operative intervention to prevent strangulation of the contents, especially if there is fluid within the hernia sac, thickening of the bowel wall, or luminal dilation. Strangulation is suggested by the presence of fluid-filled loops of bowel with proximal dilation, abnormal attenuation of the thickened abdominal wall, engorgement of the mesenteric vessels, mesenteric haziness, and ascites (Fig. 6.4a, b). In contrast, the absence of these findings on imaging and clinical examination indicates a low risk for incarceration and strangulation, allowing an elective approach to the hernia repair after optimization of the patient's general medical condition if necessary (Fig. 6.5).

Barium Studies with Small-Bowel Follow-Through

Barium studies with small-bowel follow-through study and barium enemas have been described as a useful diagnostic modality [26]. Diagnosis of a hernia is made when contrast-filled bowel loops are seen extending beyond the fascial planes of the anterior abdominal wall (Fig. 6.6) [27]. Reducibility is determined by manual compression of the loops under fluoroscopy. The presence of obstruction can be identified by a difference in bowel caliber proximal and distal to the hernia and a failure to return the bowel loops to their normal position with manual reduction. Use of barium studies has largely been replaced by CT with oral or rectal contrast. Barium studies, however, might have utility in regions of the world with limited resources where CT might not be available.

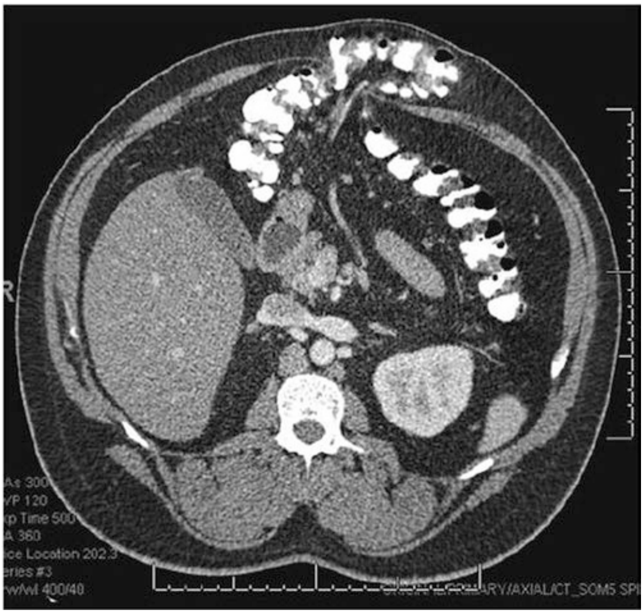

Fig. 6.5 Use of oral contrast allows determination of the caliber and quality of the bowel. There is no wall thickening or lack of contrast in the distal bowel, and the vascular supply to the segment of bowel appears intact. In conjunction with physical examination, these findings are comforting in that the bowel is not at risk, and an elective operation can be planned

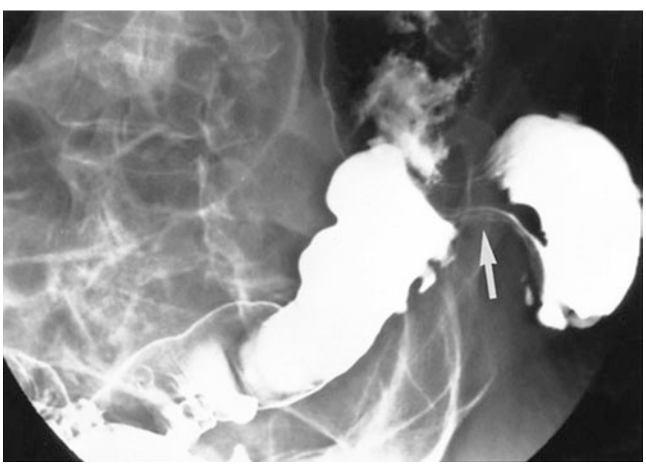

Fig. 6.6 Single-contrast barium enema demonstrating a short segment of herniated descending colon lying lateral to the iliac crest. (Reprinted with permission of BMJ Publishing Group from Hide et al.)

Magnetic Resonance Imaging

MRI, similar to CT, allows delineation of the layers of the abdominal wall, highlighting the presence of the hernia and its contents (Fig. 6.7) [28]. However, MRI offers no particular advantage over CT and is not routinely obtained in making the diagnosis. Theoretically, MRI might be the preferred modality in the pregnant woman because of its favorable safety profile for the fetus.

Operative Planning Guided by Imaging Techniques

No imaging modality in isolation can guide selection of the operative intervention best suited for the individual patient. Imaging must be used in conjunction with a clinical assessment of the patient to select the operation that has the greatest likelihood of success. Of the various imaging modalities, CT has the greatest impact on decision making. The use of multiplanar reconstruction allows the anatomy of the defect and abdominal wall musculature to be better understood. It also allows for better conceptualization of the defect in three dimensions, giving the surgeon a mental image of the operative intervention required (Figs. 6.8a, b and 6.9). CT also visualizes the entire abdominal wall, allowing multiple hernia defects to be identified (Fig. 6.10a–d). A failure to identify all defects present results in the selection of operative procedures that are less than ideal for the patient and increases the risk of hernia recurrence.

In giant ventral hernias, a large proportion of abdominal contents is contained in the hernia (Fig. 6.11a–c). Consequently, there is a reduction in the volume of the peritoneal cavity, resulting in a loss of domain. Returning the abdominal contents into the peritoneal cavity during hernia repair has significant physiologic consequences because of the development of an abdominal compartment syndrome with respiratory consequences, renal dysfunction, intestinal ischemia, and hemodynamic compromise. Although some studies described complex calculations to help target patients at risk [29] and others relied on a defect size greater than 10 cm in width as an indicator for recurrence [30], neither approach is clinically useful. The best current approach likely relies on using axial CT scan images to compare the contents of the native abdominal cavity with that in the hernia or "second abdomen." In giant hernias with over 50% of the contents located within the hernia sac, a progressive preoperative pneumoperitoneum is recommended [31].

A second important factor in decision making is the need for reapproximation of the musculature to create a dynamic functional abdominal wall. In the elderly, who typically lead a sedentary lifestyle with significant comorbidities, the use of a mesh to cover the defect with adequate overlap via open or laparoscopic techniques is sufficient. Here, no additional analysis of the CT is necessary. In contrast, for patients in whom a dynamic abdominal wall is desirable, a critical assessment of the CT is essential. It is important to measure the size of the defect, the size and mass of the rectus, and the quality of the lateral abdominal wall musculature.

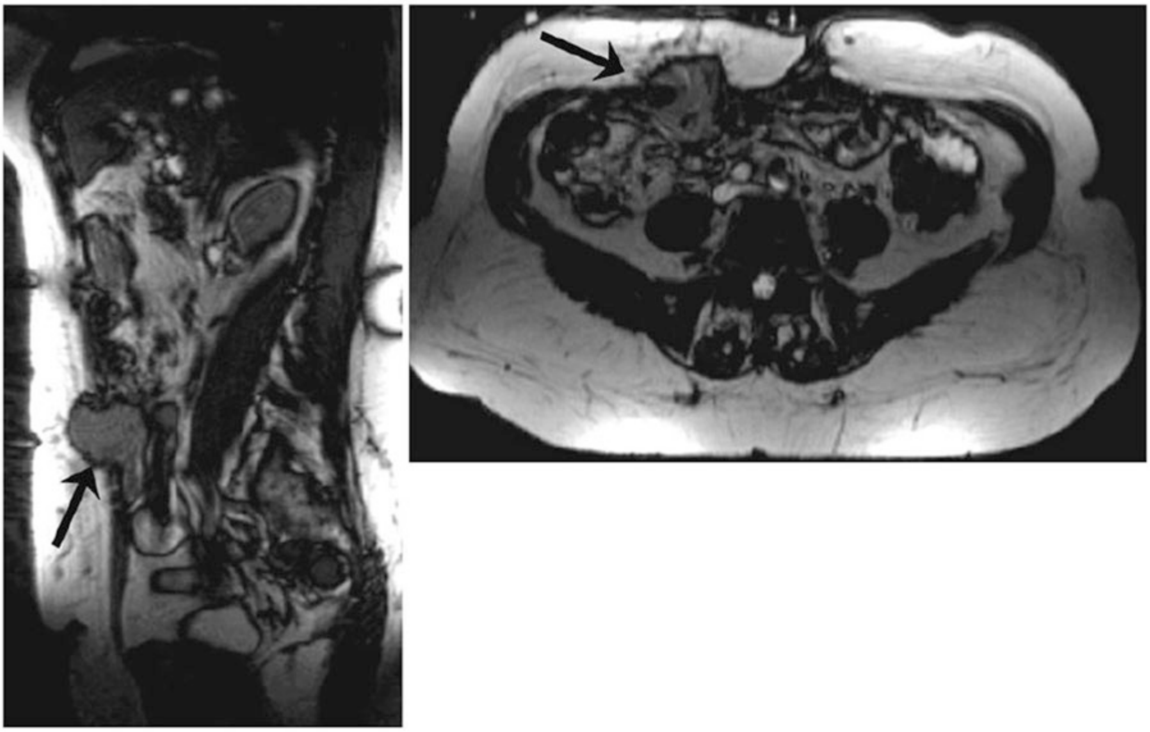

Fig. 6.7 Recurrence of a laparoscopically treated incisional hernia in the right abdominal wall (*arrows*). (Reprinted with kind permission of Springer Science + Business Media from Kirchhoff et al.)

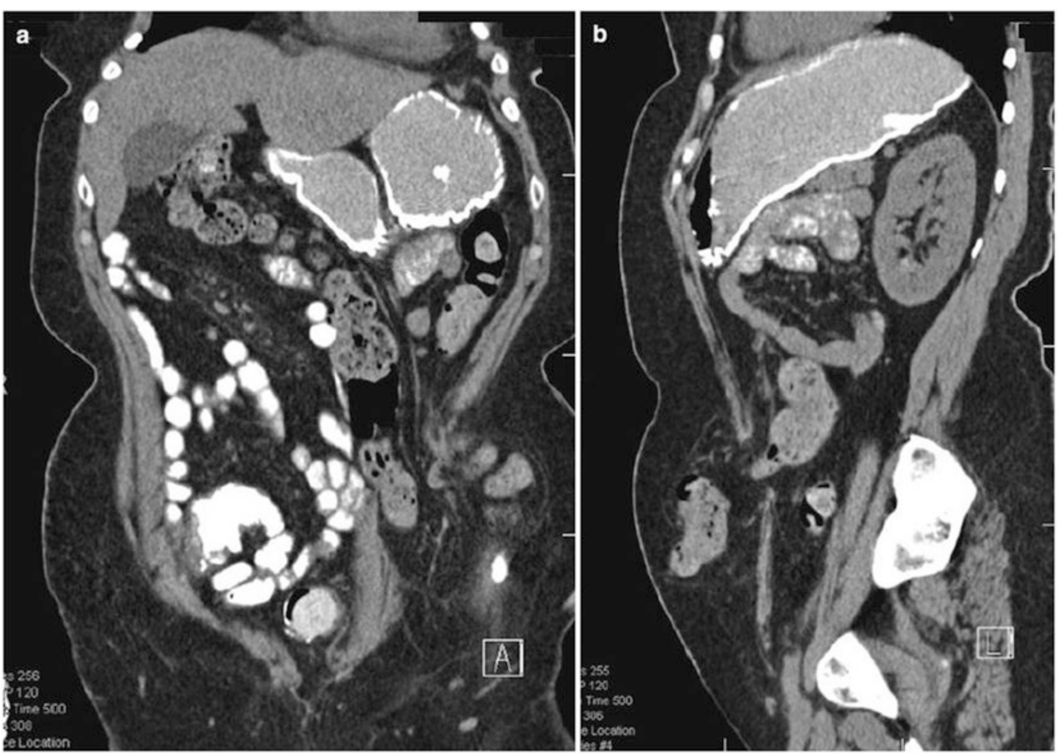

Fig. 6.8 (**a**, **b**) Multiplanar reconstruction allows the defect to be better understood in terms of surgeon familiarity

Fig. 6.9 Traumatic lumbar hernia following a motorcycle accident. The lateral musculature has been avulsed from the iliac crest. Repair requires access to the space between the transversalis fascia and the peritoneum. The mesh is allowed to drape well down into the pelvis and is secured to the iliac crest using tacks that will penetrate bone. No tacks are placed below the iliac crest for fear of injuring neurovascular structures

CT images allow the dimensions of the hernia defect to be accurately measured. We use the size of the hernia defect in its largest dimension as a guide to subsequent operative intervention when a dynamic abdominal wall with medicalization of the rectus muscles is desired. The decision regarding need for approximation of the musculature is made after considering the patient's general health status, functioning, and the need for a functional abdominal wall. In patients with significant underlying disease who would not tolerate an extensive reconstructive procedure and whose level of function and daily activities do not involve significant physical exertion, placement of a mesh in the intra-abdominal position with at least a 5-cm overlap beyond the edges of the hernia defect is generally adequate. However, there might be tension at the interface between the static mesh and the dynamic abdominal wall. Increased tension prior to incorporation of the mesh will result in disruption at the point of maximal stress, with resultant recurrence of the hernia (Fig. 6.12).

For defects with a size less than or equal to 6 cm, the hernia defect can almost always be closed primarily with reinforcement using a synthetic mesh [32] (Fig. 6.13). For hernia defects greater than 6 cm, release of myocutaneous flaps is performed to allow the muscles to come together in the midline. The nature of the myocutaneous flap procedure selected depends on the size and status of the abdominal wall musculature. If the rectus abdominus muscle is of adequate size, approximately 8 cm for an average size adult, component separation involving the external oblique muscles can be performed using open, minimally invasive, or endoscopic techniques (Fig. 6.14). If, despite adequate release of the external oblique, the defect cannot be closed, a posterior component separation is added. In contrast, if the rectus muscles are inadequate as a result of either previous operative intervention or fibrosis, the lateral musculature is evaluated. If adequate lateral musculature is present, a transversus abdominus release will allow for all but the largest of defects to be closed in the midline, supported in almost all cases by a synthetic or biologic prosthesis to potentially reduce recurrence rates. Large defects with a relatively inadequate rectus abdominis and lateral wall musculature suggest that the defect cannot be closed primarily. A bridging type of repair will most likely be necessary, requiring the surgeon's and patient's expectations for the repair to be adjusted accordingly (Fig. 6.15). In patients who have undergone damage control laparotomy because of severity of the injury or surgical process, bowel edema coupled with loss of domain caused by fascial retraction precludes closure in a large proportion of patients. Here, the exposed bowel is covered by a split-thickness skin graft with a planned ventral hernia accepted in lieu of almost certain death. Repair of the resultant defect requires a careful analysis of the relative size of the defect and the available abdominal wall musculature. In cases of large defects with limited lateral wall musculature, the Fabian modification of the component separation is preferred (Fig. 6.16). In certain circumstances, the hernia defect might involve the lateral aspect of the abdominal wall. This might be seen following the creation of a stoma, as with parastomal herniations; laterally placed incisions, as with incisional herniations; and with injury as occurs following penetrating trauma or blunt rupture of the abdominal wall (Figs. 6.17 and 6.18).

Even in the presence of relatively large defects, the presence of redundancy of the lateral wall musculature indicates that, subsequent to a component separation procedure, the muscles can be stretched adequately, resulting in an ability to cover the defect (Figs. 6.19 and 6.20).

The CT scan also allows for the identification of the location of enterocutaneous fistula, stoma, and the quantity and caliber of the bowel. In addition, the presence of an overt or occult parastomal hernia can be identified. These factors might significantly alter the operative plan. Specifically, component separation techniques will have to be altered when stoma or fistula are present, and a significantly decreased degree of advancement is to be expected on the side of the ostomy (Fig. 6.21). CT accurately

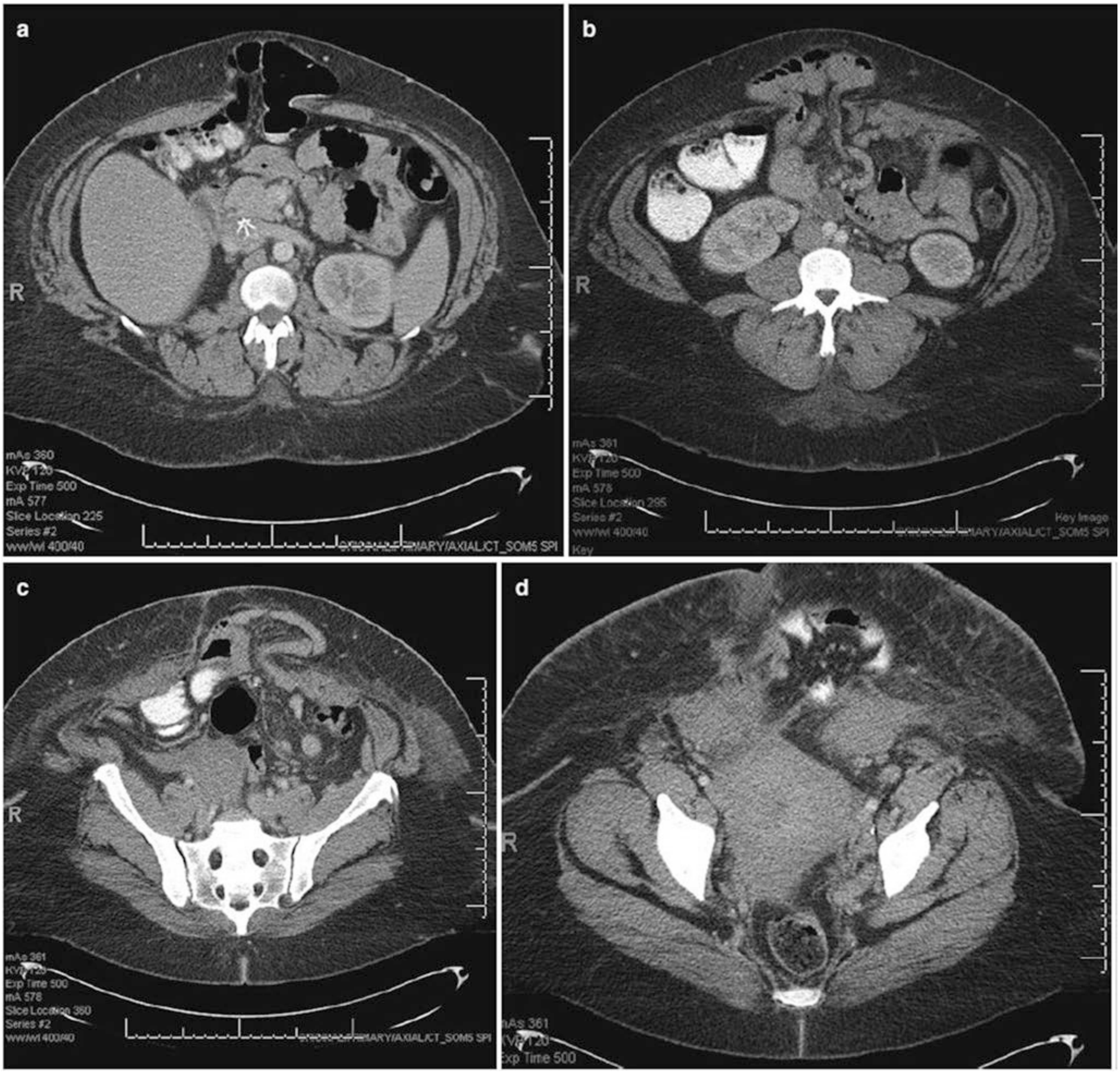

Fig. 6.10 (**a**–**d**) Multiple hernia defects along the entire length of the midline of the abdominal wall. There is an adequately sized rectus muscle and good lateral wall musculature. An endoscopic component separation of the external oblique aponeurosis with a retrorectus placement of the mesh is likely to have a high chance of success

identifies the presence of undrained foci of the intra-abdominal pressure following reconstruction of the abdominal wall (Fig. 6.22).

Intraoperative Guidance

Complex abdominal wall defects result in significant distortion of the abdominal architecture. As a consequence, the linea semilunaris is often displaced laterally. This is even more challenging when this occurs in obese patients. When performing an endoscopic component separation, the initial incision is made at the tip of the 11th rib, with the intention of entering the space between the external and internal oblique muscles. The lateral displacement of the linea semilunaris might lead to accidental entry medial to the rectus sheath and balloon dissection of the incorrect plane. This might result in injury to the epigastric vessels with potentially significant hemorrhage. This complication can be bypassed by measuring the width of the rectus muscle on the

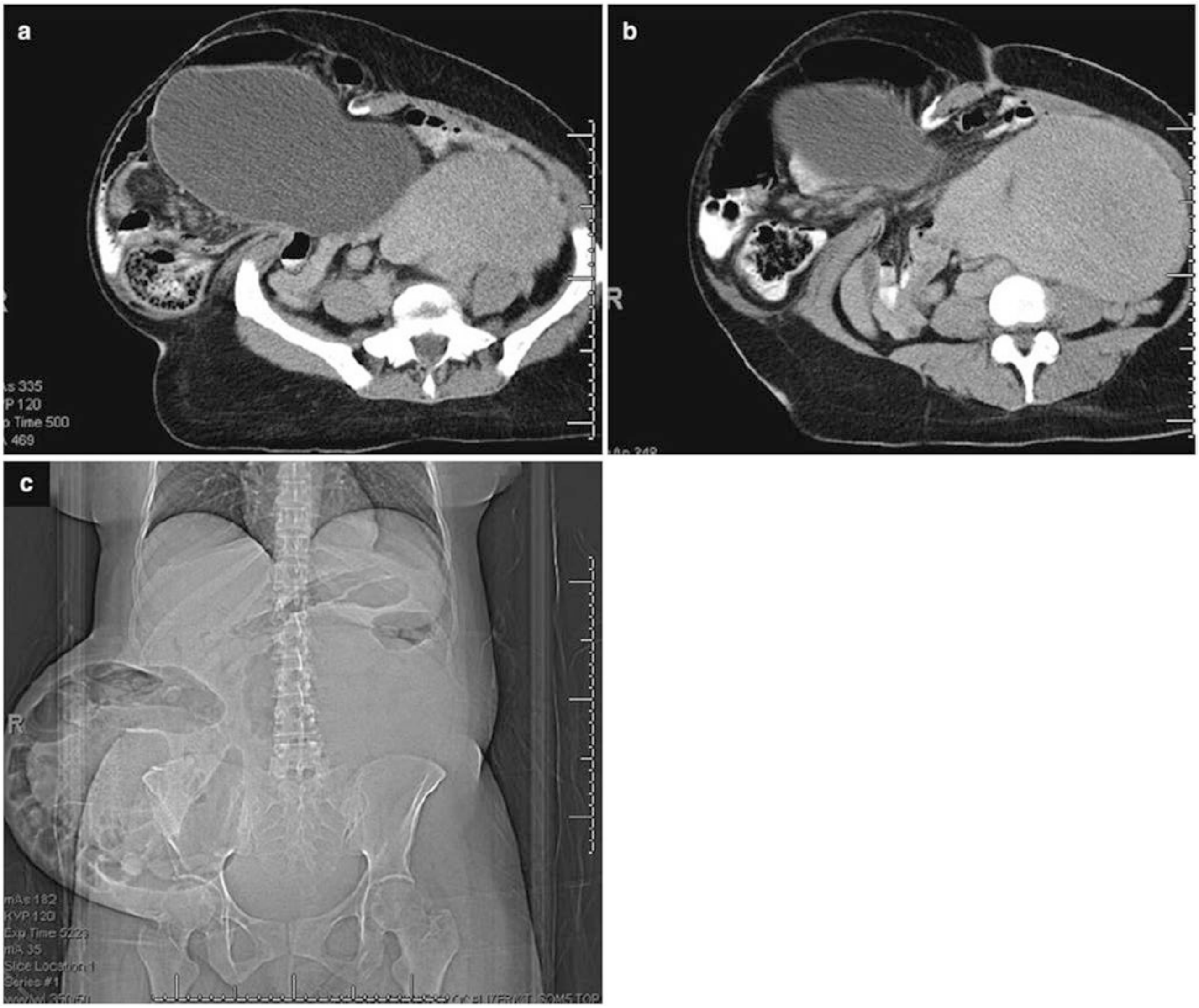

Fig. 6.11 (**a**–**c**) Location of over half the intra-abdominal contents in the hernia sac is highly suggestive of the need for a preoperative pneumoperitoneum

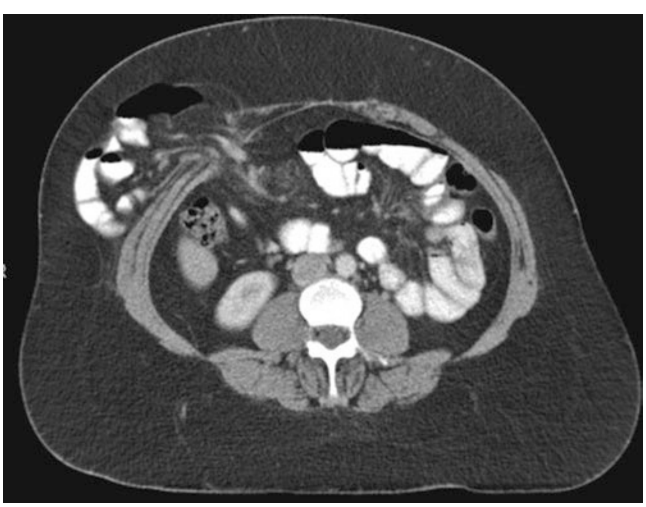

Fig. 6.12 Small hernia defect that can be repaired laparoscopically with primary closure of the defect using the "shoelacing" technique and subsequent reinforcing of the defect with a synthetic mesh

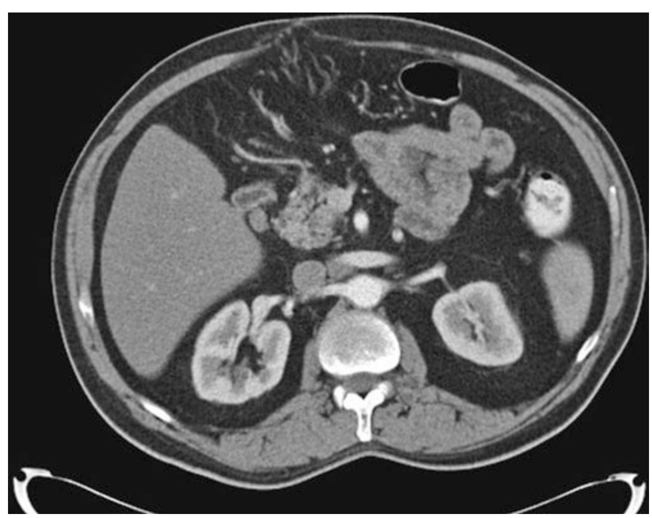

Fig. 6.13 The interaction of the adynamic mesh with the dynamic abdominal wall results in separation at the edge. The use of component separation with reapproximation of the musculature avoids this complication

Fig. 6.14 A moderate midline defect with adequate residual abdominal wall musculature. CT findings suggest success with an endoscopic component separation of the external oblique aponeurosis with a retro-rectus placement of the mesh

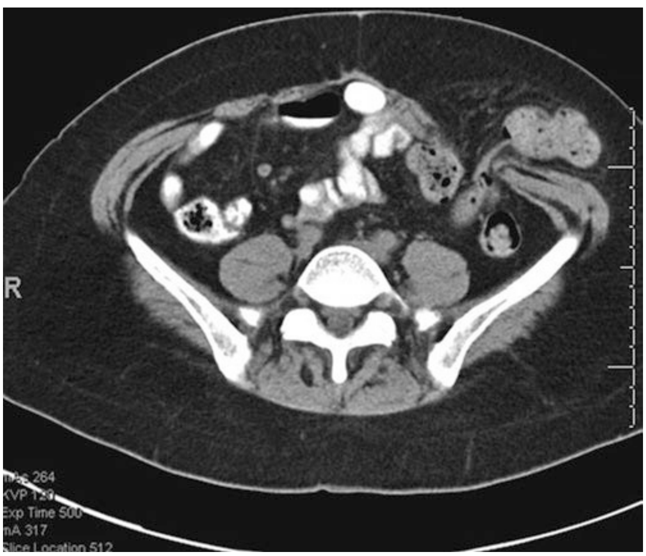

Fig. 6.15 Midline defect with associated parastomal hernia. The rectus muscles are relatively small with a disrupted left lateral wall musculature. Despite component separation, a bridging repair is likely and must be anticipated in setting patients'/surgeon expectations

preoperative CT scan and incising beyond the measured location of the linea semilunaris.

Alternatively, intraoperative ultrasonography can be utilized [33]. A 7.5-MHz transducer is used to image the abdominal wall, starting at the lateral edge of the hernia defect at about the level of the 11th rib. Scanning is performed medially to laterally and identifies the echogenic linea semilunaris and the subsequent decussating of the lateral abdominal wall musculature. Scanning can then be repeated at several points along the abdominal wall to trace the outline of

Fig. 6.16 A large defect with bowel covered by a skin graft. The Memphis modification of the component separation technique would be appropriate in this circumstance

Fig. 6.17 Herniation at the site of a previous stab wound. A unilateral component separation on the affected site allows the defect to be closed with physiologic tension. Support with an intra-abdominal prosthesis further reduces the risk of recurrence

Fig. 6.18 A large parastomal hernia, the stoma, and resultant attenuation of the musculature on the affected side make repair challenging

Fig. 6.19 Large abdominal wall defect with significant redundancy of the lateral abdominal wall musculature and moderate size rectus muscles. A transversus abdominus release will bring the musculature back in the midline

Fig. 6.21 Large incisional hernia with parastomal component indicating need for complex reconstruction with an inability to perform an adequate component separation of the left side; a transverse abdominus release with a bridging repair using a biologic scaffold is likely to yield the best results

Fig. 6.20 Despite the large size of the hernia, buckling of the left lateral abdominal wall musculature suggests that a component separation will allow the defect to be closed primarily with additional reinforcement using a biologic scaffold

Fig. 6.22 Large abdominal wall defect with significant intra-abdominal contents. Abdominal wall reconstruction has a high risk of postoperative abdominal compartment syndrome. Mechanical bowel preparation reduces intraluminal contents and increases the space in the abdominal cavity

the linea semilunaris. The initial incision for the endoscopic component can then be placed in the appropriate location.

Postoperative Radiologic Assessment

Postoperative complications are common following abdominal wall repair, especially when the hernia is large and the operative approach is complex. A large majority of these complications will require some intervention; hence, imaging is a crucial component of the assessment and management of postoperative problems.

Ultrasonography is useful in both the diagnosis and the management of postoperative complications. In addition, the examination can often be performed at the patient's bedside and repeated as often as necessary. On US, seromas appear as well-defined anechoic fluid collections. Although most seromas resolve spontaneously, those that persist beyond 6 weeks cause discomfort or are suspected to be infected are aspirated for therapeutic or diagnostic reasons.

The aspiration might be performed using US guidance (Fig. 6.23). Imaging might be challenging when the fluid collection is located beneath the mesh, where CT might be preferable (Figs. 6.24 and 6.25a). US can also potentially distinguish seromas from hematomas (Fig. 6.25b, c) from recurrence.

Fig. 6.23 Large seroma anterior to the reconstructed abdominal wall, causing pain. In addition, if left alone, this might result in pressure necrosis of the tissue. Percutaneous drainage with placement of a catheter is easily performed using ultrasound guidance

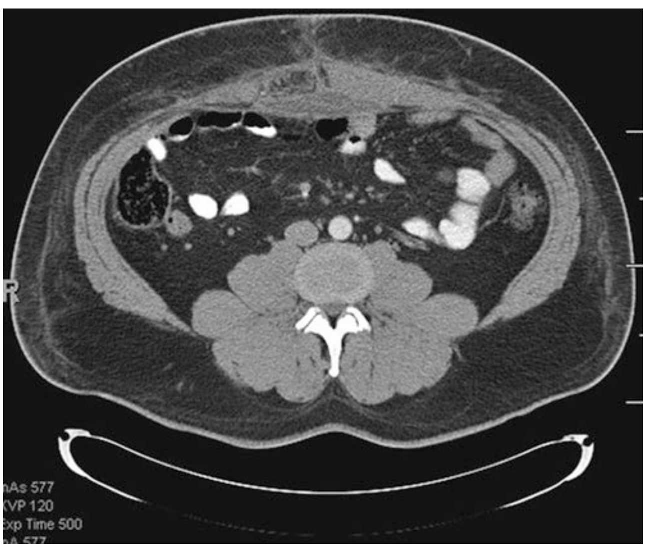

Fig. 6.24 Fluid collection between the reapproximated anterior abdominal wall and the biologic prosthesis placed in the retrorectus position. CT-guided drainage can be performed to evacuate the collection if symptomatic

CT scanning is more expensive than US and exposes the patient to ionizing radiation, but it has the distinct advantage of demonstrating greater anatomic detail. It can easily distinguish between seromas, hematomas, and recurrence. The location of the collection can be defined even if it lies deep into the mesh. In addition, CT guidance can be used to evacuate the collections accurately. This becomes especially useful when the collection is located deep to the muscles or adjacent to critical structures and must be approached from unusual angles to avoid inadvertent injury. Inflammatory response to the implanted mesh can also be detected using CT. Irregular enhancement of the tissue surrounding the mesh is seen following the administration of intravenous contrast (Fig. 6.26). Localized fluid collections or air in the soft tissue, however, indicates mesh infection and the need for its removal. The presence of air-fluid levels indicates the likely presence of an abscess (Fig. 6.27a, b). In the past, this mandated removal of the mesh and the acceptance of a recurrence with plans for later reoperation. Current management varies with the type of mesh used. Biologic scaffolds are likely to disintegrate owing to the enzymatic activity of the bacteria and the resultant host inflammatory response. Continued drainage is usually adequate in these cases. Imaging must be performed again prior to drain removal to prevent recurrence of abscess because of incompletely drained collection. Among synthetic meshes, those composed of lightweight polypropylene can often be salvaged with drainage and long-term antibiotic therapy. Polyester mesh, on the other hand, poorly resists infection and often results in multiple draining sinuses. The presence of air in the tissue might suggest the diagnosis of a necrotizing infection requiring emergent intervention. Use of oral contrast will allow for detection of the dreaded complication of enterocutaneous fistula.

CT also remains a key imaging technique to distinguish these complications from that of a rectus sheath hematoma, which might be a consequence of intraoperative injury or from inadvertent injections into the inferior epigastric vessels. The hematoma appears on unenhanced images as a well-defined mass with high attenuation, and there is lack of enhancement with intravenous contrast. Further, the hematoma resolves over time with no specific treatment. Correction of any coagulopathy, analgesics, and warm compresses for comfort are all that is required.

Recurrence

Currently, recurrence remains the benchmark by which the success of complex abdominal wall reconstruction is measured. Both US and CT scan have uses. US can be used to follow patients serially on their postoperative visits to screen for asymptomatic recurrences. In questionable cases, real time US with performance of the Valsalva maneuver can identify recurrences that might not be otherwise detected. In the majority of cases, CT scan remains the mainstay for the diagnosis of a recurrence of postoperative defects (Fig. 6.28a, b). The incidence of recurrence is influenced by the imaging modality used and the rigor with which its presence is sought. Mesh bulge, seromas (Fig. 6.29), hematomas, and retained hernia contents might result in pseudorecurrences [34].

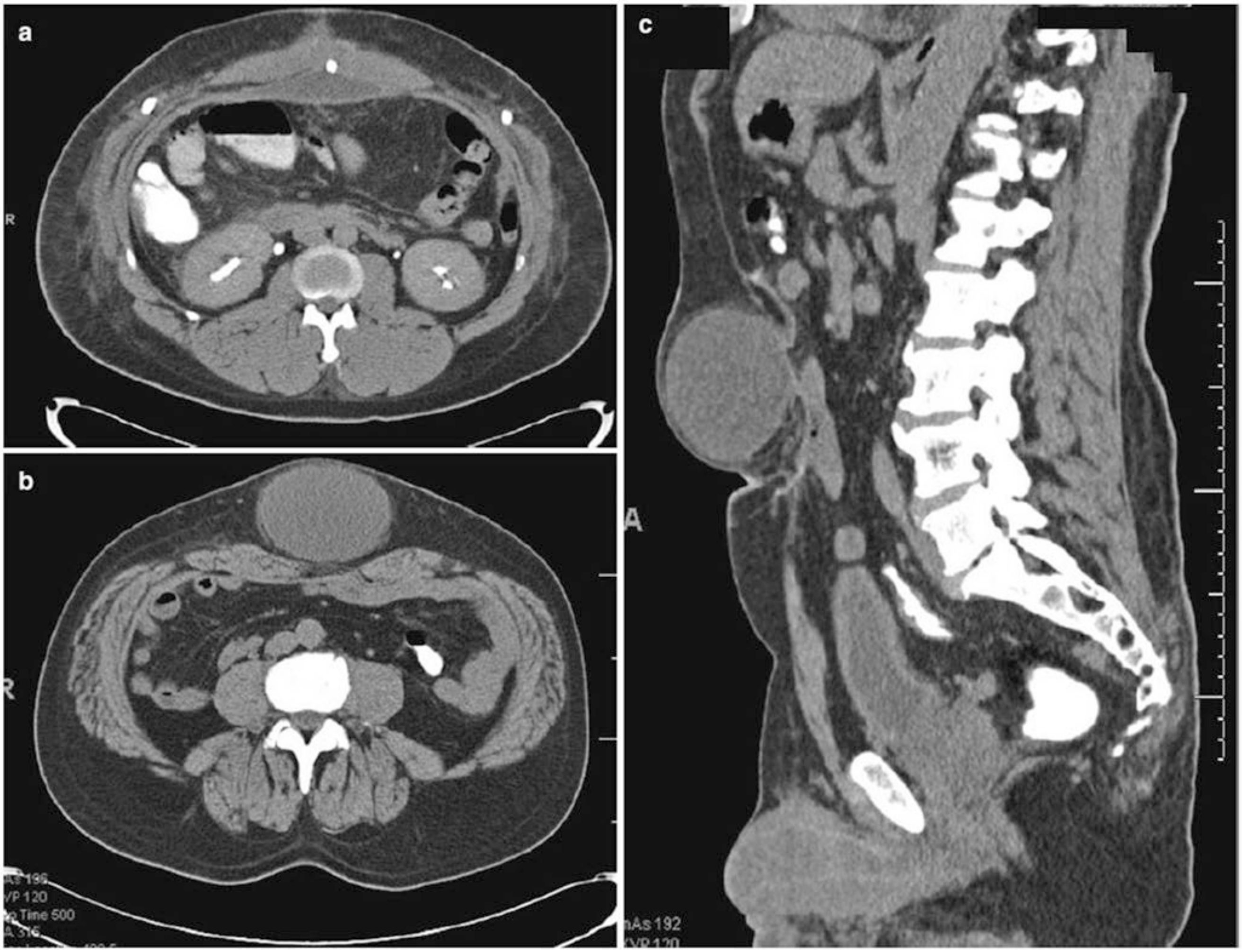

Fig. 6.25 (**a**–**c**) Retrorectus fluid collections are common despite prolonged drainage of the space using closed suction drains. If asymptomatic, they are best left alone, and they resorb over time

Fig. 6.26 Inflammatory changes without localized collections representing postsurgical changes and reaction to the prosthesis used

The characteristics of the recurrent hernia are then used to determine the optimal approach to its repair. Following complex abdominal wall reconstruction, the majority of recurrent hernias are small defects found most often at the edges of the original repair where the static mesh interfaces with the dynamic abdominal wall (Fig. 6.30). Reconstructing the abdominal wall with approximation of the abdominal wall musculature at the original operation can prevent this. When a bridging technique is used, herniation can occur through the central portion of mesh if a synthetic mesh has been employed [35]. This is increasingly more common when lightweight meshes are used. When biologic scaffolds, either human acellular dermis or porcine dermis, are used, there might be progressive bulging of the scaffold [36, 37] (Fig. 6.31). While truly not a recurrent hernia, intra-abdominal contents migrate into the new bioprosthesis and bulge, producing discomfort and impairing the patient's

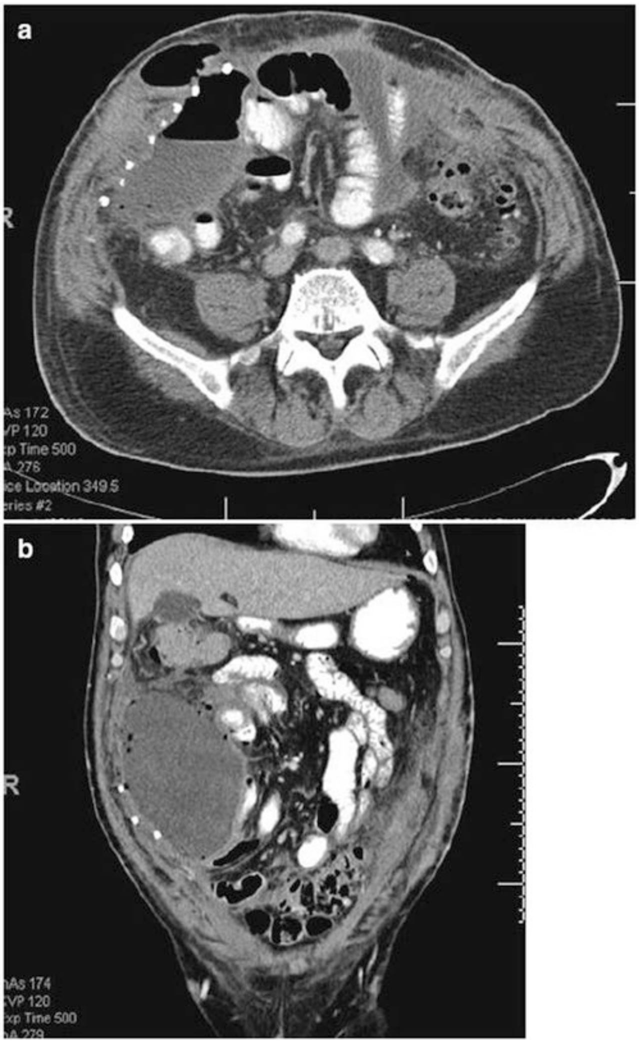

Fig. 6.27 (**a**, **b**) Large fluid collection on either side of the mesh with radiopaque tacks indicating the location of the mesh. Air within the collection suggests that the collection is likely an abscess. CT-guided drainage of the collection will be necessary to drain the abscess and obtain fluid for microbiologic evaluation. Lightweight polypropylene mesh can often be salvaged with drainage and long-term antibiotics

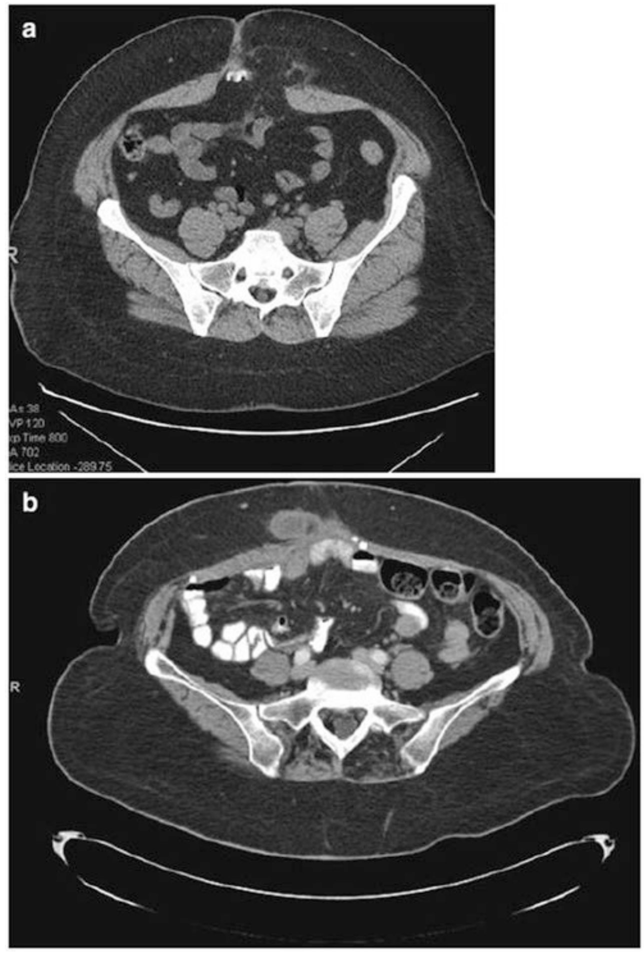

Fig. 6.28 (**a**, **b**) Recurrence at the edge of the previous repair. The small size of the defect lends itself to primary laparoscopic closure of the defect with intra-abdominal placement of synthetic mesh

ability to generate adequate intra-abdominal pressure for physiologic activities such as defecation and micturition. The resultant bulge is also cosmetically displeasing. The presence of these features must be considered when deciding to proceed with re-repair.

When the ideal operation is selected as indicated by patient factors such as underlying disease and comorbidities, radiologic imaging can guide selection of the ideal procedure, resulting in optimal outcome with long-term success rates (Fig. 6.32).

Fig. 6.29 Development of a second hernia at the medial edge of the mesh placed for the repair of the initial hernia. The defect is small and can be approached laparoscopically

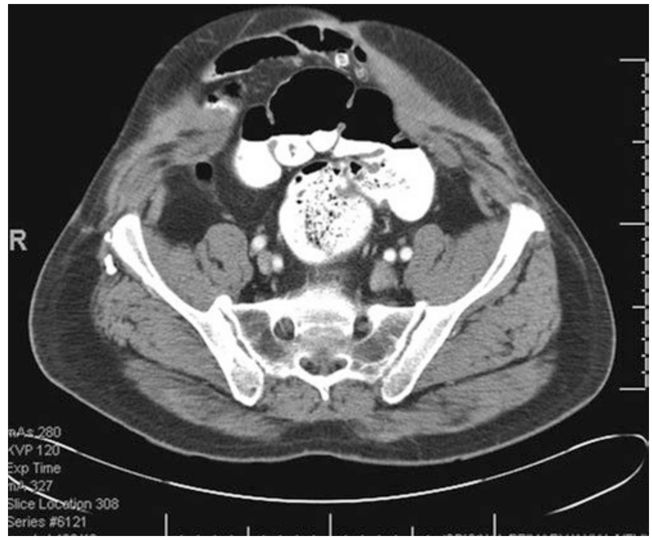

Fig. 6.31 Bulge of the biologic scaffold without actual herniation of abdominal contents in a bridging repair. Although it might cause discomfort and give the appearance of a recurrence, there is no risk of incarceration or strangulation, so this might be an acceptable outcome in most patients, considering the size and nature of the initial defect

Fig. 6.30 Small seroma anterior to an intact repair. CT helps differentiate this not-uncommon postoperative occurrence from recurrence

Fig. 6.32 Excellent results with component separation and use of a biologic scaffold at scheduled postoperative imaging of two tears following repair

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Part II

Surgical Consideration: Techniques and Outcome

7 Abdominal Wall Reconstruction in Patients with Complex Defects: A Nine-Step Treatment Strategy

Rifat Latifi

Introduction

With advances in abdominal surgery and the management of major trauma, abdominal wall defects have become the new surgical disease, and the need for complex abdominal wall reconstruction has increased dramatically. Subsequently, how to reconstruct these large defects has become a new surgical question. While most surgeons use native abdominal wall whenever possible, evidence suggests that synthetic or biologic mesh needs to be added to large ventral hernia repairs. One particular group of patients that exemplify "complex" situations are those with contaminated wounds, enterocutaneous fistulas (ECFs), enteroatmospheric fistulas (EAFs), and/or stoma(s), where synthetic mesh is to be avoided if at all possible. Most recently, biologic mesh has become standard in high-risk patients with contaminated and dirty-infected wounds. While biologic mesh is the most common tissue engineered in this field of surgery, Level I evidence is needed on its indication for use and long-term outcomes. Various techniques for reconstructing the abdominal wall have been described; however, the long-term outcomes for most of these studies are rarely reported. In this chapter, I will outline current practical approaches to perioperative management and definitive abdominal reconstruction in patients with complex abdominal wall defects, with or without fistulas, as well as those who have lost abdominal domain. I will also describe both anterior lateral and posterior component separation.

Enterocutaneous fistulas (ECFs) and or enteroatmospheric fistulas (EAFs) remain among the most serious complications of open abdomen management techniques and damage control surgery, particularly in acute care and trauma surgery. ECFs/ECAs are associated with significant morbidity and mortality [1], despite significant advances in surgical techniques and technologies for patients with complex abdominal wall hernias. Especially challenging is the combination of fistulas and any or all of these conditions: large abdominal defects, an open abdomen, enteroatmospheric fistulas (EAFs), or stomas. The frequency of patients treated for ECFs in concurrence with reconstruction surgery for large abdominal wall defects is unclear; however, in our practice, this percentage is about 20% [2]. Of the ECFs, 75–85% are postoperative, and most patients with ECFs also have some sort of abdominal wall defect (through which the ECFs become evident); therefore, the surgeon should treat both conditions in tandem. The incidence of ECFs in combination with an open abdomen, on the other hand, has been reported to be as high as 75% [3].

A Nine-Step Management Strategy

Closing the open abdomen and establishing a functional abdominal wall in patients with fistulas and stomas represents a major challenge, often requiring surgical creativity, as well as a strategy that encompasses various aspects of care from diagnosis to long-term follow-up. Multidisciplinary approaches and advanced surgical techniques are required as well [4]. In order to optimize the outcomes, there has been a suggestion that these patients are managed on a specialized unit [5], with large experience in the overall management of these patients that is not limited to surgical expertise only, as in my opinion, surgical expertise is just one aspect of complex management required for these patients.

When one approaches patients with a complex abdominal wall defect (CAWD), with or without fistulas, there are significant challenges that need to be understood primarily by the surgeon, the managing team, and by the patient and his/her family. These challenges range from recognizing the etiology, defining the pathology, understanding the impact of the clinical condition and physiology, nutritional status, and

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wound care, and of course what it takes to restore functionality. Furthermore, redefining the anatomy and physiology, timing the definitive surgery, executing the operative plan, making intraoperative decisions that are often considered "outside surgical dogma," long-term follow-up, and ensuring full recovery of the patient to normal functional status are all basic requirements. One very important factor is the dedication of the surgeon to these patients and to their surgical problems. These operations are not to be performed by an "itinerary surgeon." While all general surgeons should be able to repair a large hernia, complex reconstructions of the abdominal wall of patients with fistulas and/or stomas should be done only by those who have both the clinical interest and the experience in this truly complex subject. The management of these patients should be approached in a step-wise fashion, ensuring that each phase is truly understood by the surgeon, as well as by the patient and their family. Establishing disciplined protocols and implementing a well-planned strategy, particularly in patients with ECFs/EAFs, will make the intraoperative management process easier, and will improve postoperative outcomes. Such a strategy has been described in a 6-step process for management of ECFs, known as "SOWATS" (*S* = Sepsis Control, *O* = Nutrition Optimization, *W* = Wound Care, *T* = Timing, *A* = Anatomy, and *S* = Surgery) [6]. These authors reported on 79 patients managed by a focused treatment for enterocutaneous fistula. Spontaneous closure occurred in 23 (29%) patients after a median period of 39 (range 7–163) days. Forty-nine patients underwent operative repair after a median period of 101 (range 7–374) days; closure was achieved in 47 (96%) patients. The authors reported a mortality of 10% during the study period, although in another publication, they reported that 44/135 or 32.5% of patients died [7]. This strategy is applicable in the acute setting, but does not address three important aspects of the management of ECFs: initial diagnosis, particularly the immediate postoperative period; postoperative care following definitive surgery, and finally long-term follow-up. To address these aspects, our group has modified Visschers et al. [6] six-step strategy to nine steps, known as "ISOWATS PL" where *I* = Identification and diagnosis of postoperative fistula or fistulas; *S* = Sepsis and Source Control; *O* = Optimization of Nutrition; *W* = Providing and Ensuring Wound Care; *A* = Redefining the anatomy and understanding the pathology at hand; *T* = Timing of definitive surgery and/or takedown of fistulas; *S* = Definitive surgery and surgical approach; *P* = Postoperative care; and *L* = Long-term follow-up. One should adhere to the "ISOWATS PL" strategy as much as possible, although deviation may occur due to various surgical outcomes or certain conditions of patients who may require emergency surgery.

Step 1: *I* = Identification of Postoperative Fistulas

The majority (75–85%) of ECFs is postoperative, and most patients with ECFs also have abdominal wall defects, through which the ECFs become evident. Identification of fistulas depends on the timing from the last operation. Early identification of fistulas in the perioperative period needs to be established in a timely fashion and without much delay, while the presentation depends on the clinical situation [8], since such delay may increase significantly morbidity and potentially mortality. The cause of postoperative wound infections and abdominal dehiscence is often difficult to distinguish between a technical or infectious catastrophe such as necrotizing soft tissue infection, and those resulting from fistulas or an intra-abdominal process, such as an anastomotic leak. Depending on the cause of the fistula, one can predict the outcomes; those that are the result of malignancy or open abdomen have the worst prognosis [9]. In all patients with abdominal wound dehiscence, especially after the creation of a single or multiple anastomoses, with or without lysis of severely dense adhesions, the surgeon must consider the potential occurrence for fistulas or some other sort of catastrophe, if the patient is not doing well postoperatively.

One should not forget that there are no secrets in the abdomen and that a surgeon should be able to identify intraoperatively any pathology. I call this the "eye-scan" technique (the old exploratory laparotomy). Thus, when in doubt, patients should be taken to the operating room promptly for an exploratory laparotomy.

For fresh postoperative patients, wound exploration, often in the operating room, is required to completely assess the wound (as well as the sub-fascial collections and intestines lying under the sutures, which could easily erode into the lumen and cause new fistulas). However, most of these patients, in practice, receive a CT scan. The ultrasound (US), CT scan, or MRI will identify any deep peritoneal or pelvic collection that could be drained, guided by CT or ultrasound. In the first few postoperative days (and in my practice the first 10–14 days), one should not hesitate to take the patient back to the operating room for an exploration and direct assessment, if clinically warranted.

In other words, postoperatively, the surgeon must make the proper diagnosis. That is, identify the fistulas, in a timely fashion. Because the majority of fistulas are postoperative, it is often difficult to distinguish wound infections and abdominal dehiscence as a result of fistulas from serious wound infections and abdominal wall dehiscence that are not a result of fistulas (Fig. 7.1a, b). In all patients with abdominal wound dehiscence, especially after the creation of an anastomosis or

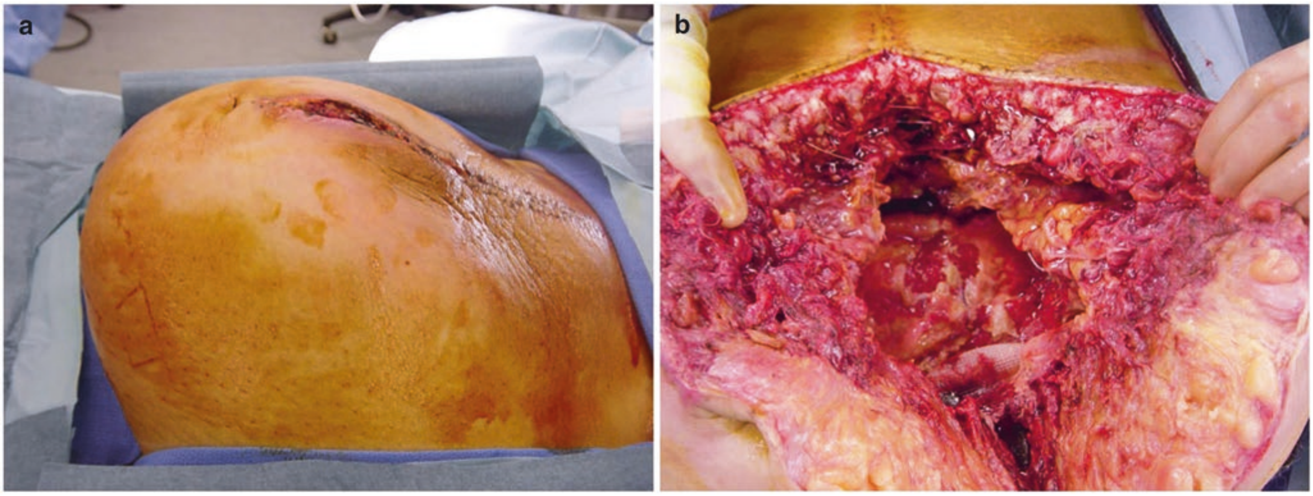


Fig. 7.1 (**a**) Large infected seroma requiring open drainage in a diabetic patient who underwent abdominal wall defect repair using synthetic mesh. (**b**) Intraoperative view of patient in (**a**). Infected synthetic mesh being removed

Fig. 7.2 Abdominal wall necrosis in a patient undergoing abdominal wall reconstruction with an interposition biological mesh; the patient developed intra-abdominal hypertension. Same patient is seen in Fig. 7.11c

anastomoses, the surgeon should be alert for the occurrence of fistulas or some other sort of catastrophe. Necrotic tissue needs to be debrided entirely (Fig. 7.2).

Step 2: *S* = Sepsis Control and Eradication

The second step of the nine-step treatment strategy for treating patients with ECFs or EAFs is sepsis control, along with electrolyte and fluid normalization and achievement of hemodynamic stability. Although intra-abdominal sepsis might be the main culprit, these patients may have other sources of sepsis, such as urinary infection, line sepsis, pneumonia, and other hospital-acquired infections, and thus require full body careful examination.

Management of a patient with a wound infection, infected seromas, acute wound dehiscence, or fistulae is complex and not straightforward. One of the greatest hesitations of a surgeon is taking the patient back to the operating room, although this hesitation is more prevalent in elective surgery than in a trauma setting.

In addition to source control, goal-directed resuscitation, proper antibiotic therapy, electrolyte and fluid normalization, achievement of hemodynamic stability, correction of coagulation factors and hemoglobin levels, and provision of nutritional support are the current standard of care.

The mainstay of therapy for intra-abdominal abscesses remains drainage, be it surgical or percutaneous [10], but broad-spectrum antibiotics may be initiated and subsequently tailored based on culture results. As stated previously, necrotic tissue needs to be debrided entirely. Recent trends, however, are worrisome, as more and more surgeons rely on interventional radiologists to drain pus and care for surgical patients for every possible nidus of infection, including paracentesis and thoracocentesis [11]. One has to remember, while the intra-abdominal or intra-thoracic sepsis may be the main culprit, these patients may still have other sources of sepsis, such as urinary tract infection, line sepsis, pneumonia, and other hospital acquired infections that require careful examination.

Step 3: *O* = Optimization of Nutrition

The third step is optimization of nutrition through initiation and maintenance nutrition through enteral feeding (when possible) or via parenteral nutrition support. In a busy practice, it is easily forgotten that patients who underwent a major surgical operation need aggressive nutrition support, particularly in the perioperative period [12]. In patients with

Fig. 7.3 Severely malnourished patient with multiple enteroatmospheric fistulas that started with complex diverticulitis

a recent weight loss of 10–15% or with a serum albumin level less than 3 grams/deciliter (g/dL), elective procedures should be postponed if at all possible. Albumin levels of less than 2.5 g/dL have been associated with a significant increase in mortality and morbidity. A strong relation was reported between preoperative albumin level and surgical closure ($p < 0.001$) and mortality ($p < 0.001$) [6].

Before major surgery, the nutritional status of all patients (unless emergent surgery is required) should be optimized to the extent possible [13–19].

Initiating, maintaining, and optimizing the nutrition in patients with fistulas (both ECFs and EAFs) is difficult and requires a planned approach, but unfortunately is not done adequately in the majority of patients. Often while we provide sophisticated cancer therapy to our surgical patients, we simultaneously allow severe malnutrition to develop in front of our eyes. Awaiting gastrointestinal function to return postoperatively before initiating oral or enteral nutrition is an old dogma that is still practiced by many hospitals across the world unnecessarily. In this scenario, the patient may start on some sort of salty and tasteless (clear) liquids 4–5 days after a major operation, if not longer. If, on the other hand, the patient develops any of the aforementioned complications, this process can be prolonged ever further. One has to remember that we should initiate and maintain nutrition enterally or parenterally throughout the hospitalization.

In a few patients, however, despite all attempts, reversing hypoalbuminemia and malnutrition will be impossible; such failure likely indicates continuous infection or sepsis or continuous losses of nutrients through fistula effluent (Figs. 7.3 and 7.4a–c).

The combination of a continuous inflammatory state and malnutrition is detrimental to the patients and their prognosis, thus it should be disrupted as soon as possible; surgery can be thought of as source control for continuous malnutrition.

A somewhat less common approach to improve the nutritional status of patients with fistulas is fistuloclysis [20, 21], which has been shown to reduce the need for parenteral nutrition and improve all hepatic and nutritional indices in a select group of patients. While technically demanding, this approach is valuable in the armamentarium of surgeons caring for these patients and should be used if at all possible, and for the most part it is tolerated by patients. A recent report on fistuloclysis used in patients who were assigned into either the fistuloclysis group ($n = 35$, receiving fistuloclysis plus total enteral nutrition (TEN)) or the control group ($n = 60$, receiving TEN) demonstrated that this adjunct technique improved hepatic and nutritional parameters in patients with high-output upper enteric fistulas, particularly those with biliary fistulas [20].

For more details on nutritional support of patients with fistulas, see Chaps. 4 and 25.

Step 4: *W* = Wound Care

The fourth step in the management strategy of patients with CAWD and associated wounds is continuous wound care in order to reduce the bioburden. Therefore, avoiding skin excoriations from the bile salts, intestinal fluids, or stool is essential. The vacuum-assisted closure (VAC) and proper stoma equipment have revolutionized wound care [22–24]; however, collecting all the fluids in patients with large open abdominal wall defects (which we have termed "fistula city") may prove extremely difficult (Figs. 7.5a, b and 7.6). The wound VAC is meant to control the output of fistulas, but the surgeon must be cognizant of the amount of fluid that the patient loses and must ensure appropriate fluid and nutritional replacement. The wound VAC therapy has become a mainstream therapy for wounds, in particular for treating surgical wound healing by secondary intention [25–27]. Yet, one has to be mindful that fistula formation with wound VAC has been reported in a range of 10–21% [28].

To help avert sepsis and to improve the spirits of the patient, it is crucial to ensure proper hygiene and to avoid skin excoriations from the bile salts, intestinal fluids, or stool. Effective use of the wound vacuum-assisted closure (VAC) and proper stoma equipment is important, although the evidence is still lacking [28].

STEP 5: *A* = Redefining the Anatomy

The fifth step is redefining the anatomy. Again, if there is any question, here the surgeon should use any of the available techniques to confirm the anatomy. Previous operative

Fig. 7.4 (**a**) Intraoperative view of patient in Fig. 7.3. Left lobe of the liver is being held up with a lap pad. (**b**) Patient in Fig. 7.3 after healing from her last surgery (**c**). Patient in Fig. 7.3 with the author (the operating surgeon) a few months post-surgery that has remained healthy about 8 years later

reports should be studied carefully [29]. Whenever available, previous operative reports and radiologic comparisons at different stages of the disease process should be obtained and studied carefully, and if possible, a direct conversation with the previous surgeon should be conducted. This is particularly important if the patient was operated on at a different hospital or by another surgeon. In patients with long standing fistulas, preoperatively, complex defects must be identified clinically or by whatever radiological method is available. The definition of the anatomy of the fistulas can be done with a CT scan, upper gastrointestinal (UGI) series with small bowel follow-through, a fistulogram, or gastrografin enemas. Most recently, the CT scan has become the standard radiographic study, although MRI is gaining more and more popularity.

A key aspect of repairing complex defects is in understanding the anatomy of the abdominal wall. The lateral abdominal wall fasciae and musculature derive their blood supply primarily from the intercostal arteries, lumbar arteries, and deep epigastric arteries (Fig. 7.7). The innervations come from the seventh to the twelfth intercostals and the first lumbar nerves (Fig. 7.8). Those intercostals and the lumbar vessels and nerves travel from the posterior midline to the anterior midline in an oblique, anterior pathway between the internal oblique and transversalis muscles (Fig. 7.9). The vasculature and innervations to the rectus abdominis muscle follow this same pathway. Vertical incisions in the abdominal wall musculature can disrupt both the vasculature and the innervations to the external oblique, internal oblique, transversalis, and rectus abdominis muscles. A transverse incision at the costovertebral margin through the external oblique fascia avoids the major vessels and nerves to the abdominal wall and allows for blunt dissection between the external and internal oblique muscles. Given the relative avascularity and absence of nerves between the external and internal oblique fasciae from the anterolateral abdominal wall to the lateral border of the rectus sheath, this space is an ideal plane for blunt dissection and subsequent expander placement. It is bordered superiorly by the costovertebral margin, medially by the lateral border of the rectus sheath,

Fig. 7.5 (**a**) Large "stoma" bag. (**b**) Patient with "stoma city," difficult to manage

Fig. 7.6 Wound vacuum-assisted closure (VAC) in progress for large abdominal wound

laterally by the midaxillary line, and inferiorly by the inguinal ligament.

Most patients who have previously undergone major abdominal surgery have had a midline abdominal incision, so their lateral abdominal wall is usually free of scars and defects, thereby providing a well-vascularized soft tissue donor site. The abdominal wall can be anatomically restored with minimal tension and without compromising the integrity of the abdominal muscles, vessels, and nerves unless major portions of the wall are missing, which can happen due to a number of catastrophes. Understanding the pathophysiology and the distorted anatomy of a difficult abdomen is paramount, and provides a major challenge.

Step 6: *T* = Timing of Operation or Takedown of ECF

The sixth step of if and when to re-operate on patients should be individualized. This decision represents perhaps the most important step in the management of this group of patients, and is dependent on the clinical situation and many other factors but particularly on the concomitant comorbid diseases and on the anatomy of the surgical problem. Let us first consider the complex abdominal wall (CAW) defects without fistulas. A large defect can be functionally devastating and leads to further weight gain and more problems. In some cases, the skin gets very thin, excoriates, and is almost transformed into a fistula and abdominal catastrophe. Many of

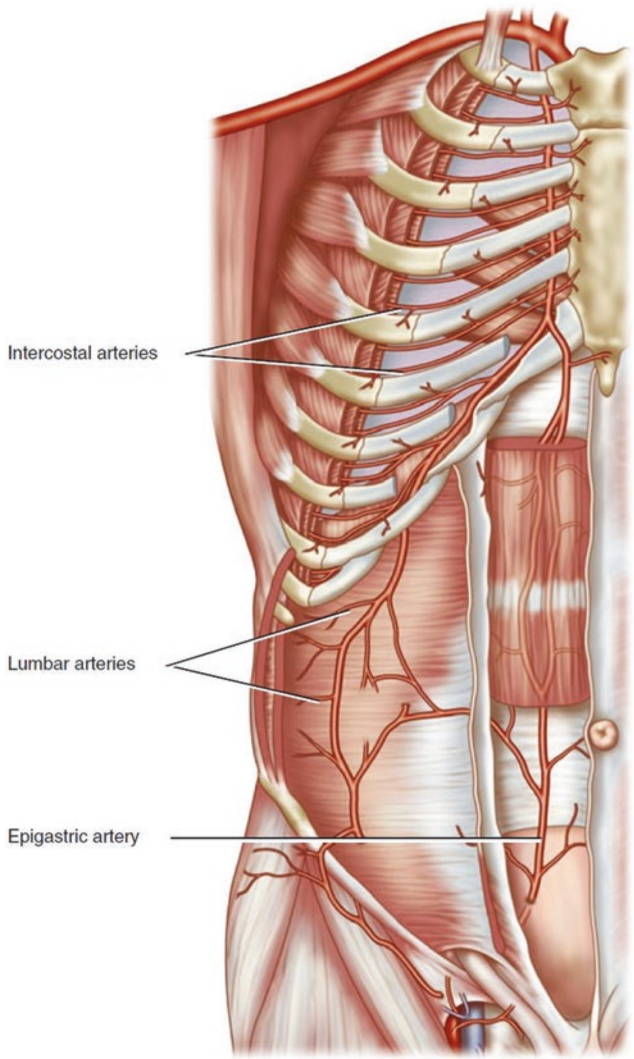


Fig. 7.7 Anatomy of the abdominal wall. The lateral abdominal wall fasciae and musculature derive their blood supply primarily from the intercostal arteries, lumbar arteries, and deep epigastric arteries

these patients cannot be operated upon, despite the fact that they have a major defect. If they have serious comorbid diseases such as extreme obesity, severe heart disease, high-grade liver cirrhosis or advanced lung disease (home 0_2 dependent), and do not have symptoms of obstructions, one should not operate without having multiple conversations with the patient and their family in order to clearly define the goals of the operation and possible complications. On the other hand, when these patients present with intestinal obstructions not responding to conservative treatment, then one has no choice but to perform a definitive surgery. While not all surgeons agree, at times the strategy for these patients should be *"more is less,"* and often the definitive surgery is the only optimal choice and should be performed. As abdominal wall defects will not get smaller over time, I prefer to operate earlier rather than later, assuming that the patient is not prohibitively at high risk for intraoperative and postoperative complications.

While timing when to repair large abdominal wall hernias is less debatable [30–32], operating on fistulas and knowing how long we should wait until takedown is more contentious. Some suggest that delaying surgery anywhere from 12 to 36 months will improve the outcomes in patients with ECF [33]. Others have reported that prolonging surgery for longer than 1 year following ECF diagnosis doubles the risk of postoperative refistulization. This risk for fistula recurrence has been found to be five-times greater if one waits longer than 36 weeks [34]. While operating on these patients may pose serious complications, often the only way to disrupt the vicious cycle of sepsis and malnutrition [33] is through surgery itself. I use the individual patient's condition as a guide, rather than any strict predetermined timeline, although I try to avoid operating in the first 2–3 months after diagnosis, unless the fistula becomes apparent in the first two postoperative weeks, and I do not think that it will close spontaneously on TPN.

To summarize, the length of time we should wait until takedown of ECFs is unclear. The surgeon should try not to intervene early if at all possible; however, these patients often continue to be septic and malnourished, so surgery itself will serve as source control.

Step 7: *S* = Surgical Approach

The seventh step encompasses the surgery itself. This section details the main elements that the surgeon must consider, including the kind of incision, definitive repair techniques, including type of mesh and technique used for mesh placement. The main surgical goals are to establish GI tract continuity and to minimize recurrence of ECFs, EAFs, hernias, and wound infections.

The approach to the definitive surgery one selects in patients with CAWD and/or fistulas depends on many factors. A combination of different approaches is often required. The key aspect of repairing complex defects is to understand the anatomy of the abdominal wall and have the requisite surgical experience. Most patients who have previously undergone large abdominal surgery have had a midline abdominal incision, so their lateral abdominal wall is usually free of scars and defects, thereby providing a well-vascularized soft tissue donor site. There are a number of exceptions, however, especially when the patient has had any lateral incision, or had stomas. Unless the patient had many surgeries, such as those with open management, or had a giant hernia with loss of abdominal domain, the abdominal wall can be anatomically restored with minimal tension and without compromising the integrity of the abdominal muscles, vessels, and nerves. Understanding the pathophysi-

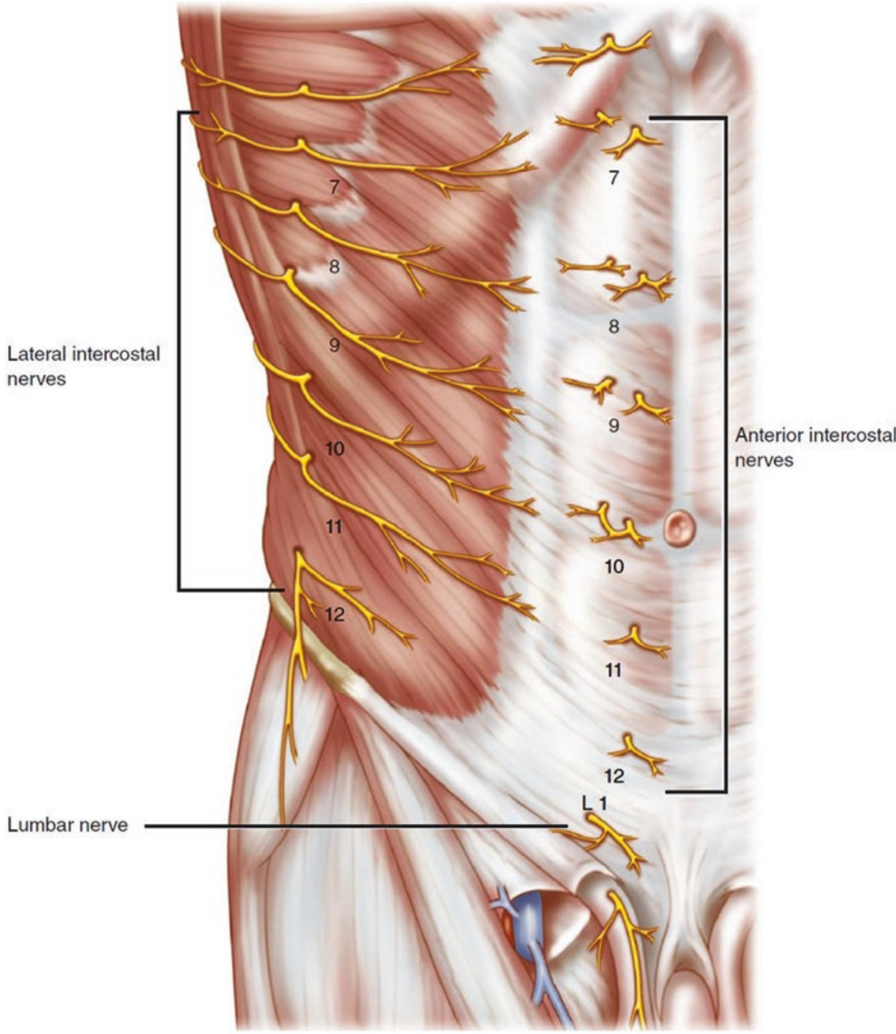


Fig. 7.8 Anatomy of the abdominal wall. The innervations come from the seventh to the twelfth intercostals and the first lumbar nerves

ology and the distorted anatomy of a difficult abdomen is paramount.

Step 7.1: Getting in the Abdomen

The abdominal wall of most patients with ECFs or EAFs is hostile; the surgeon might find that even entering the cavity itself presents a significant challenge. When possible, the surgeon should avoid going through the same incision used in prior operations, instead attempting to enter from non-violated areas of the abdominal wall such as the superior epigastric region or just over the pubic region and making your way in under direct vision from the inferior or superior aspect of the wound. It is really of great significance to avoid cutting on top your finger blindly, as the finger can easily be lifting small or large intestines for that matter that have been adhered to the abdominal wall, rather, this needs to be done under direct vision. An alternative method of entering the abdomen through a transverse incision has been advocated [35, 36], although I have not used that method in my practice.

A large number of patients cared for with an open abdomen have a split-thickness skin graft (STSG) (Fig. 7.10a, b). Such patients require special attention to ensure the success of their completion of surgery. Before the skin graft is excised, the neoskin, when pinched between the surgeon's thumb and forefinger, should be easily elevated from the underlying tissue. Some surgeons do not attempt to excise the skin graft at all, but close the abdomen over it. When excision is attempted while the skin graft is adherent, dissection is very difficult and likely results in enterotomies and risks recurrent fistula formation [35].

Step 7.2: Adhesiolysis

Once the abdominal cavity is entered, the surgeon often faces a large ball of intestines wrapped by adhesions. Should these adhesions be separated? That question is as old as the

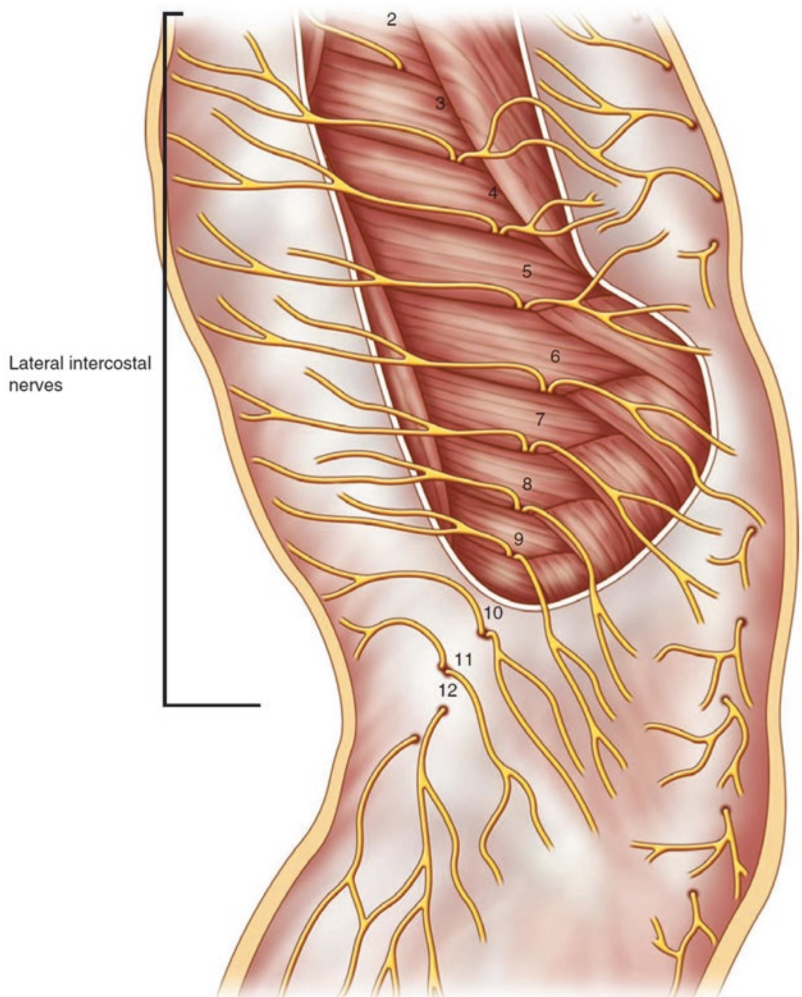


Fig. 7.9 Anatomy of the abdominal wall. The intercostals referenced in Fig. 7.8 and the lumbar vessels and nerves travel from the posterior midline to the anterior midline in an oblique, anterior pathway between the internal oblique and transversalis muscles

surgery itself [36]. In my opinion, the surgeon should mobilize the entire segment of intestines, from the ligament of Treitz to the rectosigmoid. Doing so is tedious and time consuming, given previous abdominal surgeries and intra-abdominal inflammatory processes, and it is often complicated by new iatrogenic enterotomies. However, this is a must and when one does not do it, often patients will develop small bowel obstruction, as the symbiosis has been lost, when one releases only partially the adhesions. Other surgeons do not agree entirely with this approach; they suggest something in-between complete lysis, perhaps partial lysis of adhesions [37].

Step 7.3: Fistula Resection

In patients with multiple ECFs or EAFs, resecting all of the fistulas may be challenging, but all of them must be resected [38–40]. The best scenario is when multiple fistulas are in close proximity to each other, so that the surgeon can excise the segment of fistulous tract *"en masse."* Yet, if the fistulas are a large distance apart, more than one resection—and subsequently more than one anastomosis may be required; all are technically challenging. Because such patients are at high risk for developing short gut syndrome (see Chap. 25 on Short Gut Syndrome), adjunct procedures, such as stricture-plasty, should be used in an attempt to avoid removing large segments of bowel. Intraoperatively, it is important for the surgeon to identify all fistulas. Care should be taken to avoid enterotomies, but if they do occur, any inadvertent injury to the bowel must be either repaired immediately or tagged with a suture so that it can be easily identified later during the course of the operation.

Step 7.4: Intestinal Anastomosis

For reestablishing intestinal continuity, the hand-sewn, double-layer technique, not staplers, should be used [39]. In my practice, I prefer using continuous Vicryl™ (Ethicon, Somerville, NJ) sutures (Connell Technique) (Fig. 7.11). During this technique, the sutures go through the wall from

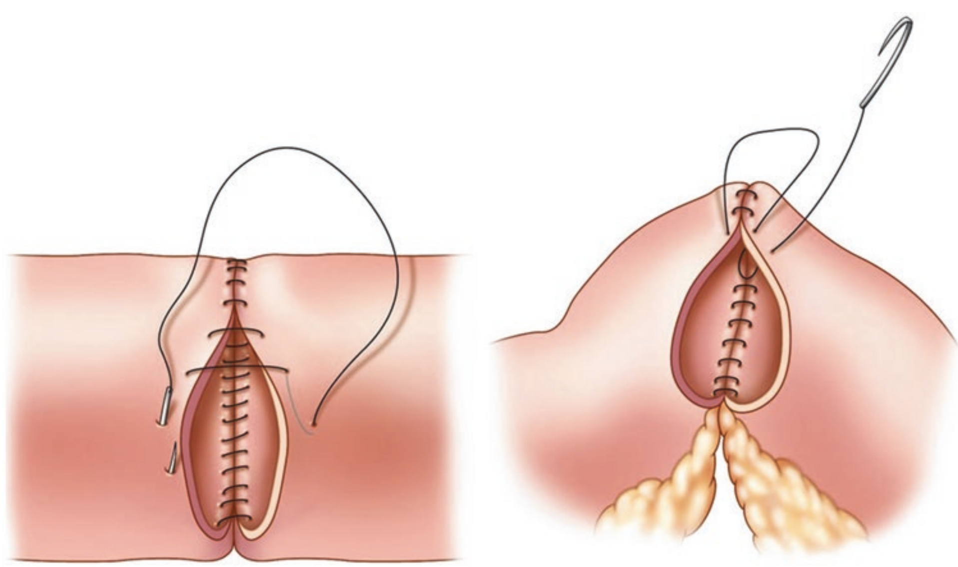
Fig. 7.10 (**a**) Skin graft in a patient managed with open abdomen after gunshot wound to the abdomen. (**b**) Same patient as in (**a**) at the end of the operation. We performed abdominal reconstruction using component separation and onlay mesh reinforcement (Fig. 7.10)

the serosa to the mucosa, then from the mucosa to the serosa on the same side. The sutures then cross the incision to the serosa on the other side, and the pattern is repeated until suturing is completed. If the integrity of the anastomosis is questionable, it is reasonable to revise it or to create a proximal diverting ostomy. Excessive trimming of the mesentery, tension on the anastomosis, and inclusion of diseased bowel in the anastomosis must all be avoided [17, 41]. Operative treatment with takedown of ECFs is successful in 80–90% of patients, although the presence of an open abdomen lowers the success rate to 77.3% [4].

Step 7.5: Definitive Abdominal Wall Reconstruction

Once the continuity of the GI tract has been established, as described previously, creating a new abdominal wall may represent a serious surgical challenge. Multidisciplinary approaches and advanced surgical techniques may be necessary [35]. Whatever approach, whether single surgeon (general surgeon) or general surgeon with a plastic surgeon, the goal is to create functional and durable coverage of the abdominal cavity and to improve the patient's quality of life. Native abdominal wall should be used; if that is not possible, biologic or prosthetic mesh can be used instead. In most patients, some sort of combination of reconstruction techniques will be needed. If native tissue can be used without undue tension, then it should be used. But, if midline tissue cannot be easily approximated or if mesh reinforcement is needed (as it is in almost all abdominal wall defects larger than 6 cm), then other techniques must be considered. For example, if midline tissue

Fig. 7.11 Connell suture technique. Note that needle always points forward or outward



cannot be easily approximated, then lateral components need to be released to create a neoabdominal wall.

Step 7.6: Lateral Component Separation

The closure of complex abdominal wall defects can be challenging. Traumatic injuries, tumor resections, necrotizing infections, enterocutaneous fistulas, previous surgeries, damage control laparotomy, and congenital defects can result in large abdominal wall defects that make reconstruction difficult. Surgical techniques, autologous and exogenous grafts have been developed to aid in the closure of such complex ventral wall defects and improve outcomes in these patients. One of the approaches is the development of musculofascial flaps that can be mobilized and brought to the midline to allow closure. In cases when there is a need for tissue transposition in order to establish a no-tension fascial closure, I use myocutaneous flap transposition through lateral component separation, as described previously [42, 43] (Fig. 7.12 a–f), although in most recent years posterior component separation has gained popularity. The component separation technique is based on an enlargement of the abdominal wall surface by separating and advancing the muscular layers.

Component separation provides additional medial transposition of musculofascial flaps that allows for reconstruction of giant abdominal wall defects often without the additional need for mesh. Defects up to the size of 20 cm at the level of mid-abdomen can be closed by this technique.

The earliest description of these musculofascial flaps dates back to the nineteenth century. These techniques were described by Guillouid in 1892, Chrobak in 1892, Gersuny in 1893, and Noble in 1895 [44]. Alfonso Albanese [42] from Argentina is credited with the first ever description of the technique that involved dividing the external oblique muscle vertically to enable the closure at midline by suturing together the rectus abdominis muscles in 1951. However in 1990, the technique was modified and refined by Ramirez et al. from Johns Hopkins University Hospital and was described as “components separation” [43]. This technique utilizes the medial advancement of bilateral, innervated, bipedicled, rectus abdominis-transversus abdominis-internal oblique muscle flap complexes to close ventral abdominal wall defects. In their landmark study, Ramirez and coworkers utilized human cadavers to demonstrate that the external oblique muscle can be separated from the internal oblique in an avascular plane by incising the external oblique fascia with an incision just lateral to the linea semilunaris [43]. Similarly, the rectus abdominis muscle with its overlying fascia can be separated from the posterior rectus sheath. This separation of the anatomic components allows significant mobilization for approximately 10, 20, and 8 cm in the upper, middle, and lower thirds of the abdomen, respectively. They subsequently utilized these findings clinically to reconstruct abdominal wall defects in 11 patients successfully.

Several other authors have also developed and utilized other autologous tissue transfer techniques for the repair of large sized abdominal wall defects. Wangansteen used the tensor fasciae latae flap from the thigh to reconstruct lower abdominal wall defects [45]. Ger and Duboys used muscle flap transfer to reconstruct full thickness abdominal wall defects [46]. However, the use of such free muscle flap transfer results in denervation of the muscle flap, which over time results in muscular atrophy, abdominal wall laxity, protuberance, and predisposition to hernia recurrence. Therefore, such an approach often requires the need for additional reinforcement of the repair with synthetic mesh. Similarly, the transfer of large sized flaps results in donor site scarring and deformity [47]. The components separation technique provides the advantage of preserving the innervation to the muscle flaps, hence maintaining the dynamic support and integrity of the abdominal wall. The absence of free tissue transfer also prevents the development of donor site morbidity and provides a more aesthetically feasible repair.

The transection of the rectus abdominis has been suggested by some surgeons as a contraindication [48, 49] for component separation. However, there is a lack of substantial evidence to support the claim that the use of component separation in patients with rectus violation results in adverse surgical outcomes.

Step 7.7: Surgical Technique of Open Component Separation

As indicated in Step 7.1 the procedure begins with a midline exploratory laparotomy to enter the abdominal cavity. Care should be exercised to dissect the entire abdominal wall free from any adhesions to the bowel and omentum under direct visualization. Following this, flaps containing skin and subcutaneous tissue are lifted off of the underlying anterior rectus sheath and the external oblique fascia. These flaps should extend caudally to the inguinal ligament and cranially beyond the costal margin. The lateral extent of the flaps should be at least 2–3 cm lateral to the linea semilunaris in order to allow adequate exposure of the external oblique fascia. The blood supply of the skin comes from perforators arising from the deep epigastric and superficial inferior epigastric arteries. Extensive dissection of the skin flaps can disrupt these perforators, predisposing the overlying skin flaps to surgical site infections, skin necrosis, and wound dehiscence. Next the semilunar line and insertion of the external oblique fascia are identified. A vertical incision is made 1–2 cm lateral to the semilunar line extending from the inguinal ligament to at least 5 cm cranial to the costal margin. The cranio-caudal extent of this incision is important to

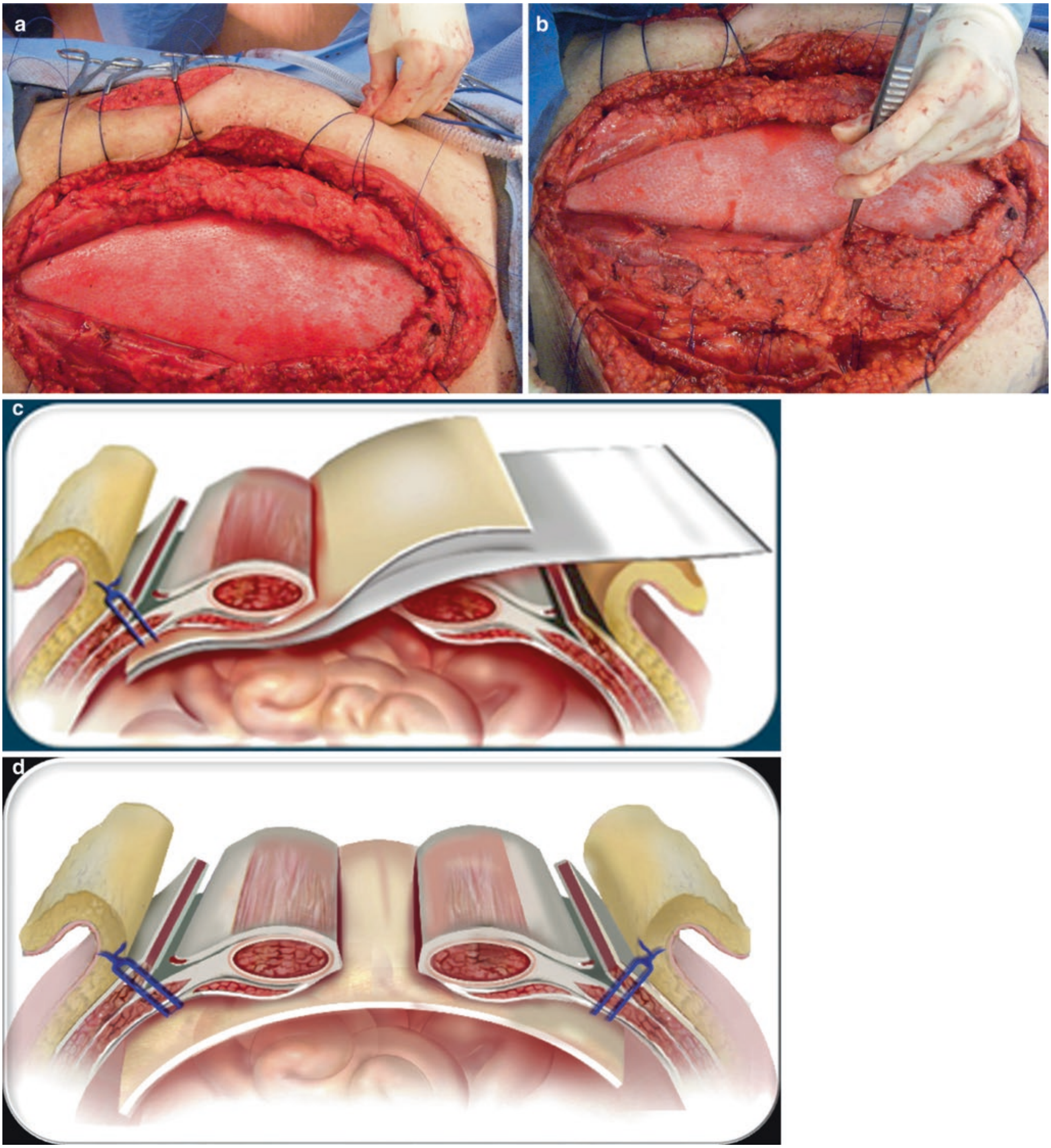


Fig. 7.12 (**a**, **b**) Abdominal wall reconstruction in a patient with right sided ileostomy. Component separation technique and underlay mesh were used. (**c**, **d**). Illustrator's demonstration of performing separation technique and placing the mesh as underlay. The mesh is fixed at least laterally to the separation of internal and external oblique muscles (Courtesy of LifeCell Corporation, Branchburg, NJ) (**e**) The fascia and the rectus muscle complex are approximated over the Strattice™ (LifeCell Corporation) mesh. (**f**) Final view of the abdominal reconstruction

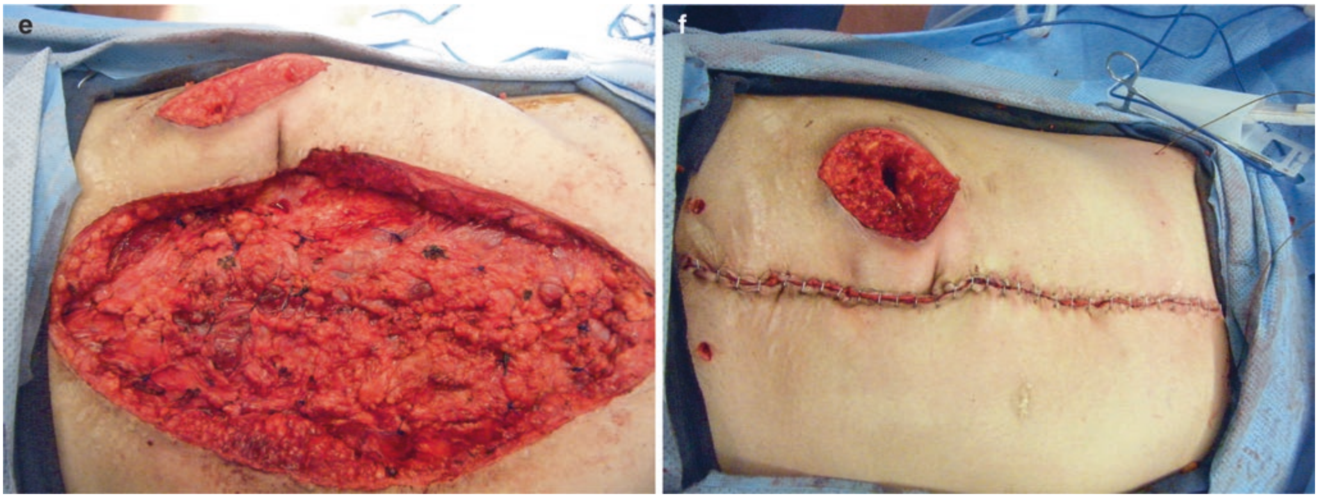


Fig. 7.12 (continued)

allow adequate release along the entire length of the abdominal wall. A plane is developed deeply to the external oblique but superficially to the internal oblique. The dissection should be continued laterally in this avascular intermuscular plane extending up to at least the midaxillary line. If midline approximation cannot be achieved and additional mobilization is required, the dissection should be extended to the posterior axillary line to allow additional release. Component release should be performed bilaterally. It is important to avoid dissection deep to the internal oblique as the neurovascular plane exists between the internal oblique and the transversus abdominis muscles where blood vessels and nerves supplying the obliques and the rectus abdominis muscle traverse. Dissection in this plane may damage this neurovascular bundle or the Spigelian fascia predisposing the patient to a Spigelian hernia [47].

If midline approximation cannot be achieved, further medial advancement of the rectus abdominis-internal oblique complex of up to 2 cm can be achieved with posterior component separation. This is performed by longitudinally incising the posterior rectus sheath 1–2 cm from the midline and separating it from the rectus abdominis muscle. Care should be exercised to avoid injury to the inferior epigastric vessels running deep to the rectus muscle. The anterior fascia is debrided and the healthy tissue is approximated in the midline. The muscles are approximated using non-absorbable interrupted sutures.

I prefer, as do most surgeons, to reinforce the hernia repair with a mesh graft following component separation to help reduce recurrence; however, a randomized controlled trial comparing component separation with and without mesh repair found similar recurrence rates between the two approaches [49]. Redundant skin flaps are excised and finally, the undermined skin edges are approximated in layers in a standard fashion. Drains are placed using separate skin stab incisions between the skin flaps and the external oblique aponeurosis to reduce dead space and fluid collection [50].

Step 7.8: Posterior Component Separation with Transversus Abdominus Release

There are various modifications of the component separation procedure. Some authors perform this procedure using minimally invasive surgical techniques (see Chap. 14), but the rates of recurrence of hernia are similar [51].Although many surgeons are familiar with anterior component separation (ACS), in recent years posterior component separation (PCS) with transversus abdominus release (TAR) has become popular. Detailed technical aspects of this procedure paying particular attention to the surgical anatomy have been reported [52]. The main principle of PCS is that the perforating vessels are spared, and the mesh is placed between rectus muscle anteriorly and posterior rectus fascia/peritoneum/preperitoneum posteriorly. Once you have dealt with all adhesions and other concomitant procedure, such as reconstitution of GI tract or other procedures as described above, the posterior approach to the retrorectus space is performed by incising the medial edge of the posterior rectus sheath at the medial edge of the rectus abdominis muscle. The edge of the transected posterior rectus sheath is grasped with clamps and retracted medially and posteriorly, allowing easy lateral dissection of the retrorectus space. During this stage of the operation one has to be cognizant not to injure intercostal nerves that perforate rectus muscle. The posterior lamina of the internal oblique aponeurosis is incised just medial to the entry of the intercostal nerves as they enter the rectus muscle posteriorly [52].

The dissection of this segment should start as cranially as you can. At the point of transition of posterior lamina of the internal oblique fascia you will be able to see the medial aspect of the transversus abdominus muscle (TAM). The muscle fibers and fascia of TAM can be separated from the underlying thin posterior transversus abdominis fascia and peritoneum with a right angle clamp. But, this separation requires a careful dissection under the muscle fibers of TAM. One has to be careful not to enter peritoneum, but if this does occur, one must make sure to identify and close with absorbable suture. Transection of TAM can be done in a number of ways but I agree with these authors the transection of the TAM should start as far cranially as possible where these muscle fibers are prominent and progressing caudally aids markedly this part of the component separation [53]. This extraperitoneal space now can be extended laterally and caudally in order to make space for the prosthesis. This dissection is facilitated greatly with a sweeping move of your hand. I prefer that this space extend to the costal margin and join the central tendon of the diaphragm in the midline. Once the space is created to your satisfaction, the posterior rectus sheaths are approximated with running absorbable suture. Fixation of the mesh superiorly, inferiorly and laterally with sutures, will help you with positioning the mesh appropriately. A number of techniques can be used to place the rest of the sutures. I prefer to use a Carter-Thomason suture passer, but other suture passers are just as good to fix the mesh to the anterior abdominal wall.

The benefits of PCS with TAR have been demonstrated with the superiority when compared with ACS by 50% decrease in wound morbidity with the posterior approach [54]. Most large series report significant lower morbidity with the PCS approach. Moreover, this technique has been suggested for patients who previously have ACS but have recurrence of hernia [55].

Step 7.9: Laparoscopic Component Separation

As with all surgical procedures, component separation is associated with several complications, the most common of which is skin ischemia and necrosis. This is due to creation of wide skin flaps that compromise the blood supply reaching it from the underlying perforators of deep epigastric artery and the superficial inferior epigastric artery. Laparoscopic component separation offers the advantage of avoiding the creation of large skin flaps which lowers the morbidity and significantly reduces the risk of avascular skin necrosis.

Several techniques of laparoscopic component separation have been described in the literature (see Chap. 14). These include techniques that use video-assistance and those that do not use video-assistance. Techniques that use video-assistance utilize an endoscope for visualization while performing aponeurosis release and dissection. On the other hand, some authors have described the use of a transverse subcostal incision to gain access to the external oblique fascia and perform component separation under direct visualization with smaller incisions. Dissection between the external and internal oblique muscles is performed using a balloon. There is a lack of data comparing the two approaches; however, there is consensus that the minimally invasive approach lowers the morbidity and the risk of skin necrosis compared to the open approach.

Step 7.10: Mesh Graft Selection

By definition, patients with ECFs, EAFs, or stomas have contaminated wounds. Synthetic mesh has been used in the past, but it was associated with high rates of wound infection (often necessitating removal of infected mesh for source control of infection) and with other complications (such as newly created fistulas). Most recently, biologic mesh has become standard in high-risk patients with contaminated and dirty-infected wounds [56]. Level I evidence, however, is needed.

In one of our earlier studies at our center, 60 patients underwent acellular dermal matrix (ADM) implantation for abdominal wall reconstruction from January 2006 through December 2009 [57]. Of the 60 patients, 4 were lost to follow-up. In the remaining 56 patients, we used two brands of ADM: AlloDerm® (LifeCell Corporation, Branchburg, NJ) in 38 patients (68%) and Strattice™ (LifeCell Corporation) in 18 (32%). A total of 9 patients had concomitant ECFs or EAFs. For the 9 patients with ECFs or EAFs, we used underlay placement in 4 (44%) and interposition or bridge placement in 5 (56%). We found that the abdominal wall reconstruction results in patients with versus without concomitant ECFs or EAFs did not statistically differ in terms of the rates of overall complications, of recurrence, and of infectious complications [1].

Others have also reported that ADM implantation can be safely used to repair large and complex ventral hernia defects in patients with clean-contaminated or dirty-infected wounds [48, 56–60]. In our 2006–2009 study mentioned previously, of the 56 patients who underwent ADM implantation with either AlloDerm or Strattice, 35 had contaminated fields as defined by the presence of intra-abdominal or soft tissue infections, stomas, or fistulas [1]. Of those 35 patients, most of them—26 (74%)—had grade 4 infections, per a hernia—grading system [48]. The grading system is used to classify the risk for infectious complications to help surgeons decide on the technique and potentially on the mesh to be used. Grade 1 refers to a low risk for infections or complications in patients who have no history of wound infections; grade 2 indicates comorbidities such as smoking, diabetes, obesity,

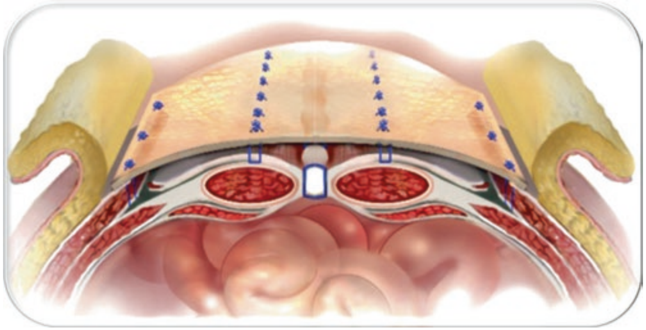


Fig. 7.13 Onlay mesh. Illustrator's view (Courtesy of LifeCell Corporation, Branchburg, NJ)

a suppressed immune system, and COPD; grade 3 refers to those with previously contaminated wound infections, stomas, or intraoperative violations of the GI tract; and grade 4 indicates infected mesh and septic foci. Obviously, grades 3 and 4 present serious medical and surgical challenges for the patient and for the health care team, whether led by a general surgeon, trauma surgeon, or plastic surgeon. But, even grade 2 means that patients may harbor a significant risk and need to be thoroughly evaluated preoperatively; otherwise, a significant problem could arise. Our results suggest that biologic mesh implantation is a valid option for complex abdominal wall reconstruction in the high-risk trauma and acute care surgery population. One group has suggested staged care in patients with giant abdominal wall defects without the use of permanent mesh [59]. In that group's report on 274 patients, absorbable mesh implantation with component separation for definitive abdominal wall reconstruction provided effective temporary abdominal wall defect coverage with a low fistula rate [59]. We have used this technique in the reconstruction of large abdominal defects. But, most surgeons attempt to complete abdominal wall reconstruction at the time of hernia repair or at the time of takedown of ECFs or EAFs, even in contaminated fields.

In our practice, we aim to complete the definitive procedure in a single operation. On occasion, we have used the principle of damage control, returning the next day or so to complete, if at all possible, the operation. Since 2005, in all of our patients with clean-contaminated or dirty-infected wounds, we have used biologic mesh, primarily AlloDerm and Strattice [1]. When there is native tissue to cover the mesh, we use four to five drains that stay in for 10–15 days. With underlay placement, we use one large drain between the mesh and fascia, and then we use three to four drains over the fascia and under the skin and subcutaneous tissue; to avoid drain displacement, we fix all of the drains to tissue with fine chromic sutures.

Step 7.11: Mesh Placement

Detailed techniques of mesh placement are described in Chap. 21. In this section of this chapter I will briefly mention the three most common techniques of mesh placement. In our practice, the three most common techniques used to place mesh during abdominal wall reconstruction are underlay placement (Fig. 7.12a–d), onlay placement (Fig. 7.13), and interposition or bridge placement (Fig. 7.14a–c). Either open or laparoscopic surgical techniques can be used to repair abdominal wall defects, but in patients with ECFs or EAFs, the open approach is the preferred method. Technically, onlay placement (Fig. 7.13) is the easiest way to place mesh.

I prefer fixing mesh to fascia using absorbable sutures, either interrupted or continuous (Fig. 7.14a–c). I use three or four large, closed-suction drains (19 French [8]) under the subcutaneous tissue, and keep them in until the individual drain output is less than 25 ml over 24 h.

The underlay placement (Fig. 7.12a–f) has now become the main technique of mesh placement. It is more involved, but once it is learned and perfected, it does not add significant operative time. Placement of the interrupted sutures should ensure complete stretching of mesh once sutures are tight. Suture placement techniques vary, but we prefer the parachuting technique [61] and the use of direct vision at all times. Our direct-vision parachuting technique minimizes the potential for bowel injury during fixing of mesh on the abdominal wall. If lateral component release is used, we prefer placing sutures in the anterior abdominal wall as far laterally as possible; clearly, the surgeon must include the medial edge of the external oblique fascia to prevent bulging laterally at the release component site, and the patient might think bulging is a new hernia.

When the abdominal wall has lost its domain and the surgeon cannot bring together its medial edges (because the wall has been either removed or retracted laterally completely), then the only remaining option is to use mesh as a bridge (Fig. 7.14a–c). The surgeon must ensure that the suture bites are placed at least 5 cm into the muscles and fascia and not on the edge of the fascia, given the risk of herniation or suture failure. When mesh is used as a bridge and when there is no skin or subcutaneous tissue to cover the mesh, then we use wound VAC with continuous irrigation, which keeps the mesh moist and speeds the process of granulation for later skin grafting (Fig. 7.15a, b). Detailed operative notes are mandatory and should be written by the most senior surgeon (Fig. 7.16).

Fig. 7.14 (**a**) Interposition Strattice graft in a patient who sustained a gunshot wound and was managed with open abdomen. (**b**) Interposition graft in a patient who, despite component separation, required bridging with a graft. Skin and subcutaneous tissue were adequate to cover the graft over the drains. (**c**) Same patient as in Fig. 7.2. Skin and subcutaneous necrotic tissue were removed, and AlloDerm was eventually covered with skin graft

Step 8: *P* = Postoperative Care

Postoperative care of patients after major exploratory laparotomy with takedown of fistulas and abdominal wall reconstruction is as complex as the operation itself. Such patients require continuation of parenteral nutrition until full return of GI tract function, at which time they may be able to resume full oral intake. Postoperatively in our practice, we prefer to give patients massive doses of vitamin C: 2 g intravenously every 4 h for at least 1 week. We also administer vitamin E, zinc, selenium, and, when appropriate, vitamin A beyond the standard doses in total parenteral nutrition. The most common complications include wound infections and other surgical site complications (20–45%), hernia recurrence (up to 20%), fistula recurrence (up to 47%, depending on the type of mesh used), small bowel obstructions, and pain. The real complication rate, however, can be extremely high, up to 82% [60, 62].

Fig. 7.15 (**a**) A 41-year-old male managed with interposition graft who has lost abdominal wall domain, including skin and subcutaneous tissue. (**b**) After a few weeks of being managed with vacuum-assisted closure (VAC), skin graft was applied successfully

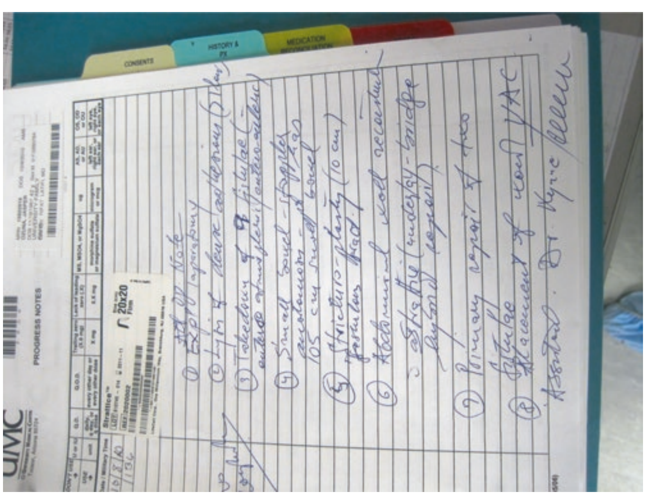


Fig. 7.16 Detail of handwritten operative notes

Step 8.1: Dealing with Complications of Biologic Grafts

One of the major complications of biologic mesh has been hernia recurrence rate, which has been reported as much as 30% a level of laxity that troubles both the patients and surgeons alike [63]. In this study, seven of the nine patients reconstructed with component separation followed by interpositional Alloderm presented with abdominal wall laxity. Laxity was defined as a condition in which patients had clinical evidence of abdominal bulge at follow-up and required secondary reconstruction [63]. In a systematic review of twenty-five retrospective studies, Slater et al. [64] found that the recurrence rate depended on wound class, with an overall rate of 13.8%, while the recurrence rate in contaminated/dirty repairs was 23.1%. Abdominal wall laxity occurred in 10.5% of patients, and the surgical morbidity rate was 46.3%. While infection occurred in 15.9% of patients, in 4.9% of cases this led to graft removal. As it has been known for a while now, there are no randomized clinical trials; however, biologic grafts are associated with a high salvage rate when faced with infection.

The use of biologic mesh has made possible "one operation only" as it is attempted by most surgeons who perform abdominal wall reconstruction at the time of hernia repair, or at the time of takedown of ECFs and/or EAFs, even in contaminated fields. Once a common practice, a staged operation for closing the open abdomen is being less frequently used as we aim to complete the definitive procedure in a single operation [65]. In a study of 128 patients (76 F, 52 M) with large hernia defects (range 40–2450 cm^2), infected mesh was present in (n = 45), stoma (n = 24), concomitant gastrointestinal (GI) surgery (n = 17), enterocutaneous fistula (n = 25), open non-healing wound(s) (n = 6), enterotomy/colotomy (n = 5), and chronic draining sinus (n = 6). Despite the high rate of wound morbidity (47.7%) associated with single-staged reconstruction of contaminated fields, the authors concluded that biologic mesh can be placed without consequences [66]. However, these authors also concluded that the long-term durability seems to be less favorable [66]. In a similar study, this group of authors reported the simultaneous reconstruction of ECF and complex abdominal wall defects resulted in successful single-stage management of these challenging cases in nearly 70% of patients [54]. To this end, many authors now believe that complex abdominal wall reconstruction (CAWRs) using ADM has low rates of surgical site occurrence (SSO) and surgical site infection, despite increasing degrees of wound contamination. If the wound is infected, or if the patient requires reoperation the biologic mesh can be saved and does not need to be removed.

Yet, AWR itself has serious complications with or without biologic mesh [63]. In a report of 106 patients [67], (seventy-nine patients of whom had preoperative comorbid conditions), sixty-seven (63%) patients developed a postoperative complication, with skin necrosis being the most common complication (n = 21, 19.8%); this is similar to our experience [1, 4]. Other complications of AWRs include seroma (n = 19, 17.9%), cellulitis (n = 19, 17.9%), abscess (n = 14 13.2%), pulmonary embolus/deep vein thrombosis (n = 3, 2.8%), small bowel obstruction (n = 2, 1.9%), and fistula (n = 8, 7.5%). Using the Methodological Index for Non-Randomized Studies, 554 patients from 16 studies from six different mesh products had an overall infection rate of 24%, and a recurrence rate of 20% [34]. The authors called for caution when using biologic mesh products in infected fields, because there is a paucity of controlled data and none have US Food and Drug Administration approval for use in infected fields. When biologic mesh was compared to non-biologic mesh in a recent meta-analysis, it was found that biologic grafts had significantly fewer infectious wound complications (p < 0.00001), but recurrence rates were not different. In addition, there were no differences in wound infections or recurrence between the human and porcine-derived biologic grafts [68]. Finally, all patients undergoing complex reconstruction require long-term follow-up; we suggest following up these patients at least yearly. Data for long-term effects of these complex abdominal wall reconstructions are lacking [60]. Furthermore, the functionality, regenerative capacity, and long-term fate of these products have not been defined [69]. Based on the surgical technique used in the repair of hernia defects, the hernia recurrence rate could be as high as 63% at 10 years, when mesh is not used [70].

Step 9: *L* = Long-Term Follow-Up

All patients undergoing complex reconstruction require long-term follow-up. In my practice patients are followed at least yearly. Data for long-term effects of these complex abdominal wall reconstructions are lacking, however [60]. Based on the surgical technique used in the repair of hernia defects, the hernia recurrence rate could be as high as 64% at 10 years when mesh is not used [71]. Others [72] have demonstrated that Mersilene™ (Ethicon) mesh has a greater incidence of ECF formation and a recurrence rate that is three times greater. In a study of long-term follow-up of patients with abdominal wall reconstruction of planned hernia after major trauma, the hernia recurrence rate was 14% [62]. Lower recurrence rates of 5% were observed when the modified component separation technique with or without mesh was employed. Increased BMI and female gender were associated with recurrence. When a modified Rives-Stoppa repair was used, the results were much better, despite the fact that the majority of the patients (60%) had significant comorbidity, and 30% of these patients had one or more incisional hernia recurrence. The hernia recurrence rate in this group of this patient population was 5% [73]. A modified onlay technique for the repair of complicated incisional hernias with a mean follow-up time of 64 months had a 16% hernia recurrence rate [74].

Data on long-term applications of biologic mesh are lacking, although its use has risen dramatically in patients with active infections or are at high risk for infection. In an experimental study examining biologic grafts in comparison to synthetic material, biologic grafts were able to clear a *Staphylococcus aureus* contamination; however, they do so at different rates [75]. Harth et al. created a chronic hernia model in rats and then used various meshes (one synthetic polyester as control material (n = 12) and four different biologic grafts (n = 24) per material). Biologic grafts evaluated included Surgisis (porcine small intestinal submucosa), Permacol (crosslinked porcine dermis), Xenmatrix (noncrosslinked porcine dermis), and Strattice (noncrosslinked porcine dermis). Half of the repairs in each group were inoculated with *Staphylococcus aureus* at 104 CFU/mL and survived for 30 days without systemic antibiotic. There was a significant difference of bacterial clearance between biologic meshes. To this end, the use of biologic mesh in Northern America has become standard in high-risk patients with contaminated and dirty-infected wounds, despite the very high cost associated with the use of biologic mesh, and a lack of empirical evidence.

Previously, we reported our own study of 60 patients who underwent acellular dermal matrix (ADM) implantation for abdominal wall reconstruction [2]. In 56 patients studied retrospectively, we used two brands of ADM: AlloDerm (LifeCell Corporation, Branchburg, NJ) in 38 patients (68%)

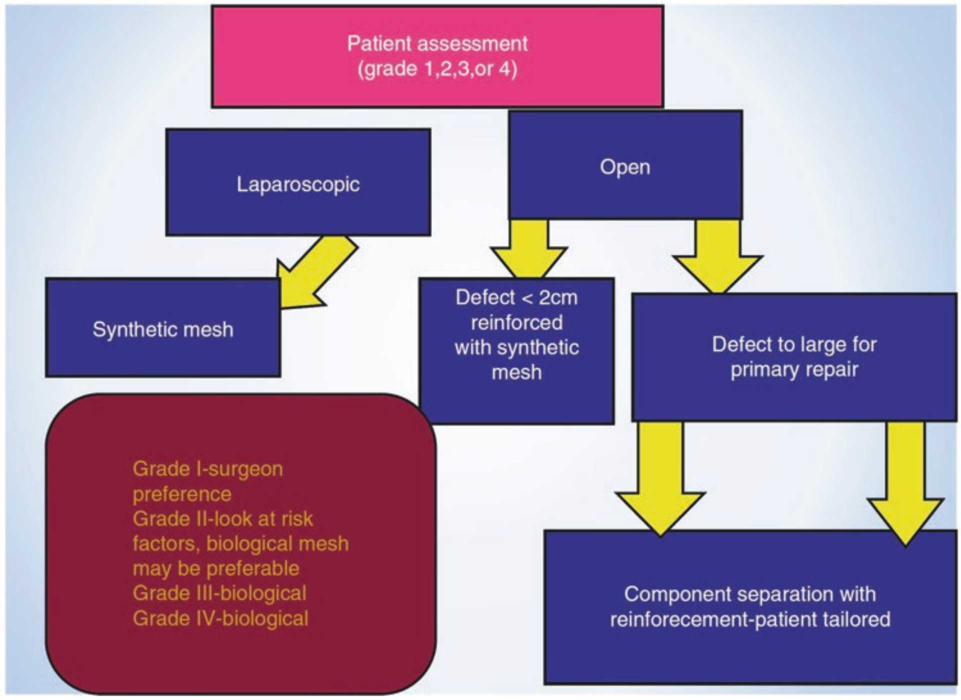


Fig. 7.17 Algorithm for use when deciding what type of repair should be implemented in abdominal wall reconstruction

and Strattice (LifeCell Corporation) in 18 patients (32%). A total of nine patients had concomitant ECFs and/or EAFs; for the nine patients with ECFs and/or EAFs, we used underlay placement in four (44%), and interposition or bridge placement in the remaining five (56%). We found that the abdominal wall reconstruction results between patients with versus without concomitant ECFs and/or EAFs did not statistically differ in terms of the rates of overall complications, recurrence, or infectious complications. However, we lack long-term data on these patients.

Others have also reported that ADM implantation can be safely used to repair large and complex ventral hernia defects in patients with clean-contaminated or dirty-infected wounds. In our study mentioned above, of the 56 of patients who underwent ADM implantation with either AlloDerm or Strattice, 35 (62.5%) had contaminated fields as defined by the presence of intra-abdominal or soft tissue infections, stomas, or fistulas. Of those 35 patients, the majority—26 (74%)—had Grade 4 infections, per a hernia grading system (VHWG). However, a recent study of 108 patients with grade II and III classification of hernias based on the Ventral Hernia Working Group (VHWG) has questioned the need to use biologic mesh in these two groups [48].

Our results suggest that biologic mesh implantation is a valid option for complex abdominal wall reconstruction in the high-risk trauma and acute care surgery population; however, long-term results are not evident yet. While long-term follow-up data are not available, other surgeons have reported abdominal wall closure in the infected field as well. In a recent study of 82 patients with ventral hernia repaired predominantly with Alloderm and Strattice, 32 (39%) had had concomitant intestinal surgery [76]. There was no difference in hernia recurrence (contaminated group—28% vs. non-contaminated group—34%, $P = 0.58$), surgical site infections (contaminated—28% vs. non-contaminated—20%, $P = 0.40$) or other complications when patients with and without concomitant bowel surgery were compared.

Summary

Surgical management of abdominal wall defects, including ECFs or EAFs, is often associated with major hernias and other complexities. Careful planning and advanced surgical techniques are required, often involving the use of biologic mesh or composite tissue transfer. Treatment of ECFs in patients with large abdominal wall defects is challenging, but with proper techniques, results can be excellent. See Fig. 7.17 for an algorithm that will help with decisions regarding what type of repair should be used in abdominal wall reconstruction. Biologic mesh is the mesh of choice in such patients [77].

We propose the usage of a nine-step process to diagnose and manage surgical care for patients who develop ECFs. This nine-step process is known as ISOWATS-PL, which stands for: *I* = Identification and diagnosis of postoperative fistula; *S* = Sepsis and Source Control; *O* = Optimization of Nutrition; *W* = Providing and Ensuring Wound Care; *A* = Redefining the anatomy and understanding the pathology at hand; T = Timing of definitive surgery and/or takedown of fistulas; S = Definitive surgery and surgical creativity; P = Postoperative care; and L = Long-term follow-up for management of ECFs. The guidance presented in this chapter will contribute to more effective management of ECFs.

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A Difficult Abdomen: Temporary Closure and Management of the Consequences

8

Rifat Latifi, Guillermo Higa, and Elizabeth Tilley

Introduction

During damage control surgery (DCS), the surgeon has several options for temporary abdominal closure (TAC). While each of these techniques has its pros and cons, and DCS has proven beneficial when used appropriately, one has to recognize that TAC may have significant consequences. In our practice most common forms of TACs are use of an intestinal bag, wound vacuum-assisted closure (VAC), or a moist gauze that serves as the "poor man's wound VAC." However, if the patient has enough skin and subcutaneous tissue, then closing the skin offers the best temporary closure. Temporary closure of the fascia should be avoided for fear of injuring the edges of the fascia and subsequently creating a hernia and dehiscence. If wound VAC is used, just enough pressure should be applied to maintain closure; pressures higher than 70 mmHg must clearly be avoided, especially for long periods of time. High pressures have been associated with creation of new fistulas in patients with an open abdomen (unpublished data from our group). If at all possible, final and definitive closure of the abdomen should be performed within 12–72 h after initial temporary closure. The final and definitive closure type is discussed in other chapters (see Chap. 7). Different techniques for abdominal wall reconstruction are described elsewhere in this book as well. However, performing DCS does not mean that you have committed the patient to long-term open abdomen management, and every attempt should be made to close the fascia primarily. If and only when you are unable to definitely close the abdomen, you will have to consider long-term management with eventual closure. As stated above, although it has been shown in numerous studies that DCS is life-saving, the consequences of DCS have been elucidated in recent years [1–4].

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Leaving the Abdomen Open

Patients who have sustained a major abdominal injury, with hemorrhagic shock or peritonitis caused by intra-abdominal sepsis, require extensive resuscitation. The resulting edema of the bowel, retroperitoneum, and abdominal wall causes loss of compliance of the abdominal wall. Primary closure under tension leads to abdominal compartment syndrome (ACS), further tissue necrosis, necrotizing fasciitis, and fascial dehiscence.

In the acute setting, due to major trauma (liver trauma requiring packing) and other complicated clinical situations such as perforated viscus and massive contamination, damage control surgery (DCS) must be performed early, before patients become coagulopathic and severely acidotic.

Another challenge for DCS is the ongoing requirement for massive resuscitation, which may render the patient susceptible to ACS or put him/her at risk for developing it. In these scenarios, the surgeon should leave the abdomen open and use any of the temporary closure techniques that will cover the intra-abdominal content. In patients with a more continuous source of severe sepsis or massive resuscitation with chances for developing ACS, the temporary closure, in fact, can be extended for a longer period of time (Figs. 8.1 and 8.2). While DCS in patients whose abdomen cannot or should not be closed is lifesaving, leaving the abdomen open has major complications, including development of fistulas, future massive hernias, and loss of abdominal wall domain, which will require major reconstruction in the future. Thus, leaving the abdomen wall open for longer periods of time commits patients to additional major surgery, longer hospitalization, higher morbidities, and costs (Fig. 8.3) [5].

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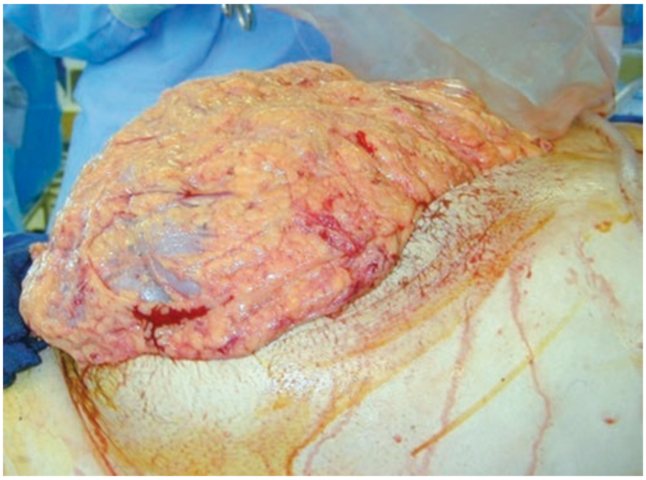

Fig. 8.1 Abdominal compartment syndrome (ACS) developed intra-operatively in a blunt retroperitoneal and extremity injury, requiring immediate decompressive laparotomy

Fig. 8.2 Abdominal compartment syndrome (ACS) resolved in 36 h. Patient was taken back for colostomy (to prevent contamination of perineum) and abdominal wall closure

Fig. 8.3 Final look at patient in Fig. 8.2 after multiple operations

Temporarily "Closing" the Abdomen

Numerous techniques have been described for handling the acute inability to close the abdomen. For detailed descriptions of how to temporarily "close" the abdomen, see extensive descriptions in various chapters throughout this book. However, the techniques discussed next merit special mention [5–7].

Towel Clip Closure

Although we rarely use towel clip closure (the senior author has used it only time), and we mention it as a possible technique only to condemn it, it is the most simple and can be rapidly performed for temporary closure of the abdominal skin and subcutaneous tissue in clinically hemodynamically unstable patients.

Depending on the length of the incision, up to 25–30 standard towel clips might be necessary to complete closure (Fig. 8.4). While some authors find the use of the towel clamp (or clip) beneficial, the authors of this chapter advise to use minimally.

Temporary Skin Only Suture Closure

All attempts should be made to cover over the viscera. Skin and subcutaneous tissue is the best choice and should be used whenever possible. The suture closure technique can be used with or without intra-abdominal packing. This technique has serious limitations and might not be applicable in

Fig. 8.4 Temporary closure of the abdomen with towel clips. We do not rely on this technique any longer

patients with extensive edema of the retroperitoneum or of the viscera itself [5–7].

If we use this technique, some sort of wound VAC over the incision should be applied. An abdominal binder should be applied as well.

Retention Sutures

Retention sutures incorporating large portions of tissue tied under tension can forcibly contain the abdominal contents. Unfortunately, retention sutures exacerbate ACS and have been implicated in the development of enterocutaneous fistulas (ECFs), even when the sutures are placed extraperitoneally, so this technique should not be used for temporary closure. Instead, simple closure of the skin, if possible, should be performed. Better yet, we employ other techniques, such as vacuum-assisted closure (VAC), that protect the skin from injuries induced by large sutures.

Pliakos et al. [8] tested whether a modification of the VAC technique would facilitate primary fascial closure and reduce morbidity in patients who had severe abdominal sepsis. They randomized 53 patients into 2 groups. Thirty of these patients were analyzed. The VAC group had patients managed only with the VAC device. The other group was comprised of the retentions sutured sequential fascial closure (RSSFC) procedure. For the VAC group, the abdomen was left open for 12 days ($P = 0.0001$) with 4.4 ± 1.35 changes per patient ($P = 0.001$) and for the RSSFC group for 8 days with 2.87 ± 0.74 dressing changes. Abdominal closure was possible in 6 patients from the VAC group and for 14 patients in the RSSFC group. These differences were significant ($p = 0.005$). Planned hernia was exclusively decided in patients in the VAC group ($P = 0.001$). The hospital stay was 17.53 ± 4.59 days for the VAC group and 11.93 ± 2.05 days for the RSSFC group ($P = 0.0001$). The median initial intra-abdominal pressure (IAP) was 12 mm Hg for the VAC group and 16 mmHg for the RSSFC group ($P < 0.0001$). These results indicated that the RSSFC procedure compared to the single use of the VAC device was superior. Pliakos et al. [8] concluded that sequential fascial closure can begin once abdominal sepsis is controlled.

Atema et al. [9] conducted a systematic review and performed a meta-analysis on incidence of temporary abdominal closure (TAC) and open abdomen (OA) in peritonitis patients in order to assess delayed fascial closure, enteroatmospheric fistula, and mortality rate overall and per TAC.

Of 78 patient series, 5 of them, which included 77 patients, had dynamic retention sutures. Best results were produced by negative pressure wound therapy (NPWT) with continuous fascial traction; however, these authors concluded that the overall quality of available evidence was poor and recommendations could not be made.

Jannasch et al. [10] conducted a topic-related, selective, PubMed-based literature search on the options of temporary closure of the abdominal wall and found that procedures with the highest fascial closure rate (Wittmann patch, STAR, 75–93%; dynamic retention sutures, 61–91%; V.A.C., 69–84%) have the lowest mortality. Dynamic retention sutures rank as one of the procedures with the highest fascial closure and lowest mortality rate according to their findings.

Temporary Silos

With extensive edema and distention of intra-abdominal organs, an abdominal silo can be inserted to cover the exposed viscera. Some authors use plastic bags or silos sutured to the skin to allow the viscera to extrude from the peritoneal cavity. We do not prefer this technique because it involves suturing into the skin or fascia; doing so may cause recurrence of ACS. Instead, we cover the intestines with an "intestinal bag" and dressing. The surgeon must be aggressive about returning patients with temporary silos to the operating room as soon as possible, either to close the abdomen permanently or at least to cover the intestines with skin and subcutaneous tissue.

Vacuum-Assisted Wound Closure

Performing DCS does not mean that you have committed the patient to long-term open abdomen management, and every attempt should be made to close the fascia primarily. A number of techniques and strategies have been described, but application of wound VAC has revolutionized the care of many surgical wounds in just about all surgical disciplines. The fundamental reasons for applying suction (via VAC) to an open wound are to allow for the rapid removal of peritoneal fluid and to collapse spaces between the viscera. Both steps will make the contents of the abdominal cavity smaller, resulting in a greater chance of subsequently performing a formal aponeurotic closure of the midline incision [11].

Numerous studies have demonstrated the effectiveness of various VAC techniques. For example, Padalino et al. [12] demonstrated that the VAFC-KCI was associated with a high fascial closure rate after conducting a prospective observational study of nine patients with a mean Acute Physiology and Chronic Health Evaluation II score of 22.62 and a Sequential Organ Failure Assessment score of 10.62. All patients had abdominal compartment syndrome (ACS) and a sepsis source that was difficult to control. However, as stated previously, Pliakos et al. [8] found significant differences in wound closure rate between patients who received RSSFC versus VAC. Their results indicated that the RSSFC procedure compared to the single use of the VAC device was superior, but other studies provide evidence for the usefulness of VAC.

Cothren et al. [13] performed a modification of the vacuum-assisted closure (VAC) technique that provided constant fascial tension, in order to achieve a higher rate of primary fascial closure. This procedure is similar to the one performed by Burlew et al. [14], which is presented later in this chapter. The steps include: [1] initial temporary closure of the abdomen after post-injury damage control or decompressive laparotomy for ACS, [2] cover the bowel with white sponges overlapping like patchwork, [3] place the fascia under moderate tension over white sponges with #1-PDS sutures, [4] place large black VAC sponges on top of the white sponges, affixed with occlusive dressing and standard suction tubing, [5] then patient is returned to the OR for sequential fascial closure and replacement of the sponge sandwich every 2 days. Cothren et al. analyzed differences in 14 patients who underwent SAC. Nine were due to damage control and five were due to secondary ACS. Average time to closure was 7.5 ± 1.0 days (range 4–16) and average number of laparotomies to closure was 4.6 ± 0.5 (range 3–8). All patients attained primary fascial closure. The authors concluded that this technique achieves 100% fascial approximation [14].

Roberts et al. [15] conducted a systematic review of published and unpublished studies that compared the effectiveness and safety of negative pressure wound therapy (NPWT) versus alternate TAC techniques in critically ill adults with open abdominal wounds. Of 2715 citations, they found two RCTs and nine cohort studies that met inclusion criteria. One RCT observed an improved fascial closure rate (relative risk [RR], 2.4; 95% confidence interval [CI], 1.0–5.3) and length of hospital stay after addition of retention sutured sequential fascial closure to the Kinetic Concepts Inc. (KCI) vacuum-assisted closure (VAC). Another reported a trend toward enhanced fascial closure using the KCI VAC versus Barker's vacuum pack (RR, 2.6; 95% CI, 0.95–7.1). One prospective cohort study observed improved mortality (RR, 0.48; 95% CI, 0.25–0.92) and fascial closure (RR, 1.5; 95% CI, 1.1–2.0) for patients who received the ABThera versus Barker's vacuum pack. Another noted a reduced arterial lactate, intra-abdominal pressure, and hospital stay for those fitted with the KCI VAC versus Bogotá bag. Roberts et al. stated that the majority of the retrospective studies exhibited low methodological quality and reported no mortality or fascial closure benefit for NPWT [15].

Use of Skin Graft in Open Abdomen Management

Failure to close the abdomen and loss or retraction of abdominal wall laterally will require a skin graft, which should be placed as soon as possible. In such patients, the wound is covered with absorbable Vicryl® (Ethicon, Somerville, NJ) mesh (Fig. 8.5), which eventually is allowed to granulate (Fig. 8.6), and a split-thickness skin graft technique is applied (Fig. 8.7). Then, at a later date (usually more than 6 months), the abdominal incisional hernia is addressed [16, 17].

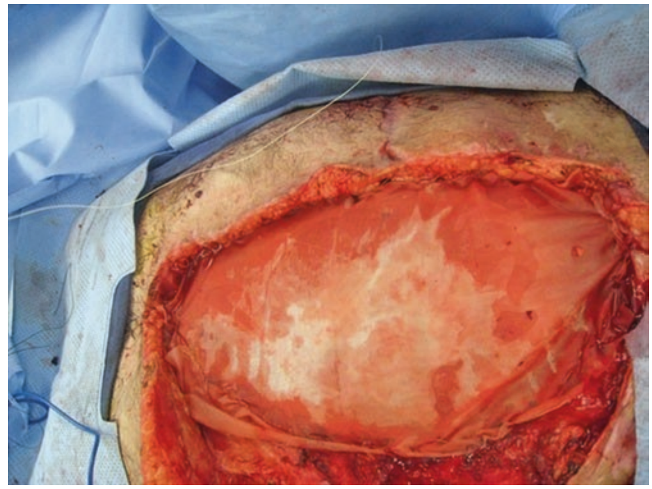

Fig. 8.5 Temporary closure of the abdomen with Vicryl. This is a useful technique when return to the operating room is expected in 24–36 h and when the abdomen is left to granulate

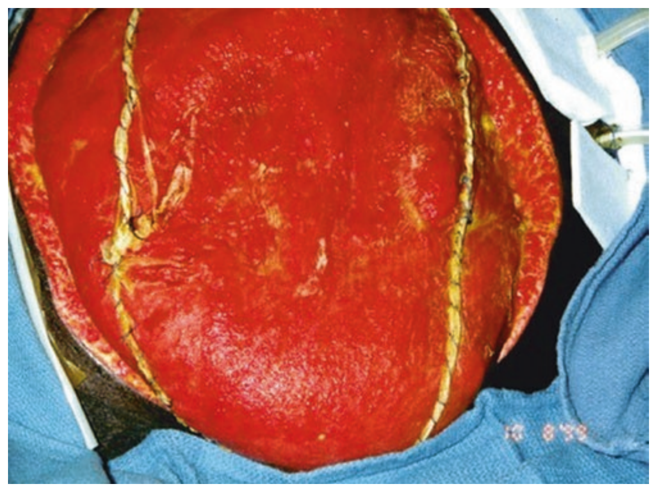

Fig. 8.6 Granulation of the abdomen wall managed with open abdomen and Vicryl "closure"

Fig. 8.7 Patient with skin graft matured. A wait of at least 9–12 months may be necessary before embarking on definitive closure and abdominal wall reconstruction in such cases

Removing the skin of the intestines is not an easy task and may be associated with new injuries to the intestines that if not recognized and repaired may cause another catastrophe in these patients.

Barnes et al. [18] reviewed whether the skin component would be beneficial as an immune-monitoring tool and found that skin transplanted as part of the abdominal wall or as a separate vascularized sentinel skin flap may aid in the diagnosis of rejection. This has the potential to improve graft survival and reduce immunosuppressive morbidity.

Sequential Closure of Abdominal Wall Following DCS

Burlew et al. conducted a comparison study of patients who underwent damage control surgery between 2005 and 2010 at their institution. They compared patients who were operated on using a systematic protocol versus those who were not [14]. The systematic protocol, similar to the one conducted by Cothren et al. [13], was implemented in order to achieve a higher rate of primary fascial closure than what had been described previously in the literature. The procedure involved the following steps: [1] VAC white sponges were used to cover the bowel [2]. Next, the fascia was placed under moderate tension over the white sponges with no. 1-polydioxanone sutures [3]. Then, the black sponge was placed on top with the standard occlusive dressing. [4] Finally, patients underwent partial fascial closure and replacement of the sponge sandwich every two days until completely closed. Protocol violations were defined as not returning to the operating room every other day and absence of fascial retention sutures. Patients who died before return to the operating room in the first 48 h were excluded from reported results. Over the course of 5 years, 51 patients required an open abdomen after the second laparotomy. Eighty percent of these patients were men with a mean age of 34.7 ± 2 years. The mean injury severity score (ISS) was 37.1 ± 2.4, mean abdominal trauma index (ATI) of 26.4 ± 2.1. The average initial base deficit was 15.7 ± 0.6 and 24-hour red cell transfusions were 20.4 ± 2.4 units. Twenty nine followed the protocol and twenty two did not follow the protocol. Of the 29 who did follow protocol, 100% had fascial closure. Of the 22 who did not follow protocol, only 55% ($N = 22$) achieved fascial closure. There were no significant differences in ISS, ATI, initial base deficit, or red cell transfusions. They concluded that a methodological approach with sequential fascial closure achieves 100% fascial approximation as well as reducing the morbidity of the open abdomen and the cost of complex abdominal reconstruction or biologic mesh insertion [13].

An important question in the management of patients undergoing DCS or damage control laparotomy (DCL) in particular is when to use mesh repair and when to use lateral component separation (CS). To answer this question, Sharrock et al. [19] conducted a systematic review and meta-analysis of studies that compared methods of restoration of fascial continuity when primary closure was not possible following DCL for trauma. They included randomized controlled trials (RCTs), cohort studies, and case series' that reported temporary abdominal closure (TAC) and early definitive closure methods in trauma patients undergoing DCL. In all, they reviewed 26 studies, with mortality, days to fascial closure, hospital length of stay, abdominal complications, and delayed ventral herniation as outcomes. Estimates for abdominal complications in delayed primary closure (DPC), mesh repair (MR), and component separation (CS) groups were 17%, 41%, and 17%, respectively, while estimates for mortality in DPC and MR groups were 6 and 0.5%. Estimates for abdominal closure in the MR and DPC groups differed; 6.30 (95% CI = 5.10–7.51) and 15.90 (95% CI = 9.22–22.58) days, respectively. Sharrock et al. [19] concluded that component separation or mesh repair may be valid alternatives to delayed primary closure following a trauma DCL.

Fantus et al. [20] used the controlled fascial tensioning device (Wittmann Patch, Starsurgical, Inc., Burlington, WI) in combination with an adhesion preventing barrier to allow for unhindered sequential medial advancement of the fascia toward the midline. The use of these two devices together may lead to a higher incidence of fascia-to-fascia abdominal wall closure than the use of fascial tension alone [20]. Frazee et al. [21] conducted a retrospective review of 37 open abdomen patients who had temporary abdominal closure. They compared 37 patients who had temporary abdominal closure with a commercial negative pressure device (ABThera, KCI) to 37 patients who had open abdomen management with the Barker technique. Patients were compared using the chi-square, t-test, and logistic regression analysis with a significance level of $p < 0.05$. Mean age and BMI were significantly higher in the ABThera patients. No statistically significant differences were seen in male:female ratio, indication for open abdomen management, preoperative albumin, number of operations, and use of sequential closure. In 33 patients (89%) ultimate midline fascial closure was achieved with the ABThera vs in 22 patients (59%) using the Barker technique ($p < 0.05$). Logistic regression analysis was performed on the three significant variables identified on bivariate analysis. Only the type of temporary abdominal closure proved significant, with an odds ratio of 7.97 favoring ABThera (95% CI 1.98 to 32.00). Frazee et al. [21] concluded that the ABThera had significantly greater success with ultimate closure compared to the Barker technique.

Managing the Consequences of Temporary Closure

Although other chapters will describe details of definitive surgical repairs, following DCS we will briefly mention here few elements of this management. Once patients have survived the acute stage—which may last for weeks or, worse, for months—deciding whether and when to reconstruct the abdominal wall defect is next major challenge. The main indication for reconstruction is a large hernia or the development of multiple fistulas enterocutaneous fistulas (ECF) or enteroatmospheric fistulas (EAFs) (Fig. 8.8). Reconstruction may also be mandated after failed attempts to close a celiotomy wound or when components of the abdominal wall, for whatever reason, are either injured or absent.

Specific criteria have been suggested to identify patients who may require special closure techniques, including one or more of the following: large defect size (>40 cm^2); absence of stable skin coverage; hernia recurrence after prior closure attempts; infected or exposed mesh; systemic compromise (concurrent malignancy); local abdominal tissue compromise (irradiation, corticosteroid dependence); and concomitant ECFs [22–24]. Other indications for reconstruction are to improve the quality of life, inability to work or to exercise, pain, and recurrent obstructions requiring hospitalizations and frequent surgeries.

Identifying a bona fide indication for reconstruction might seem simple, but it is not an easy task in patients with massive hernias or complex abdominal wall defects. Many surgeons do not consider the mere presence of a hernia to be a sufficient indication for major surgery. But, we believe that large defects should be repaired unless a serious contraindication exists or unless surgery would put the patient at major risk. So, the decision will be between the patient and the surgeon on how they will proceed.

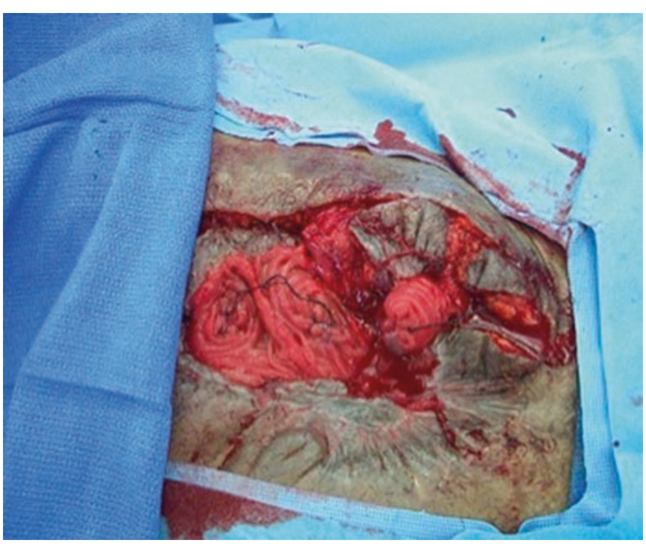

Fig. 8.8 "Fistula city"

Choosing Materials for Repair

With any incisional ventral hernia repair, the overriding recommendation is to reinforce the primary fascial closure with a prosthetic repair material. But, deciding on what kind of materials to use in hernia repair is difficult. The surgeon has to consider the individual patient's biology, physiology, infection status, and religion, as well as the cost.

Synthetic Mesh

Synthetic mesh is currently the most common material used for reinforcement of ventral hernias. It is associated with lower recurrence rates, ease of use, and low cost. Its disadvantages include the risks of visceral adhesions, of erosion into bowel leading to formation of ECFs or bowel obstructions, of extrusion of the repair material, and of infections. Permanent synthetic mesh often requires later surgical removal, necessitating a reoperation. After mesh removal for an infection, the surgeon is left with a contaminated field and a hernia defect larger than the original that still requires a repair material, leading to a high reinfection rate. Patients may have acute postoperative mesh infections or wound dehiscence that may expose the mesh. Reoperations through synthetic mesh may also lead to infections. A seroma may become infected, leading to subsequent contamination and necessitating mesh removal [25–29].

In the late 1990s, biologic materials were introduced as a possible ventral hernia solution [30, 31]. Currently, along with synthetic materials, multiple biologic products are available for use. Still, no consensus exists regarding which patient populations are best served by which materials, how products should be implanted, and what their overall risks of complication and recurrence are.

Biologic Mesh

In our practice, previously infected wounds and contaminated abdominal wall defects or when the wound infection risk is high, we use biologic mesh instead of synthetic mesh. Some biologic repair materials remain intact even in patients with active infections; such materials are more resistant to infections and do not require removal when exposed or infected. Some biologic repair materials have also demonstrated antimicrobial activity, both in vitro and in animal models [32–34]. The ability of certain biologic materials to support revascularization may contribute to clearance of bacteria. We have previously reported good outcomes with AlloDerm® (LifeCell, Branchburg, NJ) and Strattice™ (LifeCell) repair for incisional hernia repair in high-risk patient groups. These patients could be treated nonsurgically, even when their wounds become frankly infected [35–37].

Use of Hernia Grading System as a Guide to Repair

For many surgeons, the choice between synthetic and biologic repair mesh is based on several considerations, including the cost, the operative technique (open vs. laparoscopic), technical expertise, the risk of SSIs, and the individual patient's religion. For patients at low risk for SSIs, the choice of reinforcement should be based on the surgeon's preference and patient factors. The Ventral Hernia Working Group (VHWG) created a system that consists of the following four grades [38]:

Grade 1 (low risk) describes hernias in patients who have no comorbidities; typically, they are younger, healthy individuals.

Grade 2 (comorbid) describes hernias in patients who have comorbidities (e.g., smoking, diabetes, or malnutrition) that increase the risk of SSIs but who do not have evidence of wound contamination or active infections. Thresholds at which the infection risk increases include a blood glucose level equal to or greater than 110 mg/dL (hemoglobin $A_{1C} > 8.0$) and patient age equal to or greater than 85 years. Patients in grade 2 have a wound infection rate fourfold greater than that predicted solely by VHWG wound classification score. The increased risk associated with grade 2 hernias suggests a potential advantage for the use of appropriate biologic repair materials to reinforce open repairs. This perceived increased risk, however, has been challenged in recent studies. Souza et al. question the recommendations of the VHWG [39]. After conducting a review of 100 studies, Souza et al. found that the classification system and the recommendation for selecting the appropriate mesh based on an individual patient's risk per the grading system did not fit the results of their review. The use of uncoated mid-weight polypropylene mesh for reinforcement of midline ventral hernia repairs was not associated with increased rates of infection, fistula formation, or clinically significant adhesions [39].

Grade 3 (potentially contaminated) is considered when there is evidence of wound contamination. Factors that suggest contamination include the presence of a nearby seroma, violation of the gastrointestinal tract, or a history of wound infections. Grade 3 hernias include those in patients with active or suspected wound contamination. Permanent synthetic mesh is not recommended for such patients; instead, biologic repair is a good option because it does not necessitate removal, even in the setting of active infections.

Grade 4 (infected) includes hernias with active infections, especially frankly infected synthetic mesh and septic dehiscence. Replacement of infected synthetic mesh with new permanent synthetic mesh leads to a high reoperation rate and to additional mesh infections and replacement. Before placement of repair material and definitive closure, infected wounds must be thoroughly prepared and the bioburden meticulously reduced. No repair material should be used in patients with gross, uncontrolled contamination; in such patients, the surgeon may consider a delayed repair.

Each grade relates to the aforementioned risk factors for SSIs but does not consider the defect's size or complexity or the proposed repair approach. A greater number of previous repairs substantially increase the risk of hernia recurrence [40–42].

Principles of Repair

The principles of incisional abdominal wall hernia repair are optimization of the patient's condition, wound preparation, centralization, and approximation of the rectus muscles along the midline to the extent possible, and use of the appropriate prosthetic repair material to reinforce the closure. Optimization of the patient's condition includes encouraging smoking cessation (>4 weeks preoperatively), maintaining acceptable blood glucose levels (<110 mg/dL), improving oxygenation in patients with chronic hypoxia (e.g., by using bronchodilators, inhaled corticosteroids, or prostaglandin inhibitors), and setting realistic expectations. Wound preparation consists of two stages. The first occurs before surgery and may include percutaneous drainage of any abscesses and management of any skin irritation from an ECF. The second stage occurs in the operating room: Sharp debridement of all devitalized or infected tissue to reduce the bioburden of the wound is critical; contaminated wounds should be cleaned by pulse lavage. Approximation of the rectus muscles must be attempted to restore normal physiologic tension. Too little tension in a hernia repair results in wound edge separation and poor collagen organization in the incision; too much tension leads to ischemia and wound dehiscence. Physiologic tension attempts to achieve a balance between those opposing outcomes. Techniques for repair of ventral hernias include retrorectus and component separation. Retrorectus allows for placement of repair material behind the defect without contacting the viscera. For larger defects, formal component separation, as first described by Ramirez et al. and modified by numerous authors, is the preferred approach for approximating the midline with minimal or no tension. Component separation creates a dynamic repair by using incisions that create fascial release to bring the rectus muscles together at the midline, thereby re-creating an innervated, functional abdominal wall. Open component separation has utility in patients with challenging defects and can reduce the recurrence rate; however, patients will still benefit from use of the appropriate prosthetic repair material, particularly if they have complex defects (e.g., degraded fascia, tight closure, multiple comorbidities, and wound contamination) [4, 43–48].

Summary

Abdominal wall reconstruction, both in the acute setting and as an elective or semi-elective procedure, presents a major surgical challenge and the approach and management of such patients should be clinically based. Dealing with difficult abdomen involves covering significant loss of abdominal wall domain and inadequate soft tissue coverage. Careful evaluation of patients with complex abdominal defects should reveal predisposing factors for herniation, including inadequate local fascial and muscular layers caused by prior tissue loss; muscle denervation or vascular insufficiency because of prior irradiation or infections; wound infections; obesity; chronic pulmonary disease; malnutrition; sepsis; anemia; corticosteroid dependency; or concurrent malignant process.

The first step in treating patients with complex abdominal wall hernias is careful assessment, starting with risk factors and the size of the defect. Smaller defects (<2 cm) might be suitable for primary repair; larger defects, if the fascia does not meet without undue tension, should be reduced as much as possible. Most defects too large for primary repair can be closed with component separation and reinforced with prosthetic repair materials. For the rare patients in whom component separation is not feasible or is insufficient to reduce the defect completely, the surgeon might consider bridging the defect with prosthetic repair materials. Hernias that are grade 4 should be repaired with open procedures. Most grade 1, some grade 2, and a few grade 3 hernias are suitable for repair with permanent synthetic mesh; all patients considered high risk for SSIs should be considered for surgery with appropriate biologic mesh repair.

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9 Timing of Definitive Reconstructive Surgery of Abdominal Wall Defects in Patients with Enterocutaneous Fistulas

Jasvinder Singh and Rifat Latifi

Introduction

Management of patients with ECFs and abdominal wall defects remains complex and choices of repair may be limited due to the presence of local contamination from fistulas, which particularly restrict use of prosthetic mesh. Moreover, often these patients have concomitant malnutrition and may have other comorbidities. All these factors can increase perioperative morbidity if surgery is undertaken without optimal preoperative optimization and careful planning (see Chap. 26 on perioperative optimization). Optimization can only be achieved using a multidisciplinary approach and advanced surgical techniques. In addition, in our opinion, such a repair should only be attempted by those with clinical and surgical interest and expertise in complex ventral hernia repair. Often these patients have both fistulas and abdominal defects, and thus, even in the face of most optimal preoperative optimization, there is a question of whether a takedown of fistulas and complex abdominal wall defect reconstruction should be performed at the same time or separately. Furthermore, what surgical techniques and what mesh to use for repair of a large hernia defect in a contaminated field are other important questions that we do not have enough evidence to answer it. Subsequently, deciding on timing of surgery is not easy and needs to be individualized. Factors such as patient nutritional status, septic complications, comorbidities, and anatomy of the surgical problem play a major role in decision-making and should be analyzed carefully before definitive surgery.

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Etiology of Enterocutaneous Fistula

The majority (75–85%) of ECFs are postoperative. Spontaneous ECFs are less common and typically occur in face of inflammatory bowel disease, malignancy, radiation, and diverticulitis. The etiology of a fistula has been shown to be predictive of the outcome. The worse outcome is seen in those with malignancy or trauma as the etiology [1]. Spontaneous closure rate of 20–37%, for patients with ECF has been achieved in recent large series [2]. The acronym "FRIENDS" is very useful to identify fistulas, which are unlikely to close spontaneously. Friends stands for: Presence of **F**oreign body, prior **R**adiation exposure, presence of inflammation (IBD) or **I**nfection, **E**pithelization of tract, **N**eoplasm, **D**istal obstruction, and **S**epsis/**S**teroids, all of which make it difficult for these fistulas to close spontaneously [3]. An ECF within an abdominal wall defect and not adjacent to viable skin the so called wide-mouth eneterocutaneous fistula is unlikely to close spontaneously. Spontaneous closure occurs most likely in patients with a closed abdomen, low output ECF, and an uncomplicated disease course. In patients with favorable factors, prolongation of the waiting period before surgery allows spontaneous closure rate to almost double from 16 to 29% [4].

With the popularization of damage control laparotomy (DCL), ECF and EAFs have become common problem in survivors, who require complex abdominal wall reconstruction [5]. Incidence of enterocutaneous fistula has been reported to be between 5 and 75%, and mortality can be as high as 40% in this subset of patients [6]. The loss of abdominal wall domain associated with such a large defect renders these patients unable to be fully functional. Although DCL has been shown to save lives, its overuse has consequences in the form of complex abdominal wall defects as well as a high risk of enteroatmospheric fistulas, and should be limited both for its use, and in particular, the length of time that the abdomen is left open [7]. Simply performing DCL should not commit the patient to open abdomen management. In setting of the open abdomen, most ECFs and EAFs develop

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early in the postoperative course (usually within 1 month). Small bowel fistulas are usually followed by large bowel and stomach fistulas. Likely etiologies in the open abdomen include anastomotic leak, mesh erosion into the bowel wall, exposed viscera, bowel injury during dressing changes, and splitting of the intestine from vigorous coughing or pulmonary toilet [8]. Significant predictors of ECF or EAF in patients with an open abdomen after DCL include large bowel resection, large-volume fluid resuscitation, and an increasing number of abdominal re-explorations [9]. These patients need to be stabilized hemodynamically and functionally with long-term nutritional support, skin graft coverage of open abdomen granulation tissue, and physical therapy before being considered for repair. Usually component separation or bridged mesh repair is required for such large abdominal wall defects.

In patients with Crohn's disease, medical treatment itself may result in closure of ECF and abdominal wall repair can be attempted later. In general, however, the diseased segment of bowel resulting in the fistula requires surgical resection after a period of watchful waiting to allow intraabdominal inflammatory process to improve [10].

Radiation enteritis is a rare cause of ECFs, but is associated with poor prognosis. It has been advocated to strongly consider diverting proximal stomas, intestinal bypass, and resection with re-anastomosis using radiation spared bowel. If a fistula develops in the face of radiation enteritis, it is important to consider more conservative approaches. Patients are likely to have multiple strictures, malabsorption, and healing is likely to be poor. Most patients in this condition will end up needing long-term parenteral nutrition. Any abdominal surgery is associated with high risk of complications and the best outcomes are likely to be achieved by experienced surgeons operating on nutritionally optimized patients [11].

When Should We Operate?

Factors Affecting Timing for Surgical Intervention

Traditional teaching has guided surgeons to wait for months in the hopes that fistulas will close, while providing adequate nutritional support, wound care, and controlling sepsis during this waiting period. However, one has to be cognizant of the fact that some patients may enter a vicious cycle of sepsis, clinical deterioration, and malnutrition resulting from ECFs. These conditions may only be disrupted by definitive surgery. Definitive surgery can be thought of as eradication and not merely source control.

As mentioned above, the timing of surgery for ECF is controversial; but, for the most part, it depends on the timing of diagnosis. Newly diagnosed ECFs in early postoperative course (usually within the first 2 weeks) may be approached surgically, but this depends on the clinical status of the patient and the presentation and output of ECF. Unless there is a small collection as a result of a small leak, surgical exploration in the operating room is required in these patients to completely assess the wounds, drain collection, and to define the anatomy. Does one "re-complete" the abdominal wall closure (repair), do we leave or remove the mesh that we used in it (in case we used a mesh), or do we perform another major clean up, use some form of temporary closure, and come back for another day to "fight" again? These are all questions that a practicing surgeon must face, answer to each of them is not an easy one.

Various factors affect the decision to operate on patients with enterocutaneous fistulas and complex abdominal wall defects. While operating in the acute phase is more controversial, there is less controversy as to when to operate in well-established and controlled fistulas; however, timing and the decision to operate needs to be individualized for each patient and each clinical situation. With clinical presentation of ECFs being one of the most important factors influencing this decision-making process, the etiology of ECF predicts the outcome [1]. More often although, surgeons wait for weeks and months and hope for these fistulas to close, during which time adequate nutritional support, wound care, and sepsis control and/or eradication (when possible) are provided. In general, the following factors influence the timing for surgical intervention in these patients and are as follows: etiology of ECFs; early identification of ECFs; achievement of sepsis control; nutritional status; anatomy of ECF; status of local wound; and associated comorbidities and their resolution.

As a general guide, the local inflammation should have subsided, adhesions softened, and skin graft matured before a definitive repair is attempted. The dense peritoneal reaction after bowel surgery is on its peak from 3rd to 10th postoperative week and may render safe dissection almost impossible [12, 13]. The bowel is very edematous, friable, and hyperemic during this period. The peritoneal cavity may be completely obliterated by granulation tissue. Any attempt at dissection would usually lead to undesired enterotomies and excessive blood loss. This inflammation takes many weeks and months to subside. With a reduction of inflammation, the abdomen becomes soft and any residual induration is usually limited to the perifistula region. Mesothelium regeneration over time leads to the formation of neoperitoneum. The fistulizing bowel that was initially fixed with granulation tissue may now prolapse like an ostomy [14, 15].

This waiting period also allows the significant contraction of granulation tissue and scarring resulting in a much smaller exposed area. If a skin graft has been applied over exposed viscera in an open abdomen, a pinch test serves as a useful guide to whether it is mature enough to allow safe dissection away from underlying bowel. The "pinch test" involves pinching the skin graft between the index finger and thumb to see if it can be lifted separately from the underlying bowel [16]. It may take months or even up to a year to achieve this, but waiting longer may prove to be counterproductive as it has been suggested that waiting longer than 12 months may result in retraction of rectus muscles laterally, leading to loss of domain and increased recurrence after attempted repair [8].

Evidence for Enterocutaneous Fistula Repair Timing

Timing of repair of enterocutaneous fistulas remains controversial and there is no Level 1 data available. An operative repair plan and timing needs to be individualized for every patient and every condition. If the index operation was performed more than 2 weeks prior, the most advantageous timing is to wait for 3 months to allow inflammation to settle down before attempting any major repair. Operating within 2 weeks or after 3 months has been shown to be associated with lower fistula recurrence rate compared to if surgery is performed between 2 and 12 weeks [17]. The only indication for surgery during this period would be complete SBO, bowel gangrene, peritonitis, or bleeding. Even under these circumstances, it should be limited to proximal defunctioning stoma formation and control of sepsis. This period should be used for improving nutritional status of patient, as it would have significant effect on morbidity/mortality associated with repair. Improved nutrition would also allow a significant percentage of fistulas to undergo spontaneous closure, simplifying subsequent abdominal wall defect repair surgery.

Once inflammation has attenuated, sepsis is controlled, nutritional status is optimized, and anatomy of the fistula is defined, operative repair should be attempted by an experienced surgeon. It has been suggested that these patients are managed better in specialized units, a suggestion with which we fully agree [18]. Specialized units with well-established protocols for stepwise staged management are much better equipped to handle care of these sick patients. Communication with patients and family is very important, as they need to understand each step with regard to goals and expectations.

We do not recommend waiting too long for repair beyond 3 months and surgery should be undertaken if conditions are favorable. Lynch et al. did argue for delaying surgery beyond 12 months to improve outcomes in patients with ECF [17]. However, Brenner et al. documented a five times increased risk of recurrence if operative repair was delayed beyond 36 weeks [19]. Owen et al. published similar results that showed that delaying surgery for longer than 1 year doubled the risk of postoperative refistulization [20]. Waiting too long also increases the risk of complications such as central line associated blood stream infections in patients on parenteral nutrition. Visschers et al. have recommended titrating the timing of restorative surgery to day-to-day patient characteristics after an initial waiting period of at least 6 weeks, but in their subsequent analysis, prolongation of the period of convalescence to a median of 101 days from 53 days was associated with an increased rate of spontaneous closure and a reduced recurrence rate after surgery [2, 4]. Rahbour et al. showed improved healing rates after surgery from 94.6 to 82% after increase in waiting time period to 12 months from 8 months previously [21]. Gupta et al. reported good results in their series when early interventions were carried out for ECF within 3 weeks of recognition. This may be a better strategy in resource poor settings where TPN may not be affordable for the long term, and delay in surgery can only worsen patient health status [22].

Abdominal Wall Defect Repair Timing

The importance of achieving closure of the abdominal wall over an anastomosis, after resection of ECF, to minimize risk of anastomotic leak and ECF recurrence cannot be overemphasized. Abdominal wall defects are commonly too large to achieve primary closure once fistula-containing bowel has been resected. This is more common with EAFs in the setting of open abdomen. Techniques such as component separation or other tissue transfer techniques are usually needed to achieve adequate fascial mobilization. The presence of ECF by definition makes it a contaminated field during surgery. Placement of prosthetic mesh is not recommended, as it would lead to increased incidence of infection and refistulization [23]. To avoid this outcome, multi-stage repair has been suggested [8, 24, 25]. Multi-stage repair involves initial surgery to control infection and planned ventral hernia. Definitive repair of the hernia defect is attempted 6–12 months later when conditions are more favorable. Disadvantages of this approach include multiple operations with associated risks, increased cumulative hospital stays, and a longer convalescence period. Furthermore, longer waiting periods result in retraction of lateral abdominal wall musculature, which makes definitive repair more complicated.

We recommend single stage repair of abdominal wall defects during ECF takedown. One stage repair provides direct physiologic protection of the anastomosis by the abdominal wall and avoids multiple surgeries. There are concerns over doing abdominal wall reconstruction in a contaminated environment especially when mesh is used, but suture repair alone is inferior to mesh repair for midline incisional hernias and carries recurrence rates almost double that of mesh repair [26]. However, with the advent of component separation and biologic mesh, single stage repair has gained acceptance. Proponents against the use of mesh advocate for component separation alone. Wind et al. evaluated the results of closure of enterocutaneous fistulas and/or stomas with simultaneous abdominal wall repair using the components separation technique [27]. In their study of 32 patients, 15 of the cases were ECFs. Four patients (27%) developed recurrent fistula. Out of 28 patients with long-term follow-up, seven developed recurrent hernias. Four of these hernia recurrences were small and did not need further surgery. The median follow-up was only 20 months and a higher rate of hernia recurrence would be expected in long term. This series demonstrated the feasibility of single stage repair with acceptable results in almost 70% of patients.

Biologic mesh use has gained popularity over the last decade for use in contaminated field. Biologic meshes are proposed to offer a collagen framework to allow for fibroblast popularization and neovascularization [28]. This may lead to a potential advantage over prosthetic mesh in a contaminated field. Rosen et al. in their series of 129 patients have shown that biologic mesh use for hernia repair is safe in contaminated field [29]. Although 47.7% of patients suffered wound complications, there were no long-term wound problems, and all wound issues resolved by 60 days. Concerns were, however, raised for increased hernia recurrence rate in long term. Connelly et al. in their study of single stage repair of ECFs with abdominal wall defect raised concerns with increased incidence of fistula recurrence (5 out of 12 cases), when biologic mesh (Permacol) was used [18]. Krpata et al. have suggested that these results may be accounted by intraperitoneal placement of biologic mesh [30]. In their study of 37 patients, 36 of these patients had biologic mesh placed during surgery. Although not statistically significant ($P = 0.11$), there were 4 fistula recurrences that were associated with intraperitoneal biologic mesh placement (15 cases), whereas only one was associated with retrorectus-preperitoneal mesh placement (19 cases). Exclusion of mesh from fresh anastomosis and abdominal contamination by retrorectus placement may explain lower fistula recurrence rates. Another study by Rosen et al. showed three times higher hernia recurrence rate in intraperitoneal versus retrorectus placement of biologic mesh in contaminated field [31]. Findings from these two studies definitely support potential advantages of retrorectus placement of mesh in these complex cases.

Slater et al. reported their study of 39 patients with single stage repair of enteric fistulas in the presence of an abdominal wall defect [32]. They used a strategy of component separation technique and on demand use of lightweight polypropylene mesh (13 of 39 patients). Almost 50% had wound complications and there were two ECF recurrences, which closed with nonoperative treatment. Twelve of 33 patients on long-term follow-up developed recurrent hernia (mean follow-up 62.7 months). Only six of these needed surgery, as the remaining were small and could be managed with conservative treatment alone. Use of mesh was not associated with higher complication rates.

Almost all of these studies with single stage repair of ECF with abdominal wall defect have reported a high morbidity rate of more than 50%. This reinforces our recommendation that such surgeries should only be attempted at centers with expertise and high volume. Although the wound morbidity rate is high, most of these are resolved in the short term and do not require mesh explantation if biologic mesh is used. The majority of patients can expect to have satisfactory outcome after single stage surgery. Use of lightweight synthetic mesh needs further evaluation before we can recommend its use in hernia repair with ECF.

Summary

Surgery for ECF/EAF and complex abdominal wall defects is complex and challenging, should be multidisciplinary and performed by surgeons with particular interest and expertise, preferably in specialized surgical units. Additionally, we recommend a timeframe of waiting for 3 months to allow inflammation from original surgery to settle down before attempting any major repair or operating within 2 weeks. Operating within 2 weeks or after 3 months has been shown to be associated with lower fistula recurrence rate compared to if surgery is performed between 2 and 12 weeks. Early identification of a fistula is the most important first step in management of these patients. Finally, where possible, enteral feeding should be provided and efforts should be made to start it early.

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10 Practical Approach to Patient with a Hostile Abdomen: Clinical Scenarios

Gary Lombardo, Rifat Latifi, and Ari Leppaniemi

Introduction

While an agreed upon definition of the hostile abdomen probably doesn't exist, most of us surgeons have seen one and probably will see it again. Interchangeable terms such as "hostile," "frozen," "inaccessible," and "difficult" are descriptive and accurate ways to characterize the pathology (Fig. 10.1a, b). The hostile abdomen is an abdomen that we as surgeons cannot enter freely, often associated with large abdominal wall defects [1]. Often, patients with a hostile abdomen have lost the abdominal wall domain as a consequence of multiple operations and previous open abdomen management [2] (Fig. 10.2a, b). Dense and fibrotic adhesions are the lattice to which the bowel and intra-abdominal organs are bound providing a landscape some have described as a "frozen lake." Adding insult to injury, the most complex hostile abdomens are associated with enterocutaneous fistulas (ECFs), enteroatmospheric fistulas (EAFs), or stomas (Fig. 10.3a–c). Given its daunting nature, reconstruction of a hostile abdomen is technically challenging and requires extensive preparation by both the surgeon and the patient.

Key Questions

When approaching a patient with a hostile abdomen, the surgeon must consider several factors. Some questions lead to additional questions and most answers are unfortunately multifactorial thus leading to the apprehension even the most skilled surgeon experiences [3]. Technical considerations, dealt with throughout this book, must be scrutinized. What surgical technique(s) should be employed in approaching and repairing massive abdominal defects? What type of mesh should be utilized? How should the mesh be placed and secured? Few would argue with the concept that the best offense is a strong defense, encompassing preoperative objective markers of physiologic as well as nutritional optimization, but this is only a small portion of the issue at hand. Paramount to the discussion involves the issue of timing. The timing of intervention is not as simple as asking, "How long should we wait until we think it is the optimal time to operate"? One must take into account management of previous or concurrent sepsis, control of pre-existing medical illness, as well as prepare for the probability of operating in a contaminated field, as described in other chapters throughout this book.

Multiple factors influence the answers to these important questions. Special attention must be paid to the patient's anatomy, physiology, and religious beliefs. Additionally, of particular importance but seldomly discussed in the literature, is the overall coping capacity of the patient and the surgeon, and expectation from the surgery.

Preoperative Conditions

Abdominal reconstructive procedures in the patient with a hostile abdomen should not be contemplated prior to the patient's condition is optimized. For the purposes of this chapter, we assume that patients have overcome the acute phase of their injury/illness and have entered a convalescent phase. In the ideal circumstance, which rarely exists, physiologic and nutritional optimization will have been achieved and well documented. The technical approach and required intervention required will be tailored to each patient individually and definitive management should be postponed pending correction of acute issues as they develop [4, 5]. Additionally, one should not overlook or

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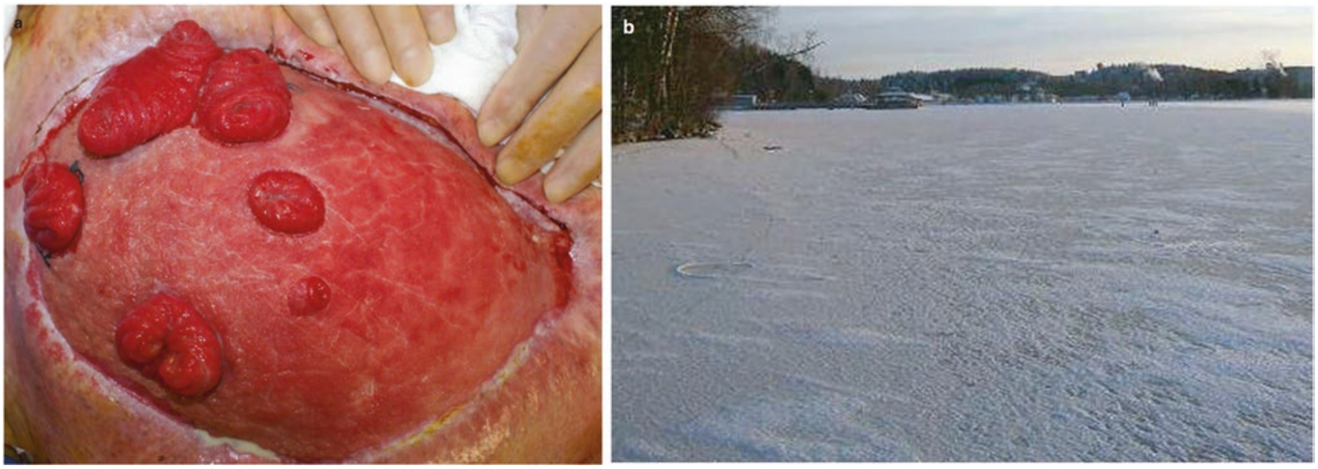

Fig. 10.1 “Frozen” abdomen with multiple fistulas following open abdomen managed by a wound VAC

Fig. 10.2 Twenty-four-year-old gentleman, status post high-velocity gunshot wound, following multiple operations and multiple enteroatmospheric fistulas managed as a single large stoma of the abdomen

underestimate the importance of the patient’s psychological state prior to any contemplated surgical intervention. Patients with a hostile abdomen have frequently undergone numerous operative procedures—some successful, others failed. Most have had multiple extended hospital stays, many with prolonged ICU care. Many patients have complex emotional, psychological, social, and financial needs. Anxiety, depression, and chronic narcotic dependence are common and should be addressed with a multidisciplinary approach preoperatively [5]. Furthermore, the patient must have reasonable expectations for the desired outcome. In addition to the “informed consent” discussion focusing on the risk/benefit and possible complications, a preoperative conversation that focuses on likelihood of attaining the desired outcome as well as a clear understanding of all possible outcomes and their implications, both positive and negative, must be entertained.

Three scenarios are presented below, each a short case report describing patients with a hostile abdomen.

Scenario 1

A 41-year-old man has survived intra-abdominal sepsis after a catastrophic traumatic event that led to right hip disarticulation and open abdomen management. His abdomen would best be described as hostile with a significant loss of anterior abdominal wall domain noted with a previous skin graft littered with multiple stomas and fistulas that drain a moderate amount of succus entericus. Management to date has focused mainly on collection and diversion of the fistula output via individually tailored stoma bags (Fig. 10.2a). Although sepsis has been controlled recently and his electrolyte and fluid levels have been normalized, he has dealt with multiple

Fig. 10.3 Intra-operative view from the same patient as in Fig. 10.2. As can be seen, he lost a significant mass of abdominal wall and has a fibrotic, cement-like abdomen (**a**). (**b**) Multiple enteroatmospheric fistulas are identified. (**c**) Intra-operative view at the end of establishment of GI continuity but before abdominal wall reconstruction

nutritional deficiencies of trace elements, proteins, and fatty acids and with multiple bouts of line sepsis. He remains total parenteral nutrition (TPN) dependent and is unable to eat other than for comfort as his multiple fistulas render him functionally with a short-gut syndrome. He resides in an extended care facility and has been out of work for almost a year and wishes to be "put together."

Scenario 2

A 45-year-old morbidly obese woman has a large abdominal wall defect after open abdomen management for trauma. The defect measures 30 cm by 20 cm in greatest dimensions and is noted to consist of a well-healed skin graft loosely veiling her abdominal viscera. She flinches at the sight of her peristalsing bowel and stated she has had recurring episodes of severe depression as she can no longer work or exercise and has "no social life" due to lack of self-confidence. The patient is currently under the care of a psychiatrist and on multiple antidepressant medications as well as chronic opioids. The patient reiterates she sees little hope for a "normal life" unless she was to undergo abdominal reconstruction.

Scenario 3

A 58-year-old man has a colostomy for 6 months after catastrophic intra-abdominal sepsis. His previous surgeon attempted to reverse the colostomy originally created to manage complicated diverticulitis but his postoperative period was complicated by an anastomotic leak with intra-abdominal sepsis. Management included multiple abdominal washouts, open abdomen management with fecal diversion via end colostomy. The surgeon was unable to close the patient's fascia primarily but was able to re-approximate skin over a vicryl mesh. The patient is noted with a large abdominal incisional hernia with a left lower quadrant colostomy. The patient states he cannot work do to recurrent abdominal pain at the hernia site and states he has increasing marital problems due to his displeasure with his physical appearance and concern for malodor. The patient is requesting hernia repair with simultaneous colostomy reversal.

Creating a Surgical Plan

Most surgeons who deal with complex abdominal defects have seen patients similar to the scenarios previously presented. Most fistulas, especially high-output fistulas, will require surgical treatment. Often the patient will have nutritional deficiencies and require treatment similar to a patient with short-gut syndrome [6]. These patients require continuous meticulous attention, both as inpatient and as outpatient, to avoid sepsis (such as catheter-related sepsis in patients on TPN), electrolyte and fluid disturbances, and malnutrition [7–16].

The timing of surgery for ECF is controversial and will be addressed separately on Chaps. 7 and 9; but, for the most part, it depends on the timing of diagnosis, anatomy, and clinical presentation. Other factors affect the decision to operate on patients with enterocutaneous fistulas and complex abdominal wall defects and include etiology of ECFs; early identification of ECFs; achievement of sepsis control; nutritional status; anatomy of ECF; status of local wound; and associated comorbidities and their resolution.

The three scenarios differ clinically but share a commonality; they have survived a hard fought battle to reach their current place in their journey through life and desire an additional chance to regain their perception of normalcy. Under these circumstances, it is understood how an individual could "forget" the bad times and wish to "move on." Thus, most of them do not focus on the weeks or months in the surgical intensive care unit (ICU); the multiple trips to the operating room, and painful dressing changes. They do not focus on the loss of dignity and autonomy but rather focus on the definitive procedure to be "fixed." However, the decision to operate is not an easy one. Surgical reconstruction of the hostile abdomen is a technically demanding procedure associated with considerable morbidity. Studies from specialized centers have reported surgical site infection in more than 30% of cases, mortality up to 5%, and fistula and hernia recurrence of 11% and 29%, respectively [17]. It is essential that prior to surgical intervention that the patient has physically and psychologically recovered from the period of the acute illness [18]. Patients should be free of sepsis, adequately nourished, and the abdomen should be soft and supple. Additionally, a significant period of time from the previous operation must have elapsed to allow neoperitonealization of the previously obliterated peritoneal cavity. This may take more than 6 months and prior to this time, a solid block of granulation tissue covers the viscera rendering them indistinguishable from one another [19].

With few exceptions, there are no published reports or definitive recommendations with regard to optimal timing of intervention. Additionally, no predictive index or score delineating success/failure exists and no strategy has been tested in large-scale, randomized clinical trials. In general, the adage that it is "impossible to undertake reconstructive surgery for an enterocutaneous fistula too late; only too early" holds true [15].

Providing Patient-Centered Care: Involving the Patient

While most surgeons agree, delaying surgical intervention on the hostile abdomen for as long as possible and perhaps indefinitely is the safest course of action for the patient, the deleterious impact of the open abdomen on the quality of life of both the patient and the family must be considered. It has been well described that early intervention prior to neoperitonealization increases the risk of inadvertent enterotomy. Studies have reported enterotomy may complicate more than 50% of cases in which 4 or more previous laparotomies were performed and has been predictive of postoperative intensive care unit admission, urgent reoperation, and acute intestinal failure [20, 21]. On the contrary, excessive delay in definitive repair will result in loss of abdominal domain subsequently increasing the difficulty of the abdominal wall reconstruction as well as a higher rate of incisional hernia occurrence [22, 23].

The limited available evidence suggests that when sepsis is controlled, nutritional status is optimized, and anatomy is defined, the surgeon may decide to operate on the hostile abdomen attempting to resect fistulas, reverse ostomies, and reconstruct the abdominal wall [24]. Additionally, the incorporation of a multidisciplinary team including expert nutritional and psychological support provides a strong foundation prior to the monumental task of entering the hostile abdomen. In all cases, employing a strategy that promotes open communication between the patient, family, and the team delineating the possible outcomes and complications as well as expectations of the team and the patient/family is the best approach.

In our practice, we explain to each patient and family, with the utmost clarity, that three main outcomes are possible with surgery:

1. We will complete the task, that is, perform lyses of adhesions, take down stomas or fistulas, restore the continuity of the GI tract, and reconstruct the abdominal wall, and then oversee a postoperative course that leads to recovery, without major incident.
2. We may not be able to accomplish any of the intended goals as specified in outcome 1 and in fact make the patient worse.
3. We may successfully complete the initial operation, but the fistulas may recur, the anastomoses may leak, and a serious wound infection may develop that requires reoperation and possible mesh explantation essentially returning to square one, or even worse, the complications may prove fatal.

These outcomes are reviewed, not only with the patient but also with the family, friends as well as the preoperative, operative, and postoperative teams. Proper mental preparation is essential for the surgeon and surgical team as well as for the patient, family, and friends.

Timing of the Operation

Regarding the timing of the operation, there are two camps of surgeons: those who wait until things are "settled down" and those who choose to operate early. Postoperative complications have unique features as described earlier depending on if an early or late approach is under taken. Common complications to both approaches include anastomotic breakdown, recurrence of fistula, and incisional hernia. The essential question of when to "attack" the hostile abdomen has been debated for years. Some authors have suggested waiting 4–5 weeks before operating, just long enough to make sure that patients are nutritionally sound and sepsis is controlled. Most surgeons, however, wait 3–6 months; others wait 12 months or more [7–15]. In our practice, we choose to operate early (but not within the first 2–3 months if possible); what defines "early" has not been defined clearly in the literature. Rather, the decision is clinical, based on the individual patient. The ability to pinch up the skin that has been grafted or that has grown over the previously exposed bowel serves as a good marker for the presence of suitable local conditions for reconstructive abdominal surgery [22].

Preparing for the Operation

Before planning reconstruction of the hostile abdomen, all available previous operative reports should be obtained and reviewed. Equally as important, the anatomy of the gastrointestinal tract should be as clearly delineated as possible. Using a combination of contrast imaging including barium enema, fistulography, and contrast enhanced cross sectional imaging, the sections of the gastrointestinal tract involved with, but also proximal and distal to the fistula sites must be defined and structuring identified. Further imaging involving the biliary as well as the urinary tract may also be necessary in certain circumstances. In preparation for the operation, key laboratory and clinical issues must be addressed; the patients' blood sugar levels must be controlled, strict smoking cessation observed, and the bioburden of the wound controlled through wound vacuum-assisted closure (VAC) or through other stoma protection techniques. Hypovolemia and chronic anemia must be corrected and the biochemical profile (including trace elements, vitamins, and essential fatty acids) repleted. During the preoperative weeks, we ensure that the patient is receiving targeted nutritional therapy, wound care, and physical therapy.

Entering the "Frozen Lake"

In patients with a hostile abdomen, the open surgical approach is standard. While local extraperitoneal approaches utilizing focused wedge resections and buttressed repairs of fistulas have been described, the results are generally poor with failure rates reported as high as 50% and a 3-fold higher rate of refistulation than a formal laparotomy with fistula resection [25–27]. Formal exploration of the abdomen allows resection of the fistula with concomitant attention to both underlying intestinal disorders discovered by preoperative imaging and the abdominal wall defect that usually accompanies the hostile abdomen. Whenever possible, the surgeon should avoid entering the abdomen initially through the same incision used in prior operations. Instead, attempts should be made to enter the abdomen from non-violated areas of the abdominal wall, superiorly or inferiorly to the previous defect (Fig. 10.3a–c). The abdominal wall is retracted vertically allowing dissection of the adherent viscera utilizing a combination of sharp and blunt dissection. Often, only millimeters of tissue are able to be dissected with each surgical move. Proceeding where dissection is easiest as opposed to proceeding systematically quadrant by quadrant will minimize iatrogenic injuries to the bowel, blood vessels, liver, splenic capsule, and other organs and structures. It is paramount to handle the tissue gently and with the utmost care. Each procedure will be unique and the surgical team will employ creativity and a combination of different techniques and repairs depending on what is encountered with each step of the case. The utmost care must be taken to avoid injury to the underlying bowel; the consequences of inadvertent enterotomies are not trivial [20]. If an enterotomy is recognized, it should either be repaired at once or be marked with a silk suture for later identification. With meticulous attention to detail, refistulation rates of 10% can be obtained [17].

Mobilizing the Entire GI Tract

As discussed in more detail elsewhere in this book, most authors agree that the entire GI tract must be mobilized and identified from the gastroesophageal (GE) junction to the rectosigmoid junction. Once entry into the neoperitoneal cavity is obtained as described above, a meticulous and painstaking dissection of the small and large bowel is performed. All adhesions must be taken down using sharp or blunt dissection. Surgical discipline must be executed, as most bowel injuries occur during excessive traction [5]. It is for this reason most authors recommend knife dissection. The intestines, especially as they become swollen (e.g., from intra-operative fluids), are prone to injuries, so they must be handled gently. Furthermore, intestines that have not been used for a long period are thinner; they are easy to penetrate or avulse, even with gentle finger dissection. The segment of bowel containing the fistula is then resected and the proximal and distal segments of bowel are tagged with suture material for identification for later reconstruction.

How Much of the Intestines to Resect and How to Create the Anastomoses

Two important intra-operative decisions concern the length of intestine that should be resected and the number of anastomoses that can be safely performed. Questions abound: Should a large segment of bowel be resected encompassing multiple fistulas but avoiding multiple resections and therefore multiple anastomoses, potentially resulting in a short-gut syndrome? Or should each fistula be separately resected attempting to preserve bowel length thus requiring more than one anastomosis exposing the patient to the risk of a leak and possible recurrence of a fistula? These are difficult questions and must be decided on a case by case basis balancing the risk and benefits of each procedure. These principles are more important than the actual technique utilized in creating the anastomosis; side to side, end to end, stapled, or hand sewn. An additional factor that must be evaluated intra-operatively intimately inherent to the question of resection and subsequent anastomosis involves the character of the distal bowel and if a staged procedure must be performed. The bowel distal to the fistula may be atrophied and the resulting disparity in bowel caliber may make anastomosis tenuous. A proximal de-functioning loop jejunostomy or gastrostomy may be invaluable which can be subsequently closed after downstream anastomotic healing has been confirmed.

Definitive Reconstruction of Temporary Closure of the Abdomen

The goal of abdominal wall reconstruction after restoration of the gastrointestinal tract is to provide effective cover of the viscera with healthy, mechanically strong material that closely replicates the dynamic properties of the abdominal wall [5]. Like most current surgeons, we have departed from a "leave-them-open" to a "sew-it-up" strategy as we do not favor leaving these patients postoperatively with an open abdomen and perform a single staged reconstruction of the abdominal wall. Closing the abdomen as soon as technically and physiologically possible is becoming the new standard [28]. At times, there will be a remaining abdominal wall defect requiring coverage with a skin graft (Fig. 10.4). The postoperative care of these patients is complex, requires a multidisciplinary approach, and is detail oriented, and must be vigilantly overseen by the operative team at all times.

Fig. 10.4 Same patient as in Fig. 10.3a–c 6 months postoperatively following reconstruction

Summary

Approach to the patient with a hostile abdomen needs to be planned and carefully executed, as it often involves a violated and altered anatomy and physiology. The potential for significant complications both intra-operatively and post-operatively abound. A close partnership with the patient and his/her family are a pre-requisite. Timing of the operation and preparation for the operation are also key elements of this multidisciplinary approach. Although each case must be individualized, the principles of optimal nutrition support, surgical discipline and aggressive preoperative support exist for every patient. Utmost surgical discipline and creativity often will play a major role on the patient's outcome. As there is a lack of literature on the timing of surgical intervention of the hostile abdomen, surgeons are required to individualize the care of each patient and their surgical approach.

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11 Staged Reconstructions of Abdominal Wall Defects

Ari Leppaniemi

Introduction

Staged abdominal wall reconstruction or planned ventral hernia is a management strategy of an open abdomen in which the fascial layer has been left unclosed and the viscera are covered with original or grafted skin. Most commonly, it is a result of prophylactic or therapeutic open abdomen that cannot or should not undergo primary fascial closure. Severe acute pancreatitis, damage control surgery for massive abdominal trauma, and surgery for ruptured abdominal aortic aneurysm are associated with primary abdominal compartment syndrome leading to an open abdomen. Loss of abdominal wall substance because of tumor excision or necrotizing infection and the removal of an infected mesh can also result in a situation requiring a planned hernia strategy. Under these circumstances, the hernia is a favorable outcome with the aim of repairing the hernia at a later stage when it is safe, possible, and tolerated by the patient.

Three Stages of Reconstruction

Stage 1: Temporary Abdominal Closure

Over the years, the methods for temporary abdominal closure (TAC) (stage 1 of reconstruction) have evolved through several stages [1]. The first-generation TAC consisted mainly of abdominal coverage, either by skin-only closure (with running suture or towel clips) or a synthetic cover, such as a plastic silo (Bolsa de Borraez, Bogota bag), mesh, or a Velcro burr. The second-generation TAC methods introduced the concept of fluid control (e.g., the vacuum pack). Third generation TAC methods are mainly commercially manufactured negative-pressure therapy sets such as the VAC™ Abdominal Dressing (Kinetic Concepts, San Antonio, TX) or ABThera™ (Kinetic Concepts). Recently, the combined use of a temporary mesh and the negative-pressure dressing has resulted in delayed primary fascial closure rates of about 90% [2] (Fig. 11.1).

Stage 2: The Maturation Period

If the TAC techniques do not achieve fascial approximation at the midline within a reasonable time frame (stage 2, the maturation period), a more sustainable cover of the abdominal viscera is needed. If there is enough viable skin to be closed without too much tension, this skin-only technique is an acceptable and preferred method as long as there is no risk for further loss of abdominal skin. If the patient's original skin does not allow skin-only closure, a split-thickness skin graft provides a readily available, cheap, foreign-body-free, and infection-resistant coverage that closes the "catabolic drain" of the open abdomen and protects the viscera from erosion (Fig. 11.2). A skin graft can be applied over exposed bowel at a relatively early stage without having to wait for mature granulation tissue to appear.

Stage 3: Definitive Abdominal Wall Reconstruction

Based on the type of skin coverage used for staged repair of an open abdomen, the abdominal wall defect can be reconstructed with several different methods in stage 3. To achieve the best functional result, the rectus muscles should be brought together in the midline using component separation or other local tissue transfer technique if possible. In patients with intact original skin, the hernia can be repaired with a mesh. However, in patients with large skin-grafted defects in the midline or extensive hernias reaching the epigastrium or

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Fig. 11.1 Vacuum and mesh-mediated fascial traction closure method of open abdomen

Fig. 11.2 Matured skin graft closure

in the presence of contamination or infected mesh, the tissue transfer or mesh-based techniques might not be possible or appropriate, and a more complex reconstruction technique is required.

Vascularized flaps provide healthy autologous tissue coverage and usually do not require any implantation of foreign material at the closure site. Small and midsize defects can be repaired with pedicled flaps within the arch of the rotation of the flap. In extensive upper midline abdominal wall and thoracoabdominal defects, a free flap that offers a completely autologous, single-stage reconstructive solution is in most cases the best option available.

Tensor Fascia Latae Flap for Abdominal Wall Reconstruction

The tensor fascia latae (TFL) myocutaneous free flap was first described by Hill and coworkers in 1978 [3]. Besides reconstructing large abdominal wall defects, it can also be used for reconstruction of complex head and neck, composite extremity, and perineal defects [4–16]. To date, the microvascular TFL flaps, sometimes in combination with the anterolateral thigh flap, have been used in more than 90 patients with abdominal wall defects [3–17].

The deep inferior epigastric vessels are the most commonly used recipient vessels for the TFL flap, but utilizing intraperitoneal vessels, such as the gastroepiploic vessels, allows the use of flaps with shorter pedicles and tight, continuous, circumferential fascial closure between the flap and native abdominal wall [11]. In contrast to the anterolateral thigh flap, however, the anatomy of the TFL pedicle is constant, and it offers large-caliber vessels matching the vessel size of the great saphenous vein loop. Furthermore, the size of the flap can be large (up to 20 × 35 cm). However, in extremely wide flaps, the relative thinness of the anteromedial portion of the fascia, especially in women, sometimes requires mesh enforcement [17].

Functionally, the TFL flap is passive, resembling a mesh. A functional dynamic reconstruction of full-thickness abdominal wall defect with an innervated free latissimus dorsi musculocutaneous flap has been described by Ninkovic and coworkers [18].

The technique used at our institution is now described [19]. A musculofasciocutaneous flap with a skin component measuring 30–35 × 15–20 cm and underlying fascia as well as the TFL muscle is harvested from the thigh, and its pedicle is dissected free toward the deep femoral artery and vein. In patients with large defects, the rectus femoris muscle can be included in the flap to ensure adequate perfusion of the distal tip. The ipsilateral great saphenous vein is divided distally above the knee, and its distal end is reflected proximally and anastomosed end to side to the common femoral artery, creating an arteriovenous loop (Fig. 11.3). The loop is tunneled subcutaneously to the edge of the defect and divided at its apex. Arterial and venous anastomoses with the flap vessels are performed with continuous 7-0 or 8-0 vascular sutures. The flap fascial edges are sutured to the fascial edges of the original defect, carefully avoiding any obstruction or kinking

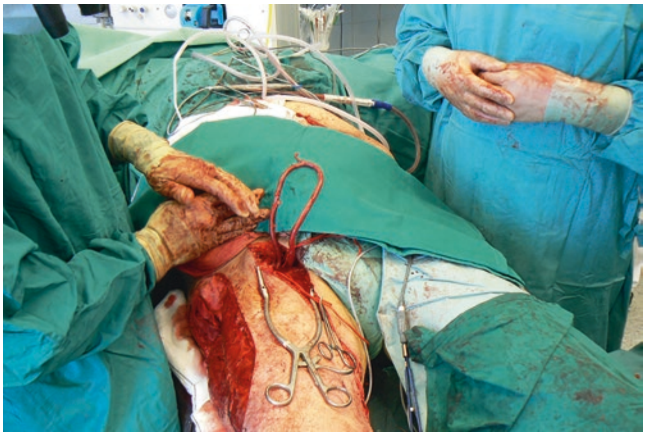

Fig. 11.3 Free tensor fascia latae flap with arteriovenous (AV) loop

of the flap vessels. Drains are placed subcutaneously, and the subcutaneous space and skin are closed with interrupted sutures or staples. The donor site is closed directly as far as possible, and the remaining defect is covered with a split-thickness skin graft. Postoperatively, the viability of the flap is monitored clinically for flap color, temperature, and capillary refill. In addition, the intra-abdominal pressure is measured at regular intervals.

Since 1990, 20 patients with large abdominal wall defects have been operated on with TFL flap in our institution [17]. The perioperative mortality was zero, and there were no intra-abdominal or deep surgical site infections. There was one flap failure, and two patients had minor distal tip necrosis requiring only revision and primary skin closure. During a follow-up period of 0.5–13 years, there was only one hernia recurrence 3 months after the TFL repair. Because of a large defect or if the fascial component of the TFL flap was found to be thin, an additional component separation procedure was used in one patient, mesh enforcement in nine patients, and a combination of both techniques in one patient.

Selection of the Appropriate Reconstruction Method

Abdominal wall defects may be categorized as type I and II defects depending on the type of skin coverage over the defect. In type I defects, there is intact or stable skin coverage, whereas type II defects have absent or unstable skin coverage [19]. Even relatively large type I defects can usually be repaired with component separation or mesh repair alone.

The most important aspect of reconstructing a functional abdominal wall is the re-creation of the linea alba and achieving midline closure, allowing the abdominal wall to be encompassed by functional muscular components in a manner similar to normal anatomy [20]. In contrast to inert material, the abdominal musculature provides dynamic support of innervated tissue to redistribute the stress applied from intra-abdominal forces. In that respect, the component separation technique is preferred over a mesh repair.

Table 11.1 Management options in abdominal wall defects

	Primary procedure	Additional (+) or optional procedures
Small or midsize hernia, intact skin		
No contamination	CS	M
Contamination	CS	Mb
Small or midsize hernia, grafted skin		
No contamination	CS	+M or flap
Contamination	CS	+Mb or flap
Large hernia, intact skin		
No contamination	CS	+Flap or M
Contamination	CS	+Flap or Mb
Large hernia, grafted skin		
No contamination	Flap	+CS + M
Contamination	Flap	+CS + Mb

CS component separation, *M* mesh repair, *Mb* biological mesh
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Fascial repair alone is inappropriate in abdominal wall defects with absent or unstable skin coverage (type II) because the repair needs to be covered with healthy skin, often requiring reconstruction techniques that are more complex. The criteria for special reconstruction techniques have been listed as a large-size (40-cm^2) defect, absence of stable skin coverage, recurrence of the defect after prior closure attempts, infected or exposed mesh, systemic compromise (intercurrent malignancy), local tissue compromise (irradiation, corticosteroid dependence), or concomitant visceral complications (enterocutaneous fistula) [19].

However, complex reconstruction techniques are rarely used and are required mainly in extensive or recurrent defects. In a series of 954 patients undergoing autologous tissue repair techniques of large abdominal wall defects, 94% of the patients underwent either local tissue repair (component separation, rectus sheath) or repair with autologous grafts (free fascial latae, autodermal graft). Pedicled or free vascularized flaps were used in only 59 patients, with 35 of these TFL flaps (pedicled in 15 and microvascular in 20 patients) [21].

Summary

The choice of the most appropriate late abdominal wall reconstruction method after planned hernia strategy is always an individualized process requiring a multispecialty approach and close collaboration with the plastic and abdominal surgeons. The guidelines used at our institution in selecting the appropriate reconstruction method are presented in Table 11.1 [22].

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Complex Abdominal Wall Reconstruction-Plastic Surgeon's Perspective

12

Donald P. Baumann and Charles E. Butler

Introduction

The goals of abdominal wall reconstruction are to re-establish the integrity of the musculofascial layer and provide stable external cutaneous coverage. Surgical planning for abdominal wall reconstruction must include the potential for loss of skin and musculofascial tissue. These tissue defects can be caused by tissue necrosis, infection, resection, incisional hernia with loss of domain, denervation of adjacent abdominal musculature, and/or scarred, retracted tissues that limit the ability to advance skin and fascia. Local wound conditions including bacterial contamination, previous surgeries, and previous radiotherapy can contribute to an increased risk of compromised wound healing, surgical site infection, and failure of the reconstruction. Patient factors such as advanced age, comorbidities, obesity, immunosuppression, poor nutritional status, tobacco use, and pulmonary disease also increase the risk of complications and thus must be considered in the perioperative planning and management [1–5]. Abdominal wall reconstructive procedures themselves can result in significant complications including mesh infection, seroma, dehiscence, recurrent hernia, abdominal compartment syndrome, and visceral injury. These may require complex reoperative surgeries, prolonged periods of wound care, and/or staged salvage procedures.

Direct suture repair of small ventral hernias can be performed with relatively low complication rates; however, hernia recurrences after direct suture repair are common, occurring in 10–60% of patients [3, 6]. When subsequent recurrent hernia repairs are performed, the recurrence rate increases each time, with progressively shorter intervals between repair and re-herniation [7]. The use of mesh reinforcement reduces hernia recurrence rates compared with primary suture repair alone [3, 8]. However, the addition of mesh does not prevent all recurrences. For example, in one long-term follow-up study, synthetic mesh reinforcement during elective repair of small (<6 cm), uncontaminated ventral hernias was associated with a 32% 10-year cumulative recurrence rate. On the other end of the spectrum, our group reported a 7.7% hernia recurrence rate in patients undergoing ventral hernia repair with inlay mesh and primary fascial closure after mean follow-up of 31 months [9]. Furthermore, despite advances in surgical technique and implantable mesh materials, other long-term outcomes of ventral hernia repair, including length of hospital stay and need for reoperation, have not significantly improved over time [2]. In addition, the incidences of surgical site occurrences, wound dehiscence, wound infection, seroma, and fascial separation in elective ventral hernia repair are higher than in other "clean" general surgery procedures [2, 3, 5]. In patients undergoing repairs of incisional hernias with previously documented wound infections, up to 41% will develop another wound infection, whereas only 12% of patients without a history of infection will develop a wound infection after hernia repair [2]. Clearly there are ongoing difficulties with hernia repair particularly wound complications and infection, and further improvements are needed.

Various meshes have been developed to improve results in hernia repair. Commonly used implantable meshes include macroporous (monofilament and double-filament polypropylene), microporous (extended polytetrafluoroethylene [ePTFE]), composite (anti-adhesive layer laminated to macroporous mesh), and bioprosthetic (decellularized, processed human, or animal tissue) meshes [10, 11]. Macroporous meshes have large pore sizes that allow for ingrowth of scar tissue. When placed in contact with abdominal viscera, macroporous meshes are associated with the formation of bowel adhesions, bowel obstructions, and enterocutaneous fistulae [12, 13]. Therefore, these materials should be avoided or used in combination with omental coverage or anti-adhesive barriers when placed in contact with bowel. Microporous

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meshes have a smaller pore size that does not allow for significant tissue ingrowth but may lead to encapsulation, periprosthetic fluid collection, and bacterial overgrowth. Therefore, microporous mesh has a lower affinity for visceral adhesions but may be more susceptible to infection. A wide variety of composite materials are now available that combine various qualities, such as having macroporous mesh on one side to promote tissue ingrowth and microporous mesh on the other to reduce the risk for adhesions to the mesh (polypropylene/ePTFE). In an attempt to take advantage of macroporous and anti-adhesive characteristics, anti-adhesive bilaminar mesh (such as Sepramesh [polypropylene/carboxymethylcellulose and hyaluronic acid, Bard, Inc., Murray Hill, NJ]) was developed to induce fibrovascular incorporation in the sublay plane and minimize visceral adhesions with the microporous component or bioresorbable component when placed intraabdominally. Clinical evidence suggests a reduced risk of adhesions for composite and coated synthetic meshes compared with traditional synthetic meshes [14–18]. The reported relative benefits of these different prostheses with regard to adhesion formation and risk for infection vary [12, 16, 19–22].

Bioprosthetic meshes are an equally diverse and expanding class of mesh materials. Certain characteristics are thought to contribute to the successful use of particular biologic repair materials in the setting of wound contamination or low-grade infection. These mesh properties include an intact extracellular matrix and the ability to support tissue regeneration through revascularization and cell repopulation. It has been hypothesized that resistance to infection for some biologic repair materials may be related to the ingrowth of cells and vasculature structures [23]. The neovascularization demonstrated in studies of some biologic repair materials may allow these materials to better resist infection when placed in a potentially contaminated field [23]. Data on the ability of some bioprosthetic meshes to support regeneration come from studies in animal models that describe the immunologic response of the host to the prostheses [24]. It should be emphasized that no prospective clinical trials have been completed to date directly comparing different bioprosthetic meshes in incisional hernia repair, and the few clinical data suggesting benefits of one product over another come from small retrospective studies of a limited number of the available bioprosthetic mesh materials. Our group compared porcine and bovine bioprosthetic meshes in 120 patients undergoing abdominal wall reconstruction and found no difference in hernia recurrence 2.9% vs. 3.9% or bulge 7.2% vs. 0% [25]. Data from animal and clinical studies are awaited for the majority of bioprosthetic mesh materials.

Current Indications for Utilization of Bioprosthetic Mesh

Indications for the use of bioprosthetic mesh are based mostly on animal data and short-term low level evidence from clinical studies and case reports. Based on our clinical experience and inferences from The Ventral Hernia Working Group we use the following indications: [24]

1. Contaminated wound (existing wound infection, adjacent ostomy, planned or inadvertent disruption of the gastrointestinal tract's continuity, enterocutaneous fistula).
2. Complex repair in a patient at high risk for the development of wound healing problems, subcutaneous infection, and/or need for reoperation.
3. Planned exposed bioprosthetic mesh or high likelihood of cutaneous exposure (open abdominal wound closure with a bridging repair or unreliable skin coverage in a patient with multiple comorbidities).
4. Unavoidable direct placement of mesh over bowel and other abdominal viscera.

Surgeon preference and the variables of any given clinical scenario, including patient comorbidities, wound contamination, prior radiation, availability of omentum, and/or posterior sheaths (retrorectus repair), and the quality of the overlying soft tissue, will determine whether bioprosthetic mesh or synthetic mesh is implanted. Regardless of mesh type, the expectations are that the mesh will maintain the abdominal wall contour and not become attenuated, leading to a hernia or bulge. In addition, the mesh should be able to interface with the underlying viscera without forming extensive adhesions that can lead to bowel obstruction or erosion that can lead to fistulization. Both synthetic and bioprosthetic meshes can meet these expectation and the decision to use either is based on patient comorbidities, wound characteristics, quality of the overlying soft tissue, and surgeon preference.

Abdominal wall defects require both reconstruction of the musculofascia and closure of the overlying skin. Musculofascial reconstruction is generally performed with component separation and/or implantable mesh. The use of component separation in complex abdominal wall repair has been described by many surgeons with numerous variations, including reinforcement with mesh [20, 26–27], and is now considered by many experienced hernia surgeons to be the standard of care [20, 28, 29]. Component separation provides an enhanced fascial closure technique and a dynamic repair of the abdominal wall without compromising motor innervation to the abdominal wall muscles.

Patient Selection

In elective hernia repair, patients should be "optimized" before surgery by improving controllable medical and surgical site comorbidities (see Chap. 8: Getting Ready: Preoperative Patient Optimization). Factors such as serum glucose levels and nutritional status should be brought under control, and tobacco use should be eliminated for at least 3 weeks before surgery to decrease perioperative morbidity [5, 30]. Compelling data from the National Surgical Quality Improvement Program highlight the risk of morbid obesity, which increases perioperative complications and deaths [31]. Obese patients undergoing elective hernia repairs should be screened by a nutritional counselor and enrolled in a diet and exercise program to reduce the risk of complications. Patients who are unable to lose weight on a personalized plan should be considered and evaluated for surgical laparoscopic bariatric procedures prior to elective hernia repair.

In non-elective or emergent abdominal wall reconstruction, contaminated wounds should be appropriately debrided and prepared to reduce the bacterial bioburden [32]. Severely contaminated wounds may require a staged approach consisting of serial debridement, dressing changes, negative pressure wound therapy, and delayed fascial closure with bioprosthetic mesh and/or component separation. Systemically ill patients with numerous comorbidities and contaminated fascial defects may benefit from early musculofascial reconstruction with bioprosthetic mesh. Early fascial closure preserves the musculofascial domain, improves ventilatory support, reduces fluid loss, reduces the risk of enterocutaneous fistula, and may reduce the acuity of subsequent wound management.

Abdominal Wall Reconstruction Principles

The general principles of abdominal wall reconstruction include optimization of the patient, preparation of the wound, centralization and reapproximation of the rectus abdominis muscles in the midline, and the use of appropriate synthetic or bioprosthetic material to reinforce the closure.

A key element of the inset of bioprosthetic mesh is to place the mesh in an inlay (intraperitoneal), preperitoneal, or retrorectus position under appropriate physiologic tension; this is in contradistinction to a tension-free repair. Mesh inset under physiologic tension facilitates and stimulates appropriate collagen remodeling to optimize mechanical strength and thus reduce the risk of bulge and laxity. The edges of the bioprosthetic mesh should overlap the undersurface of the musculofascial edge by at least 3–5 cm to allow for remodeling and fibrovascular incorporation. This method of bioprosthetic mesh inlay takes advantage of the mesh's remodeling mechanism, rather than simple scarring mechanisms, and increases the tensile strength of the junction between the mesh and the musculofascia [24, 33, 34].

The anatomic plane of the bioprosthetic mesh inlay has direct implications for the degree of incorporation at the mesh-musculofascia interface (Fig. 12.1). When possible, it is preferable to avoid insetting the bioprosthetic mesh in direct contact with the peritoneum or preperitoneal fat. To avoid this, the preperitoneal fat pad is dissected away from the posterior rectus sheath and the mesh is placed in direct continuity with the posterior sheath fascia. This improves the fibrovascular infiltration and mechanical strength at the mesh-musculofascia interface better than suturing the mesh

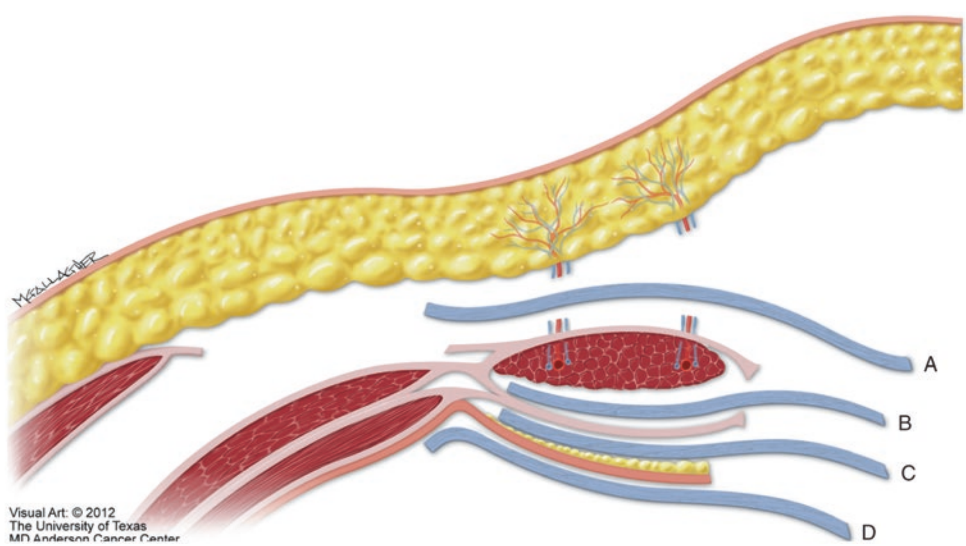

Fig. 12.1 Anatomic planes of mesh inset. (*A*) Onlay. (*B*) Retrorectus. (*C*) Preperitoneal. (*D*) Intraperitoneal. (Copyright © 2012 The University of Texas MD Anderson Cancer Center)

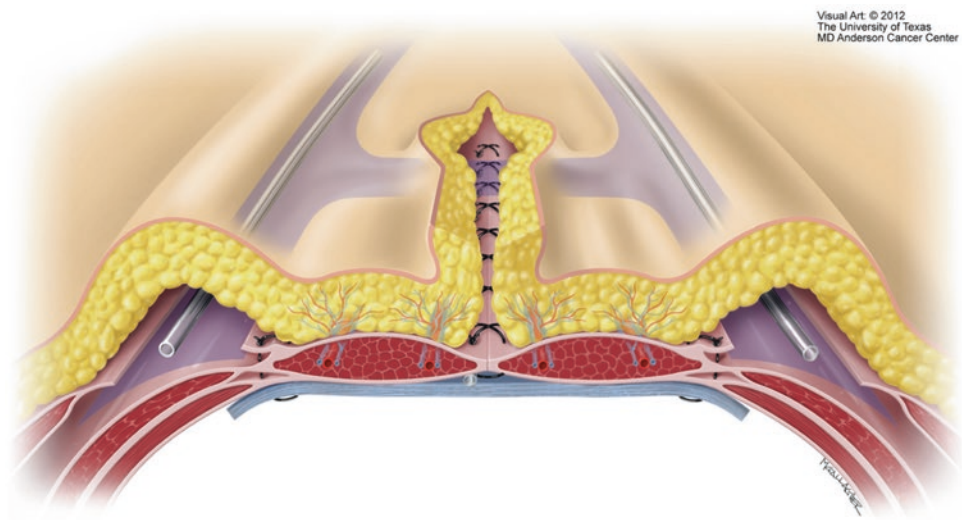

Fig. 12.2 Reinforced mesh repair with primary fascial closure and Minimally Invasive Component Separation. (Copyright © 2012 The University of Texas MD Anderson Cancer Center)

to the preperitoneal fat/transversalis fascial layer would. Alternatively, a retrorectus repair can be used, whereby, mesh can be sutured to the semilunar line between the rectus muscle and the posterior rectus sheath.

Onlay mesh placement is technically easier but has several significant drawbacks and is not often recommended. If a reinforced repair is going to be performed, one generally must be able to close the fascia first, which is not possible before mesh placement in many cases of large defects; the inset of the mesh as an inlay actually helps reduce the tension needed to close the fascial defect. Thus, an inlay mesh placement facilitates primary fascial closure, whereas an onlay mesh placement can be performed only after primary fascial closure is achieved. However, there may be some situations in which an onlay repair is the only safe option, such as when it is impractical to re-enter a hostile abdomen. Although onlay reinforcement avoids placement of mesh directly against intraperitoneal viscera, its positioning in the subcutaneous space may increase the risk of seroma formation and/or cutaneous mesh exposure if wound dehiscence occurs.

When technically feasible, a bioprosthetic mesh inlay repair should be reinforced with a second layer of primary fascial closure over the mesh (Fig. 12.2). This dual-layer repair is preferred to a bridging interposition repair. Centralization of the rectus abdominis muscle complexes reduces the fascial defect and facilitates primary fascial closure. Primary fascial coverage also allows for complete apposition of the bioprosthetic mesh and the overlying musculofascial defect edge. Every attempt should be made to re-approximate the fascia over the inlay mesh as this has a significant impact on outcomes. Our group evaluated the difference in hernia recurrence outcomes between patients reconstructed with primary fascial closure repairs versus those who required bridging repairs. There was a statistically significant higher incidence in hernia recurrence in patients undergoing bridged versus reinforced repairs, 55.6% vs. 7.7%, respectively [9]. Bridging the fascial defect with mesh was an independent predictive factor for hernia recurrence using logistic regression analysis. Bridging the fascial defect was more predictive for recurrence than fascial defect size itself. When primary fascial closure is not attainable, a bridging repair is performed (Fig. 12.3). This is done using a dual-circumferential inlay technique, which allows two concentric suture lines to affix the bioprosthetic mesh directly to the musculofascia [34–37]. Creating direct apposition of the bioprosthetic mesh and the undersurface of the fascial defect itself prevents the collection of fluid between the two layers, which could prevent or delay fibrovascular incorporation and remodeling. To prevent the collection of fluid at the mesh-musculofascia interface, closed-suction drains are placed between the musculofascia and the bioprosthetic mesh.

Combining bioprosthetic mesh inlay repair with component separation may improve abdominal wall reconstruction outcomes further. Component separation has the ability to medialize the rectus complexes and reduce the defect size with the ultimate goal of allowing primary fascial closure over the inlay bioprosthetic mesh and therefore a reinforced repair. Component separation also reduces the subsequent tension on the midline fascial incision closure and the mesh-musculofascia interface. Component separation involves releasing the external oblique aponeurosis and delaminating the external oblique muscle from the internal oblique muscle interface. This results in an offloading of the bilateral superolateral vector pull of the external oblique muscle on the central wound closure. Component separation can be performed as an open procedure that divides all cutaneous perforators or as a perforator sparing minimally invasive procedure. Minimally invasive component separation (MICS), though technically more demanding than open C5, has been shown to decrease the incidence of skin dehiscence, wound

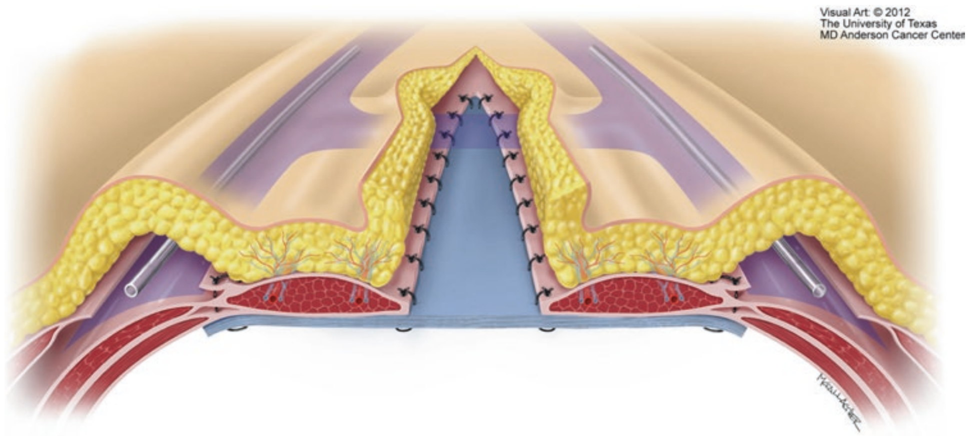

Fig. 12.3 Bridged mesh repair and Minimally Invasive Component Separation. (Copyright © 2012 The University of Texas MD Anderson Cancer Center)

healing complications, and bulge [38]. These improved outcomes are likely attributable to preservation of the vascularity of the overlying skin flaps and reduction of paramedian dead space—both of which MICS was designed to do.

Component separation can be performed in the face of a violation of the ipsilateral rectus sheath through either an ostomy or transection of the rectus abdominis muscle. At our institution, patients with a previously violated rectus myofascial complex who have undergone component separation have surgical outcomes (early complications and late recurrent hernia/bulge rates) equivalent to those of patients without such violation [39]. Although posterior sheath release was originally described as a maneuver included in component separation, it adds minimal additional medialization of the rectus complexes in most cases. The exception is cases with prolonged, severe loss of domain. These patients often have a "tubularized" rectus complex, and a posterior sheath release unfurls the rectus complex and enables considerable medialization of the rectus complex toward the midline. Posterior sheath release is also used as an access incision to the retrorectus space for mesh placement, as in the Rives-Stoppa ventral hernia repair technique [40].

Component Separation Technique

In the open component separation technique, after exploratory laparotomy, lysis of adhesions, and definition of fascial edges, bilateral subcutaneous skin flaps are elevated over the anterior rectus sheath circumferentially, transecting the medial and lateral rectus abdominis perforator vessels. The linea semilunaris is exposed, and the external oblique aponeurosis is incised 1–2 cm lateral to the linea semilunaris, from 5 to 15 cm above the costal margin to near the pubis. The external oblique and internal oblique muscles are separated by blunt and sharp dissection laterally to the mid-axillary line. Release of the external oblique aponeurosis and separation of the internal and external oblique muscles allows medialization of the rectus sheath fascia to the midline fascia. The midline fascia is then closed with interrupted polypropylene sutures. Closed-suction drainage catheters are placed in the subcutaneous space, and absorbable quilting sutures are placed between Scarpa's fascia and the anterior abdominal wall fascia to obliterate dead space.

In the Minimally Invasive Component Separation (MICS) with inlay bioprosthetic mesh (MICSIB) technique, [38] bilateral 3-cm-wide subcutaneous access tunnels are created over the anterior rectus sheath from the midline to the linea semilunaris at the level of the costal margin (Fig. 12.4). Through these access tunnels, the external oblique aponeurosis is vertically incised 1.5 cm lateral to the linea semilunaris. The tip of a metal Yankauer suction handle (Cardinal Health, Dublin, OH), without suction, is inserted through the opening into the avascular plane between the internal and external oblique aponeuroses, separating them at their junction with the rectus sheath. The suction tip is advanced inferiorly to the pubis and superiorly to above the costal margin. A narrow (2.5-cm-wide) subcutaneous tunnel is created with electrocautery and blunt dissection superficial to the external oblique aponeurosis, over the planned release location, using a narrow retractor and a headlight (Fig. 12.5). The external oblique aponeurosis is then released approximately 1.5 cm lateral to the lateral edge of the rectus sheath from 5 to 15 cm above the costal margin superiorly to near the pubis inferiorly. Next, lateral dissection between the internal and external oblique muscle is performed to the mid-axillary line. Subcutaneous skin flaps are elevated over the anterior rectus sheath circumferentially to the medial row of rectus abdominis perforator vessels. If the posterior sheath can be re-approximated then a rectrorectus mesh repair is performed. Frequently, however, the defect width is too great, even after component separation, to approximate the posterior sheaths together. In this case a preperitoneal mesh inset repair is preferred. The preperitoneal fat is dissected from the posterior sheath circumferentially to allow the bioprosthetic mesh to be inlaid directly against the posterior sheath or rectus muscle (below the arcuate line). Mesh is inset using a preperitoneal inlay technique; interrupted, #1 polypropylene sutures are

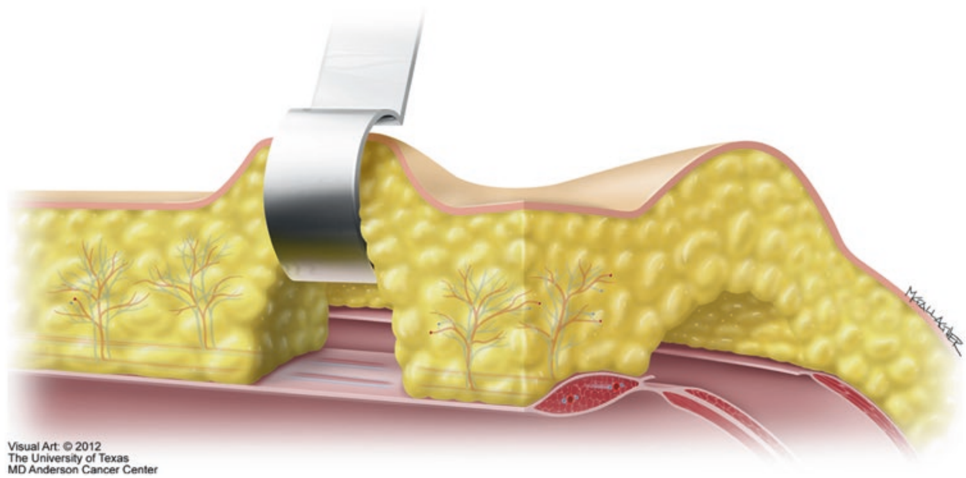

Fig. 12.4 Minimally Invasive Component Separation. (Copyright © 2012 The University of Texas MD Anderson Cancer Center)

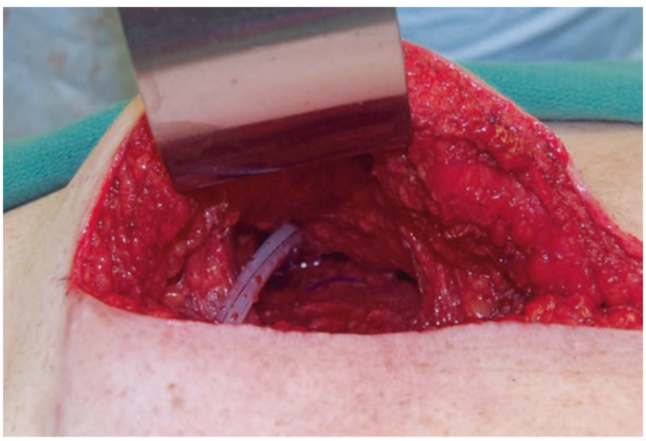

Fig. 12.5 Minimally Invasive Component Separation subcutaneous access tunnel. (Copyright © 2012 The University of Texas MD Anderson Cancer Center)

placed at the semilunar line through the bioprosthetic mesh and back through the musculofascial to create "U" stitches. All sutures are preplaced and tagged with hemostats to allow assessment, and potentially adjustment, of the inset tension. Then, the musculofascial edges are advanced and coapted over the mesh with sutures placed through the musculofascia and bioprosthesis. Interrupted resorbable 3–0 sutures are placed to affix the posterior sheath to the mesh, thus reducing dead space and potential fluid collection. The fascial edges are closed with interrupted permanent #1 monofilament sutures. If complete musculofascial midline closure is not possible, the musculofascial edges are sutured to the surface of the mesh using interrupted, polypropylene sutures to create a "bridged" repair, with the mesh spanning the defect between the musculofascial edges.

With both open component separation and Butler's MICS technique the redundant medial aspects of the skin flaps are carefully excised in a vertical panniculectomy. Closed-suction drainage catheters are placed in each component separation donor site area, in the space between the rectus complex closure and bioprosthetic mesh, and in the subcutaneous space. The remaining undermined skin flaps are quilted to the musculofascia with resorbable 3–0 quilting sutures to reduce dead space and potential shear between the subcutaneous tissue and musculofascia. The midline skin incision is then closed in layers.

At times, unfavorable wound healing scenarios will be encountered, and wound infection, dehiscence, or breakdown of overlying skin flaps will lead to exposure of the bioprosthetic mesh. Bioprosthetic meshes' tolerance of bacterial contamination and exposure allows an area of wound separation to be reclosed over drains after clearing any infection, assuming there is adequate skin laxity for closure. Small defects can be left open to heal by secondary intention with the use of standard saline-soaked dressing changes or negative pressure wound therapy devices. The goal of negative pressure wound therapy is to prevent desiccation and dehydration of the bioprosthetic material. Negative pressure wound therapy can be used to develop a revascularized mesh granulation bed suitable for skin graft coverage or serve as a temporizing measure to facilitate a delayed primary closure or flap coverage, as the clinical circumstances dictate. The use of non-adherent barrier dressing materials between the polyurethane negative pressure wound therapy foam and the bioprosthetic mesh prevents trauma to the bioprosthetic mesh and helps retain the foam. Various materials can be used for this purpose, such as petroleum-impregnated wide mesh gauze or perforated silicone dressings. Alternatively, microporous foam, such as polyvinyl alcohol foam, can be placed directly over the bioprosthetic mesh. A skin graft can be applied onto granulated bioprosthetic mesh. If the defect is large with bioprosthetic mesh exposed at the base, the best choice is generally autologous skin flap tissue, either a local advancement flap from the abdomen, a rotation advancement flap, a pedicled regional flap, or a free flap.

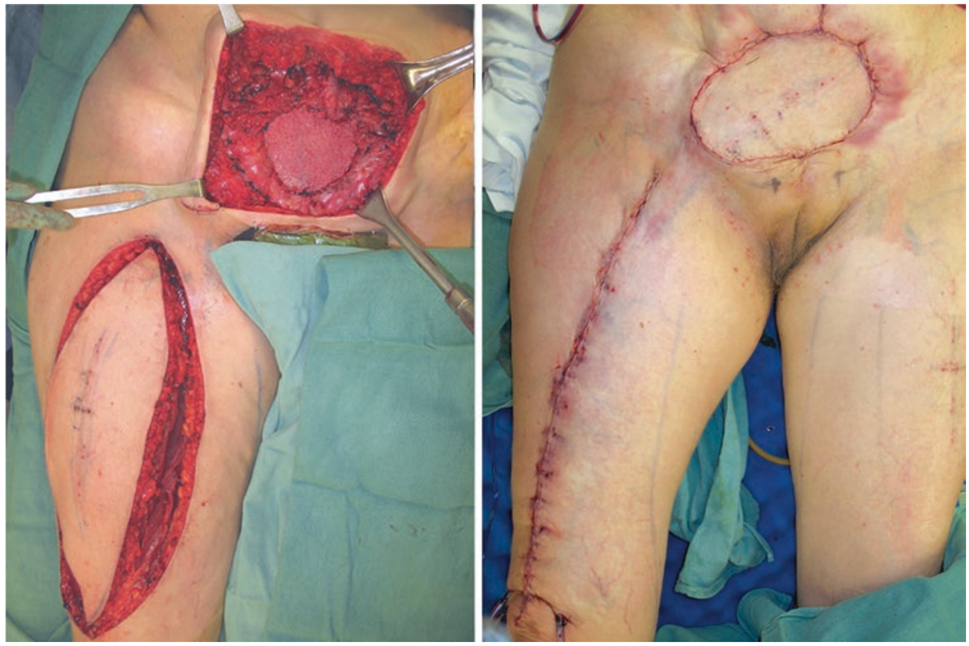

Fig. 12.6 Cutaneous deficit coverage with a pedicled anterolateral thigh flap. (Copyright © 2012 The University of Texas MD Anderson Cancer Center)

Management of the Skin: Deficiency and Redundancy

The success of any abdominal wall reconstruction depends on a stable wound healing environment. Durable soft tissue coverage is required to avoid mesh exposure and reduce the risk of seroma formation, periprosthetic infection, and subsequent explantation. The goals of soft tissue coverage are to achieve a tension-free closure and obliterate any potential dead space. Redundant skin and subcutaneous flaps are often encountered after a bilateral component separation is performed because of the extensive medialization of the musculofascia. The paramedian skin edges in an open component separation can become marginally devascularized, a complication MICS is designed to eliminate. Compromised attenuated paramedian skin is resected as a vertical panniculectomy to minimize skin redundancy and subcutaneous dead space [41]. In patients who require resection of both horizontal and vertical redundancy, a Mercedes pattern skin excision can be performed to avoid skin necrosis at the confluence of the vertical and horizontal panniculectomy incisions [42].

In patients with large cutaneous defects and insufficient skin available for closure, wound coverage may require a local advancement flap, locoregional flap, or free flap. Coverage can generally be accomplished in the torso by local fasciocutaneous flap advancement. The overlapping angiosomes of the abdominal wall's skin allow for wide undermining and skin advancement. In cases of prior radiation, prior surgery, or excessive skin resection, a pedicled regional flap or free flap may be required to provide adequate soft tissue coverage. Options for pedicled flaps in the upper lateral abdomen include latissimus dorsi musculocutaneous flaps. Pedicled thigh-based flaps such as anterolateral thigh flaps, vastus lateralis flaps, and tensor fascia lata flaps are able to reach the lower abdomen and flank; for massive defects, a pedicled or free subtotal thigh flap [43] can be used (Fig. 12.6). If a pedicled flap is not available or feasible, a thoracoepigastric bipedicled fasciocutaneous flap may provide adequate local tissue in a patient not suitable for free tissue transfer. When the above options are not feasible, a free flap is required for soft tissue coverage. The thigh can serve as a source of fasciocutaneous flaps and myocutaneous flaps that provide large skin paddles and significant muscle volume. Recipient vessels for the abdominal wall include the deep inferior epigastric vessels, right gastroepiploic vessels, superior epigastric vessels, internal mammary vessels, intercostal artery perforators, and thoracolumbar perforators. When no local recipient vessels are available, vein grafts to the internal mammary or femoral vessels may be required.

Staged Abdominal Wall Reconstruction

Abdominal wall reconstruction at the time of unplanned bowel resection, excessive bowel edema, or extensive intraperitoneal inflammation presents formidable challenges in replacing the musculofascia and overlying skin. Intraabdominal complications such as infection, obstruction, and fistula can be life-threatening. Local wound conditions including bacterial contamination, previous incisions, and abdominal wall radiation injury can increase the likelihood of compromised wound healing, surgical site infection, and failure of the reconstruction. When local skin flaps and regional flaps are unavailable for soft tissue coverage in such cases, the remaining flap options may be limited. A useful strategy in these cases is to perform the reconstruction in stages. Bioprosthetic mesh is placed as an initial musculofascial replacement, and soft tissue wound closure is done once bowel function has been re-established. Early fascial closure preserves the musculofascial domain, reduces the risk of enterocutaneous fistula, and may reduce the complexity of subsequent wound management. After a period of optimal wound care, cutaneous coverage can be achieved by delayed primary closure, healing by secondary intention, skin grafting, or flap reconstruction. Negative pressure wound therapy provides temporizing wound care that allows for early flap coverage with preservation of the bioprosthetic mesh's integrity.

Early reoperation after complex abdominal wall reconstruction can be necessary for a myriad of reasons, including hematoma, bowel obstruction, and intraabdominal sepsis. Re-entry into the abdominal cavity under these circumstances can require conversion of a dual-layer "musculofascia over mesh" closure to a bridging mesh repair or make the further use of mesh difficult owing to intestinal edema, infection, or loss of domain. If mesh is temporarily removed during one reoperation and reinset with less tension as a bridged repair edema and friability of the abdominal wall fascia can lead to a weakened interface. One strategy to preserve the abdominal wall repair during reoperation for intraabdominal complications is to perform a midline laparotomy incision through the midsubstance of the bioprosthetic mesh. This allows the lateral mesh-musculofascia interface to be preserved, and the mesh can be coapted to itself in the midline for abdominal closure.

Postoperative Care

After abdominal wall reconstruction, postoperative care includes gradual diet advancement based on intestinal function, epidural pain management transitioned to oral analgesics, and early ambulation (postoperative day 1). Patients are generally discharged from the hospital on postoperative day 4–7. Drains are removed when the output is ≤25 ml over 24 h. Patients are directed to avoid heavy physical activity and sports for 8 weeks postoperatively. Patients are typically followed up with a physical examination daily while in the hospital, then weekly for 1 month after discharge, and then every 3–6 months.

Conclusions

Surgical planning in complex abdominal wall reconstruction requires the combined efforts of plastic surgeons and general surgeons. To achieve the goals of re-establishing the integrity of the musculofascial unit and providing cutaneous coverage of the abdominal wall defect, surgeons must take into consideration local wound conditions, optimize the utility of remaining tissues, reinforce the abdominal wall with mesh, and provide durable skin replacement. To minimize hernia recurrences and maximize preservation of function, this type of complex abdominal wall reconstruction should be attempted only by teams of highly experienced surgeons.

Disclosures The authors do not have any relevant disclosures.

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Complex Tissue Transfer in the Management of Abdominal Wall Defects

13

Shigeki Kushimoto

Introduction

The concepts of damage control and improved understanding of the pathophysiology of abdominal compartment syndrome have proven to be great advances in trauma care [1–3]. Furthermore, these insights have been incorporated into the care of nontraumatic surgical condition [4, 5]. Massive fluid resuscitation for hemorrhagic and septic shock results in significant tissue edema, which does not spare the bowel. The consequent visceral edema can preclude abdominal wall closure after laparotomy because the fascia cannot be reapproximated without excessive tension. Abdominal wall closure under excessive tension often leads to abdominal compartment syndrome and fascial necrosis. Clear recognition of these complications has led to the widespread practice of leaving the abdominal cavity open after either damage control surgery or decompressive laparotomy for abdominal compartment syndrome. However, these approaches require prolonged open abdomen management. During this interval, the musculofascial structure of the abdominal wall contracts laterally, leaving patients with a large midline defect if standard fascial closure is not possible. Although abdominal wall defects result from multiple etiologies, including trauma, previous abdominal surgeries, congenital abnormalities, and infection [6], the concept of leaving the abdominal cavity open after damage control and abdominal compartment syndrome as a therapeutic strategy has markedly contributed to the increased frequency of abdominal wall defects.

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Temporary Abdominal Wall Closure for Acute Abdominal Wall Defect and During Open Abdomen Management

To reduce the need for an intermediate period with a large ventral hernia requiring later abdominal wall reconstruction, several techniques, such as vacuum-assisted wound closure and application of a Wittmann Patch® (Starsurgical, Burlington, WI), have been employed [7–9]. Recently, several studies have shown that delayed abdominal fascial closure is safe and effective for achieving successful closure in 65–100% of patients with an open abdomen [10–12]. There is evidence that vacuum-assisted closure devices facilitate delayed primary fascial closure, with high success rates and low morbidity [8, 11, 13, 14] by both commercially available devices (V.A.C.® Therapy, KCI, San Antonio, TX) and noncommercial "vacuum-packed dressing," although the effectiveness of vacuum-assisted closure devices to achieve delayed fascial closure in patients with abdominal sepsis has not been as high as in trauma patients [15].

In the setting of ongoing intra-abdominal infection or the formation of an enterocutaneous fistula, abdominal fascial closure is often not possible [16], because of ongoing visceral edema, with loss of the abdominal domain or loss of fascia secondary to infection. Although Miller et al. demonstrated that early abdominal fascial closure can be achieved in the majority (63%) of damage control cases during the initial relaparotomy, delayed abdominal fascial closure before 8 days was associated with fewer complications (with rates of 12% in those closed before 8 days and 52% with closure after 8 days), suggesting that early fascial closure might be crucial for minimizing complications associated with open abdomen/abdominal wall defects [12].

To evaluate the efficacy of negative-pressure wound therapy for critically ill adults with open abdomen for critically ill adults with open abdomen, a systematic review has been published, in which only two randomized controlled trials and nine cohort studies (three prospective/six retrospective)

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were analyzed [17]. Although negative-pressure wound therapy may be linked with improved outcomes, the clinical heterogeneity and quality of available studies preclude definitive conclusions regarding the preferential use of negative-pressure wound therapy over alternate temporary abdominal closure techniques [17]. Recently, a prospective observational study regarding the technique of negative-pressure wound therapy, i.e., comparison of Barker's vacuum-packing technique and the ABThera(TM) open abdomen negative-pressure therapy system, demonstrated that the use of ABThera(TM) system is associated with significantly higher 30-day primary fascial closure rates and lower 30-day all-cause mortality among patients who require an open abdomen for at least 48 h [18]. Although negative-pressure wound therapy can be a choice of the method of temporary abdominal closure, the specific technique and device should be considered based on patients' conditions.

Abdominal Wall Reconstruction Following Temporary Closure in the Management of Abdominal Wall Defects

Surgical options available for abdominal wall defects, if primary suture is not possible, are limited to (1) bridge repair of the fascial defect using a mesh to create a bridge closure; (2) acute abdominal wall reconstruction, most commonly using component separation and its modifications; or (3) a planned ventral hernia [11]. Although acute abdominal wall reconstruction using tissue transfer techniques has been reported [11, 19, 20], in the typical care of patients requiring open abdomen management who are not candidates for early standard fascial closure, many still require a period with a large ventral hernia in which granulated abdominal contents are covered with only a skin graft, necessitating subsequent complex abdominal wall reconstruction. Moreover, the risk of enterocutaneous fistula may increase as the duration of open abdomen management is prolonged [21]. Although it is recommended that definitive fascial closure or earlier reconstruction of abdominal wall in acute or subacute phase to prevent complications associated with open abdomen, specific techniques, and the timing must be clarified by future studies [22].

To accomplish late reconstruction of the abdominal wall for patients after a period with a planned ventral hernia following open abdomen management, several tissue transfer methods have been proposed, such as component separation [23], rectus turnover flap [24], and modified component separation techniques [21, 25]. Although these methods have been reported for abdominal wall reconstruction at 6–12 months or even later after the initial operation, application of these techniques in the early phase of the open abdomen has not been adequately evaluated. Even the techniques used in abdominal wall reconstructions are constantly changing, the goals of treatment remain the same: protection of abdominal contents and restoration of functional support. Vascularized autologous tissue repair is extremely useful in cases at high risk of infection, such as those with abdominal sepsis and those requiring prolonged open abdomen management.

Complex Tissue Transfer in the Management of Abdominal Wall Defects

Although several flap techniques for abdominal wall reconstruction have been demonstrated, including free tensor fascia lata flap, anterolateral thigh flap, latissimus dorsi muscle free flap, and rectus femoris musculocutaneous free flap [26], here we focus on the component separation technique, including its modifications and the anterior rectus abdominis sheath turnover flap method of complex tissue transfer.

Basic Musculoskeletal and Neurovascular Anatomy of Anterior Abdominal Wall

The anterior abdominal wall consists of paired rectus and oblique muscles that coalesce in the midline to create a myofascial sling that resists internal pressure, provides a stable platform for movement and assistance with respiratory excursion. Flexion of the abdominal wall is mainly facilitated by the midline rectus abdominis muscles, with their origin at the pubic symphysis and the insertion at the xiphoid process and the fifth to seventh costal cartilages. Lateral support of the abdomen is provided by three layers: external oblique, internal oblique, and transverse abdominis muscles. These muscles interdigitate toward the midline bilaterally to form the anterior and posterior rectus sheaths, with their corresponding medial insertions into the linea alba. Above the arcuate line, the aponeuroses of these muscles divide, with the external oblique providing fibers to the anterior rectus sheath, the transversalis muscle donating its fibers posteriorly, and the internal oblique splitting to contribute fibers to both the anterior and the posterior sheath. However, below the arcuate line, all three aponeuroses run anterior to the rectus muscle, with only the transversalis fascia providing posterior support.

A neurovascular plane exists within the anterolateral abdominal wall, traversing between the internal oblique and transversalis muscles. Coursing within this plane is the innervation to the oblique and rectus muscles, provided by the inferior six thoracic nerves (T7–T11 and the subcostal nerve T12), and the iliohypogastric and ilioinguinal nerve branches of L1. Huger classified the vascular supply of the anterolateral abdomen into three zones [27]. Zones I and II, the midabdomen and lower abdomen, respectively, are supplied by the vascular arcade of the superior and inferior deep epigastric arteries, with contributions from the superficial inferior epigastric, superficial circumflex iliac, and deep circumflex iliac arteries to the lower abdominal wall. Laterally, in zone III, the intercostal, subcostal, and lumbar arteries course toward the midline with their corresponding nerve branches. This anterolateral configuration allows for a relatively avascular and nerve-sparing plane to exist between the external and internal oblique muscles on either side of the midline, which is the site of muscle splitting for the component separation method as described in the next section.

Component Separation Method

Albanese was the first to describe in 1951 [28], Ramirez et al. popularized this technique for reconstruction of large abdominal wall fascial defects without the use of prosthetic mesh [23]. In its basic form, the technique is as follows (Fig. 13.1):

1. Anterior abdominal wall skin flaps are developed and dissected out to the anterior superior iliac spine and the chest wall. The procedure is initiated by elevating the skin and subcutaneous flaps off of the underlying abdominal musculature in a lateral direction toward the anterior axillary line to explore the anterior surface of the external oblique aponeurosis 2–3 cm lateral to the linea semilunaris. The linea

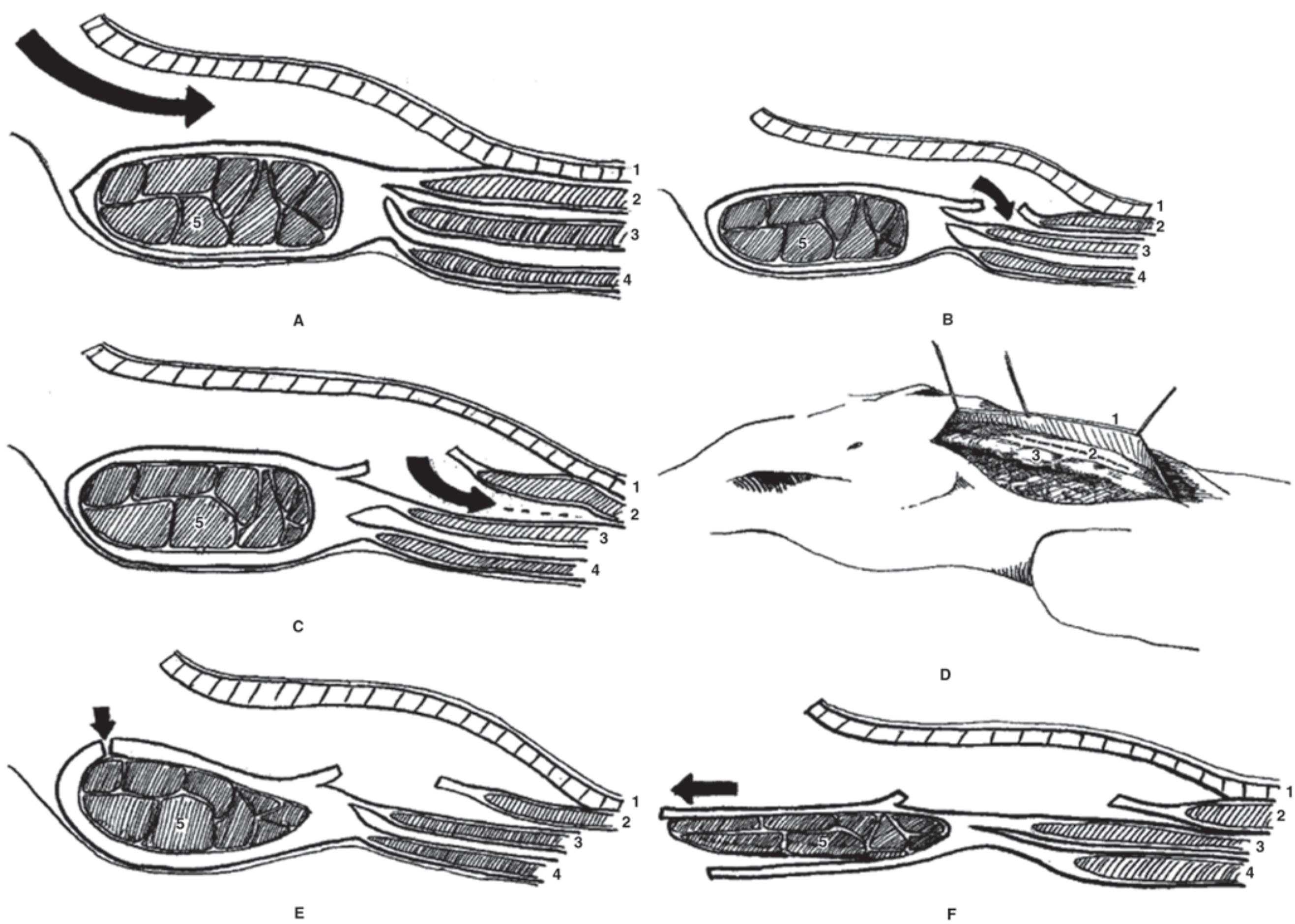

Fig. 13.1 The "component separation" technique. After abdominal cavity entry, the bowels are dissected free from the ventral abdominal wall. (**a**) The skin and subcutaneous fat (*1*) are dissected free from the anterior sheath of the rectus abdominis muscle (*5*) and the aponeurosis of the external oblique muscle (*2*). (**b** and **c**) The aponeurosis of the external oblique muscle (*2*) is transected longitudinally about 2 cm lateral to the rectus sheath, including the muscular part on the thoracic wall, which extends at least 5–7 cm cranially from the costal margin. (**d**) The external oblique muscle (*2*) is separated from the internal oblique muscle (*3*), as far as possible laterally. (**e** and **f**) If primary closure is impossible due to tension, a further gain of 2–4 cm can be obtained by separation of the posterior rectal sheath from the rectus abdominis muscle (*5*). The rectus muscle and the anterior rectal sheath can be advanced to the midline over a distance of about 10 cm at the waistline. Care must be taken not to damage the blood vessels and nerves that run between the internal oblique and transverse (*4*) muscles and enter the rectus abdominis muscle at the posterior side. (Adapted with permission of Elsevier from de Vries Reilingh et al. [43])

semilunaris is dissected, along with the insertion of the external oblique fascia.

2. The aponeurosis of the external oblique muscle is divided lateral to the semilunar line on to the chest wall to the level of the xiphoid. A vertically oriented incision parallel to the linea semilunaris is made 2–3 cm lateral to it, extending from the inguinal ligament to the level of the costal margin and above it. This superior extension is important in cases with defects extending up to the xiphoid process to obtain adequate release of tissues for these superior closures. The incision should be made well lateral to the linea semilunaris, just medial to the musculofascial junction of the external oblique muscle itself. The figure is a diagrammatic illustration showing elevation of the skin flap laterally and development of the plane between the external oblique and internal oblique muscles. This plane was opened all the way to the posterior axillary line.
3. Free up the external oblique to allow the rectus myofascial component to be mobilized medially. After division of the external oblique fascia, the deep surface of the external oblique muscle is identified and the plane between the external and internal oblique muscles is developed. When making the initial incision in the oblique fascia the surgeon must be careful not to dissect deep into this layer of the external oblique fascia, to avoid injuring the internal oblique fascia or muscle.
4. The midline is sutured together.

Degree of tissue advancement at various locations on the abdominal wall for the innervated rectus abdominis, internal oblique, transverses abdominis muscle complex:

The dissection proceeds in this relatively avascular intermuscular plane and is continued in a lateral direction to at least the level of the midaxillary line. At this point, the mobility of the innervated rectus abdominis-internal oblique-transversus abdominis muscle complex is determined. If additional mobility of these structures on either side of the midline is desired, then the dissection in the intermuscular plane can be continued to the posterior axillary line. Each ipsilateral complex can be expected to advance toward the midline 4 cm in the upper abdomen, 8 cm at the umbilicus, and 3 cm in the lower abdomen. Using specific modification of the components separation technique, up to 20 cm of advancement of native tissues in the umbilical region has been demonstrated [29].

Modifications of Component Separation Method

The original component separation method has several disadvantages, as suggested previously. Mass et al. described three disadvantages [30]. First, the skin and subcutaneous tissue must be mobilized laterally over a large distance to reach the aponeurosis of the external oblique muscle lateral into the flank. This creates a large wound surface that covers the entire abdominal wall, from costal margin to pubic bone. Second, mobilization of the skin endangers its blood supply, which may lead to skin necrosis at the midline if circulation through the intercostal arteries is interrupted. Third, the technique is difficult to use in patients with an enterostomy or when a new enterostomy must be made.

The purposes of modifying the original component separation method are as follows: (1) additional advancement of components; (2) preservation of the blood supply to the skin and subcutaneous tissue; (3) overcoming the problem of stoma reconstruction; and (4) reduction of the subcutaneous tissue mobilization area. The first and second goals are especially important.

For additional advancement of components to the midline, separation of the rectus muscle from the posterior rectal sheath has been used in almost all reported techniques [20, 21, 30–32]. With this modification, the rectus muscle and the anterior rectal sheath can be expected to advance to the midline over a distance of about 10 cm at the level of the umbilicus (Fig. 13.2).

Maas and colleagues described a modification of the original technique of component separation, designed to preserve the blood supply to the skin and subcutaneous tissue and to overcome the problem of stoma reconstruction in these patients [30]. Using their technical modification, the aponeurosis of the external oblique muscle is dissected free through a separate, longitudinal skin incision at a distance of about 15 cm from the median skin border (Fig. 13.2). The aponeurosis is transected just lateral to its insertion in the rectal sheath, from the costal margin to 5 cm above the pubic bone. The external oblique muscle is separated from the internal oblique muscle. A well-vascularized compound flap is created and can be advanced to the midline. The rectus muscle is separated from the posterior sheath to further mobilize this flap. Modification of "component separation" technique for preservation of blood supply skin. For the dissection of skin and subcutaneous fat from the anterior sheath of the rectus abdominis muscle and the aponeurosis of the external oblique muscle, perforating arteries from the anterior sheath of the rectus abdominis can be preserved to prevent skin and subcutaneous fat ischemia (Fig. 13.3).

Component separation has become the most commonly used surgical technique for closure of large "planned" ventral hernias covered with a skin graft during the elective reconstruction phase [33–35]. Its use for acute definitive closure in the setting of an open abdomen has not been fully evaluated. Formal component separation is generally considered to be an "elective" reconstruction technique. Although its use in the acute setting aimed for resolving intra-

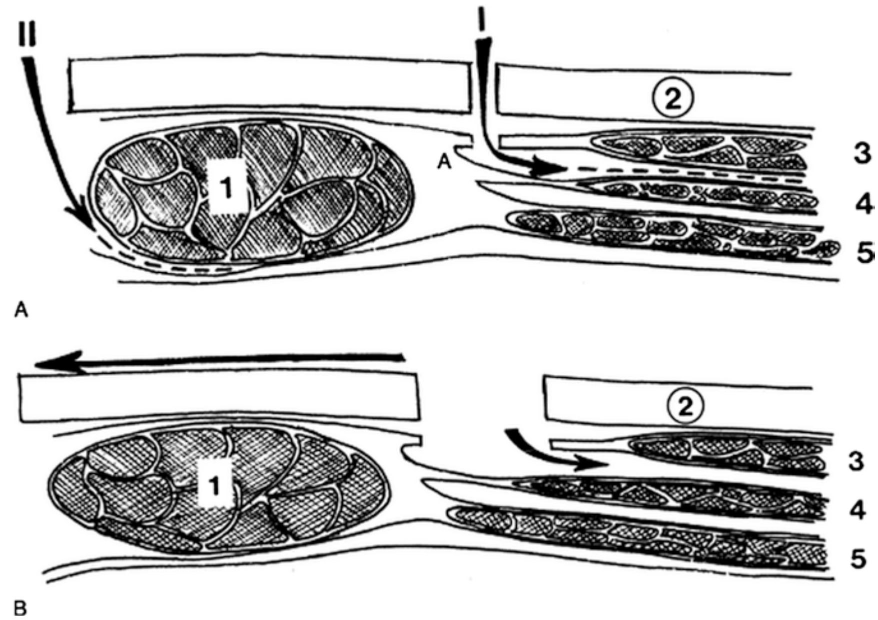

Fig. 13.2 Modified "component separation" technique. (**a**) I, the external oblique muscle is transected through a separate incision, just lateral to the rectal sheath; II, separation of the rectus abdominis muscle from the posterior rectal sheath. (**b**) The compound flap can be advanced to the midline. The skin is vascularized through the perforating branches of the epigastric arteries. (*1*), rectus abdominis muscle; (*2*), skin and subcutaneous tissue; (*3*), external oblique muscle; (*4*), internal oblique muscle; (*5*), transverse muscle. (Adapted with permission of Elsevier from Maas et al. [30])

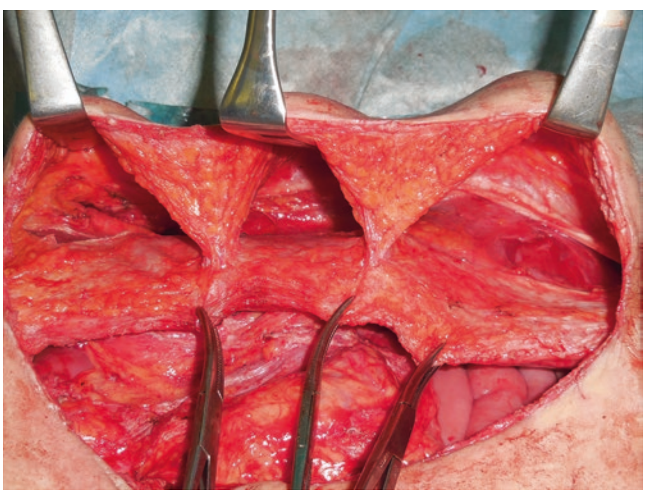

Fig. 13.3 Modification of "component separation" technique for preservation of blood supply skin. For the dissection of skin and subcutaneous fat from the anterior sheath of the rectus abdominis muscle and the aponeurosis of the external oblique muscle, perforating arteries from the anterior sheath of the rectus abdominis can be preserved to prevent skin and subcutaneous fat ischemia

abdominal sepsis, visceral, and abdominal wall edema as a result of systemic inflammatory responses, and ongoing sepsis has not yet been recommended [11], early definitive abdominal wall closure can reduce the need for skin grafting and later abdominal wall reconstruction and may decrease risks associated with open abdomen/abdominal wall defects, especially enteric fistula.

The Anterior Rectus Abdominis Sheath Turnover Flap Method

We recently demonstrated the usefulness of this method for early fascial closure in patients requiring open abdomen management [19]. This technique may reduce the need for skin grafting and later abdominal wall reconstruction. It can also be used for later reconstruction, as previously reported [24, 36].

During open abdomen management, care must be taken to prevent damage to the fascia, including the linea alba, to allow a definitive turnover flap of the anterior rectus sheath. If the abdominal fascia could be fully approximated without tension, standard fascial closure was performed. At 10–14 days after the initial laparotomy, a turnover flap of the anterior rectus abdominis sheath was considered instead if the distance to be closed with fascia was less than 15 cm in patients who were not candidates for standard fascial closure because of prolonged visceral edema. Formation of a planned ventral hernia using a skin graft over granulated abdominal contents was employed in patients without edema resolution 3 weeks or more after the initial laparotomy who were not candidates for either method of fascial closure.

Surgical Procedures

The procedure starts with separation of the skin and underlying adipose tissue from the anterior rectus sheath as a flap, with a base several centimeters beyond the lateral border of the rectus sheath. Next, turnover flap creation from the anterior sheath

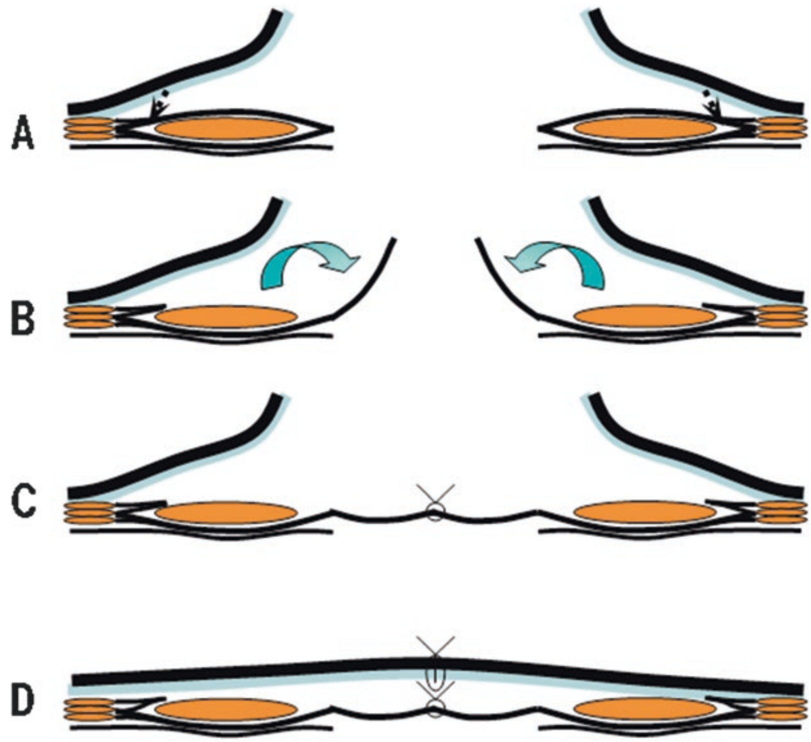

Fig. 13.4 Cross-sectional schematic diagram of the technique for turnover flap creation from the anterior rectus abdominis sheath. The procedure is started by separating the skin and underlying adipose tissue from the anterior rectus sheath as a flap, with a base several centimeters beyond the lateral border of the rectus sheath (**a**). The turnover flap is then fashioned from the anterior sheath by longitudinally incising the sheath along the entire length of its lateral border. The site of this incision must be chosen carefully to avoid entry at the conjoined point of the internal oblique aponeurosis and the external oblique aponeurosis (**b**). The anterior sheath is then dissected from lateral to medial, freeing it from the rectus muscle. The linea alba is kept intact to serve as a medial hinge. The turnover flap of the anterior rectus sheath is approximated by interrupted sutures (**c**), and the skin is closed primarily (**d**). (Adapted with kind permission of Springer from Kushimoto et al. [19])

is initiated by incising the anterior sheath along the entire length of its lateral border. When making this longitudinal incision, the specific incision site must be chosen carefully to avoid entry at the conjoined point of the internal and external oblique aponeuroses, which could weaken the anterior sheath and predispose the patient to subsequent hernia formation. Because the largest fascial gap is in the midabdomen, where a wide flap is needed to approximate the fascia in most patients, longitudinal incision of the anterior rectus sheath should be started at the upper or lower abdominal surface of the anterior sheath to avoid entry at the conjoined point. The anterior sheath is then dissected laterally to medially, freeing it from the rectus muscle. Kept intact, the linea alba serves as a medial hinge to mobilize the flap (Fig. 13.4). If the linea alba is no longer intact, suture repair must be performed. The fascial flap is then reflected medially, with careful attention not to damage the anterior sheath.

After creating bilateral turnover flaps, we approximate the flaps to cover the abdominal contents using interrupted sutures (3–0 polyglactin 910). We never use prosthetic materials to reinforce the turnover flaps or to repair exceptionally large fascial defects. Thereafter, the skin and underlying adipose tissue are approximated with drainage to the base of the adipose tissue dissection (Figs. 13.5, 13.6, and 13.7).

Blood Supply to the Anterior Rectus Turnover Flap

Blood supply to the anterior rectus turnover flap is an issue awaiting clarification. Ennis et al. stated that “the flap is vascularized autogenous tissue”; “small anterior venules at the medial portion of the flap” were described as constituting a major vascular element of the flap in Ochsner’s comment at a conference discussion session [25]. However, the blood supply to the anterior rectus sheath has been suggested to arise primarily from perforating intramuscular branches of the deep superior and inferior epigastric arteries [37–39], and some of these perforators to the anterior fascia are inevitably transected during reflection of the anterior rectus sheath flap as it is freed from the rectus muscle. Numerous small

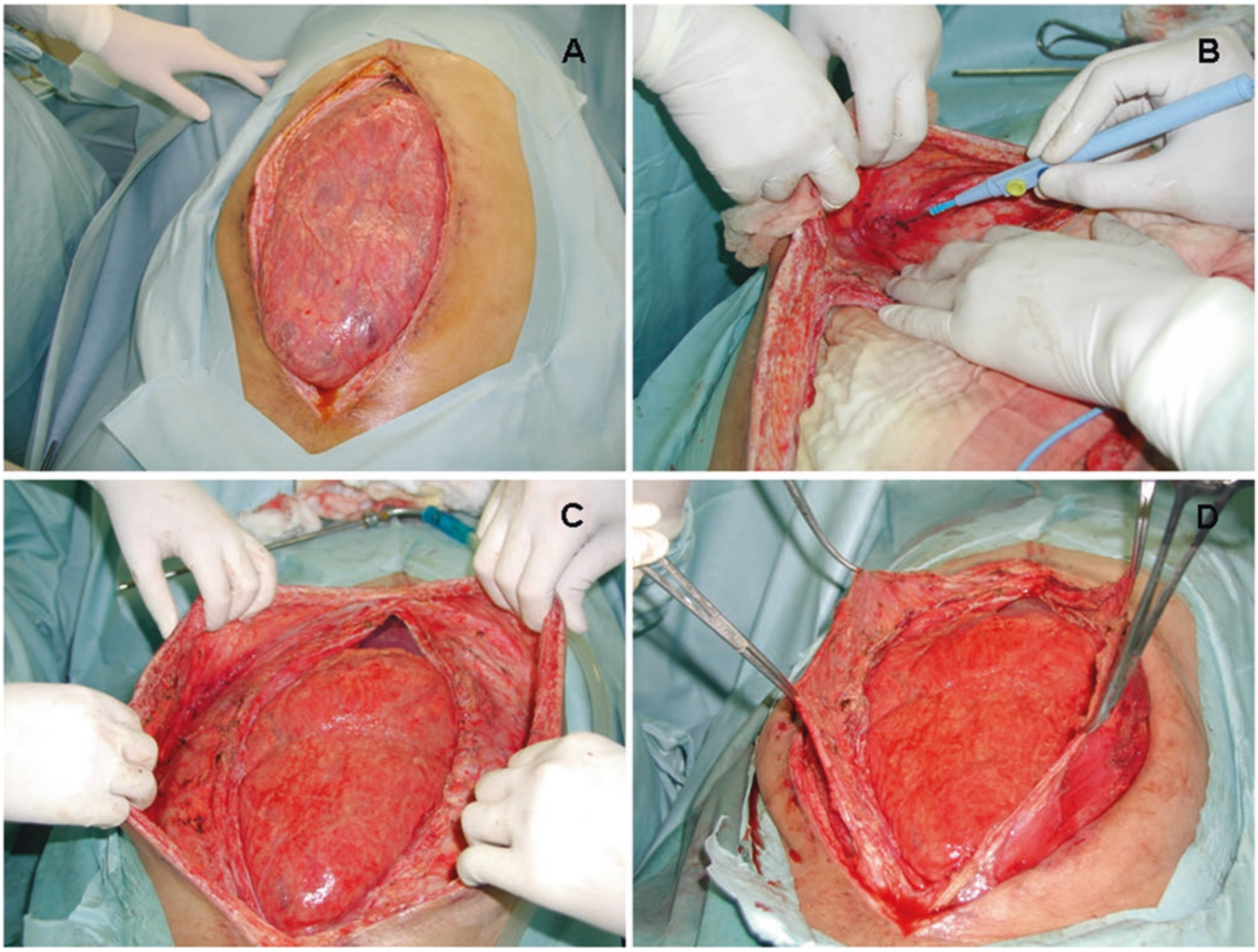

Fig. 13.5 Intraoperative view of the anterior rectus abdominis sheath turnover flap method (initial steps). (**a**) View just after vacuum-packing removal (11 days of open abdomen). (**b**) Kin and underlying adipose tissue are first separated from the anterior rectus sheath as a flap. (c) Skin and adipose tissue have been completely dissected from the anterior sheath bilaterally beyond the lateral border of the rectus sheath. (**d**) The anterior rectus sheath flap is reflected medially by dissecting from lateral to medial, freeing it from the rectus muscle. The linea alba is kept intact as a medial hinge. (Adapted with kind permission of Springer from Kushimoto et al. [19])

arteries on the anterior surface of the anterior rectus sheath may be supplied by branches of deep epigastric arteries along the linea alba, complementing the blood supply to the anterior rectus sheath [39]. Although the blood supply to the anterior rectus sheath turnover flap remains uncertain, we observed the flap to be completely intact even in a patient with major wound infection whose entire midline skin closure had dehisced.

In our series, the duration of open abdomen was 17.6 ± 24.6 days for all study patients. Twelve of 18 non-trauma patients survived, as did 8 of 11 trauma patients. Turnover flap closure was performed in nine non-trauma patients (1–31 days after the initial surgery [9.4 ± 9.2 days]). Among trauma patients, turnover flap closure was used at 6 days in one and at 30 days in another. None of our patients developed enterocutaneous fistula or abdominal abscess. Although mid-abdominal bulging is observed in more than half of patients with anterior rectus abdominis sheath turnover flap closure, no abdominal wall hernias requiring secondary reconstruction developed during follow-up periods of up to 65 months.

Conclusion

In caring for patients requiring open abdomen management/abdominal wall defects, negative-pressure wound therapy reportedly raises the likelihood of early fascial

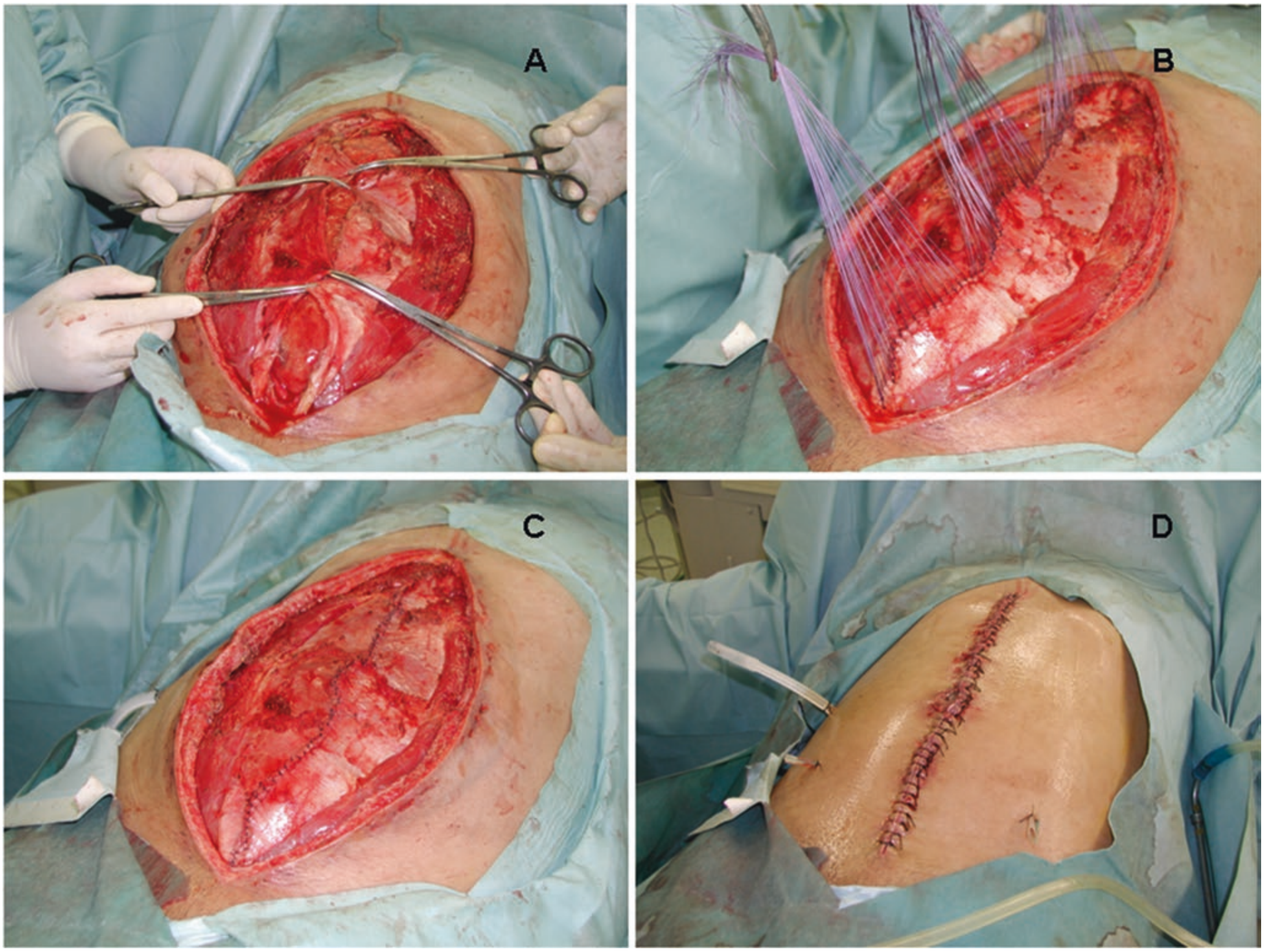

Fig. 13.6 Intraoperative view of the anterior rectus abdominis sheath turnover flap method (later steps). (**a**) Approximating the bilateral turnover flaps. (**b** and **c**) Turnover flaps from the anterior rectus sheaths are approximated by interrupted sutures. (**d**) Skin and subcutaneous tissue are sutured primarily. (Adapted with kind permission of Springer from Kushimoto et al. [19])

reapproximation and decreases the need for later complex abdominal wall reconstruction [7, 40]. However, in the typical scenario necessitating open abdomen management for cases unable to undergo early standard fascial closure, many patients require prolonged open abdomen because of visceral edema. During this period, the laterally displaced muscles of the abdominal wall retract, shorten, and scar in their altered positions. Next is an interval with an intentional large ventral hernia, during which granulated abdominal contents are covered only by a skin graft. This abdominal wall defect requires late reconstruction 6–12 months after the initial surgery. Enterocutaneous fistula formation is a devastating complication of open abdomen. This reportedly occurs in 5–25% of cases [8, 21, 41, 42], although lower fistula rates have been reported using negative-pressure wound therapy [7, 8, 40]. Enterocutaneous fistula formation can develop even after skin grafting of the granulated open abdominal wound. Early definitive wound closure is essential to prevent fistula formation. From this perspective, the complex tissue transfer method for early fascial closure can benefit patients by reducing the risk of this devastating complication.

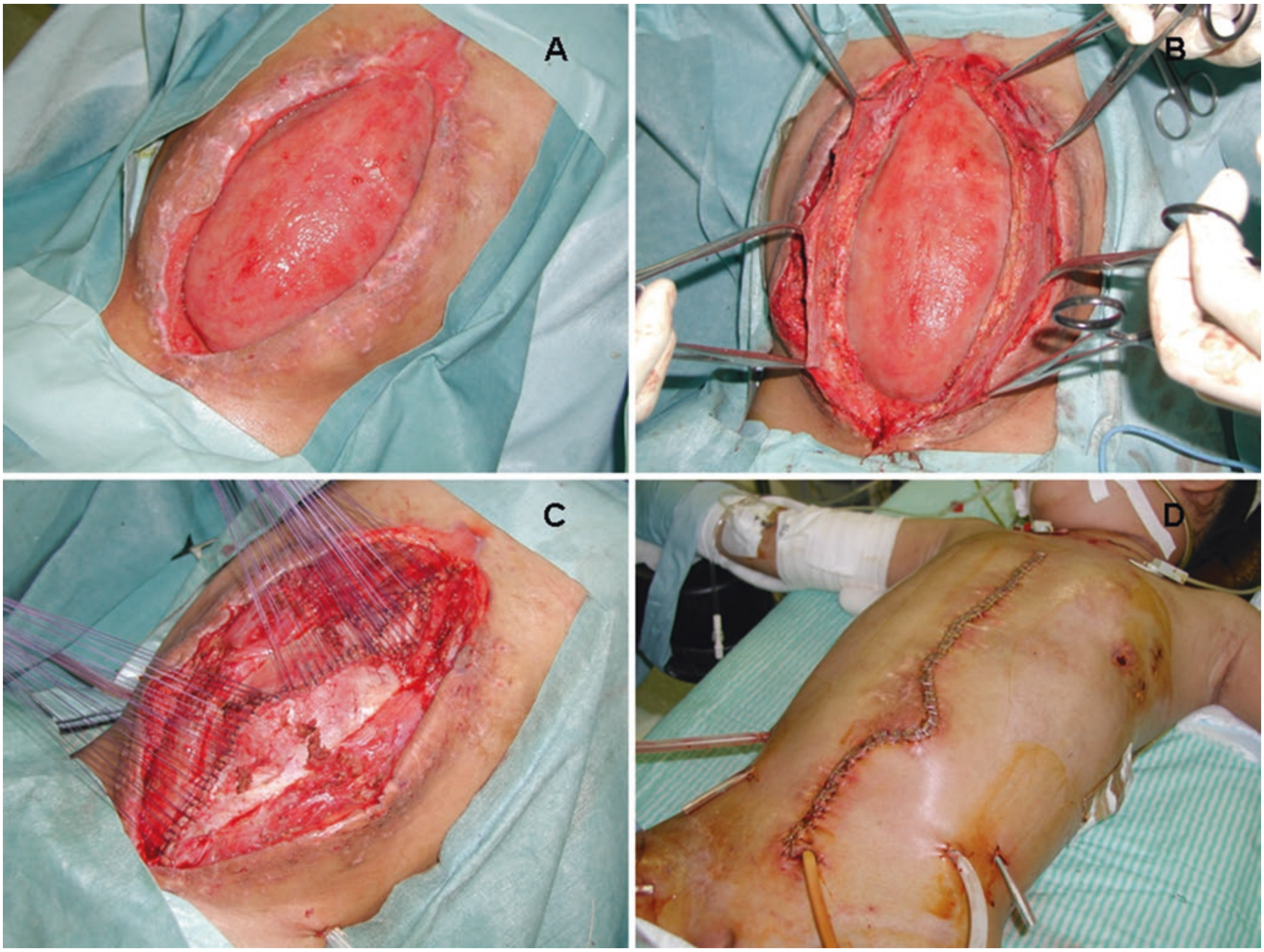

Fig. 13.7 Intraoperative view of the turnover flap method using the anterior rectus abdominis sheath carried out 30 days after initial laparotomy. (**a**) View just after vacuum-packing removal (30 days of open abdomen) showing granulated abdominal contents and retracted musculofascial structures of the anterior abdomen. (**b**) The anterior rectus sheath flap is reflected medially, dissecting from lateral to medial to free it from the rectus muscle. (**c**) Bilateral turnover flaps from the anterior rectus sheaths are approximated using interrupted sutures. (**d**) Skin and subcutaneous tissue are sutured primarily. (Adapted with kind permission of Springer from Kushimoto et al. [19])

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14 Minimally Invasive Component Separation for the Repair of Large Abdominal Wall Defects

E. Barbosa and F. Ferreira

Introduction

Complex abdominal wall reconstruction (AWR) poses many challenging problems to deal with in order to obtain the best short and long term results.

When treating massive hernias several questions need to be addressed in order to achieve the best possible outcome. Most often these patients are multioperated, with serious impairments on their lives, waiting for the operation that will give them back abdominal function, quality of life (many times there are other important coexisting problems such as chronic infections and bowel fistulas) and with reasonable cosmesis. The only way to achieve these goals in such complex patients is through profound knowledge of anatomy and physiology, attention to every detail, careful planning, and the domain of several techniques. The AWR surgeon must tailor the surgery to the patient instead of trying to include the patient into the technique.

According to the known forces of the abdominal wall [1] the best AWR is achieved when there is midline closure [2]. This is not always possible but still every attempt should be made to avoid as much bridging as possible. In large defects a simple midline closure is not achieved without tension unless some techniques are used such as component separation.

Anterior component separation technique for the treatment of large abdominal defects was popularized by Ramirez et al. in 1990 [3], yet first described by Albanese in 1951 [4, 5]. However, subsequent literature reviewed the results of this technique pointing out some problems such as a relatively high recurrence rate and post-operative skin complications such as ischemia and frank necrosis [6]. Nevertheless the anterior component separation technique became appealing for the treatment of complex patients, specially in the contaminated setting where synthetic mesh is not recommended [7, 8] and in massive hernias with loss of domain [9], thus avoiding complex mutilating muscle flaps as an alternative reconstructive technique. To avoid the early problems described with open component separation, minimally invasive techniques appeared in the literature are the scope of the discussion for this chapter.

More recently, posterior component separation with transversus abdominal release (TAR), described by Novitsy in 2012 [10, 11] poses an important alternative to the anterior component separation and preferred by the authors in many of the AWR. Still this approach may not be suitable for every patient leaving an important role for anterior component separation either open or minimally invasive.

Definition of Large Abdominal Defects

It is difficult to find in the literature a consensus terminology to classify the abdominal wall defects. Many terms like massive hernia, large abdominal defect, loss of domain, and complex abdominal hernia coexist and are not clearly defined. This presents a drawback when it comes to achieving a clear and common scientific language to compare results between procedures and centers. Some groups have proposed a classification systems for incisional ventral hernias in order to fill this gap and allow comparison of publications and standardization of terminology [12] but prospective studies are still needed to assess the clinical relevance of these classification studies and probably an individual

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classification for complex abdominal defects is required. Slater et al. recently classified incisional hernias according to complexity, proposing as a complex hernia the following criteria: size greater than 10 cm, presence of enterocutaneous fistulae, multiple previous operations, loss of domain greater than 20%, and presence of infected mesh [13]. Petro et al. also proposed a staging system that could correlate with morbidity and recurrence [14].

Size of the defect is a constant variable included in every system proposed and a cutoff of more than 10 cm in a transverse measure for the definition of large hernias is generally accepted. However, how accurately can one measure the abdominal wall defect in a consistent and reproducible manner is yet to be consensual. Pre-operative or intra-operative measures have some degree of surgeon bias and some authors defend a CT scan for more accurate and reproducible measures of the abdominal defect [15]. Also the method of area calculation should be always explained for accured comparison between studies as huge differences can be seen with different measuring methods. The authors usually measure the defects by CT and calculate the area of an ellipse.

Loss of domain can be tracked in the literature to the 1940s [16] but historically has no standard definition. It usually refers to a massive hernia with visceral contents outside its fascial boundaries in a manner that their return to the abdominal cavity cannot simply be made without a high chance of developing respiratory complications or even abdominal compartment syndrome. The relation between viscera outside/inside fascial boundaries is yet to be determined as a definition of loss of domain, specially because it is important to have in mind other aspects besides size, given that smaller defects may have important repercussion in ventilation considering the previous co-morbidities of the patient. Nevertheless, an extraperitoneal volume, measured by CT, of 20–25% is generally accepted [17, 18]. More accurately loss of domain is when the ratio of the volume of the hernia sac to the volume of the abdominal cavity is equal or greater than 0.5. In the presence of this type of massive hernias several pre-operative stages may be used as progressive pneumoperitoneum and chemical component separation with botulinum toxin in order to increase abdominal volume and abdominal wall compliance, to prevent dreadful post-operative complications such as pulmonary insufficiency and abdominal compartment syndrome.

In summary, size is not the only issue when considering the complexity of an abdominal wall defect and consequently choosing the best closing method. Other issues such as patient co-morbidities, the presence of an enterocutaneous fistula [19], and infected mesh or loss of domain pose additional important technical decisions.

Surgical Options in Complex Abdominal Hernias

Although beyond the scope of this chapter it is important to briefly review the surgical options available for complex abdominal reconstruction, for a better understanding of the place for minimal invasive procedures.

Achieving the right timing for AWR is crucial. Controlling contamination, assuring the best control of patient co-morbidities and waiting enough time in order to avoid a hostile abdomen after a planned ventral hernia is a key for success. The presence of an enterocutaneous fistula take-down and simultaneously bowel continuity reconstruction with AWR has widely been proven to be safe [19, 20]. This is also the experience of the authors, leaving the two-stage approach only for heavily infected scenarios, such as in case of removal of an infected mesh, where the AWR is performed a few days after sepsis control.

Laparoscopic ventral hernia repair has established popularity for the correction of ventral hernias [21]. Although it has many advantages, the laparoscopic reconstruction technique involves intraperitoneal mesh bridging of the defect, which does not achieve a dynamic physiologic reconstruction [22]. However, with the association of a video-assisted component separation it is possible, in selected cases, to achieve midline closure. The combination of anterior component separation and laparoscopic hernia repair gives the patient the benefits of both techniques with high functional results and low recurrence rates [23–25] but literature data is still scarce. Unfortunately, in large and complex abdominal wall defects, laparoscopy may be technically challenging and therefore not feasible. Also in the presence of enterocutaneous fistulae, poor skin quality (skin graft, ulcers, and excessive pannus), loss of domain, and mesh infection or extrusion an open procedure imposes, although in selected cases a minimally invasive anterior component separation still may be applied as an adjuvant of the laparotomic approach.

For functional abdominal wall reconstruction the midline reapproximation is a key point. In some complex cases as with simultaneous enterocutaneous fistulas but not a very wide defect this can be achieved with a Rives-Stoppa–Wantz where the posterior rectus sheath is mobilized and closed and a mesh is placed in the retrorectus muscle space, with anterior sheath closure. Unfortunately, in large defects this technique is not enough for midline closure and either an anterior or posterior component separation with TAR may be necessary. There has been a shift towards posterior component separation with TAR in the last years which the authors also follow [26]. Nevertheless, which of the two techniques achieve the best cosmetic, functional and long term results is yet to be established in a definitive way and probably both have a place in the complex AWR.

Anterior Component Separarion Technique

The concept of anterior component separation involves the release of the external oblique fascia from the anterior rectus sheath, starting 5–6 cm above the rib cage to the inguinal ligament, causing the midline slide of the muscle complex formed by the rectus—internal oblique—transversus abdominis (see Fig. 14.1). Extra mobilization can be achieved by release of the posterior rectus sheath (see Fig. 14.2).

The anterior component separation technique, besides the capability of closure for large abdominal defects without using prosthetic material, reconstructs a functional abdominal wall. This is impossible to achieve in the classical methods of mesh bridging without midline approximation.

Since the original technique of anterior component separation was described, many variations have been made, mostly to avoid the morbidity associated with extensive cutaneous flaps. Even in the open technique perforating vessels

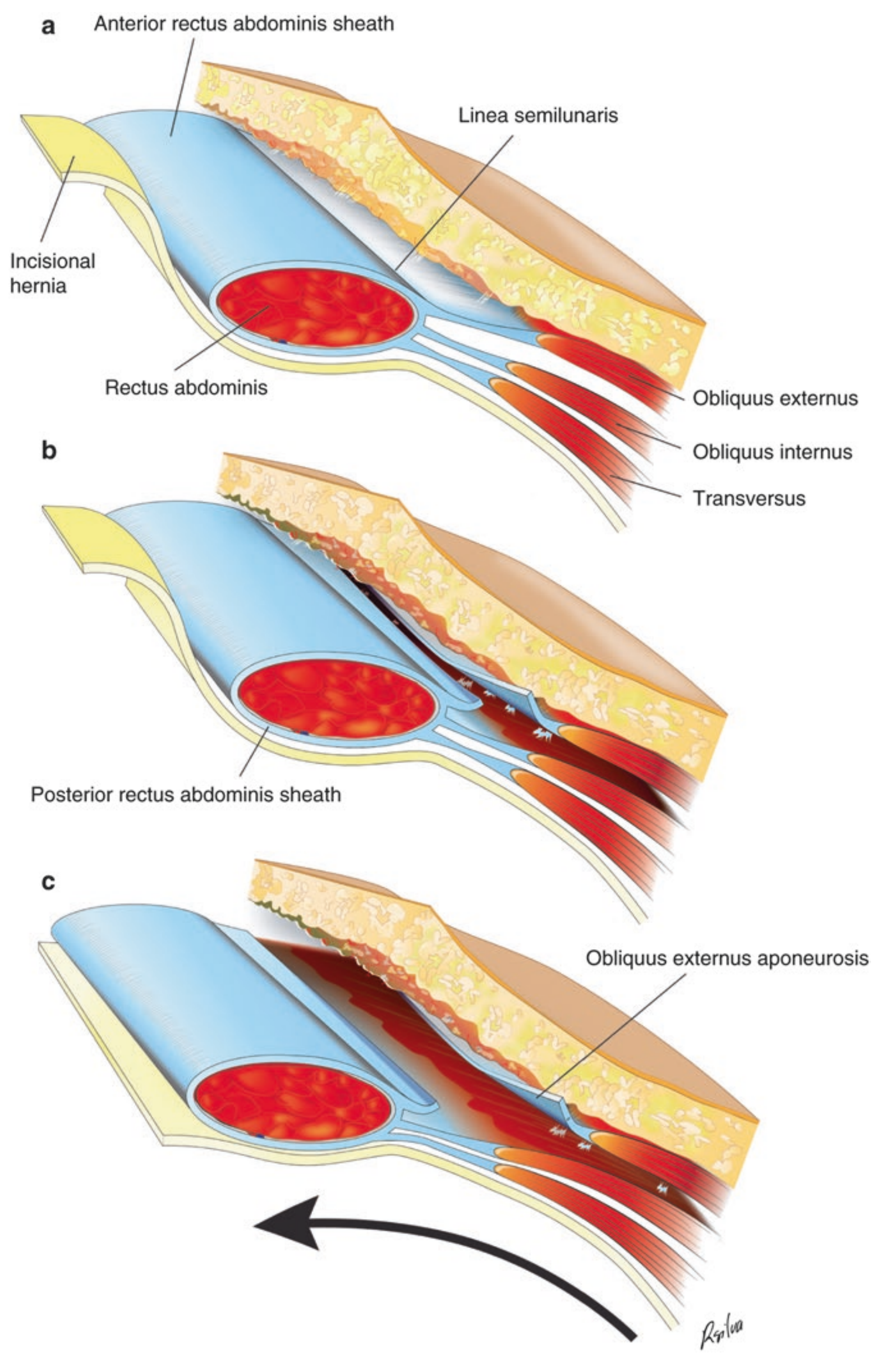

Fig. 14.1 (**a**) Normal anatomy of the abdominal wall. (**b**) Section of the external oblique 1–2 cm lateral to the semilunaris line. (**c**) Dissection of the external oblique muscle from the internal oblique in order to allow the muscle complex formed by the rectus–internal oblique—transversus abdominis to slide towards the abdominal midline

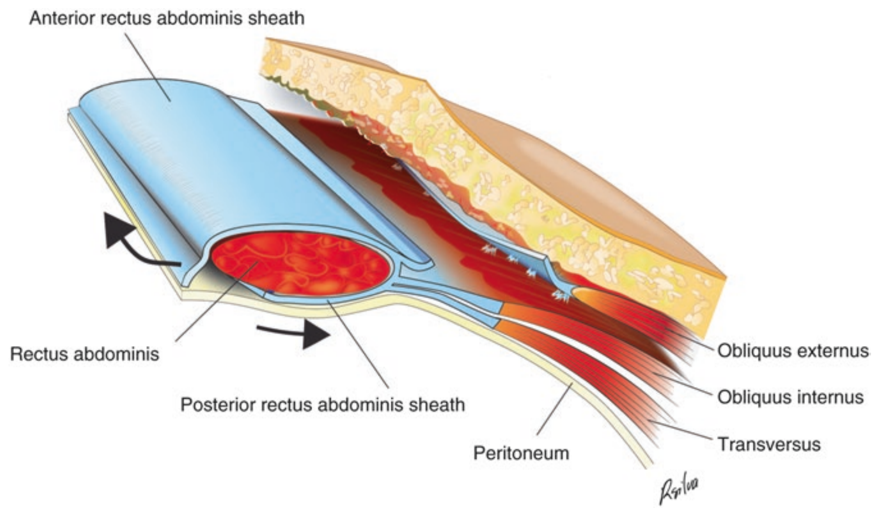

Fig. 14.2 Section of the posterior rectus sheath to allow extra mobilization of the rectus complex

must be preserved in order to avoid skin ischemia, significantly lowering the morbidity of the procedure [27, 28].

Open anterior component separation is still an important armament for the abdominal wall surgeon in difficult cases, moreover for those defects that reach the lateral abdominal wall. Nevertheless the significant associated skin related morbidity, even with perforator preservator, must be taken into consideration.

Minimally Invasive Anterior Component Separation Technique

Introduction

When it comes to defining minimally invasive anterior component separation, a wide range of different techniques appears in the literature instead of a single well-defined approach. This concept can be divided into two large subgroups with a fundamental distinguishing characteristic: the use or not of video-assisted equipment to perform fascial dissection. In order to understand the different techniques under the same general name we have summarized the surgical approaches and descriptions based on these two subgroups.

Minimally Invasive Component Separation Technique Without the Use of Video-Assisted Equipment

To avoid the large skin flaps and injury to perforating vessels, smaller incisions can achieve the same final goal on the release of the external oblique fascia. Dumanian et al. use a transverse subcostal incision to gain access to the external oblique fascia and perform the component separation under direct vision and their release takes about 15–20 min [15]. Buttler and Campbell also published their data on approaching the external oblique fascia through a tunnel created from the midline incision, avoiding two additional lateral incisions [29]. In this study, comparison to other methods is difficult, given that no description of operative times for the component separation alone, was reported.

It is necessary to have in mind that all these approaches are in fact less invasive, with lower complication rates than classical open techniques but they do not use video-assisted equipment and therefore need bigger incisions.

Video-Assisted Anterior Component Separation Technique

Many different names are used under the same basic technical principles as endoscopic component separation, video-assisted component separation, and laparoscopic component separation. *Laparoscopy* derives from the Greek words *lapara*, which means "the soft parts of the body between the rib margins and hips" or "loin," and *skopeo*, which means "to see or view or examine" [30]. By analogy with laparotomy it generally implies the entrance in the abdominal cavity in order to examine or make a procedure inside the abdomen, which actually does not happen in the anterior component separation technique although the same surgical material is used. *Endoscopy* is derived from the Greek word *endon* "within" and *skopeo* "examine" [30]. Usually procedures take place through the endoscope itself with imaging guidance through imaging projection on a screen and actually some minimal invasive component separation are done by this method. Video-assisted surgery is a procedure that is aided by the use of a video camera that captures and projects the image on a screen. It is our opinion that despite the points of truth in every designation, the one that most accurately corresponds to anterior component separation is video-assisted (although it uses laparoscopic material) and will be described later in this chapter.

Comparing Results from Different Anterior Component Separation Techniques

When comparing anterior component separation techniques there appears to be a general consensus regarding the beneficial effects of minimally invasive techniques compared to open anterior component separation, specially regarding post-operative pain and skin complications [31–35]. However, one of the main questions posed is if minimally invasive anterior component separation technique can offer the same rectus advancement as the open technique. Knowing that the release of the external oblique fascia alone does not promote complete advancement, it is mandatory to add the dissection of the external from the internal oblique muscle, moving the external oblique as laterally as possible, usually to the posterior axillary line. Rosen et al. have used a porcine model and demonstrated an average of 86% of the myofascial advancement with video-assisted component separation compared with a formal open release [36]. To our knowledge no similar comparative study exists between different minimally invasive techniques.

Regarding comparison of operative times, rectus complex advancement, complications, and costs between the different minimally invasive procedures studies are definitely needed. One of the problems pointed out in the video-assisted approaches are the costs and extra material involved when compared to the minimally invasive procedures without video-assistance. Rosen et al. reported that the total direct costs associated with video-assisted and open anterior component separation technique were actually similar because other issues are more important to global cost [37]. In fact, these patients usually represent extremes instead of daily realities and many other factors account for global cost and success such as the use of synthetic or biological meshes, post-operative complications, and hospital length of stay.

Pre-operative Care

Treating massive and complex abdominal defects does not start on the day before surgery. It is usually a long curvy path until final reconstruction and many issues should be anticipated with meticulous surgical strategy. A detailed plan with alternative options should be used for successful closure in these challenging situations.

When using complex abdominal reconstructive techniques in the open abdomen it is important to make sure all the intra-abdominal problems are resolved. The use of CT or other appropriate imaging is helpful and adequate. In these critically ill patients it is very important to assure they are in the recovery phase of their illness, with fluid control for an optimized negative fluid balance, good nutritional status, and exclusion of any major infection. Although surgical aggression promotes another catabolic phase before the final recovery phase, the closure of the open abdomen ends a vicious cycle of pro-inflammation. With this in mind, the patient should be at his best physiological status before reconstructive surgery.

Nutritional status is essential for the post-operative recovery and should never be underestimated before any kind of major abdominal reconstruction. Special consideration should be addressed towards the high output intestinal fistula. The intestinal rehabilitation previous to surgery is often a challenging difficult step for the patient, the family, and the physician. Dealing with high output enterocutaneous fistulae is an extra burden for a physically and mentally exhausted patient. Even when no nutritional parameters are altered except for weight lost over 10%, their physiological reserve is at the limit. These individuals may not be able to recover well after surgery, increasing the probability of infection, anastomosis breakdown, poor wound healing, and should be managed in an experienced unit [38].

Determining the size of the defect is a critical step for meticulous detailed surgery preparation and future success. Our measurement is estimated in two ways: (a) transverse and longitudinal measurements when the patient is lying down in the supine position. These parameters allow the calculation of the area of the hernia equivalent to that of an ellipse; (b) measurement of the defect with a CT scan in every patient prior to surgery. It is our experience that CT measurement is usually smaller comparatively to directly measuring the patient either pre or intra-operatively. However, CT scan measurements are more objective limiting any surgeon bias [15]. Another important aspect of ordering a CT scan before every reconstruction is the evaluation of the abdominal wall muscles status given that true successful anterior component separation technique relies on the integrity of these muscles. Therefore CT imaging and 3D CT reconstructions may be helpful to fully access the complexity of the abdomen and properly plan surgery and are used by the authors in any major reconstruction [39] (see Fig. 14.3).

When dealing with planned ventral hernias with previous skin graft, it is best to allow enough time before reconstruction, usually 9–12 months [38, 40], in order to lower the risk of bowel injury during adhesiolysis (see Fig. 14.4). Closure of patient skin without any grafts can be approached earlier.

Assessing healthy skin status is essential for a good outcome and independent from the reconstruction of the abdominal wall. It is crucial to anticipate lack of skin coverage and adequate surgical technique either through skin expanders or flaps.

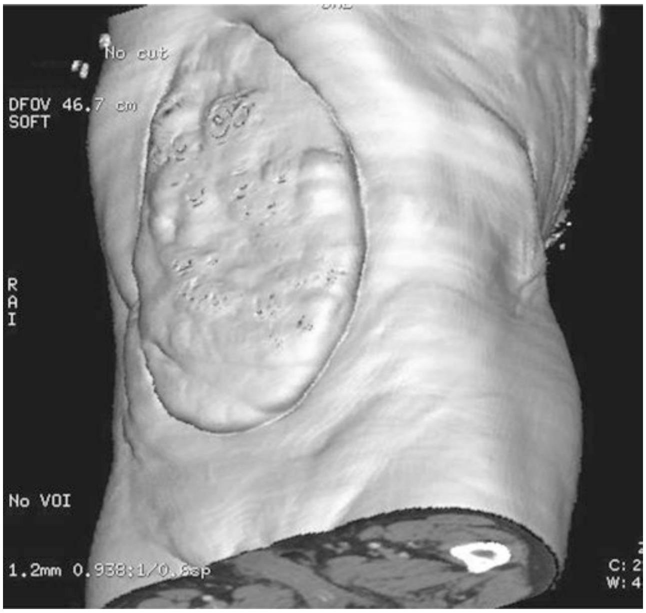

Fig. 14.3 CT 3D reconstruction as a tool for pre-operative surgical technique programming

Fig. 14.4 Skin pinch of the mature graft

Whenever possible, consideration must be taken to include the management of bowel and abdominal reconstruction in a single step or a two-step approach with bowel reconstruction before the definitive repair of the abdominal wall in order to avoid a contaminated procedure that may increase post-operative morbidity. This, however, has its risk, as patient will undergo two major operations. The authors experience, just as reported by others, that "one-stage" procedures are viable and, with the exception of superficial skin infections, do not increase morbidity [19, 20, 41].

Risk factors should be accessed and specially those known in the literature to predict post-operative complications like obesity, smoking, chronic pulmonary lung disease, immunosuppression, and diabetes [42]. The authors promote respiratory optimization/rehabilitation that prepares patients for a faster and uneventful post-op recovery.

Contamination also plays a role in pre-operative planning. Potential contamination may be expected with a previous wound infection, either superficial or deep, presence of a stoma or violation of the gastrointestinal tract. The presence or potential for contamination play a role in choosing the adequate mesh, at times in favor of a biologic, but there is still no consensus for the choice between a synthetic, biosynthetic, or biologic mesh [38, 43, 44].

During the anesthetic procedure it is extremely important to reduce intra-operative fluids to strictly the necessary amount. Goal-directed fluid policy has proven to be useful in reducing bowel edema and post-operative complications in a number of surgical areas [45]. We think this concept can also be safely applied when dealing with abdominal closure of massive defects. Good muscle relaxation is mandatory during the procedure in order to avoid excessive tension and technical difficulties. Thoracic epidural analgesia should be the standard of care as recent studies show a positive effect in lowering the intra-abdominal pressure. This type of specific analgesia leads to abdominal muscle relaxation lowering the risk of pulmonary associated complications. It is also associated with less post-operative complications in AWR [46].

Antibiotics are given 30 min prior to the beginning of surgery (except for vancomycin which is given 2 h before) and the choice depends on the type and degree of contamination of the wound and previous results of microbiologic cultures.

Finally, the surgery should be reviewed with the patient in order to discuss real patient expectations regarding cosmetic issues, because, eventhough almost always improved, they are definitely not the main goal of the surgery.

The success of this surgery requires on careful planning, attention to details of details and early involvement of other specialties as anesthesiology and the Intensive Care specialist when necessary in the whole process.

Surgical Technique

Clear pre-operative landmarks are drawn on the abdominal wall. This allows everyone on the team to perceive the anatomic landmarks and major defects, facilitating understanding and communication (see Fig. 14.5).

Step 1

Start with a 1–2 cm incision under the tip of the 11th rib, usually on the anterior axillary line. Continue dissection of the anatomical planes until the external oblique fascia is identified (see Fig. 14.6). Open the muscle fascia and make a blunt dissection of the underlying plane, between the external and internal oblique, in order to make Step 2 easier (see Fig. 14.7).

Fig. 14.5 Abdominal wall anatomical landmarks and defect (Fig. 18.6 from previous edition)

Fig. 14.8 Insertion of the trocar balloon for blunt dissection of the avascular plane between the external and internal oblique muscles

Fig. 14.6 Opening of the external oblique muscle fascia through a 1–2 cm incision on the tip of the 11th rib

Fig. 14.9 Connection of the CO_2 insufflator

Fig. 14.7 Blunt dissection of the underlying plane of the external oblique, making insertion of the trocar balloon easier

Step 2

Insert the trocar balloon (Spacemaker™ Plus Dissector System—Covidien, Dublin, Ireland) (see Fig. 14.8). After creating an avascular plane with blunt dissection between the muscles with the trocar balloon, connect it to the CO_2 insufflator aiming for an 8–12 mmHg pressure (see Fig. 14.9). Introduce a 10 mm 30° camera after removing the balloon (see Fig. 14.10).

Step 3

Introduce a 5 mm trocar at the level of the posterior axillary line, in order to have a good dissection angle (see Fig. 14.10).

Make sure to identify the area above, the line of the fascia of the external oblique, 1 cm lateral to the semilunaris line, and cut the external oblique fascia all the way to the inguinal ligament (see illustrative Fig. 14.11). It is extremely important not to cut the semilunaris line or else a very complex defect will result.

Step 4

Introduce another 10 mm trocar in the right iliac fossa in order to extend the component separation 5–6 cm above the costal margin. Here it is important to use a cautious haemostatic dissection, as the muscular fibers tend to bleed.

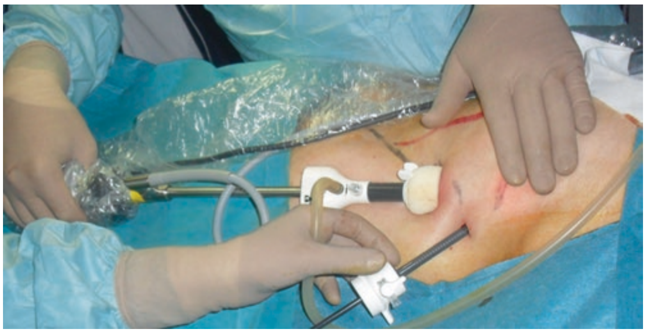

Fig. 14.10 Insertion of a 10 mm 30° camera and introduction of a working 5 mm trocar in the posterior axillary line as it's a difficult working angle

Step 5

It is important along the process to make sure the external oblique is well dissected from the internal oblique in order to achieve the best rectus advancement.

Step 6

Sealed suction drains are placed through the most caudal trocar incision at the end of the surgery.

If a totally laparoscopic procedure is planned the surgery will proceed laparoscopic, midline closure is achieved in a shoelace manner, and a double layer mesh in an IPOM fashion is applied.

In massive defects laparoscopy is almost always technically challenging and not feasible. So, after video-assisted component separation the authors open the midline, and takedown any adhesions present which is many times a lengthy and meticulous job. Afterwards make the dissection of the posterior rectus sheath, close it with running suture long term absorbable monofilament 2/0 and preferably apply a retrorectus mesh and close anteriorly the linea alba.

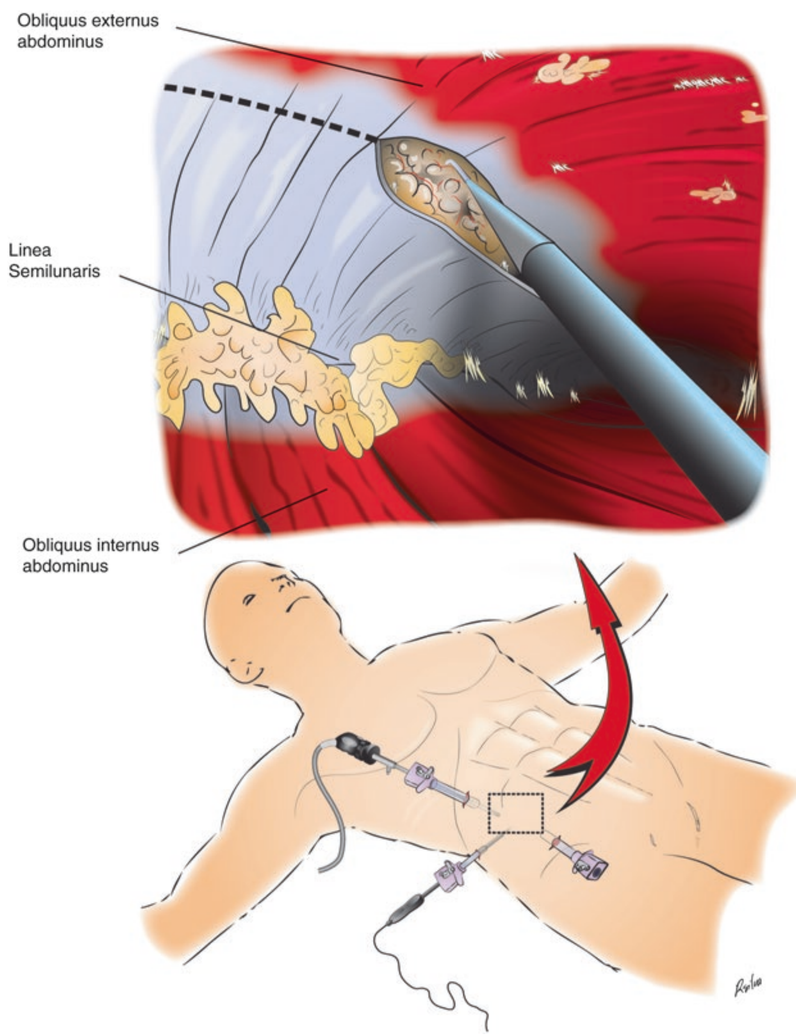

Fig. 14.11 Trocar placement view and image projected on the screen. Section of the external oblique fascia lateral to the semilunaris line

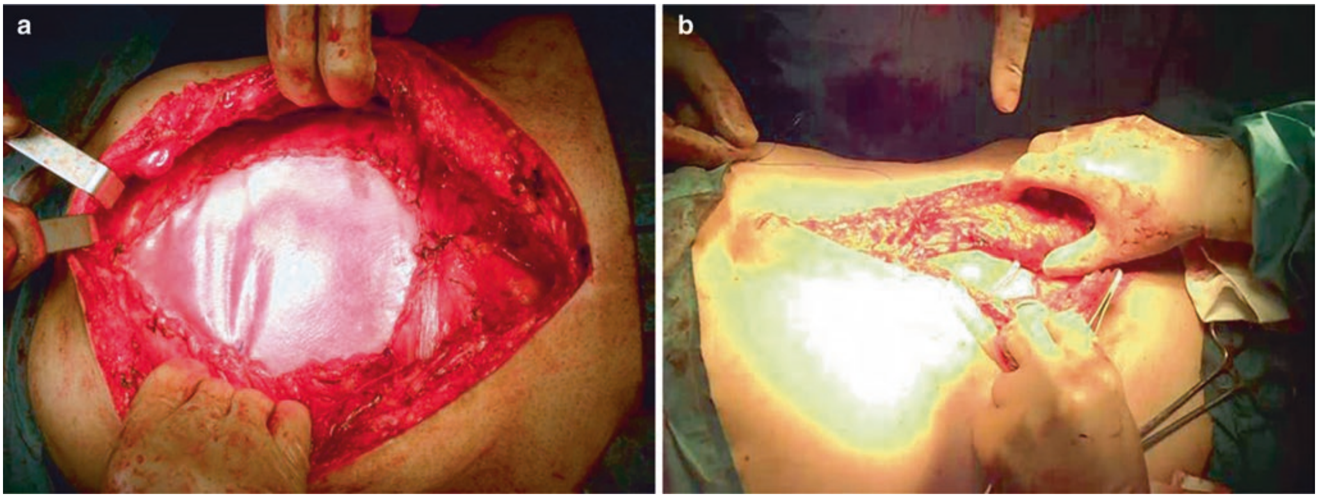

Fig. 14.12 (**a**) Dissection of the posterior rectus sheath. As it was impossible to close the sheath in the midline, a biological mesh was placed intraperitoneally and fixed with transabdominal sutures. Inferior partial closure of the posterior sheath was performed, with a running suture over the mesh. (**b**) Anterior rectus sheath closure with a running suture over a closed-suction drain

Sometimes it is not possible to totally close the posterior sheath but its mobilization allows us an extra few cm to achieve the necessary mobilization of the muscle complex formed by the rectus-internal oblique-transversus to slide over the midline and achieve closure (see Fig. 14.12a, b). When midline closure is not feasible then an IPOM procedure is made, with transfascial mesh fixation in the cardinal points and closure of fascia over mesh in order to diminish the bridging defect as much as possible. This can be challenging to achieve after a video-assisted component separation that lack the large skin flaps of open procedures. We use a "clock," transabdominal technique, to secure the mesh with 12 corresponding "hour" sutures. The sutures are secured to the mesh and then passed through the abdominal wall with a suture passer. Some authors find it useful to introduce the laparoscope intra-abdominally at the end of the surgery and secure the rest of the mesh with tackers [47]. This may diminish the risk of bowel entrapment and difficulty in mesh incorporation which leads to increasing associated complications but it is not technically feasible for biologic meshes.

Either way, for proper abdominal wall reconstruction it is extremely important to have wide mesh overlap of the abdominal defect under correct physiological tension. Floppy mesh will increase complications as seromas, poor mesh integration, and in bridged defects, specially with biological meshes, a budging will be seen.

The skin is usually closed with staples and incisional negative pressure wound therapy is used for all the major AWR surgeries. Still there is no established evidence that this procedure reduces wound complications but there are some literature pointing that way [48, 49].

Post-operative Care

As previously explained, effective analgesia, ideally with a thoracic epidural catheter, is extremely important for a good outcome. This aids in avoiding intra-abdominal hypertension (IAH) and also helps to prevent respiratory complications, specially in patients with chronic obstructive pulmonary disease (COPD).

After correction of massive hernias with loss of domain there is always a concern that the return of abdominal contents to its cavity may induce diaphragmatic compression and raise the intra-abdominal pressure, leading to an eventual abdominal compartment syndrome. Agnew et al. published data from abdominal volumetric studies that proved the existence of significant increased volume after anterior component separation, providing less pulmonary restriction and consequent complications [50]. Care is taken to administer to high risk pulmonary patients respiratory kinesiotherapy in the early post-operative period and in many cases, pre-operatively.

Unless patients are admitted to the intensive care unit (ICU) they sit up 6–12 h after surgery. Walking, as early as post-operative day 1, is incentivated.

Drains are usually left in place until less than 30 mL a day output is achieved.

Most of the patients submitted to minimally invasive anterior component separation, although going through a major abdominal wall reconstruction, recover faster and with less morbidity than those with an open technique. Most of the differences between the two groups are due to greater skin complications and post-operative pain in the open group. Usually patients are discharged around the sixth or seventh post-operative day physically active and doing situps. Longer hospital stays are usually related to previous co-morbidities instead of the procedure itself. Heavy physical activity is usually postponed until 6–8 weeks after surgery but the cutoff depends on individual characteristics and type of surgery.

Special Cases

The Open Abdomen

A vast majority of open abdomens are primarily closed without planned ventral hernias. Yet, in some cases this is simply impossible, specially in severe abdominal trauma or in a non-trauma setting with abdominal catastrophes. When closure cannot be achieved easily by suturing fascia, some techniques may be used to gradually assist in the closure of the abdomen with associated negative pressure wound closure. Negative pressure wound therapy with mesh mediated fascial closure is the preferred method of the authors [51–53]. Even with these procedures there are some cases where ventral hernia repair must be avoided and these techniques cannot be applied or were used without achieving the goal of primary abdominal closure. In this setting component separation technique can be used to achieve primary closure, usually with biological mesh reinforcement.

In order to achieve maximum results from this technique it is extremely important that the open abdomen be a Grade I or II [54]. This represents an abdominal wall without adhesions to the underlying bowel. Only in this manner can a complete abdominal rectus complex advancement be achieved (see Figs. 14.13, 14.14, and 14.15). If the patient has a temporary stoma and an open abdomen, it is best to save component separation for the definitive surgery.

Even in difficult cases such as cirrhosis with ascites, minimally invasive component separation technique can achieve abdominal physiological closure with low morbidity (see Figs. 14.16 and 14.17a, b), but mostly depends on institutional expertise.

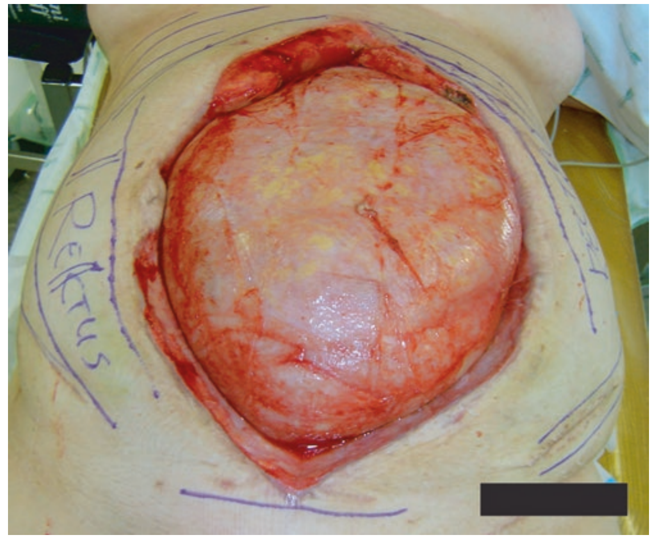

Fig. 14.13 Open abdomen Grade IIa with a massive defect after post-operative shock due to a large spontaneous retroperitoneal hematoma. Previously treated with ABTheraTM–(KCI, San Antonio, TX)

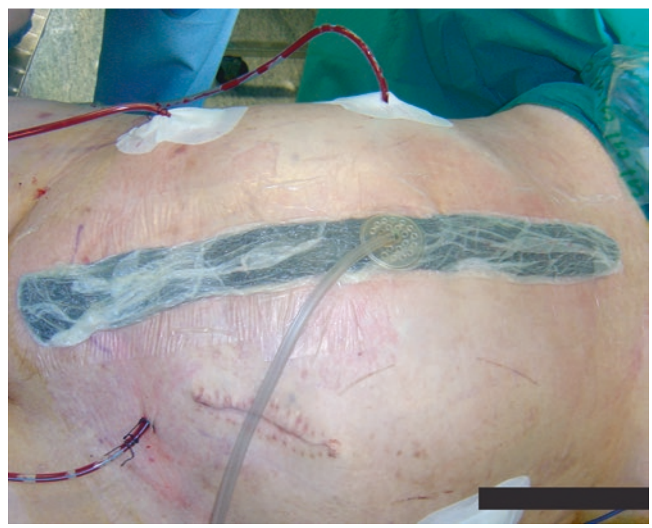

Fig. 14.14 Abdominal reconstruction with minimally invasive component separation on the right and open component separation technique with perforating vessel preservation on the left due to a previous stomal hernia repair with synthetic mesh that was removed during the laparostomy. Underlay biological mesh with some degree of bridging was necessary to achieve reconstruction. Skin closure with staples and negative pressure wound therapy (V.A.C.® GranuFoam™ with silver gaze interface) applied to the wound due to high risk of infection

The Use of Chemical Component Sepration and Tissue Expanders

Some patients with massive abdominal wall defects are expected to have significant abdominal wall retraction and fibrosis minimizing the advancement of the rectus muscle during component separation. In these cases tissue expanders prior to surgery could aid in obtaining a successful reconstruction [55, 56]. In order to achieve major rectus advancement, tissue expanders were placed between the internal and external oblique muscles and are gradually filled up to 4 months. This will create a foreign body response and a thick fibrotic capsule. When video-assisted component separation is performed the anatomical landmarks are distorted, and minimally invasive procedure is difficult and not feasible. Currently the authors no longer use tissue expanders between muscles and when there is a need for "loosening" of the abdominal wall muscles we prefer a chemical component separation.

Fig. 14.15 (**a**) Two months after surgery, fully recovered with a functional abdominal wall even during abdominal contraction while standing up from the supine position. (**b**, **c**) 4 years after AWR. Needed a second intervention 3 years after the AWR to do a rectus plicature due to some bulging

When tissue expanders are subcutaneously inserted due to lack of skin, the video-assisted component separation is not compromised and may be performed in a standard manner (see Figs. 14.18 and 14.19).

Stomas

There are few reports in the literature reporting the use of minimally invasive anterior component separation technique and stomas. Rosen et al. described the use of myofascial advancement flap combined with other techniques for the simultaneous repair of large midline incisional and parastomal hernias, with good results [57]. In our experience a pre-operative CT assessment determining the position of the stoma is critical for decision-making. A trans-rectus and not a para-rectus stoma must exist to proceed for a video-assisted anterior component separation technique, otherwise bowel injury and complex defects may result. When relocation of the stoma is best warranted, the procedure must start with a minimally invasive procedure on the future side of the stoma. After re-location of the stoma a safer component separation

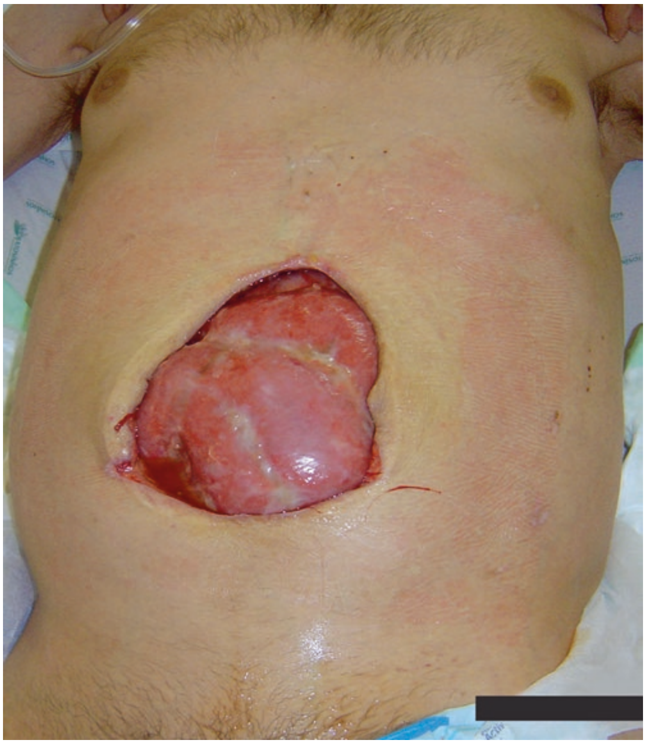

Fig. 14.16 A cirrhotic patient with multiple eviscerations and infected ascites after a strangulated umbilical hernia and small bowel resection. Child-Pugh B score

can also be performed on ipsilateral side with adequate mesh reinforcement.

Previous Anterior Component Separation

Repeating an anterior component separation is feasible but poorly described in the literature. The main issues are the real value of successful recurrent hernia repair adding a new anterior component separation and the possibility of achieving it by another minimally invasive procedure since fibrosis is expected. It appears that for these complex cases the best solution may be in fact a posterior component separation with TAR [58].

Summary

Minimally invasive anterior component separation technique is a feasible and reproducible technique. This procedure allows, in some large defects, the restoration of the abdominal midline, helping to promote a more physiological abdominal reconstruction. If complete midline restoration is not possible, component separation helps in reducing the abdominal wall defect, decreasing the amount of mesh material necessary for a bridge repair, respecting as much as possible the physiology and movement of the abdominal wall.

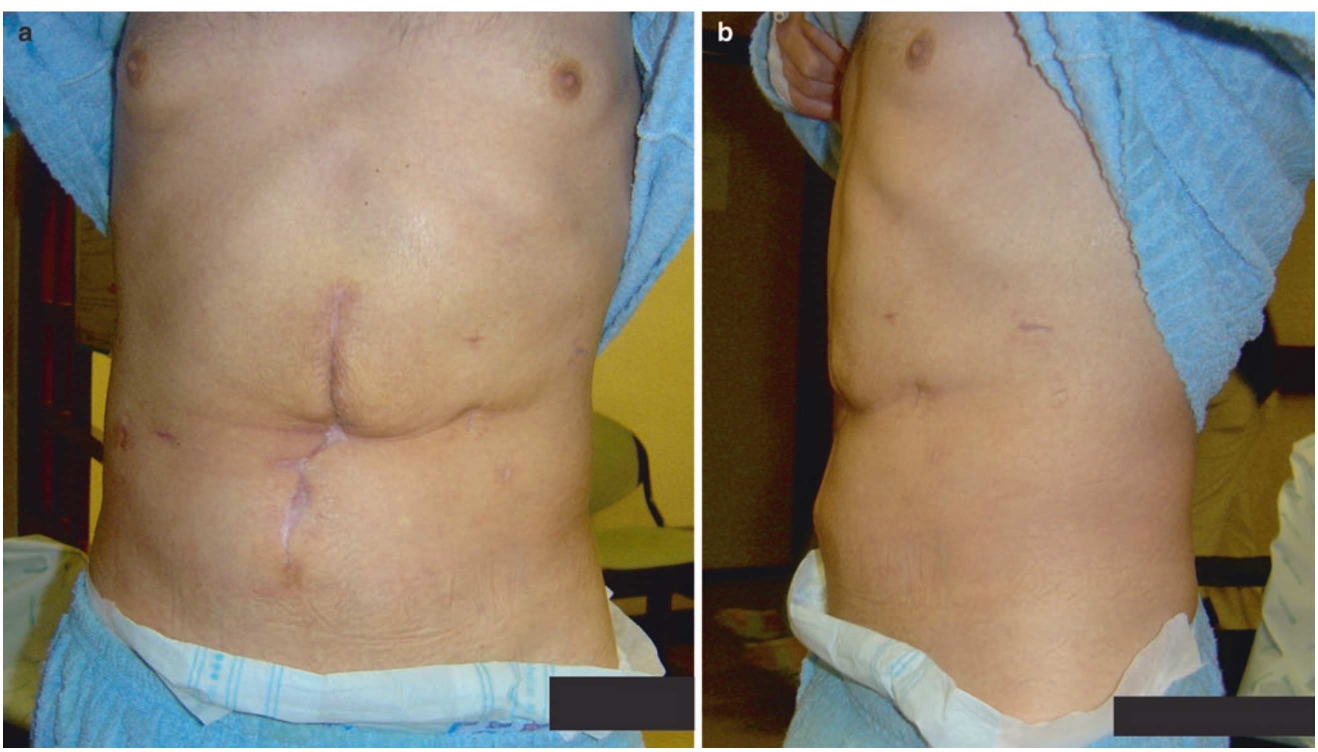

Fig. 14.17 (**a**, **b**) Seven weeks post-operatively after video-assisted component separation technique achieving midline closure and reinforcement with biological mesh

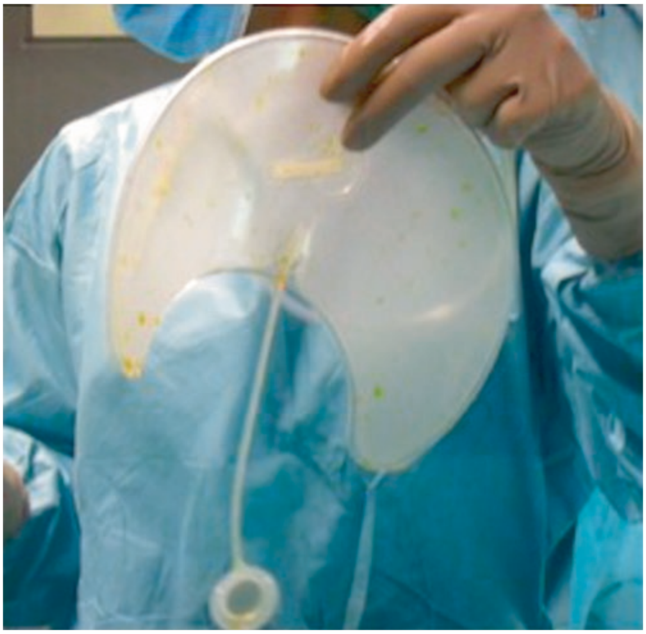

Fig. 14.18 Tissue expander used nowadays only for cases when there is lack of skin

Fig. 14.19 Complex ventral hernia with subcutaneous tissue expanders

Minimally invasive anterior component separation technique has many advantages over open identical techniques avoiding large skin flaps and consequent wound healing related problems. More studies are still needed to compare different minimally invasive techniques regarding advancement myofascial flaps and costs are also needed.

Finally, it is important to keep in mind that a minimally invasive anterior component separation technique is just a helpful part of a puzzle in the treatment of large and complex abdominal defects. Proper planning and attention to details are important for successful achievement and the abdominal wall surgeon must master several techniques in order to give the best possible result for a specific defect in a unique patient.

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Abdominal Wall Reconstruction in the Pediatric Population

15

Emma C. Hamilton, Richard Andrassy, and Mary T. Austin

Introduction

Congenital abdominal wall defects present an interesting challenge to surgeons. Surgical management of these entities has changed over the past 50 years with no single method emerging as the best treatment option [1]. The eventual objective is to complete fascial and skin closure without undue tension or excessive abdominal compartment pressures. Three broadly defined strategies have emerged to address closure of these defects: immediate primary closure, staged closure, and delayed closure [2]. Patient factors and surgeon's experience and judgment influence the decision to follow a specific strategy and surgical technique.

History

Abdominal wall defects were first described by Aulus Cornelius Celsius in Rome during the first century AD [3]. The first successful treatment of an omphalocele was described by William Hey in 1772 with primary reduction and application of a compress for several weeks [4]. He also developed a truss in 1791 to maintain constant gentle pressure on a reduced omphalocele until spontaneous closure. Clarence Visick described the first surgical repair of a ruptured omphalocele in 1873. After reduction of the intestines, the skin was closed with wire sutures [5]. Shortly thereafter, Olshausen reported removal of the peritoneum and skin flap coverage over the defect. In the mid-twentieth century, Gross popularized staged closure for large omphaloceles with freeing and approximating of the skin over the intact sac. A second staged operation was then performed at 6–12 months of age [6]. However, secondary ventral hernia repairs were often complicated by adhesions between the bowel and skin. This observation led Schuster and others developing the use of a prosthetic Teflon patch fashioned into a silo in the initial operation to aid in the reduction of the viscera [7, 8]. Schwartz later described using Silastic sheeting sutured to form a sac with gradual daily reduction for gastroschisis and omphaloceles [9]. The development of a preformed Silastic silo (Dow Corning, Midland, MI) with a spring-loaded ring (Ben Tec, Sacramento, CA) in the 1990s revolutionized the ease and simplicity of staged reduction for gastroschisis [10]. The so-called paint and wait technique for large omphaloceles was first described in 1899 by Ahlfeld who used alcohol to produce an eschar and epithelialization [11]. Mercurochrome replaced alcohol as the agent of choice until the detrimental toxic effects of mercurochrome were described [12–15]. Hatch and Baxter [16] first reported the use and safety of silver sulfadiazine for escharotic therapy in 1987. Silver sulfadiazine has since become the preferred topical agent for epithelialization [17]. Innovative methods to gradually reduce omphaloceles and increase abdominal domain include the use of tissue expanders and negative pressure wound therapy [18, 19].

Gastroschisis

Epidemiology

Gastroschisis is a full thickness defect of the abdominal wall that occurs to the right of the umbilicus. The prevalence of

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gastroschisis has increased since the 1980s, especially among young mothers. The estimated prevalence between 2006 and 2012 was 4.9 per 10,000 live births overall and as high as 18.1 per 10,000 live births among mothers <20 years [20]. The underlying cause for this increase in prevalence has not been identified. [21] While the exact mechanism of gastroschisis is unclear, the etiology is believed to be multifactorial and caused by genetic , environmental, and maternal factors [22]. Risk factors associated with gastroschisis include younger maternal age, low socioeconomic status, poor nutrition, smoking, illicit drug use, alcohol, analgesic medicines (salicylates, ibuprofen, and acetaminophen), decongestants (phenylpropanolamine and pseudoephedrine), and genitourinary infection [22–26].

Surgical Management

Initial management after delivery focuses on reducing evaporative losses of water from exposed bowel and preventing volvulus and ischemia. The quickest and easiest method is to place the exposed viscera and lower half of the infant in a plastic bag ("bowel bag") and place the infant on their right side for transport [27]. Alternatively, the herniated bowel can be wrapped in clingfilm, stabilizing it over the middle of the abdomen. The infant is then placed on the right side for transport to prevent kinking of the mesentery [1, 28].

Definitive management of the bowel should be undertaken as soon as possible. The primary goal of surgical management is the reduction of viscera into the abdominal cavity while minimizing further trauma or ischemia to the bowel. Management techniques include immediate operative closure, ward reduction and closure without general anesthesia, and silo placement with delayed operative or sutureless closure [1, 28, 29].

Historically, emergent surgery for primary fascial closure under general anesthesia was advocated for all patients. Staged reduction and delayed closure was reserved for when the bowel could not be safely reduced and for those patients who were unstable, had significant intestinal damage, or had large defects [28, 30–32]. However, in several centers, the spring-loaded preformed Silastic silo is routinely placed at the bedside on arrival of the patient [33, 34]. Gravity, compression, traction, and expansion are the four main forces used in staged reduction [1]. This technique has the theoretical advantage of preventing intra-abdominal hypertension and can be placed at the bedside without the need for general anesthesia.

The safety of reduction is related to the degree of viscero-abdominal disproportion and the risk of increased intra-abdominal pressure [35, 36]. In practice, many surgeons have used non-invasive methods such as end-tidal CO2, peak inspiratory pressure, and pulse oximetry to gauge the risk for intra-abdominal hypertension while others have relied on more subjective measures such as bowel color and abdominal wall tension [35, 37, 38]. Other more invasive means of estimating the risk for intra-abdominal hypertension include measuring intra-vesicle pressure, inferior vena cava (central venous) pressure, gastric pressure, and gastric tonometry [35, 39–41]. Small single center studies have demonstrated that primary closure can safely be achieved when bladder pressure is <20 mmHg [35, 39, 42]. However, few surgeons routinely rely on invasive measurements to monitor intraabdominal pressure at the time of closure [29, 43–45].

The debate of the safest way to reduce and close gastroschisis defects is ongoing. Some surgeons advocate for routine staged reduction with use of a preformed silo and delayed closure in all patients to avoid complications associated with sudden increase in intra-abdominal pressure [33, 34, 46]. Others have cited increased infection, hospital length of stay, and increased ventilator days with prolonged use of silos as reasons to reserve silos for those cases when primary closure is not possible [47–50]. However, retrospective and prospective randomized multi-institutional studies have demonstrated no significant difference in most outcomes based on closure method, especially when silo use is limited to <5 days [43, 45, 48].These varied findings suggest that neither technique is clearly superior for uncomplicated gastroschisis.

Primary Closure

With primary reduction and operative fascial closure under general anesthesia, the infant is brought to the operative suite as soon as possible after birth for definitive closure. While some surgeons recommend normal saline or Gastrograffin enemas and milking of the bowel prior to attempted primary closure, later studies found no benefit and similar primary closure rates and ventilator requirements [30, 31, 51]. Placement of an orogastric tube is adequate for decompression. The patient is prepped with povidone-iodine and draped in standard sterile style. The bowel is closely inspected to identify any obstructing bands, perforation, or atresia. Obstructing bands should be divided before placement of the bowel back into the abdominal cavity. Some surgeons recommend manually stretching of the abdominal wall in posterior-to-anterior direction in all quadrants [30, 31]. The skin edge of the right side of the defect is then elevated off of the underlying fascia. The defect opening can also be widened a few centimeters if it is very small. The umbilical vessels and urachal remnant are identified, ligated, and divided. To reduce the bowel, the umbilical cord is held up and the bowel gently reduced one loop at a time until all of the intestines have been returned to the abdomen. Care must be taken not to twist the mesentery as the bowel is reduced. To close the fascia, 2-0 non-absorbable mattress sutures are placed through the rectus abdominus muscles without tying them. The sutures can then be pulled together to see how the patient will tolerate fascial closure, as determined by increased end-tidal CO_2, increased peak inspiratory pressure, desaturation, increased bladder pressure, or increased gastric pressure [35, 37–41]. If it appears that the patient will tolerate closure safely, the sutures are tied in place. The skin is often ragged and loose and multiple techniques have been developed to improve the cosmetic appearance after closure. It often suffices to close the skin incision with a subcuticular purse-string using an absorbable monofilament suture (Fig. 15.1) [30, 31].

Staged Reduction and Closure

Although several methods and materials for staged reduction have been developed over the years, most surgeons utilize preformed silos with a spring-loaded ring [10, 29, 33, 34, 43, 46, 52]. The Silastic preformed spring-loaded silo comes in a variety of diameters and can be placed at the bedside upon arrival of the patient without the need for general anesthesia. Before placement of the silo, it is important to closely inspect the bowel. Absolute contraindications for bedside placement include any perforation or necrosis [29]. Obstructing bands and adhesions from the fascia to the bowel are gently disrupted with manual blunt dissection, electrocautery, or sharp dissection. The bowel is then gently pushed up into a preformed Silastic silo and the base of the spring-loaded ring slipped beneath the fascial defect (Fig. 15.2). In some instances, the fascial defect may be small and require widening either laterally or vertically in the midline in the operating room before placement of the silo. In these situations, the preformed silo cannot be utilized and a custom silo must be fashioned and sutured to the fascia. It is important that no twisting of the mesentery occurs during placement into the silo. The silo is then suspended above the bed to provide upward traction on the silo and the abdominal wall. The bowel will begin to reduce with gravity alone during the first 24 h after silo placement. The viscera is progressively reduced either daily or twice daily with sequential ligation of the silo using umbilical tape, an umbilical cord clamp, or silicone tubing with a slipknot [1, 33, 34, 43, 53]. The transparency of the Silastic silo allows continuous inspection of the bowel for any changes in perfusion. In the event of bowel ischemia, the fascia may be enlarged and a larger silo applied or a custom silo can be created and sewn to the fascia [1, 29]. Complete bowel reduction usually occurs by 4–7 days after silo application [29, 33, 43]. Once the bowel is completely reduced, the fascial defect is closed primarily in the operating room [33, 43]. If the defect cannot be closed primarily, a synthetic or biological patch can be used [1, 33, 34, 54].

Sutureless Closure

An alternative to primary fascial closure is primary reduction with a "plastic" sutureless "flap" closure of the abdominal wall defect using the umbilical cord. After reduction of the bowel, the umbilical cord is laid over the small residual defect and held in place with an adhesive dressing (Fig. 15.3) [55]. The technique was first described by Bianchi in Dickson [56] in 1998 and later modified by Kimble [57] and Sandler [55]. At our institution, we have adopted the use of a negative pressure wound vacuum to aid in closure [58]. The umbilical cord is tailored to fit into the abdominal wall defect and covered with a non-adherent dressing (Adaptec, Johnson and Johnson, Langhorne, PA). The black foam (KCI, San Antonio, TX) is then cut to an appropriate size and applied directly over the wound bed and secured in place using clear adhesive film. The Trac pad (KCI, San Antonio, TX) is then applied over the black foam and placed to 50 mmHg continuous suction. The wound vacuum is removed on postoperative day 5 and the umbilical cord is allowed to desiccate.

The use of sutureless closure has gained popularity since the early 2000s. Compared to fascial closure of the defect, sutureless closure is associated with equivalent outcomes [59]. A recent meta-analysis of twelve studies demonstrated that there were no significant differences in mortality, length of stay, and days on TPN between patients who had suture-

Fig. 15.1 Primary closure (**a**) Newborn with simple gastroschisis (**b**) Primary fascial closure (**c**) Purse string closure of skin

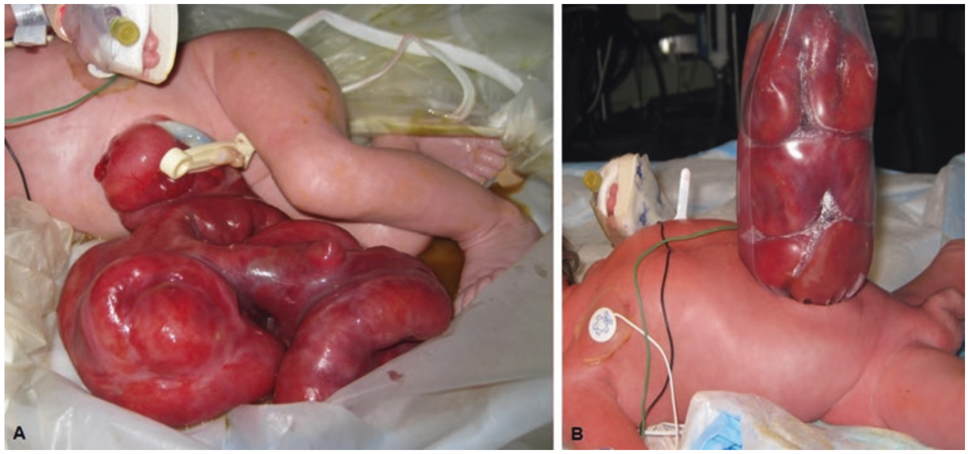

Fig. 15.2 Staged reduction for gastroschisis using a preformed Silastic silo (**a**) Gastroschisis with significant matting of bowel (**b**) Silo placement

Fig. 15.3 Sutureless closure gastroschisis

less closure versus fascial closure [59]. Furthermore, the sutureless group had significantly less surgical site infections compared to the fascial closure group even among patients who initially had a silo placed for reduction [59]. The rate of umbilical hernia after sutureless closure ranges from 22–91% and is significantly higher than after fascial closure [59–62]. However, the majority of these hernias will spontaneously close and will ultimately not require an operative repair [55, 61, 62]. This is in contrast with hernias after fascial closure which require operative repair significantly more often [59]. The cosmetic result after sutureless closure is often excellent with little to no scar formation [55, 63].

Ward Reduction Versus General Anesthesia

One of the appeals of the sutureless closure is that reduction and closure of the defect can be done at the bedside and general anesthesia avoided. Ward reduction of gastroschisis without the use of general anesthesia was first introduced by Bianchi and Dickson in 1998 [56]. The technique was further modified with the addition of analgesia and/or sedation [57, 64, 65]. Although some initial reports had unsatisfactory outcomes, the subsequent introduction of selection criteria demonstrated that more than 80% of neonates were suitable for ward reduction [1, 57, 61, 64, 66, 67]. Exclusion criteria for ward reduction include unstable patient with poor general condition, poor bowel condition including intestinal perforation or necrosis, bowel/mesentery attached to the defect, narrow defect, gross viscero-abdominal disproportion, and conversion in the presence of deteriorating metabolic acidosis, patient distress/tenderness, and increased respiratory support [57, 64, 65, 67].

Some have advocated silo placement at beside without general anesthesia followed by sutureless closure as a preferred method for uncomplicated gastroschisis because of the advantage of avoiding general anesthesia and similar outcomes to primary fascial closure [29]. The cord is protected from desiccation by wrapping it in antibacterial-impregnated paraffin gauze and cling film. The bowel is then serially reduced until the entire bowel is reduced below the level of fascia for at least 12 h. The silo is removed and the cord is elevated and pulled to the contralateral side to attempt to close the defect. If closure is possible, steri-strips and a dressing are applied to approximate the skin edges. The umbilicus is allowed to desiccate and cicatrize [29].

Management of Intestinal Atresia

Complex gastroschisis includes those patients with bowel complication including intestinal atresia, perforation, and necrosis (Fig. 15.4) [68]. Compared to patients with simple gastroschisis without associated bowel abnormalities, complex gastroschisis patients have worse outcomes including delayed enteral feeding, prolonged TPN use, longer ventilator days, longer hospital length of stay, and possibly increased mortality [68, 69]. When there is associated bowel abnormality such as intestinal atresia, the bowel can be reduced and the abdomen closed. After 4–6 weeks of nasogastric decompression and supplementation with TPN, the patient is re-evaluated for the presence of intestinal atresia with contrast studies. If an atresia is present, the patient can undergo an elective resection and primary repair [63]. Alternatively, some surgeons will remove the area of atresia and perform a primary anastomosis in the presence of minimal inflammation at the time of defect closure [70–72]. If the atresia is located distally or associated with a perforation, an ostomy can be created followed by ostomy closure at a later date [73]. Delayed intestinal surgery in patients with gastroschisis complicated by intestinal atresia allows bowel inflammation to decrease and facilitates an anastomosis, possibly decreasing anastomotic leaks and other complications [73, 74]. However, a recent study from the Canadian Pediatric Surgery Network demonstrated that early establishment of intestinal continuity in patients with gastroschisis complicated by intestinal atresia is safe, allows for earlier initiation of enteral feeding, and does not increase complications [70].

Omphalocele

Epidemiology

An omphaloceles occurs when the intestine fails to return inside the abdominal cavity at 6–10 weeks of development after normal herniation into the umbilical cord. The defect is characterized by a covered amniotic membrane that contains bowel and may contain other abdominal organs such as the liver and spleen. The etiology of omphalocele is not entirely understood but is believed to be a folding defect [75]. Some authors categorize omphaloceles based on location into central, epigastric, and hypogastric [76]. Pentalogy of Cantrell is a severe cranial fold abnormality associated with epigastric omphalocele, anterior diaphragmatic hernia, sternal cleft, pericardial defect, and cardiac defect [77]. Hypogastric omphaloceles are associated with the omphalocele-imperforate anus-exstrophy of the bladder-spinal defects (OIES) complex [76].

Fig. 15.4 Complicated gastroschisis demonstrating intestinal atresia

The diagnosis is readily made on prenatal ultrasound at 18 weeks and has an incidence as high as 1/2000 fetuses. However, the incidence among live births in the USA between 2004–2006 was 1/5386, suggesting that there is considerable hidden mortality among fetuses [76, 78]. Unlike gastroschisis, chromosomal anomalies occur in almost half of fetuses with omphalocele [76]. The most common abnormal karyotype associated with omphalocele is Trisomy 18, followed by trisomy 13, trisomy 21, trisomy 14, and trisomy 15 [76, 79]. Furthermore, among those with a normal karyotype, up to 88% have an associated anomaly [76, 79, 80]. Limb and cardiac defects including atrial septal defect, ventral septal defect, and tetralogy of Fallot are common [76, 79, 80]. Many syndromes are also associated with omphalocele with Beckwith-Wiedemann (omphalocele, macroglossia, hypoglycemia, gigantism) being the most common [76, 79, 80].

Surgical Management

Primary Closure

Defects that are less than 4 cm in diameter are considered umbilical cord hernias and can be repaired primarily shortly after birth. Primary closure is also possible for the majority of small centrally located omphaloceles without much loss of abdominal domain [30, 81–83]. Interestingly, chromosomal anomalies, syndromes, dysmorphism, gastrointestinal abnormalities, and nervous system abnormalities occur more often in patients with small defects [79]. The outcomes in these patients are often dependent on the associated anomalies and degree of pulmonary hypoplasia [2, 30, 76, 84–86].

For primary fascial closure, the skin is incised a few millimeters away from the sac and skin flaps are raised circumferentially. The sac is then excised taking care to identify and ligate the umbilical vessels and the urachus. The bladder must also be carefully identified and not injured during excision of the sac. The sac is often adherent to the liver and tears in the Glisson capsule can result in significant hemorrhage [27]. Therefore, the sac is divided such that any adherent areas are left on the liver. The intestines are then reduced into the abdominal cavity followed by the liver. The fascia and skin closure is then similar to that described for gastroschisis.

A few authors have recommended primary closure for large omphaloceles with the use of a synthetic or biological patch [80, 87, 88]. While this technique offers the advantage of abdominal wall closure and skin in a single procedure, the patients have a mean herniation rate of 58% and may require subsequent abdominoplasties [17, 88]. Furthermore, synthetic non-absorbable patches such as Gore-Tex (W.L. Gore and Associates, Flagstaff, AZ), Teflon, or Prolene (Ethicon, Johnson & Johnson Intl, Brussels, Belgium) are at risk of infection and most require removal at a later date [80].

Giant Omphalocele

The definition of giant omphaloceles is not standard in the literature with defect sizes varying from greater than 4 cm to greater than 10 cm [80, 89–92]. Other authors use the presence of another organ, such as the liver, within the sac as a contributing factor for the characterization of a giant omphalocele [80, 93, 94]. We use the criteria of a defect exceeding 10 cm in diameter containing viscera and liver within the sac as our definition. The management of giant omphaloceles is challenging due to the degree of viscero-abdominal disproportion. Primary fascial closure is not feasible, and a variety of techniques have been developed to manage giant omphaloceles. However, most of the published reports in the literature are of small case series, and there is no established standard of care [17]. Furthermore, a recent survey of authors of published studies concerning the treatment of giant omphalocele (1967–2009) found that almost half of the authors had changed or stopped their reported technique regardless of the initial technique used [17]. In general, there are two methods of treatment that have persisted over the past 30 years: staged closure and delayed closure [17].

Staged Closure

Staged closure of the abdominal wall offers the advantage of early closure of the defect, gradual reduction of the viscera, gradual increase in the intra-abdominal volume, and minimal risk of abdominal compartment syndrome [17]. In 1948, Gross described a staged closure technique for large omphaloceles by freeing and approximating of the skin over the intact sac. A second staged operation was then performed at 6 to 12 months of age for definitive fascial closure [6]. While this technique provides immediate coverage of the viscera, the secondary ventral hernia repair is often complicated by loss in abdominal domain from fascial separation and dense adhesions between the bowel and skin [27].

The most common technique for staged reduction of giant omphaloceles is the creation of a prosthetic silo with or without excision of the amnion sac [7–9, 52, 89, 95–100]. With this method, the amnion sac is either excised or left intact, skin flaps are raised circumferentially, and the sheets are sutured to the rectus abdominus fascia to create a custom silo [7–9, 89]. Alternatively the silo can be attached to the full thickness of the abdominal wall [95, 97, 99, 101]. Sequential reductions of the silo contents are then performed in the neonatal unit or the operating room by progressive compression and closure of the silo by suturing or stapling [9, 89, 100, 101]. We do not recommend the removal of an intact amnion sac and reserve the use of silos for ruptured omphaloceles.

Application of the silo beyond 7 days is associated with a high incidence of complications including infection, wound dehiscence, fistula formation, sepsis, and disruption of the silo from the fascial edges [7–9, 90, 97, 101, 102]. However, aggressive reduction of the contents to achieve definitive closure is associated with prolonged mechanical ventilation, bowel ischemia and infarction, renal insufficiency, wound dehiscence, and recurrent hernia [7, 9, 52, 101]. The mean hernia rate after staged closure is 18% [17].

Once the contents are fully reduced below the level of the fascia, primary closure of the defect is attempted. Oftentimes, complete closure of the fascia is not possible and a mesh closure is performed [80, 88, 89, 100, 103, 104]. Multiple synthetic and biological materials have been used as a prosthetic patch for definitive closure. Gore-Tex (W.L. Gore and Associates, Flagstaff, Ariz), a nonabsorbable polytetrafluoroethylene mesh; Prolene (Ethicon, Johnson & Johnson Intl., Brussels, Belgium), a monofilament polypropylene mesh; and reinforced Silastic sheeting have all been used as a bridge to fascial closure. The mesh can be sequentially excised or imbricated to gradually approximate the fascia and allow for native fascial closure [100, 105, 106]. Alternatively, the mesh may be left in situ with primary dermal closure (Fig. 15.5).

Prosthetic materials carry a risk of infection and frequently require removal. There are several reports of using biological materials such as Surgisis, a biodegradable acellular, non-immunogenic material derived from porcine small intestinal submucosal extracellular matrix (Cook Medical Inc., Bloomington, Indiana); Alloderm, a human acellular tissue matrix (LifeCell Corp, Branchburg, NJ); and Permacol (TSL, Hampshire, UK) [80, 88, 103, 107]. Biological mesh serves as a scaffold to allow interstitial ingrowth of fibroblasts and vascular tissue and may have a lower rate of infection compared to prosthetic materials [88, 103, 107]. Furthermore, they can support granulation and incorporation of an overlying skin graft in cases of inadequate tissue cover [93, 103, 107–109].

Delayed Closure

Staged reduction with a silo may not be well tolerated in infants with prematurity, severe pulmonary hypoplasia, cardiac abnormalities, or chromosomal abnormalities [16, 52, 93]. Non-operative management with epithelialization and delayed closure is the preferred method of treatment of non-ruptured omphaloceles. It offers the advantage of

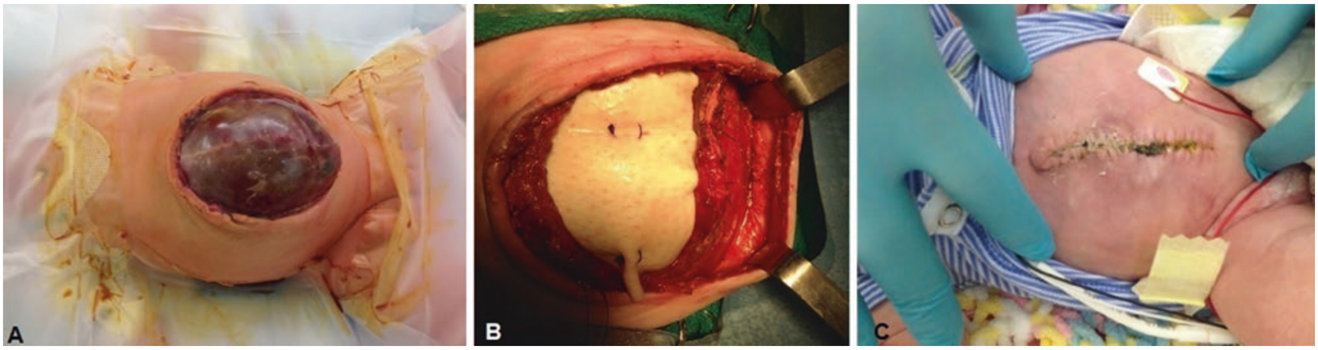

Fig. 15.5 Ruptured omphalocele treated with custom silo (**a**) Omphalocele reduced to level of the fascia (**b**) Fascial closure using biological mesh underlay with component separation technique (**c**) 1 week post-op

avoiding major abdominal surgery in the newborn period and acts as a bridge to delayed closure [52, 86, 93]. Non-operative techniques involve the use of a topical agent to develop an eschar over the intact amnion sac. The eschar epithelializes over an average of 6 months and the resulting large ventral hernia can be repaired electively once the child is medically stable (Fig. 15.6) [92]. Non-operative management with epithelialization may be associated with earlier enteral feeding, decreased need for mechanical ventilation, decreased length of stay, and decreased mortality as compared to patients with staged closure using a silo [52, 86, 93].

Several eschar producing agents have been described. Initial agents such as alcohol and mercurochrome were associated with detrimental toxic effects [12–15, 110]. In 1987, Hatch and Baxter [16] first reported the use and safety of silver sulfadiazine for escharotic therapy. Subsequent reports supported the safety and efficacy of silver sulfadiazine as a topical agent, and it quickly became the preferred topical agent for non-operative management [52, 85, 92, 93, 111]. However, treatment with topical silver sulfadiazine is complicated by frequent daily dressing changes, prolonged duration of healing, and prolonged hospitalization. Furthermore, a study of over 20 patients treated with silver sulfadiazine reported complications including sac rupture in 3 patients, staphylococcal sepsis originating from the sac in 2 patients, and 1 patient with jejunal perforation [92]. Povidone-iodine is an alternative agent and offers the advantage of easy application. Although there have been case reports of hypothyroidism, a prospective cohort study failed to demonstrate any clinical hypothyroidism following treatment with povidone-iodine [110, 112].

There have also been reports of using neomycin, polymyxin/bacitracin ointments, and silver-impregnated hydrofiber dressings [113, 114]. Oquendo et al. [113] in a series of 8 patients treated with silver-impregnated hydrofiber dressings reported an average time to epithelialization of 2.9 months as compared to 4–12 months with silver sulfadiazine. Furthermore, silver-impregnated hydrofiber requires dressing changes only every 5–7 days, may decrease the possibility of sac disruption, and provides topical prophylactic broad spectrum antimicrobial activity [115].

More recently, negative pressure wound vacuum therapy has been proposed as an initial method of management for giant omphaloceles [18]. The sac is cleansed and covered entirely in Mepitel (Molnlycke Health Care, Gothenburg, Sweden). White foam (VersaFoam, Kinetic Concepts Incorporated, San Antonio, TX) followed by black foam (GranuFoam, Kinetic Concepts Incorporated, San Antonio, TX) is trimmed to an appropriate height and shape and applied over the Mepitel. The foam is secured in place with clear adhesive film and the Trac pad applied. The pressure is set to −25 mmHg initially and can be increased to −50 mmHg continuous suction if the mean arterial pressure remains above 50 mmHg. The dressings are then changed twice weekly. Aldrige et al. [18] reported complete wound healing with epithelialization of the sac after 1–2 months of negative pressure wound vacuum therapy. Delayed closure of the defect was performed after 5–12 months by primary closure of the fascia in 5 patients while 2 patients required mesh. Negative pressure wound vacuum therapy has also been used as salvage therapy for sac disruption, wound dehiscence, and fistula formation after unsuccessful treatment with silo reduction or topical agents [116, 117].

Definitive Surgical Management

The timing of definitive closure after non-operative management varies greatly in the literature from as early as 2 months to up to 3 years [18, 85, 92, 93, 113]. However, most advocate for definitive closure before the child is ambulating. Delayed closure allows for stabilization of underlying comorbidities, time for tissue expansion, and an increase in

Fig. 15.6 Delayed treatment of omphalocele (**a**) Large omphalocele at birth (**b**) After 7 days of treatment with silver sulfadiazine (**c**) Complete epithelialization of omphalocele (**d**) Primary fascial closure

abdominal domain. Multiple techniques have been described for delayed closure including primary fascial closure when possible, use of prosthetic and biological patches, component separation technique, and fascia and skin flaps [80, 88, 94, 100, 103, 118–122]. The mean herniation rate after delayed closure with epithelialization is 9% as compared to 58% for primary closure and 18% for staged closure [17].

The degree of viscero-abdominal disproportion often makes it difficult to reduce all of the extaperitoneal viscera without causing a rapid increase in intraabdominal pressure. Delayed external compression of the ventral hernia using elastic bandages, pneumatic devices, and negative pressure wound vacuum therapy has been described [123–126]. Tissue expanders are an innovative method for intra-abdominal expansion. Unlike external compression, tissue expanders gradually stretch the abdominal wall and increase the abdominal domain without using the herniated viscera as the source of pressure. Tissue expanders can be placed in the abdominal wall intramuscular space or within the peritoneal cavity [19, 105, 106, 114, 127, 128]. Optimal expansion of the peritoneal cavity and abdominal wall is reached within several months by gradually increasing the expander volume. The amount of expansion can be guided by the use of CT scans to compare the volume of the tissue expander and the volume of the extraperitoneal viscera contained within the hernia sac [105].

A number of techniques have been proposed for definitive closure of the defect when primary closure is impossible [94, 118–122]. Component separation technique is useful for the repair of large pediatric abdominal wall defects [94, 118, 122, 129]. First described by Ramirez et al. [129] in 1990, the

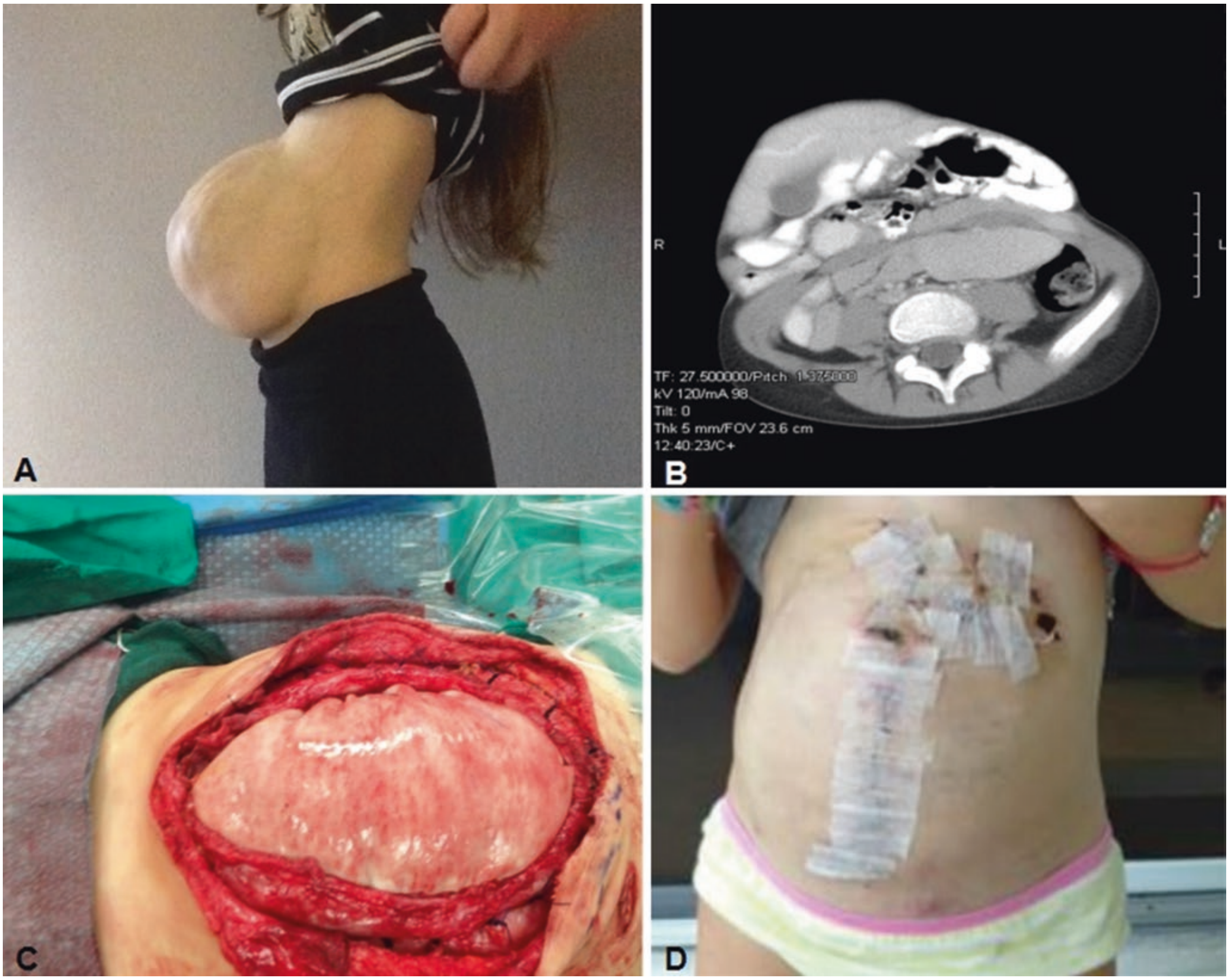

Fig. 15.7 (**a**) Six-year-old female with history of giant omphalocele treated with delayed closure and epithelialization with large resulting ventral hernia (**b**) CT demonstrating liver and bowel in hernia (**c**) Fascia closure using biological mesh underlay with component separation technique (**d**) 1 week post-op

component separation technique is based on enlargement of the abdominal wall by separation and translation of the abdominal muscles. The hernia sac is excised and the abdominal cavity is entered. The liver and bowel are dissected free from the abdominal wall. Bilateral subcutaneous tissue flaps are created to expose the external oblique fascia. The aponeurosis of the external oblique muscle is then incised approximately 1 cm lateral to the rectus muscle. The incision is carried longitudinally along the entire length of the external oblique. The external oblique muscle is bluntly separated from the internal oblique muscle up to the midaxillary line. The rectus muscle and its attached internal oblique-transversus muscles can then be advanced approximately 5 cm on either side. The rectus sheath is then closed with a continuous polydioxanone (PDS) suture (Ethicon, Inc., Norderstedt, Germany). Biological mesh can be used as an underlay or onlay to alleviate the tension and reinforce the fascial closure (Fig. 15.7) [118, 130]. Comparisons between synthetic and biologic mesh use with component separation technique for ventral hernia repairs among adults demonstrated similar low recurrence rates and complication rates [131].

Component separation technique is associated with several complications including surgical site infection, hematoma, seroma, and wound breakdown [131]. The extensive dissection and frequent transection of epigastric perforators can lead to skin necrosis and wound healing problems, especially in patients with prior abdominal surgeries [94, 132, 133]. Hernia recurrence rates are low after component separation technique [94, 118, 131]. Van Eijck et al. [94] in a series of 10 patients with a median follow-up of 23.5 months found no recurrent hernias on examination. Although many of these children later developed rectus diastasis, motor function and abdominal wall musculature remained normal in 8 of these children at a mean follow-up of 54 months [134]. Levy et al. [118] also demonstrated no evidence of recurrence in a series of 9 patients after a median follow up of 16 months.

Cosmetic Outcomes

Regardless of closure technique, cosmetic outcome is important to survivors of abdominal wall defects [135–137]. The appearance of an abdominal scar can be a source of morbidity in survivors of abdominal wall defects [137]. Fifty-seven percent of patients reported that the lack of an umbilicus during childhood caused distress [136]. Furthermore, almost all young adult patients with a history of giant omphalocele are not satisfied with the cosmetic result of their closure compared to 1/3 of patients with minor omphalocele [135]. Preservation of the umbilicus or simultaneous umbilicoplasty at the time of defect closure might give superior cosmetic results and patient satisfaction [55, 61, 137–140].

Summary

The closure of congenital abdominal wall defects in children poses an interesting challenge to surgeons. Various techniques to manage these defects have been described and generally fall into one of three categories: immediate primary closure, staged closure, and delayed closure. Although the armamentarium of strategies to treat congenital abdominal wall defects continues to expand, no single operative technique has achieved universal acceptance or success. Long-term outcomes from large randomized controlled trials are lacking in the literature. Ultimately, the selected treatment will depend on the patient's presentation and comorbidities and the personal experience and training of the surgeon.

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16 Surgical Approach to Abdominal Wall Defects and Hernias in Patients with End Stage Organ Disease and Transplantation

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Abbreviations

CAPD	Continuous ambulatory peritoneal dialysis
CCPD	Continuous cycling peritoneal dialysis
CLD	Chronic liver disease
CNI	Calcineurin inhibitors
ESRD	End stage renal disease
GI	Gastrointestinal
IH	Incisional hernia
LDLT	Living donor liver transplant
LT	Liver transplantation
LVHR	Laparoscopic ventral hernia repair
MIS	Minimally invasive
OLT	Orthotopic liver transplantation
PD	Peritoneal dialysis
PFC	Primary fascial closure
SSI	Surgical site infections
VHWG	Ventral Hernia Working Group

Introduction

In the USA, approximately 10% of the population will develop a type of hernia throughout their life. Over one million abdominal hernia repairs take place in the USA, and approximately 75% of all hernias are inguinal; two thirds are indirect with a right side predominance (7:1 male-to-female ratio), and a third are direct. In the general population about 14% of hernias are umbilical, 10% are incisional or ventral hernias with a female-to-male ratio of 2:1, and only 3–5% of hernias are femoral [1].

The three main groups that we will discuss in this review are patients with chronic liver disease and status post abdominal organ transplantation in specific liver and kidney; the incidence is variable depending on the group.

Chronic liver disease patients on average can develop an abdominal wall defect or hernia between 3 and 20% [2]. In transplantation according to Hegab et al. [3] incisional hernia incidence following orthotopic liver transplantation (OLT) can be as high as 23%.The incidence of hernia after kidney transplantation is remarkably lower with only 1–7% [4].

Abdominal wall defects can be related to End Stage Organ Disease (ESOD) especially in patients with chronic liver disease or as a result of organ transplantation and the immunosuppression required afterwards. These hernias can be difficult to resolve, the complexity of the defect depends fundamentally on its dimensions and comprise of the abdominal wall, different muscle groups involved in these complex surgeries (rectus abdominis, external and internal oblique muscles, and transversus abdominis), the suboptimal conditions that the patient with ESOD, and the factors related with a new organ and its volume.

Many factors have been associated in the development of incisional hernias before and following transplantation. The metabolic and hemodynamic derangements caused by ESOD and the complications associated add a significant burden and increase the complexity of the hernia management. The administration of immunosuppressive agents, in particular high dose steroids early in the first months after transplantation and mTOR inhibitors used in some particular cases, can delay wound healing [5, 6]. Large allografts may lead to mechanical strain at the incision site, and thus contribute to the development of an incisional hernia.

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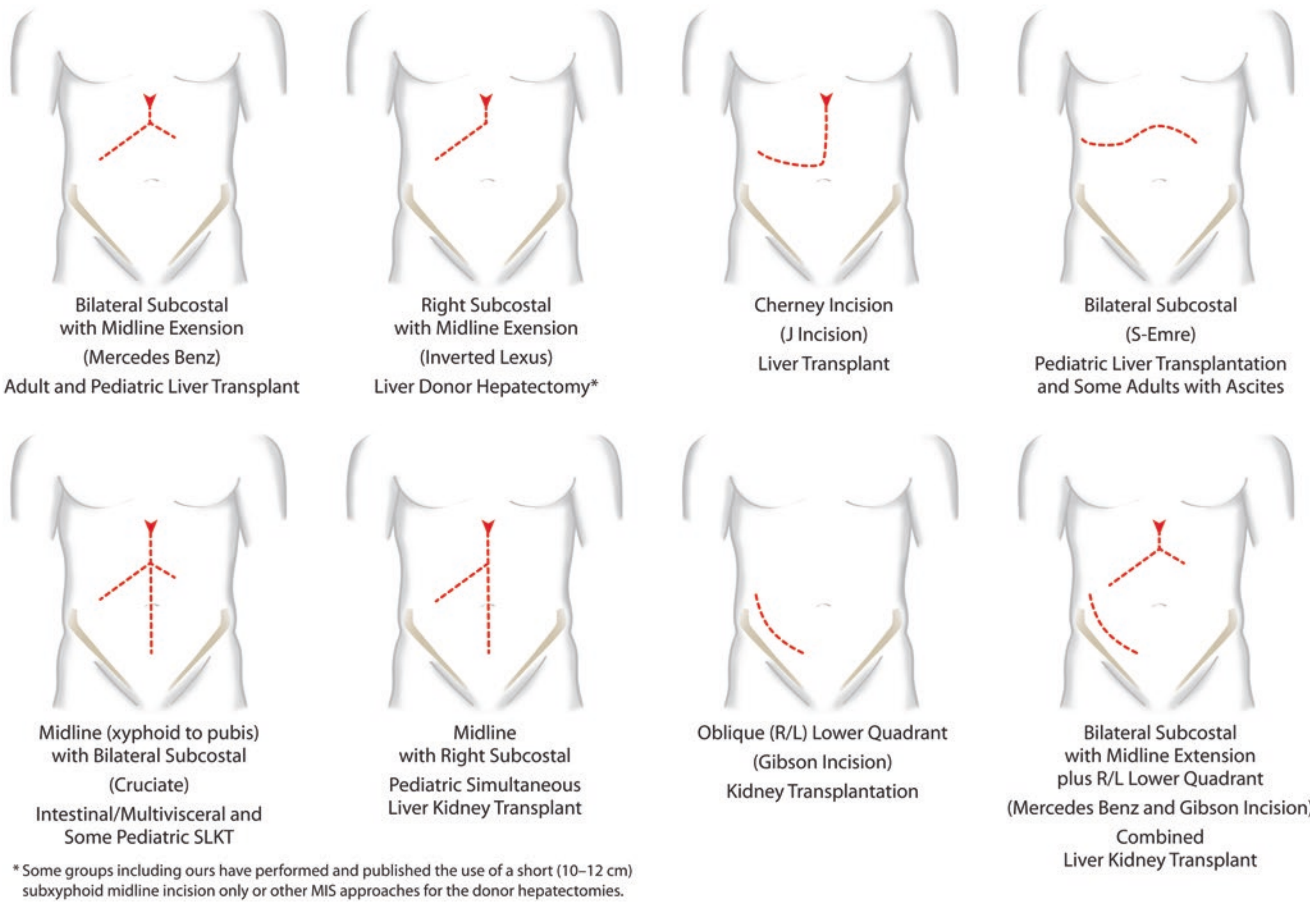


Fig. 16.1 Incisions used in transplant surgery

Ascites and hypoalbuminemia, seen often in patients with end stage liver disease (ESLD) and an elevated model of end stage liver disease (MELD) score, also contribute to impaired wound healing to comprise fascia integrity. Patients with significant portal hypertension, delayed graft function or small for size in the setting of living donor liver transplant (LDLT) resulting in early dysfunction can similarly lead to protracted wound healing disturbances, and subsequently to the formation of a hernia [7].

In the present chapter we review hernias on complex patients that either have diagnosis of ESOD (liver and renal) or post-transplant patients. In particular, our group has developed significant experience in hernia repair after liver transplant (LT) patients. The OLT patients are at high risk of developing incisional hernias, where the incidence can vary from 4 to 23% [3, 7, 8]. In this chapter we also review renal transplant recipients, which are the most common abdominal transplants as well as some personal experience with donors after hepatectomy, intestinal and multivisceral transplantation has been discussed by Dr. Tsakis in previous editions of this book and will not be addressed.

Different surgical incisions have been described in transplantation and hepatobiliary surgery. The post-transplantation defects will depend on the type of incision, for either isolate orthotopic liver transplant, kidney transplantation, or simultaneous liver and kidney transplantation (SLKT). This may also vary in the adult versus the pediatric patient and multivisceral transplant and in the presence or absence of ascites (Fig. 16.1).

As mentioned previously in the author's experience we also encounter frequently umbilical, inguinal, and ventral hernia in patients with ESOD especially patients with CLD.

Factors such as the location of the defect and the surrounding areas influence can add to the complexity of the hernia. Even though the techniques used in the reconstruction of the abdominal wall are changing constantly, the goal for all abdominal reconstructions continues to be the same: obtain a good healing scar of the affected area with healthy tissues to allow for restoration of rigidity, resistance, and functional support of the abdominal wall in order to prevent herniation, a challenging process when it comes to a patient with ESOD or after transplantation.

In order to understand the approach to this complex group it's important to review previous classifications and grading, we will then underline in which of these apply to our patients.

Hernia Classification and Grading

Grading

Efforts to increase successful outcomes and minimize recurrence have led the Ventral Hernia Working Group (VHWG) to stratify and grade hernias according to the risk of developing a surgical site infection (Table 16.1) [9]. Unfortunately, there is no universal grading system that has been established to effectively evaluate surgical outcomes. The lack of ambiguity along with a wide mixture of incisional hernias (IH) and ventral hernias has not permitted standardization. This table proposes a classification with criteria that helps clinicians predict risk of developing surgical site infections (SSI). Grade 1 proposes a "low risk" and no history of wound infections. Grade 2 includes "co-morbidities" and considers patients who smoke, are obese, diabetic, immunosuppressed, or have been diagnosed with COPD. Grade 3 includes patients who are "potentially contaminated" and patients who have had a previous wound infection, a stoma, or violation of the gastrointestinal (GI) tract. Lastly, Grade 4 takes into consideration "infected" mesh and septic wound dehiscence. Most of the hernias on patients with ESOD and after organ transplantation fall into Grade 2 and in rare occasions Grades 3 and 4.

Classification

Abdominal hernias can be classified differently depending on their location, size, reducibility, recurrence, and symptoms. In the year 2000, Chevrel and Rath proposed a simple classification for IH for the comparison and study between similar groups. The aim of this classification is to direct the assessment of multiple techniques for the different types of ventral hernia repairs (Table 16.2) [10].

End Stage Organ Disease

End Stage Organ Diseases (ESOD) such as end stage liver disease (ESLD) in chronic liver disease (CLD) and end stage renal disease (ESRD) are the terms used to refer to diseases in which the organ functions are completely abolished or severely damaged. In both cases, organ transplantation has shown to be the definitive treatment when medication therapy can no longer control the complications or progression of ESOD. Unfortunately, many of these patients will not meet criteria for listing, but due to the complexity of their medical disease they are often referred to transplant centers where a multidisciplinary approach and collaboration with

Table 16.1 Hernia grading system

Grade 1 Low risk	Grade 2[a] Co-morbid	Grade 3 Potentially contaminated	Grade 4 Infected
Low risk of complications No history of wound infection	Smoker Obese Diabetic Immunosuppressed COPD	Previous wound infection Stoma present Violation of the gastrointestinal tract	Infected mesh Septic dehiscence

[a]The majority of cases in ESOD and transplant population

Table 16.2 Hernia classification

	According to localization (modified Chevrel)	According to size	According to recurrence	According to the situation at the hernia gate	According to symptoms
Vertical	Midline above or below umbilicus Midline including umbilicus right or left Paramedian right or left	Small (<5 cm in width or length)	Primary incisional hernia	Reducible with or without obstruction	Symptomatic
Transversal	Above or below umbilicus right or left Crossed midline or not	Medium (5–10 cm in width or length)	Recurrence of an incisional hernia (1, 2, 3, etc., with type of hernioplasty: adaptation Mayo-duplication prosthetic implantation autodermal etc.	Irreducible with or without obstruction	Asymptomatic
Oblique	Above or below umbilicus right or left Combined midline + oblique midline + parastomal etc.	Large (≥10 cm in width or length)			

Table 16.3 Hernias in CLD and post-transplant patients

	Eker et al.	Marsman et al.	Leonetti et al.	Mekeel et al.	Harold et al.
Risk factors	Ascites Cirrhosis Increased intra-abdominal pressure Weakening of the abdominal fascia Muscle wasting Poor nutritional status	Ascites Cirrhosis Increased intra-abdominal pressure Weakening of the abdominal fascia Muscle wasting Poor nutritional status	Ascites Poor liver function Malnutrition High intra-abdominal pressure	Male gender Steroid Immunosuppression Reoperation Living donor Prolonged ICU Acute rejection BMI > 25 Severe post-transplantation ascites	Malnutrition Immunosuppression Systemic steroid use Abdominal ascites
Management	Elective surgery Open technique	Elective surgery Primary suturing	Elective and emergent Open technique	Laparoscopic hernia repair	Laparoscopic hernia repair
Recurrence	7%	24%	16%	7.6%	7.9%

hepatology, nephrology, registered dietitians, specialized nurses and interventional radiology offer hope to the patient with ESOD and this difficult population can be managed appropriately by these teams. Patients with ESOD and hernias are referred to these centers since most of the time only transplant surgeons are skilled enough to manage these cases, and in the postoperative period they will have the support of the multidisciplinary team. In the following section the characteristics and approaches to the ESOD patients with hernias are described.

Liver

Compensated Chronic Liver Disease

The complications related to CLD make it one of the major causes of death in the USA. Such complications include ascites, hepatic encephalopathy, renal failure, and variceal hemorrhage; in consequence, patients with CLD require increasingly complex medical care and treatment, which has a direct impact on their quality of life, survival, and economy [11].

Some complications of CLD may predispose or lead to abdominal wall pathology. The development of ascites in these patients increases the tension on the abdominal wall. This, along with the decreased synthetic function of the liver that affects protein synthesis can end up weakening the layers of the abdominal wall with herniation as an end result. Also, these patients often require paracentesis, a procedure that alleviates the ascitic burden but may increase the risk of hernia complication as reported by some authors [12] this is particularly important in individuals listed for liver transplantation in which a potential incarceration could complicate their candidacy. It is estimated that approximately 10% if patients with CLD will require a surgical procedure within the last 2 years of life, and up to 20% with ascites will develop an umbilical hernia. These hernias might eventually become symptomatic, grow in size, and will require surgical repair [13–15]. Once the hernia has already developed, thorough evaluation before intervention is required, to assess their functional status, synthetic function, and risk of perioperative complications [12, 16].

The management of hernias in patients with CLD varies according to the situation and each patient health status; thus, different systems have been developed to assess the severity of disease and predict the morbidity and mortality in this complex population. These systems can aid in decision-making algorithms for the treatment of CLD patients that have developed a hernia. Defining, stratifying, and classifying the stage of liver disease and the type of hernia are necessary for planning its appropriate treatment (Table 16.3).

Risk Stratification

In order to have a proper evaluation of the patient with liver disease that presents with a hernia, an assessment of the severity of disease, the type of hernia, and other co-morbidities need to be determined. Although liver disease patients are complicated, fortunately, in the present era and with advancements in the field of transplantation, the multidisciplinary management of transplantation centers allows the cirrhotic patient to have enough time to undergo a proper evaluation of the need for surgery to be performed while the liver disease complications are controlled. Pre-transplant patients are expected to undergo a preoperative evaluation, and their conditions should be optimized prior to elective surgery. This type of evaluation can also be performed in CLD that require hernia repair.

It is imperative to mention that there are contraindications for hernia repair or any abdominal surgery with liver disease, such as acute liver failure, acute renal failure, acute hepatitis, coagulopathy, hypoxemia and alcoholic hepatitis, or active alcohol abuse [17] thus, in this chapter, we are focusing on CLD, where the patient is expected to have synthetic function of the liver. It is also always important to consider that patients found to have CLD may benefit from conservative management [17]. However, some series have shown that conservative management can lead to more complications such as incarcerated hernias [18], for that reason, the preoperative assessment and workup for potential repair should be performed in a timely manner.

Many decades ago, predictor scales were developed to determine the mortality risk in patients with cirrhosis; such scales have proven their utility to assess surgical risk as well [19]. Two commonly tools used by most centers in the USAs including ours are the Child-Turcotte-Pugh (CTP) score and the Model for End Stage Liver Disease (MELD).

The Child-Turcotte-Pugh score, developed in the 1960s (Child CGG) and modified in the 1970s [20], bases its classification criteria on the following parameters: Total bilirubin, serum albumin, prothrombin time, and ascites and hepatic encephalopathy. Each parameter is scored 1–3, 3 indicating the most severe alteration on that parameter. The interpretation is based on the added score, and can be divided into Class A (5–6 points) associated with a 100% one-year survival rate, Class B (7–9 points) with an 81% one-year survival rate, and Class C (10–15 points) with a 45% one-year survival rate [21].

In elective surgery, it is well known that Child A patients can tolerate the procedure well and surgery is permissible on Child B patients if compensated and with a platelet count preferably higher 100,000. In our experience at the Yale New Haven Transplantation Center we are mainly using the MELD score and portal hypertension assessment as described later in this section.

Hernia repair should be contraindicated in Child C; some exceptions have been done in cases of incarcerations by some teams in which an adequate informed consent and a clear understanding of the high mortality of patients should be discussed. Park et al. [22] demonstrated that when it comes to hernias, CTP Class A and B are safe and the recurrences rate is low.

The MELD system, created to predict mortality after transjugular intrahepatic portosystemic shunt (TIPS), at the Mayo clinic more than two decades ago [16, 23], and since February of 2002 is used in the United States as a stratification system and organ allocation for liver transplantation (modified MELD-Na is currently utilized by the United Network of Organ Sharing). The system is utilized by many as described by Befeler et al. to predict perioperative mortality in CLD patients undergoing elective and urgent procedures, not only in hepatobiliary surgery, but also in any intervention that may require anesthesia. The MELD system focuses on the following criteria: Bilirubin, creatinine, and International Normalized Ratio (INR). The MELD formula allows assessment of 3-month mortality.

The risk of an additional operation for patients who have high MELD scores is considered greater than the risk of waiting until transplantation in which cases the hernia would be corrected during the transplantation procedure, for that reason, hernias in patients with a MELD score of more than 22 or a close date to transplant are not recommended to be treated unless they present signs of incarceration, due to the high risk of complications in CLD patients [12, 24]. Saleh et al. developed a nomogram that included MELD score to predict 30-day postoperative mortality in patients with ascites undergoing umbilical hernia repair. In their study MELD score, low albumin, high WBC, and low platelet count were found to be significant predictors of mortality. With the use of their nomogram it was noted that mortality begins to increase at a MELD score of 12, and the non-survivor patients had an average MELD of 19 [25]. In our group based on the experience obtained we rarely performed a hernia repair open or laparoscopically in patients with MELD over 14 (average MELD of 12). Also, when the patient meets criteria for transplantation, a discussion in a multidisciplinary fashion takes place prior to repair.

This algorithm represents the previously suggested management of hernias in which factors such as signs of incarceration, cirrhosis, ascites, and transplant possibility are taken into account in the process of decision making (Fig. 16.2).

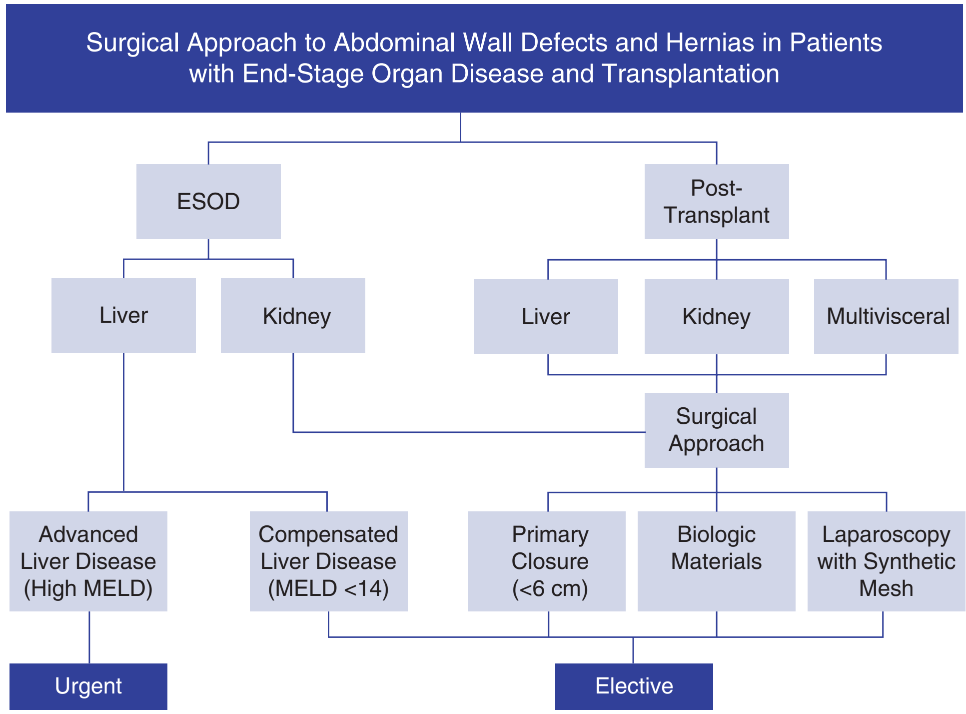
Kidney

Patients with end stage renal disease (ESRD) that need peritoneal dialysis have increased intra-abdominal pressures and increased risk for developing abdominal wall complications such as peritonitis, wound infections, and hernias [24].

Literature shows patients being treated with continuous ambulatory peritoneal dialysis (CAPD) and continuous cycling peritoneal dialysis (CCPD) have a higher rate of hernia development in the first 3 months following initiation of CAPD/CCPD with a subsequent rapid decrease. Patients not eligible for peritoneal dialysis (PD) may be those with massive kidneys, abdominal hernias, or previous episodes of diverticular disease. In theory, transplant patients are at an increased risk for incisional hernia due to the time they spend on dialysis before transplantation, the use of immunosuppressors and co-morbidities. We have in our experience seen this to be a particular issue with PKD patients in pre and post-transplantation setting.

Transplantation and immunosuppressive therapy have shown to increase the risk of hernias in patients with ESRD. In order to minimize risks and treat pre-transplant hernias it is recommended the place a tenckhoff catheter for peritoneal dialysis through minimally invasive surgery (MIS), which is a surgical technique with proven superior outcomes related to wound complications, hospital stays, infections, scarring, and pain compared to the open technique [24].

Fig. 16.2 Guidelines of surgical approach in ESOD and transplant patients



Post Transplant Hernia Repair

Liver

Even though much improvement has been made in surgical techniques and immunosuppressive therapy, hernias in the post-transplant setting are still common, which influence patient and graft survival. The incidence of incisional hernias after liver transplantation can range from 1.7 to 34.3% [25]. Recent literature reports 350,000 incisional hernia repairs each year in the USA and close to 200,000 are associated with a previous surgery. Among potential complications are abdominal pain, skin necrosis, and intestinal incarceration and perforation [26–28].

Risk factors such as increased age, smoking, persistent ascites, obesity (BMI > 30), diabetes, malnutrition, connective tissue disorders [29–31], and immunosuppression therapy can increase the risk of developing incisional hernias. Among the most influential agents of immunosuppression Cortisone and Sirolimus have demonstrated negative outcomes in relation with post-transplant wound complications [32]. Conditions such as (SSI's) may increase the possibility of developing an incisional hernia by up to 25%.

The group of Modena, Italy, suggests a safe approach towards cessation of mTORs one month before surgery and reinstating 3 months' post-surgery. At the Yale New Haven transplantation center our current practice is to stop the use of mTOR inhibitors 1 week prior to surgical repair, especially in the cases of open procedures in which we use biological materials. At that time, we would switch or adjust the dose of Tacrolimus, which is the most common Calcineurin Inhibitors (CNI) used in our program. Therapy is reinitiated 3–4 weeks after the repair, except in the cases where we suspect SSI [26]. Systemic use of Sirolimus in animal studies has proven to decrease tensile strength of wound healing and the deposit of collagen.

Patients who are tobacco users will see their wound healing mechanisms altered, predisposing them to complications, and recurrence of incisional hernias. This was confirmed by Moller et al. [33] who observed smoking cessation, at least 3 weeks before surgery, produced an improved post-surgical healing wound due to the recovery of collagen structure and the immune system in general. Evidence shows cigarette smoking may contribute to poor graft function, cardiovascular disease, and secondary malignancies post-transplantation. In current practice unfortunately we observe 40% of patients will resume smoking habits soon after their liver transplant.

Outcomes from a retrospective study performed by Wiederkehr et al. [34] reported a protective factor for SSI, incisional hernia, and overall satisfaction from J-shaped incision vs Mercedes incision. Results from their 2-year study demonstrated a significant difference in regard to IH between the J and Mercedes incision, the number of IH doubled in the Mercedes group. It is also proven that making an incision through the rectus muscularis, a less traumatic experience is provided, which leads to a decrease in complications postoperatively. We do not use the "J" incision performed by some of the European team as described above, but we will attempt a bilateral subcostal without midline extension or a right subcostal with midline extension in selected cases with good results.

Minimally Invasive and Open Surgery

Laparoscopic surgery for ventral hernia repair is being suggested more often to patients because of the low reported recurrence rates 3.4–10% and lower infection rates 1–3% as well as a reduction in hospital length of stay [35, 36].

The goals of abdominal wall reconstruction, which include restoration of structural support and prevention of recurrence, have gained popularity among patients and surgeons. Laparoscopic repairs have been shown to be a safe and effective approach for IH. Minimal Invasive Surgery (MIS) offers decreased postoperative pain, less bleeding during surgery, and shortens the recovery period [37].

Laparoscopic Ventral Hernia Repair (LVHR) with mesh composites positioned inside the abdominal wall cavity has proved to be an effective approach towards reducing recurrence of ventral hernias, these also allow mechanical separation between the viscera and mesh to prevent adhesions. Large or giant fascial ventral defects >15 cm, as proposed by Chevrel in his hernia classification, are difficult to repair and limited literature is found to decide the technique to be implemented for its repair and the surgeon may not always prefer the LVHR method.

Success of this repair relates to wide overlap of defects; onlay technique, which is the most popularly used tension free method, requires for the surgeon to place the mesh anterior to the anterior sheath, with a surrounding overlap of 5 cm. This method prevents interaction with the bowel and avoids the formation of enterocutaneous fistula.

In the Yale experience, laparoscopic cases have been selected specifically for post-transplant patients with single defects larger than 7 cm with minimal adhesions. We will often obtain informed consent for LVHR with the understanding that we will switch to our open technique with biologic mesh in case of extensive adhesions more than one defect and increased risk of infection. Literature in the last decades has reported that primary fascial closure (PFC) with laparoscopic ventral hernia repair is possible and has improved patient function at 6 months, minimized bulging and decreased recurrence rates (Figs. 16.3, 16.4, and 16.5).

Laparotomy with prosthetic mesh repair presents recurrence rates of 10–20%, but infection rates range from 5 to 12% in studies with large number of patients [38, 39]. Postoperative complications from open prosthetic mesh repairs are mainly related to incisional infections, including sepsis, hematomas, and necrosis. While implementation of prosthetic mesh for ventral hernia repair gives acceptable rates of recurrence in open surgery, it can still have in immunosuppressed patients' higher infection because of its foreign material nature, therefore our team has championed the use of biologic material.

Several complications including herniation of both laparoscopic and open surgery in patients who are being immunosuppressed with Sirolimus and Prednisone have been reported. Therefore, cessation or reduction of the immunosuppressive therapy should be considered before surgery in transplant patients [37].

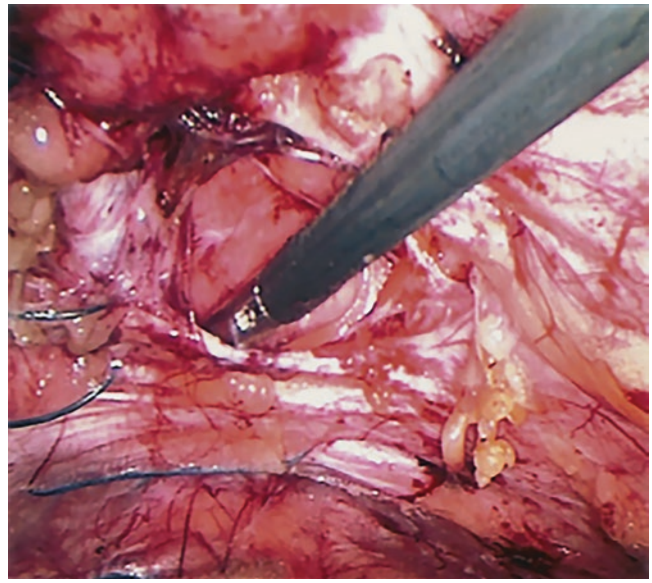


Fig. 16.3 Laparoscopic view of post-LT hernia with demonstration of the hernia defect and hernia ring

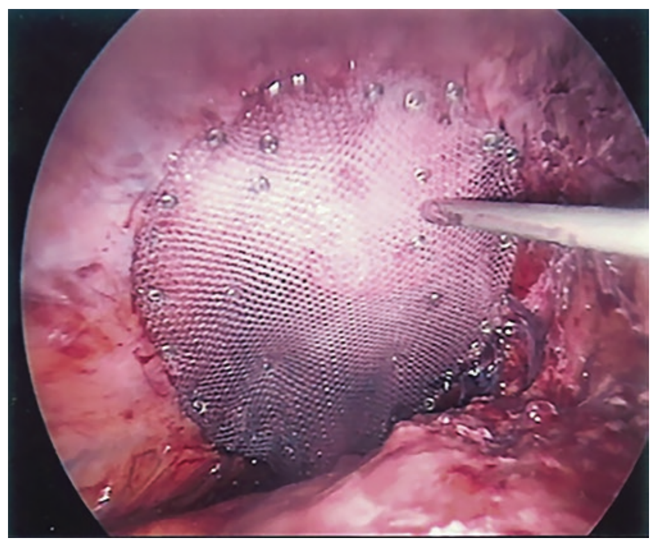


Fig. 16.4 Laparoscopic view of hernia repair with synthetic mesh and titanium tackers (we now use absorbable tacks since some of these patients may need retransplantation in the future)

Primary and Staged Closures

A shortage of size-matched organs is a common problem in transplantation surgery, especially in regions with long waiting times. We often are obligated to use larger allograft

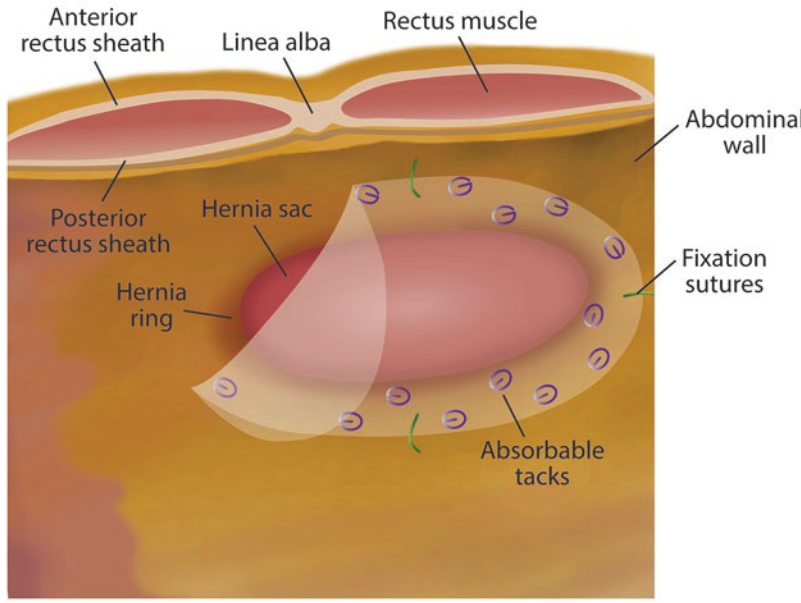


Fig. 16.5 Laparoscopic incisional hernia repair with 4 trans-abdominal fixation sutures and absorbable tacks

before the patient deteriorates. Multiple complications may follow from deterioration of the patient's health as their MELD score increases, therefore, increased deaths on the waiting list. The problem of using large grafts include: vascular thrombosis, abdominal compartment syndrome (ACS), impaired renal perfusion, and hepatic outflow obstruction, which could lead to graft loss and related deaths [40].

Where PFC cannot be done, several techniques are implemented in order to reduce abdominal wall complications and ACS due to size discrepancy between the graft and recipient. Such techniques are splitting of the liver and intestine, preoperative intra-abdominal expansion, staged reduction, prosthetic patch closure, skin flap, and abdominal wall transplantation [40, 41].

Based on the evidence, the surgical approach for procedures with an elevated abdominal wall tension at the moment of abdominal closure that prevents complications like ACS or hernias is the staged technique, which consists in partially closing the abdominal wall using a patch with drains or VAC system on top of the biologic that will be monitored while the tissue approximation takes place. This technique will allow a controlled tension method employed on the margins, preventing an ACS due to intra-abdominal inflammation. The presence of tension may result in increased abdominal pressure and may produce changes in hemodynamic parameters, renal and organ perfusion, as well as alterations in the respiratory mechanism.

Patients presenting with strangulated hernias, obstruction, and peritonitis direct suture are recommended unless the defect is large thus making it complex to perform a direct suture, in such case, biological mesh is an alternative technique.

Primary Repair VS Mesh Repair

For ventral hernia repair, primary closure was the routine technique of choice until the use of mesh came into use, especially for defects under 6–7 cm. A breakthrough study published in the NEJM by Luijendijk et al. showed that mesh repair was superior to primary repair with suture with regard to the recurrence of hernia, even in patients with small defects. Primary repair with sutures might lead to excessive tension in the tissue and subsequent dehiscence thus, surgeons elect to close larger ventral defects with prosthetic mesh and primary closure in smaller cases [42]. Studies report ventral hernia repair with mesh to have favorable results in regard to hernia recurrence even for smaller hernias with a size of 10 cm or less since the mesh allows the tissue repair without tension. Also, synthetic mesh can induce an inflammatory response that sets up scaffolding that can induce the synthesis of collagen [42].

The use of prosthetic mesh is mostly indicated in clean wounds with no signs of bowel strangulation and in large wound cases where primary closure would create excessive tension in the abdominal area, increasing the risk of abdominal compartment syndrome.

Large, complex, or infected abdominal wall defects may be approached by the use of biologic prosthetic meshes, which have the particularity to become vascularized and remodeled into autologous tissue after implantation. With such characteristics, biologic mesh is a highly competitive and low morbidity alternative when used in patients undergoing immunosuppressive therapy [40]. Data published shows fewer recurrence rates with mesh repair compared to non-mesh repair.

Human Acellular Dermal Matrix (HADM) is a biological material derived from donor human tissue, as a fascial auxiliary for difficult wound closures after liver transplant. The benefit of using HADM in post-transplant and immunosuppressed patients is its resistance to infection in addition to its mechanical properties, suppleness, malleability, strength to failure, and in case of re-exploration it maintains its strength for reclosure and helps prevent intra-abdominal adhesions [43] (Figs. 16.6 and 16.7).

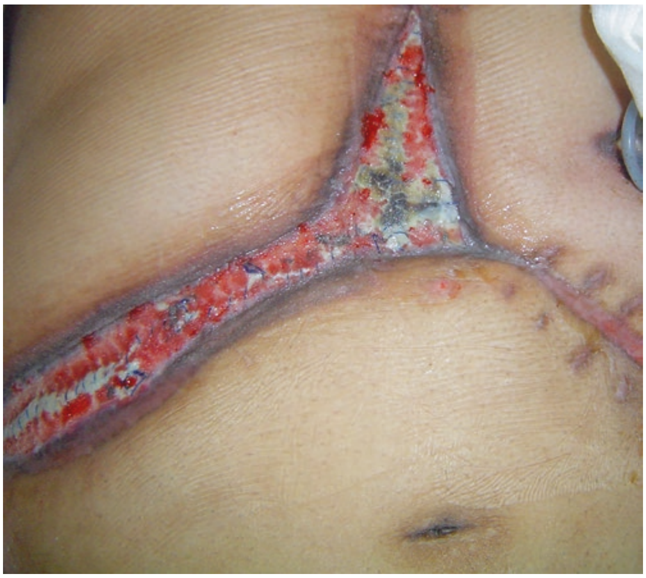


Fig. 16.6 Abdominal wall closure of a complex infected post-liver transplant case with underlay use of biologic tissue matrix (biologic mesh) relieving tension and reinforcing the fascia

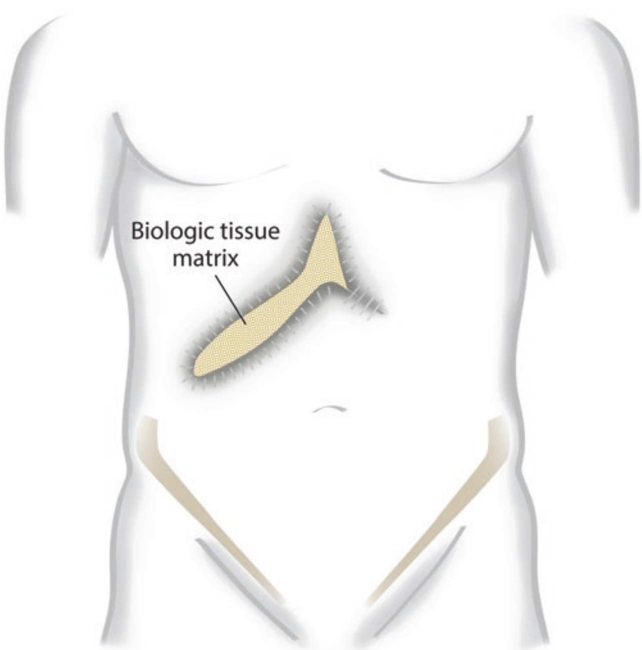


Fig. 16.7 Biologic tissue matrix after liver transplantation in complex wounds

In our institution we have observed great results with the use of biological mesh, showing very low recurrence or infection rates both in pre-transplant and post-transplant liver patients despite the complexity of these hernias, and we have used this approach both for small and for large hernia defects.

Kidney

As the number of patients with end stage renal disease (ESRD) increases and the lack of highly effective non-invasive therapies continues, renal transplantation remains the most cost-effective treatment for end stage renal disease patients, providing an extended survival rate and improving patients' quality of life.

The incidence of incisional hernias after kidney transplantation has shown to be in between 1 and 7% [4]. As mentioned earlier in this chapter certain risk factors have shown to predispose kidney recipients to develop incisional hernias, such as obesity, concurrent abdominal hernias, history of smoking, peritoneal dialysis, duration of surgery, and multiple explorations.

Laparoscopic repair of incisional hernias after kidney transplantation has demonstrated to be a safe option for this patient population and according to Hegab, shows significantly superior outcomes against the open repair in clinical, economical aspects and patients comfort expressed in shorter hospital stays, less pain, less scarring, reduced wound complication and recurrence rate [44].

Hernias in Pediatric Recipients

Pediatric patients are prone to develop hernias and other surgery related complications due to the small size of their abdominal cavity and the discrepancy in size with the transplanted organs, this situation forces the surgeon to use splitting techniques for the grafts and delayed closure of the abdominal wall or both to achieve a tension free closure [45], which is a key aspect for avoiding complications in these patients. In the authors' experience appropriate selection of the graft using technical variants we have been able to avoid delay closure and hernias in the last 100 patients over the last decade with the exception of a retransplant case and two cases in which due to ACS we had to take back to the operating room and close with a delay closure method using silastic mesh ±VAC (Fig. 16.8, left and right).

The use of temporary patches provides the surgeon a helpful tool for achieving a tension free closure and avoids complications such as deficient liver perfusion or high intra-abdominal pressures. Some of the disadvantages the medical staff may find with the use of temporary patches are leakage of

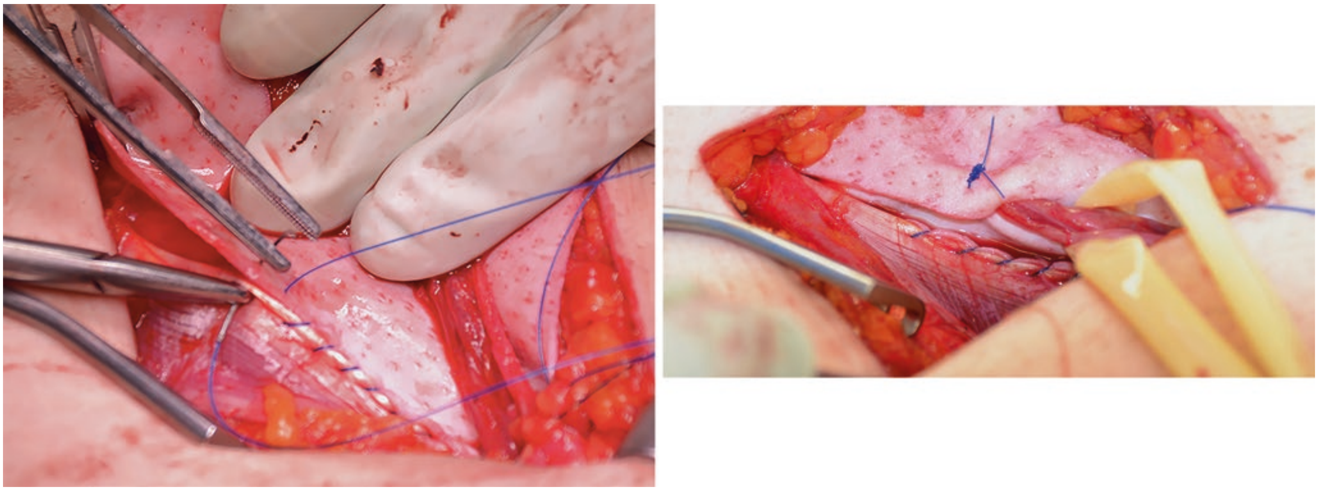


Fig. 16.8 *Left:* Use of biologic tissue matrix (biologic mesh) for hernia repair on a post-transplant patient. *Right:* Inguinal hernia with biologic tissue matrix

intra-abdominal fluid, additional postoperative wound care, interference with ultrasound, and the necessity to perform surgical procedures in order to achieve the final closure [46].

Urgent Vs. Elective

Hernias in the setting of ESOD and transplant patients are a challenging setting for the surgeon and hospital staff, for this reason, most small centers around the country prefer not to operate these cases since the complication rate is significantly increased. On the other hand, when the case is presented as an emergency the intervention has to be done as soon as possible due to the risk of necrosis of the intestinal tissue and its further consequences in the patients' survival.

The World Society of Emergency Surgery guideline proposes several ways to manage abdominal hernias based on wound classification (clean wounds, clean-contaminated wounds, contaminated wounds, dirty or infected wounds).

The presence of strangulated hernias has shown evidence of increasing morbidity because of its complications and due to the challenge they represent for diagnosis. Among the possible diagnostic tools for strangulated hernias are CT scan, serum creatinine phosphokinase (CPK), and lactate, as well as clinical signs of SIRS (fever, tachycardia, leukocytosis, abdominal wall rigidity) or signs of abdominal compartment syndrome [47].

For patients in unstable situations, for example, those experiencing severe sepsis or septic shock, open management, and staged closure are recommended because these techniques have shown evidence of producing a tension free closure of the abdominal wall and reducing risk factors for complications [47]. Inform consent with a thorough discussion of potential complications including death is detrimental especially in the CLD population with high MELD in which the medical team has to have a multidisciplinary discussion, patients that do not meet transplantation criteria in many cases may not be candidates for repair.

Live Donors

Living Donor Liver Transplant (LDLT) started its usage in pediatric transplants, but after showing efficacy and excellent results it has now been used in the last decade for adults as well, this has increased the pool of donors and reduced the waiting list for organs worldwide in center with expertise in this technique [48].

Although most complications presented in donors after LDLT are classified, as being low risk, there have been cases of high severity complications [49].

The percentage of donors who develop postoperative complications varies between 9% and 19%. Some of the most commonly described surgical complications are biliary in nature, which occurs in 5% of the donors, but other complications such as wound infection, small bowel obstruction, and incisional hernia may as well occur [50, 51].

The impact of donation for donors has been evaluated recently, reports showed that all donors were alive and feeling well and that 96% were returning to their employment status in an average time of 10 weeks post donation [52].

Finally, living donor liver transplantation is considered to be a safe and successful procedure with a low complications rate for the donors and which has shown graft and recipient survival similar to cadaveric full organ transplantation [51]. The rate of hernias is approximately 1–2% in most western series and in our experience LVHR is the procedure of choice in order to provide fast recovery, better pain control, and prompt return to their normal activity. The same applies to donors after laparoscopic nephrectomy in which cases the incidence is much lower than LDLT due to the size of the extraction site.

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Management of Flank Complex Hernia

17

Fernando Carbonell Tatay, Alfredo Moreno Egea, and Rifat Latifi

Introduction

Flank hernias or lateral incisional hernias are due to secondary defects on the abdominal wall located outside the *linea alba* and originated from a previous incision or due to traumatic event. Therefore, it includes all lateral defects on the same group (paramedial, subcostal, iliac and inguinal, lumbar).

Lateral hernia is a surgical and social problem of great magnitude. The frequency of lateral eventration is around 6–17% of all hernias according to the consulted literature [1–3]. In the authors' experience, it reaches a 25%, maybe due to their work on the *Specialised Unit on Abdominal Wall*. It is surprising the lack of publications about this group of hernias, that seems to be forgotten inside our own area. While there is main particular etiology, of these hernias, one has to consider a number of factors that may cause of be factor in these hernias. We have divided these factors into:

1. Local: wound infection, long-lasting seromas and hematomas, technical mistakes on the previous closure, type of incision, closeness to a bone structure, etc.
2. Increase on the intra-abdominal pressure: obesity, ileus, chronic obstructive pulmonary disease, cough, chronic constipation, prostatism, ascites, peritoneal dialysis, compartment syndrome, etc.
3. Systemic factors affecting the typical wound healing process: malnutrition, vitamin deficiency (A, C, B1, B2, and B6), chronic use of steroids, chemotherapy and radiotherapy, renal failure, cirrhosis, etc.
4. Metabolic disorders and soft-tissue defects: smokers, abdominal aortic aneurysm, polycystic kidney disease, Marfán, Ehlers–Danlos, diverticulosis, elderly people, etc. [3–6].

Classification

Despite being rare these hernias have been described by a number of authors and thus a number of classification exist. Subsequently, none of them has been accepted by a majority of surgeons, and nowadays, it is estimated that only a third of surgeons in fact use a classification. We advise to use one of these two (Fig. 17.1) [3]:

1. *Chevrel*, 2000. Lateral hernias = L1 (subcostal), L2 (transversal), L3 (iliac), and L4 (lumbar).
2. *Moreno-Egea*, 2007. Non-medial hernias (NM) = S (subcostal), I (iliac), and L (lumbar).

In both cases, the regional anatomic borders are the same. Subcostal hernias are located between the costal limit and a horizontal line 3 cm above the navel. These are a result of subcostal incision (liver resection or liver transplantation, pancreas or biliary tree).

Iliac hernias, on the other hand, are located between a horizontal line 3 cm below the navel and the inguinal region. Most of them are related to appendicitis surgery, urological or gynaecological surgery, kidney transplant, bone extraction (autologous transplant of bone), ostomies closure, recurrent inguinal hernias, recurrent Spiegel hernias, trocars in iliac fossa, and drainage incisions. Other cause can be herniation of abdominal content through a defect on iliac bone following bone grafting of complex trauma. The rest are considered lateral (L2) and are located in the flank, outside

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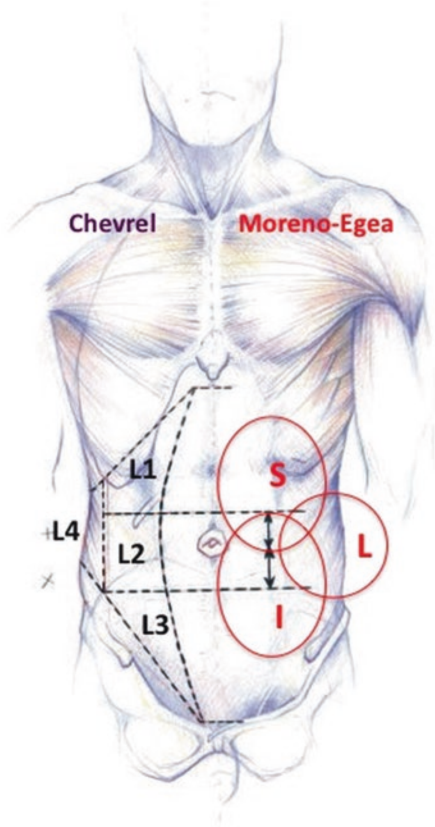

Fig. 17.1 Classification of lateral hernias. Chevrel: *L1* subcostal, *L2* lateral, *L3* iliac, *L4* lumbar hernias. Moreno-Egea: *S* subcostal, *I* iliac, *L* lumbar hernias

Fig. 17.2 Clinical presentation of iliac hernia

the rectus sheath and up to 3 cm above and below the navel. One very difficult type of hernias to deal with are traumatic lumbar hernias that need to be diagnosed early and dealt with once the other major injuries have been addressed [6–8].

Topographic Anatomy

The area defined as lateral on the abdominal surface cannot be accurately delimited. The costal and iliac bone limits and the lateral edge of the rectus abdominis muscle are the only recognizable structures. The fibers of the external oblique muscle descend from its posterior costal origin to insert on the external edge of the iliac crest. Therefore, we propose to consider the anterior axillary line as the limit for the separation of the lateral areas (L2–3) from the lumbar zone (L4 or "L"). The proper knowledge of the morphology and function of the abdomen lateral muscles will allow us to perform a more accurate operation, focused on restabilizing their function. The anatomic structures to be considered during this operation are: skin, subcutaneous tissue with the fascia of Camper and the deep fascia of Scarpa, and a triple muscular layer, the oblique, and the transverse abdominal muscles.

Knowledge on aponeurosis and muscular insertions is essential to fix hernias safely, layer by layer. Between the external and internal oblique muscles, there is an avascular area that allows its separation. The internal and transverse oblique muscles cannot be separated easily and between them we can find the neuro-vascular package of lumbar and inferior intercostal branches. On the medial level, both intramuscular areas are very limited because they are part of the rectus sheath. Thus, it is difficult to extend a mesh to the hernia defect medially.

Clinical and Diagnosis

The clinical presentation depends on the size and the location of the hernia. They can appear right after the surgery or two or more years later. Patients report subjective discomforts and often pain that impacts their quality of life. Objectively, a protrusion on the abdominal wall with effort is obvious and that can reach big dimensions. Hernia can become painful indicating tissue suffering, evolving to incarceration or strangulation with mechanical ileus and viscera distress. The risk of complications is usually low but cannot be predicted (Fig. 17.2) [3].

The diagnosis is usually made clinically, but most patients will have already a CT scan when they see a surgeon. Decubitus exploration, without tensing the abdomen flat muscle, helps recognize hernia mass. The elevation of the extended legs increases the intra-abdominal pressure and tenses the rectus and flat muscles, which can hide the hernia. The elevation of the head tenses the rectus muscles but not the flat ones, which allows hernias to be become more visible and easily palpable. If patient does need a CT a scan, we advise to use a dynamic CT to complete the

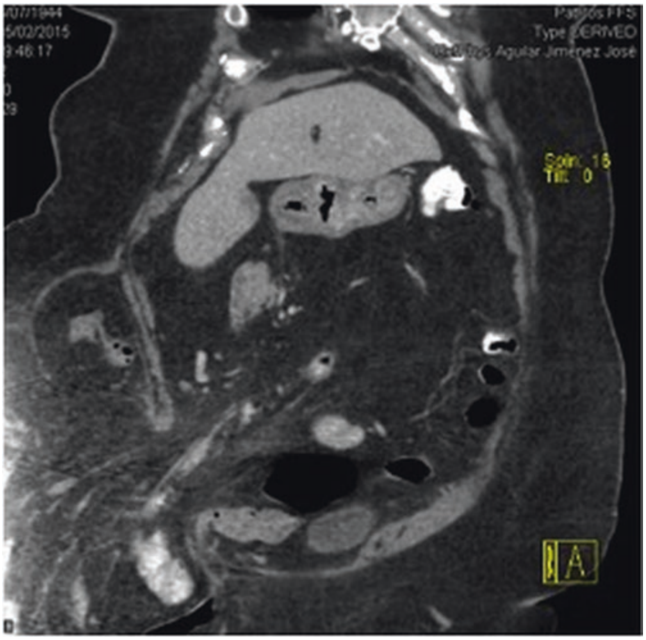

Fig. 17.3 CT: Iliac hernia

preoperative study and plan surgery. It allows to calculate accurately the size of the hernia and to value the adjacent tissues (Fig. 17.3).

Surgical Treatment

General Considerations

Initially, we can apply the same rational criteria that we follow for medial ventral hernias. Any patients presenting with a lateral hernia must be considered for surgery after initial work up. Delaying the surgery must be avoided due to its progressive growth and potential complications including deterioration of functional and esthetic status with most advanced hernia. When the hernia size is small, the expected results are better and the chance of recurrence is considerably smaller. Individual risk assessment of each patient must be performed before surgery and those at high risk should not be operated upon unless there is an emergency.

Hernias near or involving bone edges (iliac hernias, for example) makes it more difficult the identification of tissue planes. As with other types of hernias open surgery and laparoscopic surgery are reasonable options, but which technique is used depends on the surgeon's expertise both for medial and lateral hernias. For small or moderate size hernias, the laparoscopic approach can be considered as an option if surgeon has enough experience. For the big defects, an open approach must always be considered. The use of the tension-free surgery with mesh is more advisable and the location that offers the best results is the deepest one. The use of a double mess is advisable on big defects and when muscle atrophy due to denervation is referred; because this technique obtains a greatest strength of the abdominal wall.

Open Technique

The open technique surgery of the lateral hernia is not standardized due to its variety, higher anatomical complexity, and its low frequency. Anatomical reconstruction techniques are not advisable, except for small cases, and performed by surgeons with high experience. The techniques of fascial imbrication or muscle flaps are complex and must be reserved for experienced groups. In our hands open lateral approach through previous incision and the use of a nonabsorbable synthetic mesh as reinforcement is the best technique of repairing these hernias.

Suprafascial Mesh

Theoretically is the least advisable option but it is increasingly being used due to its technical simplicity and its efficiency, if it is performed correctly. It is not very traumatic because it requires less dissection, it does not cause the devascularization of the rectus muscle and can complete and separation of components (Carbonell Technique) [3]. Furthermore, it does not require special meshes because it is far from the abdominal cavity (PP of medium/low density). The aponeurosis of the external oblique must be dissected at least 5 cm past the defect in all directions. It is advisable to attempt a full or partial closure of the defect. The mesh must overlap the tissues and must be fixed safely (lateral to the muscular fascia, medial to the aponeurosis, inferior to the iliac crest and the anterior superior iliac spine, and superior to the costal edge).

Intramuscular Mesh

On lateral hernias, the dissection of the preperitoneal area can be complex, especially on an internal level due to the edge of the rectus muscle or when there is a tissue deficit or previous meshes. When this dissection is not possible, the deep layer of the defect is sutured (transversal and internal oblique muscles), the area between the external and internal oblique is cleaned and the mesh is put between them. It is advisable to ensure a total overlap. On this area, the mesh should be of low density, even self-adhesive, or fixed with cyanoacrylate.

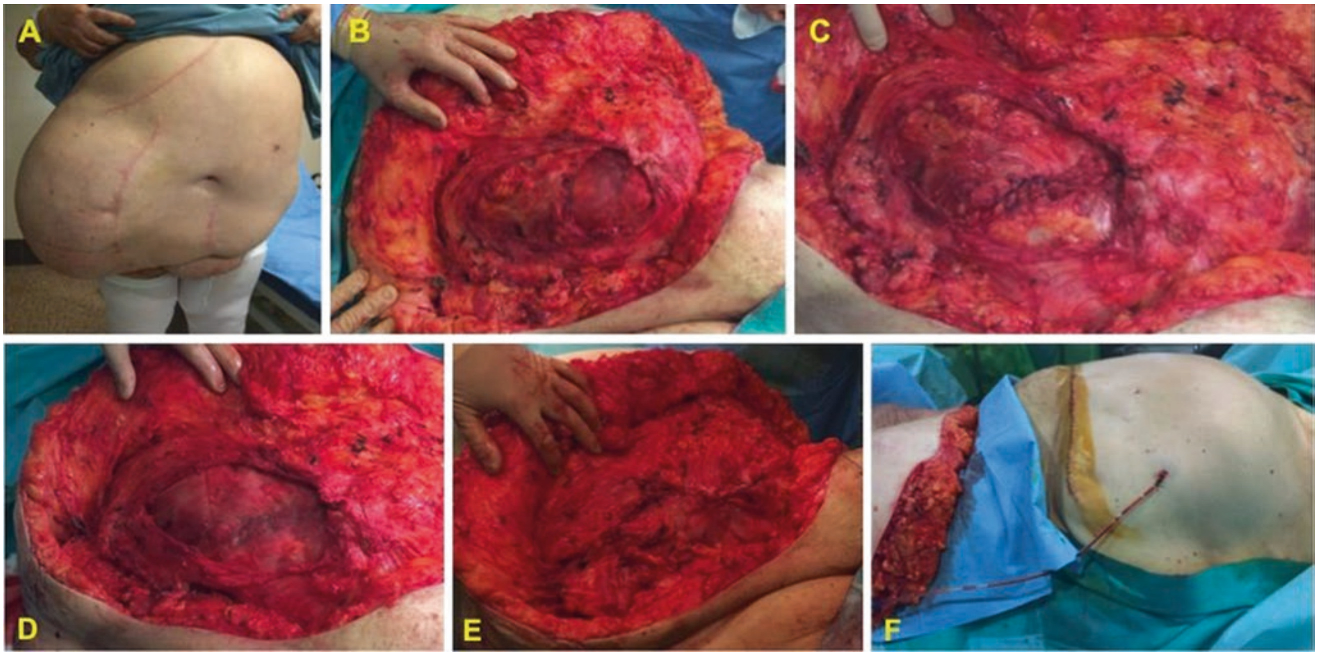

Fig. 17.4 Double prosthetic repair: Moreno-Egea's operation. (**a**) Iliac complex hernia; (**b**) Preperitoneal mesh repair; (**c**) First fascial repair; (**d**) Intermuscular mesh repair; (**e**) Second fascial repair; (**f**) Abdominoplasty

Preperitoneal Mesh

Placing the mesh preperitonealy may have theoretical advantages. The intra-abdominal pressure favors mesh contact with the abdominal wall and distributes the forces on the material homogeneously. Practically, however, it can be difficult to differentiate this layer on the big lateral hernias and frequently during the dissection surgeon enters the abdominal cavity. The dissection must separate the peritoneal cavity from the oblique and transversal muscular fibers, taking into account that the three muscles apeneuroses create the hernial ring.

Maintaining pressure on the hernia sac without opening it facilitates this maneuver and allows us to separate the area between the peritoneum and the other layers. Before placing the mesh we must verify that there is a continued layer and there is no opening where intestines can migrate. Then, it is fixated with transfixive stitches to the layer of the transversal and minor oblique muscles. The aponeurosis of the external oblique is closed if possible or sutured to the mesh. On this approach the mesh must be properly chosen (low density and coated), depending on the safety of the peritoneal closure.

Intraperitoneal Mesh

This is not an optimal option to begin with but may be necessary for many of these hernias. We must use intraperitoneal mesh when we cannot obtain a continuous preperitoneal space (previous meshes or multiple recurrences). Nowadays, there is wide clinical experience to prove its viability. The advantage of this option is that it allows a proper visceral identification and a maximum overlap without parietal injury of the dissection on the different levels. Therefore, some authors consider it the best choice. The fixation must be secured, through transmural stitches or with staples (as on the laparoscopic approach). It is compulsorily that the mesh is bilaminar or coated with titanium (compatible with visceral contact) [8–10].

Double Mesh

The characteristics of lateral hernias make of this double-mesh technique an advantageous possibility for these patients. It is advisable when the preperitoneal mesh cannot guarantee a wide overlap due to dissection problems. Moreno-Egea, in 2006, described it as an intraparietal repair that avoids mesh splitting which increases surgical morbidity. This technique avoids any type of parietal tension and the possibility of recurrence. The author describes two types according to the location of the first mesh: Type I on a peritoneal level; Type II intra-abdominal (2015) and shows that the use of two meshes, introducing the concept of "combined fixation" (associating to the suture a synthetic tissue adhesive). Unlike medial hernias, on lateral ones we can perform a deep double-mesh technique (preperitoneal + intramuscular), avoiding a superficial mesh. This option is relatively simple to perform and it obtains the best aesthetic results, associating it with an abdominoplasty without increasing morbidity (Fig. 17.4) [7–13].

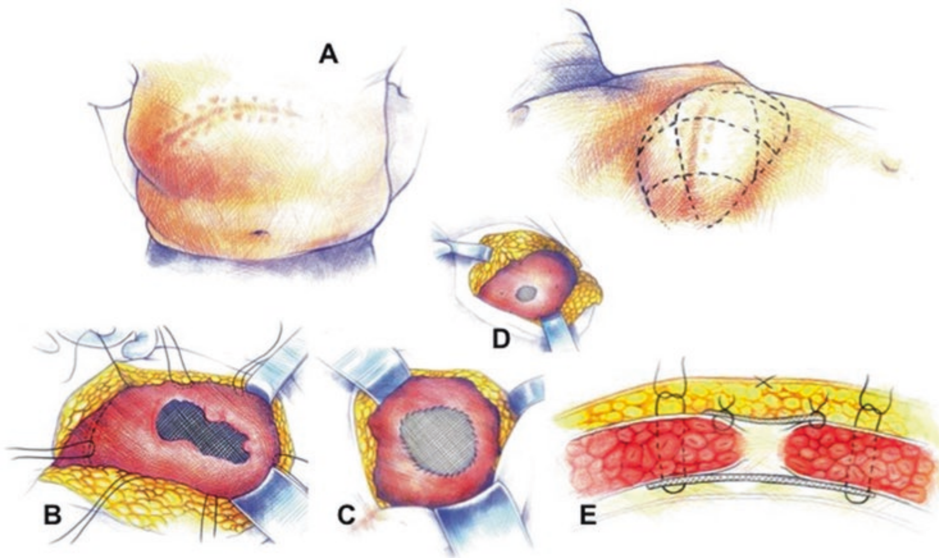

Fig. 17.5 Double prosthetic repair: Carbonell-Tatay's operation. (**a**) Subcostal hernia; (**b**) Preperitoneal mesh repair and fixation; (**c**) Second supraaponeurotic mesh repair; (**d**) Detail of retraction of second mesh repair; (**e**) Operative view

Tight Double-Mesh Technique

Another double-mesh modality has been proposed by Carbonell-Tatay. It differs from the previous one on the fact that the second mesh adapts to the hernia defect. The incision is performed removing the old scar and the subcutaneous tissue is cleared to expose the aponeurosis on about 10 cm around the hernia defect. We discover the edges of the defect and the preperitoneal level, using blunt or electrocautery dissection. The first prosthesis is placed on the preperitoneal level, with a size bigger than the defect on at least 5 c. and is fixated with transmuscular stitches (PPL 2/0) in U. The stitches are knotted in the end with a soft traction to achieve the complete expansion of the mesh. On this level, we can apply adhesive tissue to minimize the dead space. The second mesh is adjusted to the edges of the defect and is fixated with continuous suture. On this second mesh, we can pulverize the rest of the adhesive. The hemostasis must be rigorous and we must leave two vacuum drainages, like Redon with heavy gauge. We finish by closing the subcutaneous cell tissue and the skin. What this options intends is to obtain a solid healing, without tension that restores the biomechanics of the abdominal wall as much as possible (Fig. 17.5) [2, 3].

Medial Approach

The preparation can be performed via a Cheatle–Henry approach, with the Stoppa technique [3]. The hernia is approached with an infraumbilical laparotomy and through the peritoneal area. The mesh is located between the peritoneum and the transversalis fascia, below the rectus and the transversal muscles of the abdomen. It can be performed on iliac and low lateral hernias. The use of a big mesh on this area does not require fixation. We advise fixation to the pubis and to the Cooper ligament.

Laparoscopic Technique

Laparoscopic Technique in Hernia Repair Has Become Common

The position of the patients varies depending on the location of the defect. Therefore, on lateral hernias the patient is located on supine decubitus and on posterior hernia on lateral decubitus on 90°. The surgery is performed with general anaesthesia and the pneumoperitoneum with a Veress needle on a subcostal level or open technique. The position of the three trocars depends on the size and the exact location of the defect. We normally search for a triangulation (two of 5 mm and one of 10 mm). It is performed with full adhesiolysis to be able to work with more space on the abdominal cavity.

(a) *Iliac hernia*

The supraumbilical optical and the lateral working trocars are placed and the hernia defect is identified. Approximately 4 cm above the defect the peritoneum is opened through the Told fascia to enter into the preperitoneum. We lower the sheet of peritoneum from the urachus triangular ligament to the iliac crest, widely surpassing the defect. That way, we reduce the content of the hernia, leaving the posterior abdominal wall free and without interfering with the sigmoid colon or the intestinal loop. We identify the bones structures (pubis, Cooper, and iliac crest), the neuro-vascular structures (epigastric

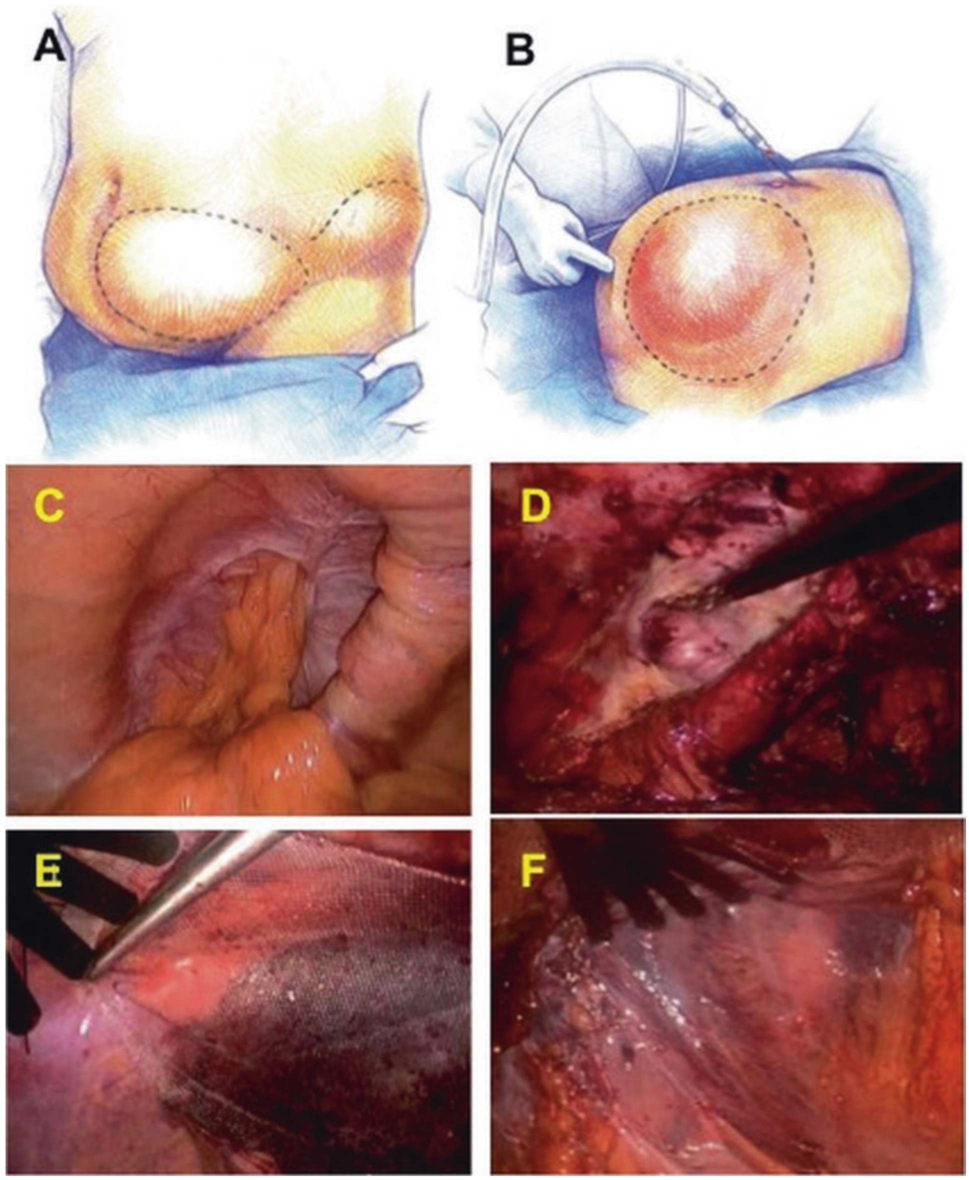

Fig. 17.6 Iliac hernia: laparoscopic repair (TAPP). (**a**) Iliac hernia; (**b**) Pneumoperitoneum with a Veress needle; (**c**) Intra-abdominal view of defect; (**d**) Preperitoneal space; (**e**) Preperitoneal mesh repair; (**f**) Peritoneum closed

vessels, obturator, femoral, and femorocutaneous nerve), and the muscles (anterior rectus, psoas, transversal, and internal oblique). The last dissection is similar to the one performed on the inguinal hernia on the transperitoneal technique. The reconstruction is performed with a bilaminar or coated with titanium mesh because we are working partially on the abdominal cavity. The mesh must surpass all the edges of the defect on at least 5 cm. The mesh is inserted through the 10 mm trocar and is extended near the defect. Once the prosthesis is placed, covering the defect properly, it should be fixed. The fixation must be initiated from the inferior side through a line of helicoidal staples. After that, we can complete it from side to side and end with the superior part. When the defect is not very big, after fixing the inferior side we can complete the lateral and medial fixation using glue (since we are working on an extraperitoneal area it is completely safe). We lift the open peritoneum and stick it to the mesh, closing the created working space (Fig. 17.6).

(b) *Subcostal hernia*

The position of the patient depends on the side of the hernia. The trocars are placed away from the target. The dissection is entirely intra-abdominal. We perform a full adhesiolysis and we can mobilize the liver to increase the cranial overlap. The reconstruction with mesh is similar to that used on any other medial defect. The extension of the mesh is usually simple on these defects. The fixation must be safe, we advise a double crown and also an adhesive to the rest of the surface of the mesh in contact with the posterior abdominal wall (Fig. 17.6E). We must inspect the abdominal cavity and the trocars must be removed under direct vision. We empty the pneumoperitoneum slowly and finish the procedure. In our experience, the laparoscopy allows an outpatient treatment of lateral hernia in more than 30% of the cases. Complications are rare and local, seroma or hematoma. Severe complications are exceptional, unlike what happens with medial hernias repair. The hematoma is more frequent on iliac hernias and the seromas on subcostal ones. Pain is more frequent on lumbar hernias treatments. The recurrence rate is at 8.2%, more frequent on subcostal hernias (25%) [9]. The esthetic result is better and there is no associated muscular atrophy. The outcomes of laparoscopic approach depend on (1) size >15 cm; (2) obesity BMI >30 kg/m^2; and (3) the type of subcostal hernia. On these three groups, the laparoscopic approach should be limited. The open approach must be chosen on these three groups of patients and on the cases where muscular atrophy is associated, previous meshes or damage on the skin. The double-mesh technique is the one that obtains better results on complex lateral hernias (more security and strength). Since lateral hernias are very different (etiology, size, location, evolution of the hernia, muscular atrophy, associated diseases, type of surgeon, experience, etc.) it is not possible to standardize the approach, and thus individual approach is advised. As stated elsewhere, these patients should be managed in experience and specialized centers [8–11, 14, 15].

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Laparoscopic Access to the Difficult Abdomen in Patients with Large Abdominal Wall Defects

18

Orhan Veli Ozkan, Selman Uranues, and Abe Fingerhut

Introduction

Laparoscopic repair of incisional hernias is safe and effective [1], touting a low surgical site infection rate and short hospital stay. However, the initial trocar access in patients with previous abdominal surgeries and/or attempts at hernia repair may be difficult and dangerous. Blind Veress needle or trocar punctures are responsible for access complications; more than half develop at this stage and can be lethal in 0.05–0.2% of patients [2]. Access injuries may involve solid organs (predominantly liver and spleen) or hollow viscus, including the bladder. Vascular injuries may affect intra- and retroperitoneal vessels (the aorta, inferior vena cava, and iliac vessels) or abdominal wall vessels [3–6]. Injuries frequently tend to become evident only at the end of surgery (when the trocar has been removed), or even hours post-operatively.

Several techniques, instruments, and approaches have been introduced with the intent of minimizing access-related risks. Optical trocars and bladeless, threaded visual cannulas have also been developed. To date, however, no surgical or interdisciplinary consensus on an optimal method has been reached [7].

General Features

Trocar access for incisional hernia repair surgery can be challenging, especially in patients with large abdominal wall defects, as after previous iterative surgeries and repair attempts (Fig. 18.1). Despite the "double-click" safety feature, blind abdominal entry with a Veress needle, one of the most commonly employed techniques, cannot be considered safe. Adherent bowel loops or mesenteric vessels can easily be injured since the double-click safety feature can be activated when the tip of the needle is in the bowel lumen or behind the bowel after going completely through it. This kind of injury is usually recognized only at the end of the operation, or sometimes, even later. Neither the Veress needle nor atraumatic trocars or bladeless and optical ports are safe options to be used in difficult abdomens. Open entry under direct vision seems to be the most advisable technique.

In the open entry technique, a small, 2–2.5 cm incision is made through the entire thickness of the abdominal wall and the peritoneum is entered either under direct vision or bluntly with the surgeon's index finger. Care must be taken when incising the fascia because the peritoneum might be absent and the intestines might be directly adherent to the fascia. In general, open entry is time consuming and carbon dioxide may leak out around the trocar.

Open entry, as described, can be created quickly and safely, even in a difficult abdomen. This technique avoids the limitations of most open techniques and eliminates the complications associated with blind insertion of a Veress needle or trocar [8].

Patient Selection

Patients even with large abdominal wall defects can be treated safely laparoscopically. The size of the defect, patient habitus (obesity), and expected intestinal adhesions both to the abdominal wall and/or to the hernia sac are no longer contraindications. The limitations of laparoscopic incisional hernia repair arise when defects are close to the chest, ribs and pelvic bones or in both flanks close to the lumbar area. Hernia imaging and localization using computed tomography may aid in planning the operation. Comorbidities such as diabetes, immunosuppression, and/or obesity may increase postsurgical complication and recurrence rates.

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Surgical Technique

The patient should be placed supine on the operating table properly fixed so that the table may be tilted as desired. A Foley catheter and a gastric tube should be inserted routinely.

Fig. 18.1 Patient with large abdominal wall defect after iterative surgery

With the above described open access technique the abdomen can be entered at any point sufficiently distant from the defect, but not beyond the anterior axillary lines. Dissection then proceeds as follows: the fascia is incised, the muscles are separated carefully, and the pre-peritoneal area is entered under direct visualization. Now the peritoneum is opened, preferably sharply. Depending on the length of the opening one or two strong non-absorbable sutures are passed through all the layers of the abdominal wall and peritoneum, and fixed using the suture (Rummel) tourniquet technique (Fig. 18.2a, b). Next, after finger palpation of the peritoneal area and loosening/separation of all adhesions within reach, a 10/11 mm trocar is put in place and the suture tourniquets are tightened. This maneuver prevents loss of gas and ensures full mobility of the inserted trocar. During surgery, all necessary material such as a mesh or circular stapler anvil can easily be introduced or removed. After the completion of surgery, the fascia is closed using the same suture and further sutures can be added as necessary.

After the first trocar has been inserted safely, the pneumoperitoneum is adjusted to 12–14 mmHg, and the abdomen is entered preferably with a 30° optic. If necessary, further adhesions can be lysed with the blunt tip of the first trocar while the optical device is still in the trocar and the surgeon can see what he/she is doing. Once enough space has been created, further trocars, preferably two 5 mm ports, are inserted under direct visualization. The maintenance of an appropriate distance and triangulation between the trocars are important to allow ease of working in all quadrants (Fig. 18.3).

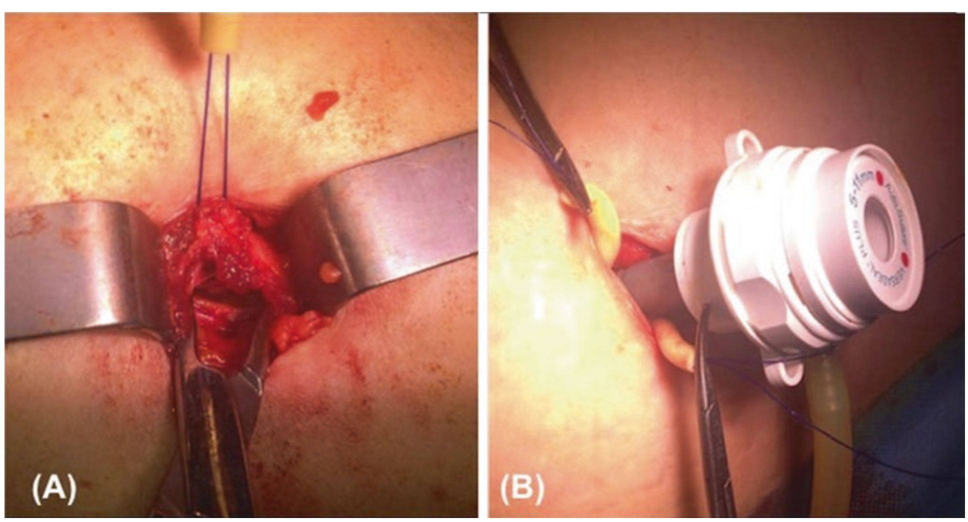

Fig. 18.2 (**a**) After separation of the abdominal wall layers under visual control sutures are placed through all layers. (**b**) Fixation of the first trocar with two suture tourniquets (Rummel) narrowing the fascia and preventing gas loss

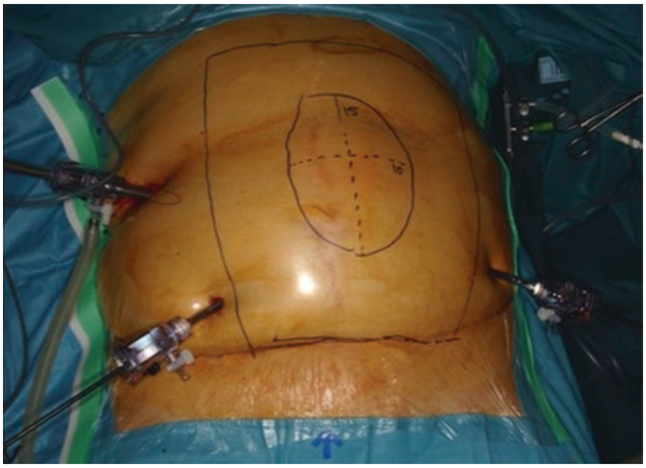

Fig. 18.3 All trocars should be introduced as far as possible from the abdominal wall defect

After the operation has been completed and the abdominal wall defect repaired, the fascia may be closed using the same sutures or other sutures as required [8, 9].

Potential Advantages

This technique does not prolong surgery and is inexpensive. The open approach allows immediate recognition of all intra-abdominal adherences to the peritoneum, and should any injury occur, it can be identified and repaired immediately. A further advantage is that the fascia suture, when closed tightly with a tourniquet, will prevent gas leakage. This method facilitates the rapid introduction of surgical materials into the abdominal cavity and specimen or material removal, as necessary. Furthermore, at the end of surgery these sutures serve to close the abdominal wall (Fig. 18.4a, b).

Conclusion

Large abdominal wall defects, usually resulting from severe complications and infections that have required repeated abdominal surgeries, can be repaired laparoscopically with few exceptions. Access to the abdominal cavity, however, is usually difficult and requires particular care and attention.

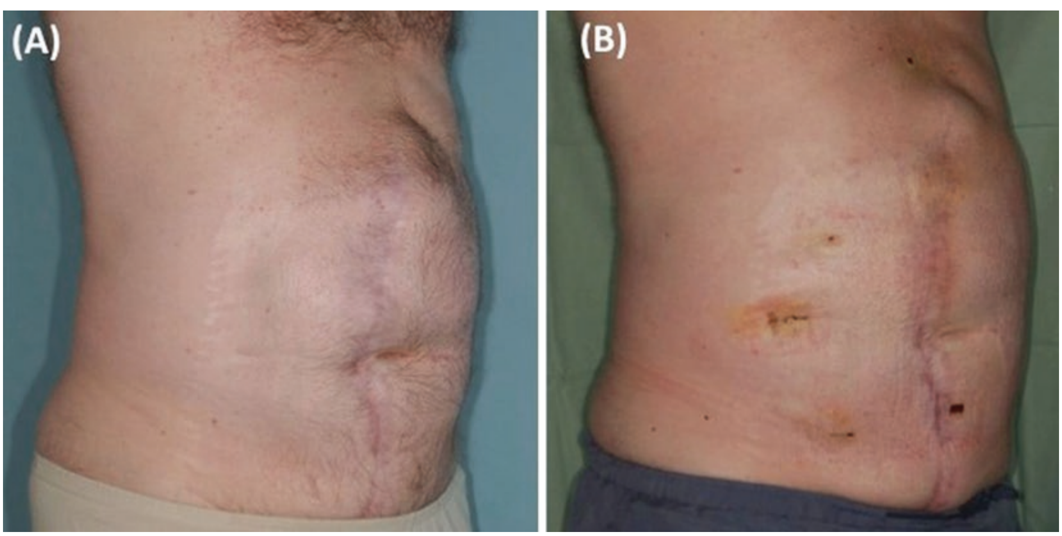

Fig. 18.4 (**a**) Preoperative view of a large abdominal wall defect with intestinal protrusion. (**b**) Postoperative view after laparoscopic repair

The open approach should avoid access-related complications, or allow their prompt recognition. The described method is simple and inexpensive, does not require any extra equipment, and is a safe and effective alternative to other means of access.

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Laparoscopic Techniques in the Repair of Large Abdominal Wall Defects

19

Selman Uranues and Orhan Veli Ozkan

Introduction

The prevalence of ventral hernia is similar in men and women and increases with age [1]. Hernias occur after 4–11% of elective operations [2]; in the United States, there are 250,000 incisional hernia operations per year [3]. After emergency surgery, patients are much more likely to develop wound complications and incisional hernias [4, 5]. The recurrence rate of up to 50% is considerably higher after both direct closure of large primary hernias and repair of incisional or recurrent hernia without mesh [4, 5]. Recurrent incisional hernia is a common long-term complication after open repair of large abdominal wall hernias. Repair of incisional and recurrent hernia remains a challenge in general surgery, and the use of mesh may lower the recurrence rate to 11–18% [6]. Mesh repair in open technique requires a large incision and extensive fascial dissection on both sides, with large wounds and a high rate of wound complications such as seromas and infections [7].

Large abdominal wall defects are usually caused by an incisional hernia recurrence following multiple laparotomies; these defects are technically challenging because of the destruction of abdominal wall structures and the presence of extensive intra-abdominal adhesions. It is suspected that both the hernia and the adhesions have an impact on gastrointestinal quality of life (GIQLI) [8]. Autopsy data indicate that adhesions are to be expected in 67% of cases with a previous laparotomy [9]. Clinically, adhesions were found on laparotomy in 93% of patients who had previously undergone one or more laparotomies [9].

In non-specialized centers, it is often thought that these patients are not good candidates for laparoscopy. Recent literature confirms that laparoscopic repair of ventral hernias can have a low recurrence rate, minimal postoperative morbidity, early mobilization, and shorter hospital stay [10–13].

Patient Preparation, Equipment, and Positioning

Patients are instructed to shower with an antiseptic wash lotion (Betadine® liquid soap) the evening and morning before the operation. We view this as an important measure for infection prophylaxis, especially with obese patients. Preoperative bowel preparation has not proven to be beneficial. The patient should abstain from food for 6 h and from liquids for 2 h before surgery.

The camera assistant and the surgeon stand on the same side of the patient. With few exceptions, abdominal wall hernias are operated from the side with the laparoscopy tower opposite (Fig. 19.1). It is ideal when there are several monitors around the operating table or when the laparoscopy equipment is ceiling mounted and can easily be shifted up and down. A high resolution optic-and-camera system is essential for the patient's safety. The diameter of the optic (10, 5, or a mini-optic of 2–3.5 mm) depends on the surgeon's preference and the extent and location of the hernia. A 30° or 45° optic is ideal as it can be turned easily for optimal viewing of parts of the abdominal wall or intestines that may be hidden behind adhesions. The angled optic facilitates the view of the abdominal wall and manipulation of the mesh, especially while it is being fixed and when the transfascial sutures are pulled through. Surgery usually requires only two atraumatic graspers, a dissector and curved scissors. The diameter of the trocars depends on the instruments preferred (Fig. 19.2).

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Fig. 19.1 Setting in the operating room for the surgical team on the near side and the laparoscopy tower opposite

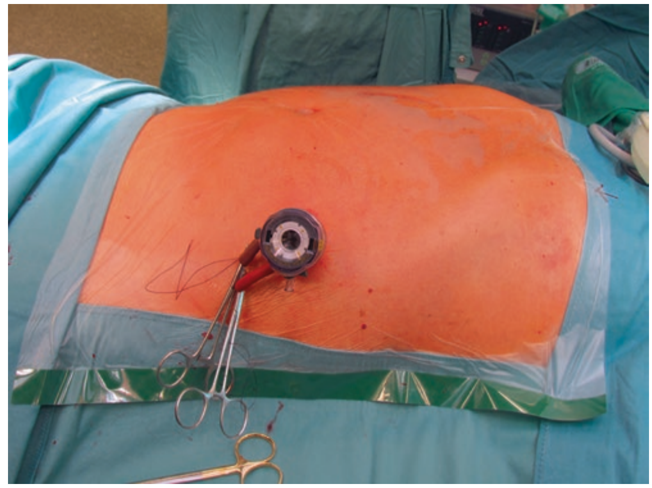

Fig. 19.3 First trocar fixed with suture tourniquet after open access entry

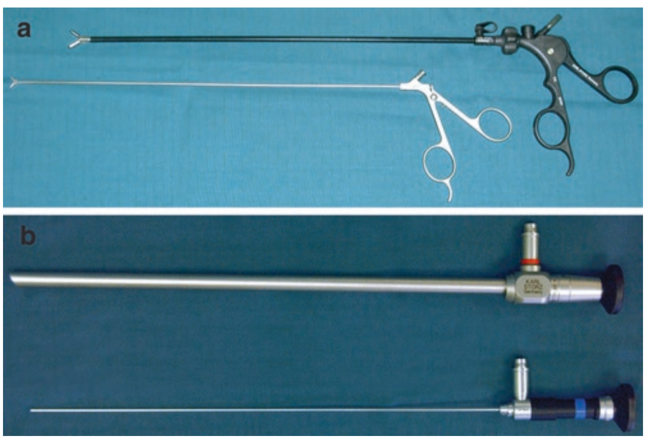

Fig. 19.2 (**a**, **b**) Instruments and optics, sizes (**a**) 5 and (**b**) 2 mm

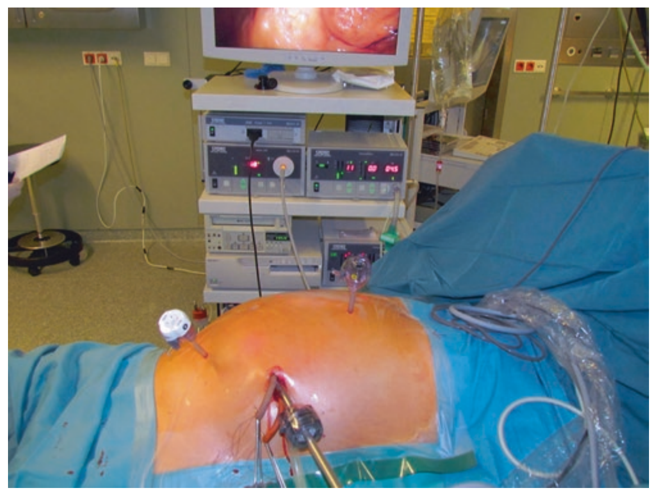

Fig. 19.4 Position of the trocars with optimal triangulation

Because an approximately 1.5–2 cm incision is always needed later to insert the mesh, a 10/11 mm port should always be introduced with an optical trocar (Visiport™) or in open access technique. To avoid loss of gas with open access, the edges of the fascia are adapted to the trocar with one or two sutures passing through tourniquets (Fig. 19.3). The camera should be as far as possible from the hernia opening between the two working trocars. To this end, a site halfway between the costal arch and the iliac crest on the right or left flank is usually chosen. The two working trocars with a diameter of 5 mm or less are placed as far apart as possible to establish optimal triangulation. The trocars should be introduced at an angle of 60° in the direction of the hernia so that the abdominal wall and hernia sac can be reached more easily for safe adhesiolysis (Fig. 19.4). Here, it should be borne in mind that prominent landmarks such as the ribs, pelvic bone, and pubic bone can limit the maneuverability of the trocars and instruments.

One hour before surgery, the patient, receives intravenous antibiotic prophylaxis. A Foley catheter is inserted routinely and left in place until the patient is mobilized after surgery. A nasogastric tube is inserted when anesthesia is induced and removed at the end of the operation. The patient always undergoes surgery in the supine position. On the surgeon's side, the arm is fixed to the patient's flank to allow as much space as possible for the surgical team. The patient should be so stabilized on the operating table that it can be turned in any direction during the procedure. In this way, the intestines can be shifted by gravity, facilitating easy manipulation during adhesiolysis. The abdomen is widely prepped on either side, above the xiphoid cephalad and below the pubis onto the upper thighs. Sterile drapes cover the abdomen, and the abdominal skin is completely covered with a transparent adhesive drape.

Surgical Technique

Surgery for abdominal wall hernias is generally standardized and consists of two steps: adhesiolysis and repair of the hernia with intraperitoneal mesh.

The first skin incision is made at the greatest possible distance from the scars from previous laparotomies. This corresponds to a location on the right or left flank far lateral to the rectus muscle along the anterior axillary line. The dissection is deepened, incising the fascia and carefully splitting the muscles until the peritoneal cavity is accessed under direct vision. Before the first trocar is inserted under direct vision, two strong, nonresorbable sutures are passed through all the fascia and muscle layers of the abdominal wall and fixed with a tourniquet (Fig. 19.5). Then, after digital palpation of the peritoneal space and separation/loosening of nearby adhesions, a 10/11 trocar is introduced anterior to the large intestine. The fascial sutures are pulled taut with the tourniquets so that no gas is lost during surgery [14]. Another option is to use an optical trocar (Visiport™) to create the first trocar access.

The pneumoperitoneum is set at 12 mmHg, followed by the introduction of a 30° optic. Two additional 5 mm or smaller ports are introduced under visual control. It is important that the working trocars in the upper and lower abdomen are so placed that there is sufficient distance for placement of the mesh, with all four abdominal quadrants within reach.

If there are adhesions, exposure is achieved by pushing and pulling with atraumatic graspers. Grasping instruments should be used carefully as long as the structures in the adhesions are not well defined (Fig. 19.6). It is always possible that there are loops of intestine in or behind the fatty tissue of the omentum. Sometimes it is helpful when the surgeon uses the grasper with the dominant hand and presses against the abdominal wall with the non-dominant hand in the area of the adhesions. This can lessen the distance to the adhesions in the uplifted dome of the abdominal cavity. The intra-abdominal gas infiltrates into the fatty tissue and adhesions, forming a soap-like foam that makes it easier to loosen the adhesions.

Matted adhesions or bands are divided by sharp dissection with cold scissors. Under normal circumstances, energy-based devices are not used to divide adhesions, although they can be useful when the falciform ligament of the liver has to be severed or the urinary bladder must be separated from the anterior abdominal wall. The goal of the adhesiolysis is to expose 4–5 cm of anterior abdominal wall around the fascial defect. Care should be taken to avoid any unnecessary dissection of adhesions within the bowel loops. With obese patients and those with numerous scars from previous operations, it may not be possible to probe and detect all herniations prior to surgery. For this reason, adhesions should be lysed in the areas of all the scars so that any such undiagnosed hernias are not overlooked. It is not necessary to remove the hernia sac.

The fascial defect is determined by probing and pressing through the abdominal wall. The size of the mesh is determined by briefly releasing the pneumoperitoneum and using a pen to mark an area extending 4–5 cm all around the hernia and measuring it (Fig. 19.7). Then, the pneumoperitoneum is reestablished, and the entire team changes gloves. Only then is a preferably expanded polytetrafluoroethylene (ePTFE) light dual mesh placed on the table and tailored to fit the measurements. The mesh is marked on the side toward the fascia, with arrows indicating the cranial or caudal end. On the four corners and between them, eight nonresorbable sutures are placed in a U shape and knotted (Fig. 19.8). The sutures should be cut to a length of 10–15 cm so that it will be easier to grasp them later with the suture passer and pull them out. The sutures are then placed in the mesh, which is rolled up along the long edge. The optic trocar is removed, and the mesh, held with a grasper, is inserted through this incision into the abdominal cavity (Fig. 19.9).

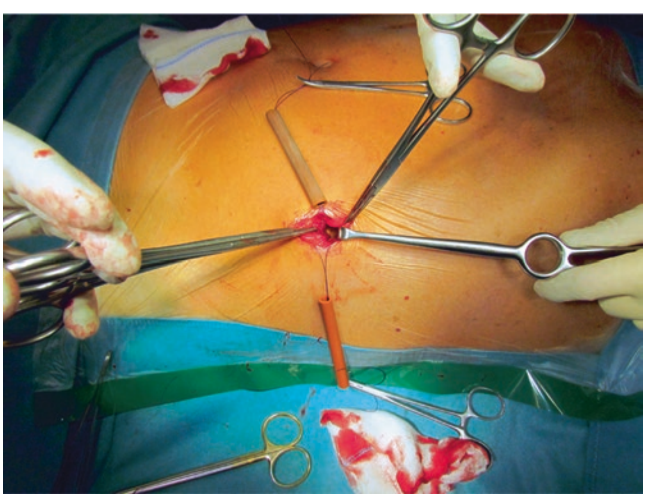

Fig. 19.5 First trocar access in open technique

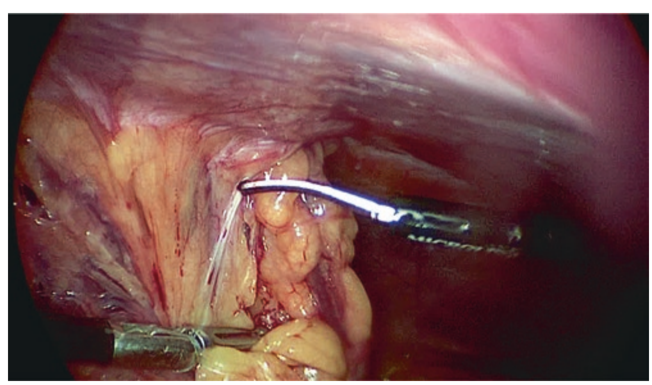

Fig. 19.6 Careful dissection of the adhesions with push-and-pull technique using a grasper and scissors

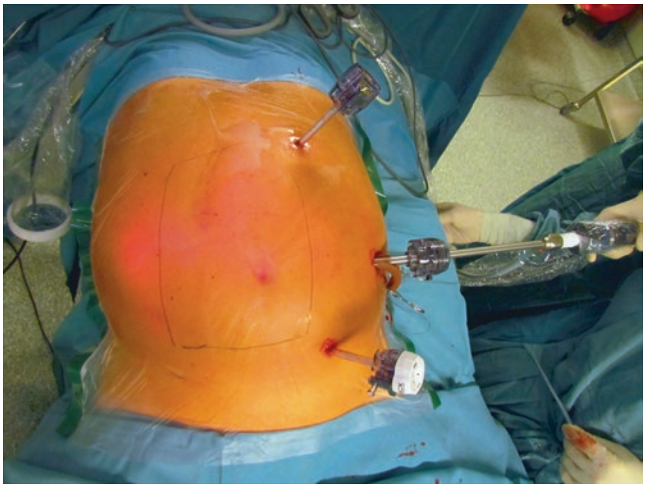

Fig. 19.7 The area to be covered by the mesh is marked on the abdominal wall

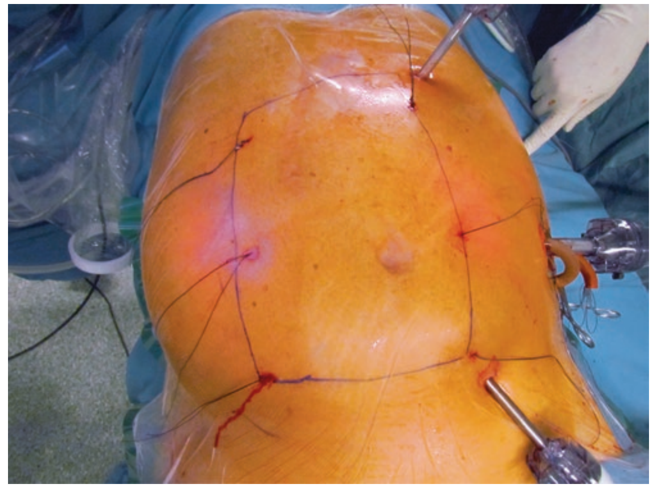

Fig. 19.10 View of the transfascial sutures after they are knotted on the fascia through small holes in the skin

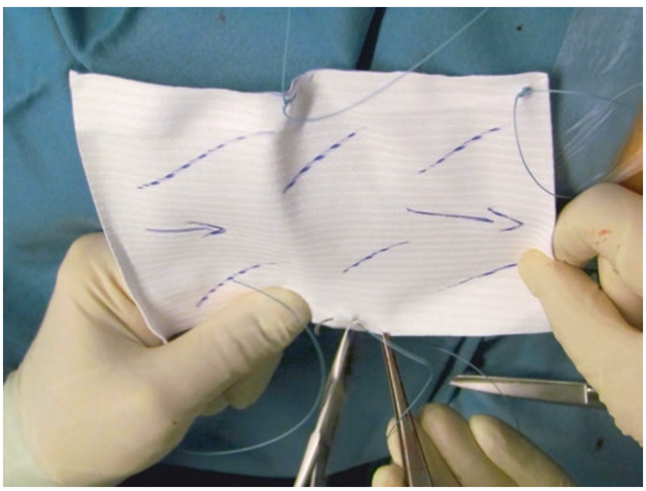

Fig. 19.8 Dual mesh with transfascial fixation sutures

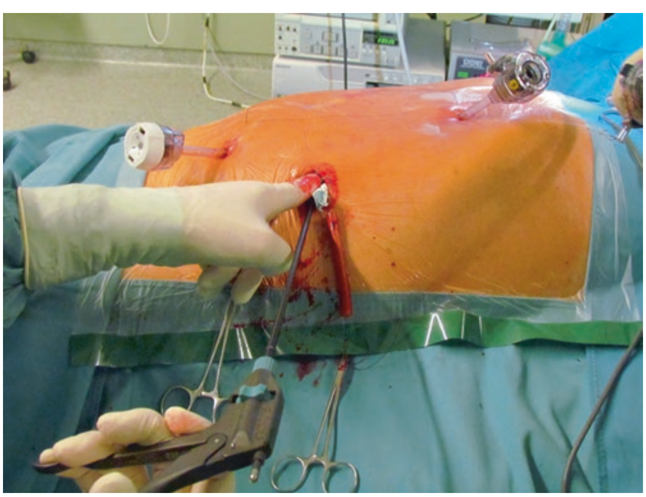

Fig. 19.9 Introduction of the mesh through the site of the optic trocar

At this point, the trocar is again inserted, the tourniquets are drawn tight, and the pneumoperitoneum is reestablished. The mesh can be unrolled and put into position with the fascial side facing up. First, the cranial sutures on the opposite side are pulled through with a suture passer or Endo Close™ (Covidien, 15 Hampshire Street, Mansfield, MA 02048 USA). To this end, a 2 mm incision is made with a pointed blade in the marked area. Both sutures of a pair come out through the same skin incision, but through separate fascial punctures, so that there is a tissue bridge of 0.5–1 cm between the two strands of the same suture pair. After both strands are drawn through separate punctures one after another, the mesh is drawn to the abdominal wall and fixed by pulling the threads. In the same way, the strands at the next site are drawn through the fascia through small skin incisions, taking care that the mesh is pulled taut. Only when the last sutures have been pulled through are they knotted, with the knots pushed in to the level of the fascia (Fig. 19.10).

The space between the transfascial sutures is fixed with spiral tacks. At this stage, the surgeon uses the non-dominant hand to press the tip of the tacking device as close as possible onto the abdominal wall to ensure secure fixation of the mesh on the fascia (Fig. 19.11). The mesh can also be fixed with absorbable tacks. There is as yet no convincing evidence for the argument that absorbable tacks cause fewer adhesions or nonabsorbable tacks cause significant adhesions or small bowel obstruction.

When fixation is completed, the abdominal cavity is again inspected for occult bleeding or intestinal wall lesions. Any blood is suctioned off. All the instruments are removed and the pneumoperitoneum is released. All incisions larger than 5 mm are closed with fascial sutures.

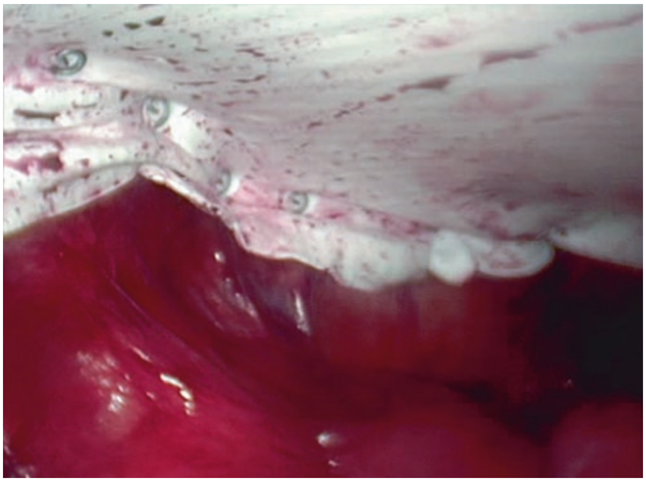

Fig. 19.11 Intra-abdominal view of the dual mesh after completed fixation

Postoperative Care

In the case of a longer operation, a second dose of antibiotics is given after surgery. Patients are mobilized after 4–6 h and receive fluids orally. On the first postoperative day, food is given as tolerated. It must be borne in mind that in the first postoperative days the transfascial fixation sutures may cause severe pain, and analgesics should be given as needed. The addition of anti-inflammatory medication improves the analgesic effect and helps reduce swelling at the surgical site. Patients with larger hernias should wear an elastic abdominal girdle for 2–3 months. Many patients develop a seroma or hematoma in the previous hernia sac; only rarely are these clinically evident and they should not be drained or punctured. The girdle prevents the development of larger seromas or helps large collections to regress.

Data with respect to prolonged or chronic pain have been shown to be very heterogeneous in terms of chronology and criteria for pain measurement, and 3.2% of patients complained of parietal pain lasting more than 1 month. In selected cases chronic pain can be managed by careful injection of long-acting local anesthetics [15], but bearing in mind that any puncture or injection can cause the implant to become infected. The use of absorbable staples or fixation of the prosthesis with glue might help to reduce chronic pain, but the long-term efficacy of these approaches is not proven [16–18]. As a preventive measure, infiltration of local anaesthetics at the end of surgery both at the port sites and at the fixation sites has been recommended, though it has not yet been shown that this significantly decreases postoperative pain medication. [19–21]. In the authors' experience, less than 1% of patients suffered pain persisting for more than 4 weeks and anti-inflammatory treatment almost always was successful [8].

Complications and Outcome

Significant complications can occur during the introduction of the trocars or adhesiolysis. The access related complication rate is 0.05–0.2% and more than half of all complications causing death develop at this stage [22]. Access with a Veress needle or even with a trocar is dangerous and cannot be recommended [8, 23–26]. Introduction of the Veress needle from the left upper quadrant has been presented as an alternative but requires further comparative studies [27–29].

Significant bleeding from the abdominal wall can be avoided if attention is paid to the anatomical position of the epigastric vessels. Bleeding from these vessels requires enlargement of the trocar incision and safe closure of the vessel under direct vision. Smaller bleeds can usually be stopped with electrocoagulation. If the first trocar is introduced with an open technique, accidental injuries, whether visceral and vascular, are rare and will be recognized immediately. Usually, these are serosal intestinal lacerations or rarely smaller full-thickness bowel lesions that can be sutured. Small serosal defects or minor lacerations of the small intestine during adhesiolysis can be sutured laparoscopically without conversion to open technique.

If there is a larger intestinal laceration with significant spillage of intestinal content, especially if the large bowel is involved, conversion to onlay technique or postponement of the repair should be considered. The problem in this case is not the safe repair of the bowel lesion but the possibility of contamination of the mesh. Thermal injury of the bowel is a serious problem and should be attended to, possibly with excision of the intestinal wall and conversion to open onlay hernia repair. A mesh infection is a severe complication and usually calls for antibiotic therapy and removal of the mesh [30]. In general, prevention of mesh infection by avoidance of full thickness bowel injuries remains the best strategy.

Other postoperative complications influencing the outcome are postoperative ileus and thromboembolic events. The incidence for both is between 1% and 2% [8, 10].

The recurrence rate mainly depends on the size of the hernia and the number of previous repair attempts. A prospective study investigating whether the defect size in laparoscopic incisional hernia repair is predictive for recurrence during the long-term, 60 months' follow-up evaluation has demonstrated that only obesity and the defect size (>10 cm) were independent prognostic factors [31]. Laparoscopic ventral hernia repair can be conducted safely and with a low prevalence of recurrence. It may work well in morbidly obese patients in whom open repair would represent a major undertaking [32]. In general, the recurrence rate tends to be lower than 5% [8, 13]. Significant weight increase is also a risk factor for recurrence.

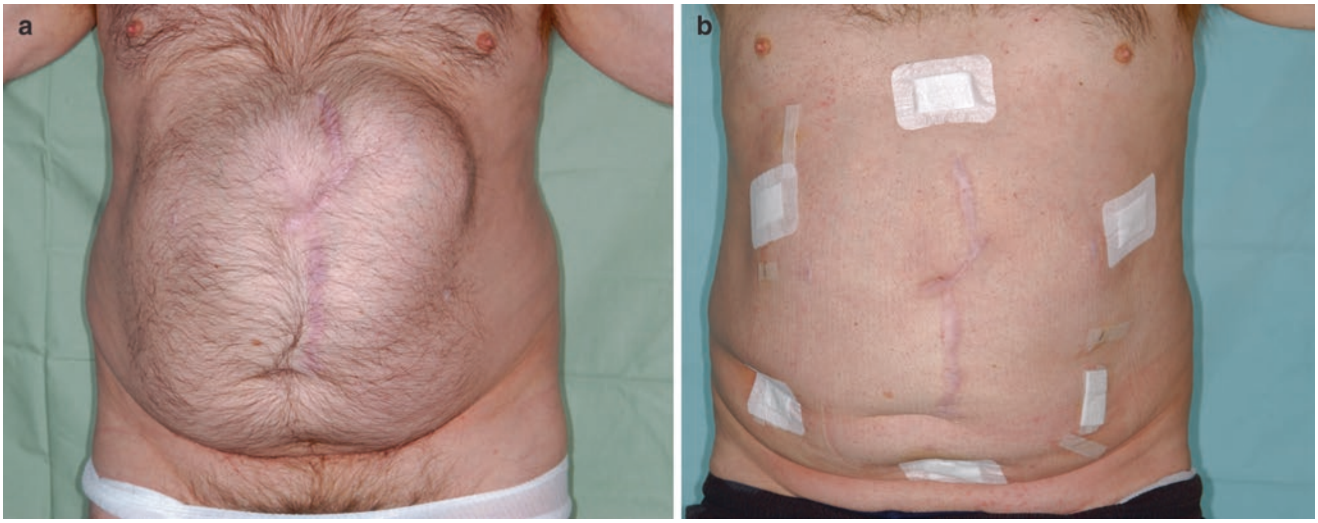

Fig. 19.12 (**a**) Large incisional hernia after several attempts at open repair. (**b**) Postoperative view after laparoscopic repair

In summary, abdominal wall hernias, primary and especially incisional, are a common problem. The advances in laparoscopic technique as well as mesh engineering have had a positive influence on results (Fig. 19.12a, b). Although laparoscopic repair of large abdominal wall hernias may be challenging, it has the potential to be become the approach of choice, regardless of patient status or hernia complexity [10]. Today, we can say that laparoscopic technique is the standard method for the treatment of large primary and incisional hernias.

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Selection of Prosthetic Materials in the Repair of Complex Abdominal Wall Defects

20

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Introduction

The development of an incisional ventral hernia is a common complication following open abdominal surgery and represents a major management challenge for the surgeon. Its incidence varies between 2% and 20%, and it is estimated that approximately 350,000 hernias repairs are performed each year at a cost of $2.5 to $3 billion in the United States [1–3]. Complex abdominal wall defects (CAWD) can be defined by the presence of any of the following, either in isolation or in combination: hernia that is recurrent with multiple failed repairs; multiple sites of abdominal wall defects; loss of abdominal domain; damage control skin graft closure, infection or other local tissue compromise; and resection of abdominal wall musculature with inadequate soft-tissue coverage [4, 5].

The incidence of CAWD has increased with bariatric surgery procedures due to the epidemic of obesity in the United States; "damage control" trauma laparotomies; increase in visceral transplantation rates; and increase in rates of failed primary herniorrhaphies [4, 6]. CAWD are associated with potentially serious complications such as intestinal obstruction, gangrene, peritonitis, intestinal perforations, and death. Therefore, the need for their correction is well-established. In general, the surgical management of CAWD can be performed with or without the use of a prosthetic material. Surgical repair of hernias is one of the most common operative procedures performed, and there is no single gold-standard operative technique in hernia repair [7].

The direct surgical repair is associated with high risk of complications including bleeding, wound infection, skin necrosis, abdominal compartment syndrome, bowel ischemia, prolonged intubation, and death. With this approach, the incidence of recurrent incisional hernia is as high as 58% [1, 4, 8–10]. Contrarily, some studies confirmed significantly lower recurrence rates and better outcomes with repairs utilizing synthetic meshes, as compared to direct surgical repairs for the correction of ventral hernias [1, 10–12]. The tension-free procedures achieved by the utilization of prosthetic materials have rapidly gained popularity, and an impressive variety of synthetic materials are now commercially available for the management of CAWD. However, controversy exists over what the best approach would be; and over which type of material should be employed. The selection of a prosthetic material should take into consideration not only the synthetic material properties and its biologic response; but also factors related to the technique to be performed, and particular patient's characteristics.

Considerations when Selecting Prosthetic Materials for the Management of CAWD

Modern hernia surgery is no longer imaginable without the application of prosthetic meshes. The recurrence rate using prosthetic repair is approximately half of the recurrence rate after suture repair [1, 10–13]. The use of prosthetic materials allows the repair of defects of any size without tension; and the mesh induces an inflammatory response, which promotes the synthesis of collagen. Currently, there are over 200 options for prosthetic materials available to the general sur-

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geon for abdominal wall reconstruction, all with varying composition, weight, cost, and indications for use in the surgical field [10].

There is debate on which type of material should be used and how they should be employed in the repair. Open surgery for prosthetic repair is a safe and common technique, but laparoscopic mesh repair is a new procedure with several documented advantages, including smaller incisions, lower risk for complications, shorter hospital stay, and patient preference [14, 15]. The decision between open or laparoscopic repair requires a detailed assessment of the individual patient's risks and benefits.

Prosthetic repair is associated with a higher incidence of hematoma, seroma, and infection. Other complications in the mesh repair group are small bowel obstruction, fistula from mesh to skin, enterocutaneous fistula, long-term pain, abdominal wall immobility, and foreign body sensation [5, 6, 16]. Complications from abdominal wall reconstruction such as infections, readmissions, and recurrence may lead to further operations and an overall increase in health-care costs. One percent reduction in hernia recurrence could result in annual savings of $32 million [17].

Prosthetic Mesh

The ideal surgical mesh should be inert, flexible, non-carcinogenic, biologically inactive, have long-term strength to prevent recurrence, have fast body incorporation; and should not affect human tissue distensibility. Unfortunately, nowadays, surgical mesh may have most, but never all of the qualities above [18].

The mesh may have mono or multifilament structures knitted to provide pores and the pore variety determines the mesh's characteristics and its successful usage. The pore size is a determinant of the tensile strength; it also affects neovascularization, the infection resistance, and collagen fiber growth.

There are three different categories of prosthetic meshes used in ventral hernia repair: synthetic polymers, composites, and biologic prosthetics (Table 20.1). Synthetic polymers can be classified into absorbable and non-absorbable [18, 19].

Table 20.1 Types of prosthetic material for the repair of complex abdominal hernias

Synthetic	
Nonabsorbable polymers	Polypropylene
	Polyester
	Expanded polytetrafluoroethylene (ePTFE)
Absorbable synthetic polymers	
Composites	
Biologic prosthetics	Human
	Bovine
	Swine

Synthetic Non-absorbable Polymers

This category includes polypropylene, polyester, and expanded polytetrafluoroethylene (ePTFE).

Polypropylene

This type of mesh is the most widely used because of its strength, ease of handling, and versatility (Fig. 20.1a). They were first used in the 1950s, and have a rough surface which prevents the mesh from slipping. They are extremely resistant to biodegradation, are not destroyed by tissue enzymes, and are very flexible in surgical use. The mesh is arranged in mono or multifilament combination and classified into lightweight or heavyweight. Heavyweight meshes consist of pore sizes smaller than 1 mm, meanwhile meshes with pores larger than 1 mm are called lightweight. Lightweight meshes result in a reduced amount of mesh material after incorporation and cause less abdominal stiffness. The heavyweight mesh supports six times normal abdominal tension. This leads to high resistance, but higher rates of severe chronic pain and abdominal stiffness when compared to lightweight mesh, which simulates more closely human tissues. Furthermore, heavyweight meshes trigger more adverse inflammatory response, although animal studies showed that the 1 month after surgery tensile strength seems to be similar. Both lightweight and heavyweight polypropylene prosthetics were noted to shrink 30–50% in a 6-month period of time. Due to this shrinkage, a 3–5 cm overlap of meshes is recommended during hernia repair to avoid recurrences at the mesh margins (Fig. 20.1b). Complications such as migration, infection, hernia recurrence, and functional impairment may occur when using polypropylene mesh. In a long term, restriction of abdominal wall movement can be observed due to mesh stiffness which is caused by an intense inflammatory response (Fig. 20.1c). Many studies have also shown that polypropylene is very adhesive to intestinal serous, when used in direct contact with abdominal organs. This explains why this type of mesh is rarely used in direct contact with the peritoneal cavity as well as in laparoscopic repairs (Fig. 20.2). Among all the absorbable prosthetic meshes, the polypropylene mesh is the type which best handles acute infection [20, 21].

Polyester

Polyester is a carbon polymer, multifilament, and nonabsorbable material which was used by the first time in 1956. Although they are less popular than polypropylene meshes, they have the same indications of usage. However, studies have shown higher rates of recurrence and infection with this mesh when compared to polypropylene meshes [20].

Expanded Polytetrafluoroethylene (ePTFE)

The ePTFE is also a non-absorbable prosthetic mesh, which varies from both polypropylene and polyester due to its micropores and its advantages in intraperitoneal hernia

Fig. 20.1 (**a**) Polypropylene mesh repairing a small abdominal wall defect. (**b**) Polypropylene mesh repairing a hernia after peritoneostomy covering scar area and part of the aponeurosis. (**c**) Polypropylene mesh repairing complex abdominal wall defect. (**d**) Result after post-operative recovery

repair. This fluorocarbon polymer, desenvolved in 1963, has a favorable biologic behavior and smooth surface with pore sizes smaller than 3 μm that can be placed in direct contact with abdominal viscera due to its low adhesive risk. Furthermore, ePTFE meshes are stiffer and can be double-faced, which have both a regular side and a side with larger pores. The viscera side is anti-adhesive while the other side allows cellular penetration and adhesion formation. Although the ePTFE is a good option for intraperitoneal contact and laparoscopic surgeries, it has less tensile strength than other meshes. Its smaller pores allow less fibrotic formation and have higher rates of infection. Finally, the ePTFE prosthesis has higher shrinkage rates when compared to polypropylene which leads to more recurrence [20].

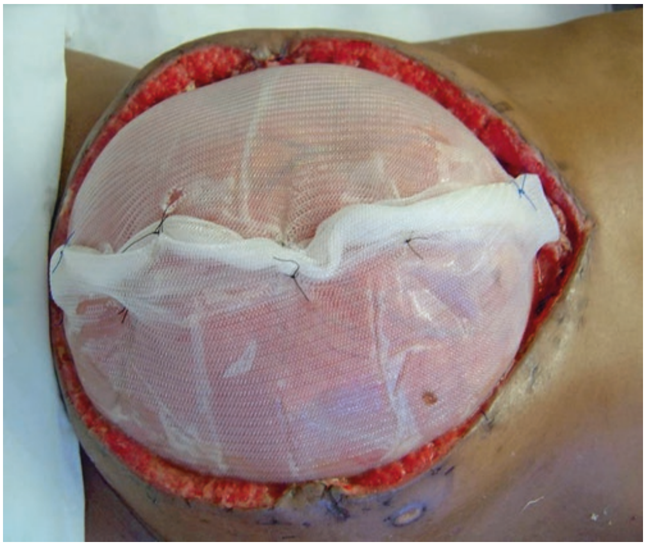

Fig. 20.2 Polypropylene mesh associated to Bogota bag to contain recurrent peritoneostomy evisceration

Absorbable Synthetic Polymers

These polymers consist primarily of polyglycolic acid, which can be or not associated with lactic acid. The use of synthetic polymers is normally restricted to temporary abdominal closure. On the contrary of nonabsorbable polymers, absorbable prostheses are hydrolyzed with time. This mesh was developed in the 1980s due to high infection rates of non-absorbable meshes when applied to contaminated surgical fields. The absorbable mesh is more flexible and easier to handle. They have been used for temporary closure of contaminated surgical wounds. Due to their absorbable characteristics, the development of postoperative incisional hernia is expected. Therefore, these meshes should not be used alone for the repair of hernias in clean surgeries. The absorbable synthetic polymers are also used together with non-absorbable polymers. This combination results in a mesh with partial absorption and less prosthetic volume after tissue incorporation, allowing long-term comfort [20].

Composites

Composite prosthetics are meshes produced with more than one type of material and are designed to be placed in contact with the peritoneal cavity because of their non-adhesive properties. They are usually made of polypropylene or polyester and one of the sides is covered with a product, which will form a barrier between the abdominal content and the mesh when applied. This product can be non-absorbable (titanium, polyurethane, ePTFE) or absorbable (omega-3 fatty acid, collagen hydrocel, oxygenated regenerated cellulose). When the protective layer is absorbable, there is a chance of adherence after degradation. Polypropylene and ePTFE composites are widely used intraperitoneally. They offer both the polypropylene advantages, such as resistance and fibroplasias, and the ePTFE's safeness due to its low adhesive properties. These composite meshes have been successfully applied on inlay position in order to repair complex and multi-recurrent anterior abdominal wall hernias in association with flaps and muscular sheath advancements [9, 20, 22, 23].

Biologic Prosthetics (Grafts)

Biologic prosthetics (usually called grafts) are acellular collagen backbones derived from allogeneic (cadaver) or xenographic (non-human) sources. These are the most recent materials used in hernia repair. The tissues used (human, bovine, or swine) undergo procedures that eliminate cellular material leaving a matrix that retains a structurally intact basement membrane, intact collagen fibers, intact elastin and laminin filaments, serving as a supporting surface for cellular repopulation and neovascularization. The most used biologic grafts are the ones derived from human dermal matrix, porcine small intestine sub mucosa, porcine dermis, and bovine pericardium. Since 1998, devices composed of extracellular matrices of human (allograft) or animal (xenograft) sources have been available for use in abdominal wall reconstruction [24]. These prostheses can be used on contaminated wounds and in general they do not cause adhesion when placed in direct contact with abdominal viscera. Although its tensile strength is similar to synthetic prosthetic, biologic grafts have been used mostly for reconstructive surgery, particularly during contaminated and complex cases. The results of use within clean and some contaminated environments have not shown significant improvement in device-related complications compared with synthetic mesh, particularly lightweight macroporous mesh [25]. These grafts may be applied intraperitoneally or extraperitoneally. Some biological prostheses need to be stored in refrigerator, while others may be stored in natural temperatures. Rehydration may be necessary 30–40 min before implanting certain biologic grafts types. The biological grafts have the highest costs. Grafts from human tissues cost approximately \$26.00/cm^2 while grafts from porcine and bovine tissues can cost from \$8.60 to \$22.00/cm^2. The synthetic absorbable and non-absorbable meshes cost approximately \$1.00–8.00/cm^2 [20, 22, 26].

Fibrin Sealant in Hernia Repairs

Fibrin sealant is proven to be an efficacious alternative to mechanical methods for the sealing of meshes used in CAWD surgery. It offers several advantages over mechanical methods. Fibrin sealant reproduces the final steps of the human coagulation cascade, making it biocompatible with the surrounding tissue. Furthermore, the results obtained in inert simulation models and experimental animals were similar to those observed in the sealing of mesh with mechanical means in patients. In patients treated with fibrin sealant, a lower prevalence of acute and chronic postoperative pain is observed, as are a lower number of hemorrhagic problems (hematoma, ecchymosis, bleeding). At the experimental level, the intraperitoneal formation of adhesions with fibrin sealant was less than that observed with the use of mechanical sealing methods. However, there are no data indicating that fibrin sealant decreases the appearance of seroma [6, 16, 27–30].

Very few studies evaluating cost effectiveness and satisfaction of the health-care professional with this technique are available and those that exist are not consistent. However, it is possible to hypothesize that the use of fibrin sealant might reduce the costs associated with abdominal hernia surgery. Two randomized clinical trials demonstrated significant reductions in hospital stay and in acute and chronic pain; faster return to normal activity; and significant reductions in bleeding complications when fibrin sealant was used in hernia surgery [27, 28].

Complications

Complications include migration, infection, delayed healing, skin necrosis, enterocutaneous fistula formation, functional impairment, and hernia recurrence (Figs. 20.3 and 20.4). Hypertension, smoking, body mass index (BMI) > 30 and diabetes are relevant risk factors for complications following CAWD surgery. Patients with two or more risk factors are at a greater risk of complications, including hernia recurrence, as compared to those with a single risk factor [5, 6].

Complication rates have been described as significantly higher when mesh is used compared with primary closure without mesh [6, 11, 31].

Conclusion

The surgeon should apply the principles of reconstruction to serve as the basis of an individualized strategy that will offer the best outcome. Meticulous attention to technique, timing, utilization of new technology, and tension-free repair in a clean, well-vascularized wound continue to be the cornerstones of the ideal repair. Focus on an individualized strategy is also important, when selecting the correct prosthetic material.

The management of complex abdominal wall defects remains challenging. The abdominal wall has a variety of functions, all of which rely on an established complex interaction between dynamic muscle layers and a static fascial framework. Various reconstructive options exist, ranging from simple to more complex. When addressing abdominal wall defects, the surgeon must be constantly focused on recreating a stable core that is both structurally strong and functional.

Risk factors, comorbidities, hernia recurrence, and presence of contamination are indispensible to be considered before facing the challenge of approaching an abdominal wall defect.

Fig. 20.3 Enterocutaneous fistula in a patient with peritoneostomy contained by Bogota bag and polypropylene mesh

Fig. 20.4 Patient who underwent damage control procedure with an impaired wound healing and colocutaneous fistula and mesh rejection

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Mesh Placement in Complex Abdominal Wall Defects: Techniques and Outcomes

21

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The Role of Mesh

Abdominal wall hernias are one of the most commonly performed operations in the United States, with over 350,000 operations performed every year. Despite improvements in surgical techniques and technology, the quest for the ideal technique for hernia repair continues. Primary repair of abdominal hernias is associated with a high recurrence rate ranging from 24 to 54% [1–4]. The use of mesh repair, however, has been widely popularized and has replaced primary repairs. Results from a prospective, randomized, multicenter trial in which suture repair was compared with mesh repair demonstrated that mesh repair was more effective and associated with a significantly lower recurrence rate even in patients with small size defects [2]. A significant proportion of ventral hernias are "complex" and the management of these patients remains particularly challenging. With the increasing number of trauma patients undergoing major abdominal procedures and the expanding utility of damage control surgery beyond trauma patients, the need for complex abdominal wall reconstruction appears to be increasing.

The goal for management of patients undergoing complex abdominal wall reconstruction is the restoration of the gastrointestinal continuity and the reconstruction of a strong resistant "neo-abdominal wall." Classically, a multi-staged approach has been utilized for these patients [3, 4]. In cases of previous operation complicated by infection of the mesh, the initial operation is performed to remove the infectious source. Since the use of synthetic grafts in patients with infected wounds is known to be associated with high re-infection rate, no mesh repair is performed during this stage. Once the infection is cleared, a definitive repair to reconstruct the abdominal wall is performed several months later. This definitive repair requires several techniques and utilizes both native tissue and biologic or synthetic mesh.

The more recent introduction of biologic mesh has shifted the paradigm towards a "single-staged" approach and repair for contaminated abdominal wall hernias [5]. Several studies have demonstrated that biologic mesh is more resistant to infection compared with synthetic mesh. Biologic mesh promotes the ingrowth of neo-vasculature and cells which may be responsible for this resistance [6, 7]. Studies have also demonstrated anti-microbial activity with the use of biologic mesh. Therefore, when the risk of abdominal infection is high, the surgeon may consider the use of biologic mesh in place of a synthetic mesh. In fact, the use of biologic mesh in contaminated fields has now become the standard of care for hernia repair [8, 9]. Repairs with biologic mesh may remain intact even with active infections and do not require removal of the mesh when infected. Another advantage offered by biologic mesh is that these patients can be managed non-surgically even when the wounds become infected [10, 11].

Choice of Mesh

The selection of mesh will be discussed in more detail elsewhere in this book. In this section we will touch briefly. What kind of mesh we should use depends on clinical situation and surgical history of the patient. Suffice to say that the risk of infection is significantly higher with the use of synthetic mesh, particularly, in a contaminated field. Once infected, this requires removal of the infected mesh and may also lead to other complications such as new fistulas. As all hernias with fistulas and stomas are contaminated by default they should only undergo repair with biologic mesh. Several types of biologic mesh exist which can be broadly classified into human derived and porcine derived. There is lack of level I evidence to suggest if one is better than the other in preventing infection or recurrence. We compared the outcomes of human derived and porcine derived acellular

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dermal matrix at our center over a six-year period. Our series demonstrated a significantly higher hernia recurrence rate of 22.5% for patients with porcine-derived mesh compared with a 2.9% recurrence rate for patients with human derived mesh placement with a mean follow-up time of 16 months. However, there was no difference in the rates of infections, reoperations, or mesh explantation between the two groups. Our data from a small study showed that the overall wound related complication rate in patients undergoing biologic mesh was 29.5% with the most common complication being superficial SSI. In another study, we evaluated the long-term outcomes of 60 patients undergoing complex abdominal wall reconstruction with acellular dermal matrix (Alloderm: 38; Strattice: 18). Of these, 9 patients had concomitant ECF or EAF fistulas. Our study showed that there was no difference in overall complications, infectious complications, or recurrence rates in patients with or without concomitant fistulas. Overall 35 patients had contaminated fields, of which 26 had grade 4 infections.

Our experience suggests that the use of acellular dermal matrix biologic mesh in patients with clean contaminated or dirty wounds is a viable option for a single staged approach to complex abdominal wall reconstruction. Our experience has been mostly limited to Alloderm (human-derived) and Strattice (porcine-derived). Although the recurrence rate has been lower in our experience with Alloderm, this may be due to a selection bias. The overall complications and infectious complications appear to be similar between the two mesh types.

Mesh Placement Technique

Several techniques exist for the placement of mesh during reconstruction of complex abdominal wall defects and an appropriate technique must be considered to achieve successful outcomes. When choosing between the best anatomic location for mesh placement, the surgeon must consider a number of factors, all of which affect long-term outcomes. First, mesh-tissue integration and greater overlap of mesh and host tissue reduce long-term recurrence. Second, wound complications, such as wound infections, increase the risk of recurrence exponentially. Thus, techniques that do not result in the development of devascularizing flaps, provide tissue coverage, and minimize exposure to the external environment and intra-abdominal contents, should be preferred. The most commonly used techniques in our practice have been underlay, onlay, and bridge mesh placement (see Chap. 7 for illustrations). Other techniques also include the retrorectus approach. Each of these techniques has its pros and cons and the choice of approach should be tailored to the clinical scenario and surgeon's experience. These techniques can be performed either openly or laparoscopically; however, owing to the complexity of the defects, open surgical approach is more commonly utilized especially in patients with coexisting fistulas.

Onlay Mesh Placement

In this technique, the mesh is placed above the primary fascial closure to provide reinforcement and this may be preferred in certain cases. Once the hernia is repaired and the fascia is closed with non-absorbable continuous or interrupted sutures, the mesh is placed over the anterior rectus sheath and covers it. We prefer fixing the mesh to the fascia using non-absorbable sutures, either interrupted or continuous. An important element of this technique is fixing the mesh both laterally and on each side of midline to reduce the risk of seroma formation under the mesh. We use three to four large, closed-suction drains (19 French) under the subcutaneous tissue and keep them in until the individual drain output is less than 25 mL over a 24 h time period.

The onlay technique is the easiest to perform. This technique prevents contact between the mesh and the underlying abdominal viscera. Despite these advantages, this technique is associated with a high morbidity and recurrence rate [12]. With the onlay technique, skin flaps must be created, which increase the risk of mesh infection and wound complications [13, 14]. For these reasons, this technique is not used very often these days.

Underlay Mesh Placement

In our practice, underlay graft placement has now become the main technique of mesh placement in all high-risk and complex ventral hernia defect reconstruction. It is more involved, but once it is learned and perfected, it does not add significant operative time. In the underlay placement technique, repair material is sutured deep to the primary repair or fascial edges. There are two types of underlay techniques: intraperitoneal underlay technique and the extraperitoneal underlay technique.

The intraperitoneal underlay technique was first described by McCarthy et al. in 1981 [15]. When this technique was introduced, polypropylene mesh was used intraperitoneally; however, the intraperitoneal use of polypropylene mesh caused adhesions to the bowel and was, therefore, abandoned. The use of intraperitoneal polypropylene mesh is also associated with bowel injuries, mesh dislocation, bowel erosions, and the development of enterocutaneous fistulas. Over time, intraperitoneal polypropylene mesh was replaced by the use of a laminar polytetrafluoroethylene (ePTFE) mesh or bilayer composite prosthesis (PTFE and polypropylene) in order to avoid adhesions with the intra-abdominal viscera [16], and eventually by biologic mesh. The key element of this technique is freeing the abdominal wall from any adhesions as far laterally as possible. Placement of sutures can be technically challenging and requires that the sutures be placed close to one another in order to prevent the intra-abdominal contents from sliding and herniating between the mesh and the abdominal wall [14]. Placement of the interrupted sutures should ensure complete stretching of mesh once sutures are tight. Suture placement techniques vary but we use the "parachuting" technique and direct vision at all times [17]. This technique minimizes the potential for bowel injury during fixing of graft on the abdominal wall. If lateral component release is used, we prefer placing sutures in the anterior abdominal wall as far laterally as possible to include the medial edge of the external oblique fascia. Doing so is an important technical step: It prevents bulging laterally at the release component site, and the patient might think bulging is a new hernia [18].

Underlay placement offers several mechanical advantages. When the mesh is placed under abdominal wall, the intra-abdominal pressure presses the mesh against the wall, helping with better incorporation. In contrast, with an onlay mesh placement, increase in intra-abdominal pressure forces the mesh away from the defect therefore increasing the likelihood of recurrence [19]. According to Pascal's law, any pressure exerted on an enclosed fluid is transmitted equally and undiminished in all directions. Therefore, with an underlay placement as the intra-abdominal pressure increases, equal amounts of force are exerted across the mesh which helps in preventing recurrence [12]. Moreover, an underlay placement also reduces the exposure of mesh to the environment which helps prevent infectious complications. One recent meta-analysis compared the outcomes between onlay and underlay mesh placement and found underlay mesh placement had a lower risk for recurrence [0.59 (0.069–1.504)] and surgical site infection (SSI) [0.878 (0.291–1.985)] compared to onlay [14]. This approach has been regarded as the gold standard for ventral hernia repair by the American Hernia Society [20].

Rives–Stoppa Mesh Placement Technique

The extraperitoneal underlay technique, also known as the sublay technique, has been described and used more recently. This technique utilizes the concept of tension-free repair, in which the mesh is placed retromuscularly (behind rectus muscle) and pre-peritoneally, after closure of the posterior rectus sheath, to form an extended mesh–scar compound. This is followed by primary closure of the anterior fascia. This technique was first described by Stoppa in 1989 and therefore is also known as Rives–Stoppa technique [21].

When performing this repair, the hernia sac is dissected down to the margins of the fascia. The hernia sac is then opened. After performing local adhesiolysis, the contents of the hernia sac are reduced. Following this reduction, the retromuscular space behind the rectus abdominis muscles and in front of the posterior rectus sheath is bluntly dissected. Care should be exercised to preserve the neuro-vascular bundles at the lateral part of the muscle [22]. According to the original description by Stoppa, the size of the mesh should be as large as possible to aim for a face-to-face overlap and not an edge-to-edge patching [21]. Dissection should be continued sufficiently cranially behind the xiphisternal junction to allow at least a 5 cm of overlap. Similar dissection is performed in the caudal direction. One has to remember that there is no posterior rectus sheath beyond the arcuate line. Once dissected, the posterior rectus sheath and the peritoneum is closed with continuous sutures and the mesh is placed in the retromuscular pre-fascial plane extending caudally in front of the bladder and behind the pubic bone. The most important aspect of mesh placement is to insure that no direct contact occurs between the mesh and the bowel to avoid the development of adhesions, erosions, and fistulas. The interposition of omentum may further help prevent this hazard. An overlap of 5 cm is essential in all directions and the mesh should be fixed to the posterior rectus sheath in all directions. Below the arcuate line, where no rectus sheath exists, the mesh should be fixed to the peritoneum [22]. Routine suction drains are then placed in the retromuscular plane in contact with the prosthesis. Finally, the anterior rectus sheath is closed using continuous sutures insuring no undue tension exists.

The Rives–Stoppa technique reduces the amount of soft tissue dissection; therefore, it is associated with lower morbidity and recurrence. This technique also protects the mesh from environmental exposure due to native tissue coverage, which reduces the chances of mesh infection following a superficial surgical site infection. In addition, the mesh lies outside the peritoneum with no direct contact to the abdominal viscera. This prevents the likelihood of abdominal adhesions, erosions, and the development of fistulas. Since the mesh is not placed in the subcutaneous plane, this reduces the likelihood of seroma formation [23]. Despite these advantages, this approach is relatively challenging, particularly in patients with previous abdominal surgeries who may have extensive adhesions and a damaged posterior rectus sheath and muscle. Moreover, the presence of semilunar lines also limits the lateral extent of the repair. A recent meta-analysis demonstrated that sublay placement of mesh is associated with lower odds of recurrence and surgical site infection compared with onlay and underlay [14].

Interposition or Bridge Mesh Placement

When the fascial defect is large enough that it cannot be approximated, an interposition graft or a bridge placement is performed. In this technique, the mesh is sutured to the fascial margins to achieve abdominal closure. This technique is associated with extremely high recurrence rates and is only used to bridge large fascial defects which cannot be closed primarily without undue tension despite performing bilateral anterior or posterior compartment release [24, 25]. Bridging repair may also be used where component separation cannot be performed. In these situations, biologic mesh is the preferred type of mesh, but patients should be advised that there is high chance of hernia recurrence and/or wall laxity that will mimic hernia. This laxity exists because no native tissue exists at the site of the interposition graft. During bridge mesh placement, the surgeon must ensure that the suture bites are placed at least 5 cm past the edge of the fascia. Closed suction drainage may reduce seromas which have the potential to become infected and jeopardize the integrity of the closure. If possible, the surgeon must avoid suturing the mesh on the edge of the fascia, in order to reduce the risk of herniation or suture failure. If at all possible, the "bridge" should be covered with native skin and subcutaneous tissue. However, when mesh is used as a bridge and there is no skin or subcutaneous tissue to cover the mesh, then the use of a wound Vacuum-Assisted Closure (VAC) with continuous irrigation is very useful to keep the mesh moist and to speed the process of granulation for later skin grafting [18].

Studies have demonstrated that bridged or interposition grafts have significantly higher odds of recurrence even after controlling the initial defect size. When bridge repair is used, recurrence rates of up to 88% have been reported [26]. This may be due to the forces exerted by the oblique muscles which have been detached from the midline [27]. In a reinforced repair, the tension is shared between the anterior rectus sheath and the mesh. In contrast, the tension lies entirely on the mesh which results in higher rate of recurrence associated with a bridge repair [28]. Since the mesh is directly exposed to the bowel and the skin in a bridged repair, studies have suggested the use of biologic rather than prosthetic mesh for these repairs to reduce the risk of direct exposure of the synthetic mesh to infection if the overlying skin undergoes dehiscence. However, in low risk patients, a synthetic mesh can still be considered. When biologic mesh is used as an interposition graft, similar recurrence rates were observed with human derived ADM and porcine derived ADM mesh use [29, 30].

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Part III

Post-operative Complications and Reoperative Surgery

22 Abdominal Compartment Syndrome and Hypertension in Patients Undergoing Abdominal Wall Reconstruction

Ajai K. Malhotra

Introduction

Normal pressure within the abdominal cavity varies between sub-atmospheric and 6.5 mmHg [1]. Intra-abdominal hypertension (IAH) occurs when the contents of the abdomen together exceed the space volume available within the abdominal cavity. It is defined as a sustained elevation of the intra-abdominal pressure (IAP) to >12 mmHg on two separate measurements at least 6 h apart [2]. While transient elevations of IAP are well tolerated, sustained elevations can have significant deleterious effects on organ system function. The association of IAH and organ system dysfunction was recognized as early as the mid-nineteenth century [3]. However, the acceptance of the syndrome of IAH with organ system dysfunction as a distinct nosologic entity—abdominal compartment syndrome (ACS)—had to wait till the late twentieth century [4]. Abdominal compartment syndrome is defined as peak IAH of >20 mmHg on two separate measurements at least 6 h apart in association with dysfunction of one or more organ systems that was not present before [2]. In other words, the elevation of IAP resulted in the organ system dysfunction. Increased pressure within the abdominal cavity leads to a cascade of events that affect each and every organ system and tissue bed of the body. As the IAP increases, the earliest manifestations occur in the respiratory system. The diaphragm is pushed cephalad, embarrassing ventilation that affects oxygenation. At the same time, there is increased pressure over the inferior vena-cava resulting in diminished venous return to the heart, negatively impacting the cardiac output. Reduction in cardiac output affects systemic perfusion and causes tissue ischemia with generalized organ system dysfunction. The increased vena-caval pressure is also transmitted via the renal veins directly affecting renal function [5]. Besides the generalized effects on every organ system due to reduced perfusion, there is evidence that ACS itself acts as a pro-inflammatory stimulus [6]. Thus in any surgery involving the abdomen, IAH and ACS should be avoided, monitored for and, if occurring, should be rapidly diagnosed and treated to avoid poor outcomes and/or death.

Many of the complex abdominal wall defects that need repair were in the past probably created by attempts at either preventing the development of ACS (by not closing the musculo-aponeurotic layer of the abdomen) and/or treating ACS after its development (by opening an intact or recently closed musculo-aponeurotic layer of the abdomen and then leaving it open). Over the past decade with improved resuscitative practices—early utilization of blood products in 1:1:1 ratio, limiting crystalloids and permissive hypotension—the incidence of "unclosed" abdomens has significantly decreased. Despite this decrease, when the abdomen cannot be closed, the resultant defect is considered complex due to the large size of the defect in the musculo-aponeurotic envelope. This large size allows for a large proportion of the abdominal contents to reside outside the confines of the musculo-aponeurotic layer of the abdomen. Over time, the volume available within the abdominal cavity is insufficient to accommodate all of the contents that have been residing outside. Forcing these contents back into the abdomen and thus raising the IAP to pathological levels and causing ACS will have disastrous consequences for the patient and threaten the integrity of the repair. Hence, prior to repairing any complex abdominal wall defect, careful consideration needs to be given to avoiding this devastating complication.

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Pre-operative Considerations for Prevention of IAH/ACS

Patient Selection

As in all surgery, first and foremost consideration is to the general condition of the patient and whether the overall health is such that the patient can tolerate the stress of anesthesia and major surgery. If a determination is made that the overall health is sufficiently good to tolerate anesthesia and major surgery, then for patients undergoing abdominal wall reconstruction for complex abdominal wall defects the next consideration would be about the possibility of developing IAH/ACS.

Morbid obesity is associated with a chronic form of IAH [7]. In such patients even minor elevations of IAP will rapidly lead to progression of the IAH to ACS. Pre-operative weight loss ameliorates the chronic IAH and thus reduces the risk of peri-operative IAH/ACS. Additionally, pre-operative weight loss, prior to complex abdominal wall reconstruction will improve the chances of a successful repair. As noted above, the earliest manifestations of IAH/ACS are on the respiratory and cardio-vascular systems, and hence the reserve available in those two organ systems determines the ability of the individual patient to tolerate IAH. In an otherwise healthy individual with relatively normal cardio-respiratory reserve, a 10% drop in venous return and/or ventilation is tolerated without significant ill effects. However, in patients with pre-existing cardiac/respiratory disease, even a <10% reduction may not be tolerated. Without performing detailed functional tests, it is not possible to quantify the state of the organ system or the reserve. However in most patients a judgment can be made as to whether after repair of the defect, the patient will have adequate ventilation. A detailed clinical examination with manual reduction of any hernia and manually "closing" the defect are crude clinical tests that can give a fair idea about the cardio-respiratory tolerance to the final repair. Additionally, a tight abdominal binder can be temporarily placed to reduce the hernia and the patient asked to walk around observing for any shortness of breath. If, based on these simple tests, it is determined the patient has adequate cardio-respiratory reserve, one can proceed with the surgery. If on the other hand, either the tests cannot be performed or after the clinical tests, it is felt that the patient has only borderline reserve, more objective testing with volumetric pulmonary function testing and/or stress tests should be considered. Each patient is truly unique and should be considered as such. It maybe helpful to communicate with the patient's medical physicians to get as much information as possible before making a final decision about the patient's ability to undergo repair without development of IAH/ACS.

Size of Hernia: "Loss of Domain"

Patients in whom a long standing large hernia has allowed the abdominal cavity proper to become so small that the herniated contents have lost their intra-abdominal domain, there is a high chance that the patient will develop IAH/ACS after reduction of contents and repair of defect. Even if the patient is able to tolerate the IAH and not develop ACS, the integrity of repair will be threatened unless proper planning is performed. Here too simple clinical tests outlined above allow for a determination to be made about the loss of domain. If there is doubt, computed tomographic (CT) measurements have been suggested that may aid in the determination [8]. However, CT can only perform static measurements of volume. The same available volume may suffice in a patient with laxity of muscle that allows for stretching, while that same volume may not be sufficient in another patient where the abdominal wall is scarred that does not allow stretching. Again a fair amount of judgment is necessary to adequately determine whether there is loss of domain. If there indeed is loss of domain, pre-operative tissue expansion techniques (e.g., pneumoperitoneum) maybe required to increase the overall volume of the abdominal cavity. In less severe cases, the choice of procedure (e.g., component separation) may need to be tailored to achieve a larger cavity and a more secure repair. These techniques are detailed in other chapters.

Size of Defect

Even if the size of hernia is not very large and reduction of contents is tolerated well by the patient, it is possible that the defect in the musculo-aponeurotic layer is so large that when closed, will lead reduction in the volume of the abdominal cavity and IAH/ACS. After reduction of the hernia, in the clinic, the edges of the defect should be brought together manually and the patient observed for signs of respiratory embarrassment. If there is no respiratory embarrassment, it is safe to presume that after repair, ACS will not develop. If on the other hand, there is respiratory embarrassment, plans should be made accordingly for either pre-operative or intra-operative expansion of the abdominal cavity.

Intra-operative Considerations

Based on the pre-operative evaluations, a determination should be made prior to surgery whether the patient can tolerate any reduction in cardiac or respiratory function. As mentioned above, in an otherwise healthy adult, a 10% reduction in ventilatory capacity and/or venous return is usually well tolerated. When the patient is under anesthesia and being ventilated, the peak pressure (for patients on volume controlled mode) and the tidal volume (for patients on pressure controlled mode) serve as an excellent measure of the effect of reduction and repair of the abdominal wall. A note should be made of these parameters after induction of anesthesia just prior to surgery. At the time of closure of the abdominal wall, these parameters should be monitored closely. An increase in peak pressures (for volume controlled mode) or a decrease in tidal volume (for pressure controlled mode) of >10% should prompt a re-evaluation of the safety of the closure. In patients where the cardio-respiratory reserve is more limited, any change should prompt a re-evaluation of the closure. Close collaboration between the operating surgeon and the anesthesiologist is essential to reduce the chances of development of IAH/ACS. In situations where unexpectedly there is/are change(s) in the parameters signaling that IAH/ACS may occur, the technique of closure may need to be modified to avoid the complication. The specifics of how the abdominal cavity can be enlarged are presented in other chapters.

Post-operative Considerations

Any patient who has undergone complex repair of the abdominal wall is at increased risk of developing IAH/ACS. The condition can develop despite careful pre-operative preparation and intra-operative monitoring. This happens because in most patients undergoing complex reconstructions, extensive dissection is usually necessary both within the abdominal cavity and also the abdominal wall. Immediately after surgery as the first phase of healing—inflammatory phase—is initiated in both these areas, the capillaries become “leaky” and “third spacing”—interstitial edema—occurs. This inflammatory swelling leads to increase in the volume of the intra-abdominal contents raising IAP that can proceed to IAH and ACS. The inflammatory phase of healing lasts 48–72 h. Following this, if healing is continuing normally, the capillaries will regain their selective function and the interstitial edema will be resorbed and the excess fluid removed from the body by the kidneys. The end of the inflammatory phase is heralded by an increase in urine output. The conceptual understanding of this pathophysiology is important in managing the post-operative patient, since if the initial inflammatory phase can be tided over without the development of organ system dysfunction, there can be a reasonable expectation of good long term outcome. If on the other hand, this early phase cannot be tided over, it is likely that the patient will need repeat surgery with either take down of the reconstruction or a modification of the technique so that there is more balance between the available space within the abdominal cavity and the combined volume of the contents.

Post-operative Care/Monitoring

Certain measures are applicable to all patients undergoing complex abdominal wall reconstruction. First, patients should have an indwelling urinary drainage catheter and a gastric tube on continuous low level suction to keep these organs completely decompressed. Second, as mentioned above, in the early post-operative period there is development of interstitial edema that can increase the IAP. To minimize the degree of interstitial edema, careful consideration should be given to keeping the patients euvolemic as opposed to hypervolemic. In cases of doubt, stroke volume variation or pulse pressure variation measurement offer an excellent tool to ensuring euvolemia and avoiding hypervolemia [9]. In patients where there is evidence of hypervolemia contributing to increased IAP, judicious use of diuretics, hemodialysis, and/or hemofiltration may prevent further rises in IAP. Lastly, even in the later stages of healing as the interstitial edema is being resorbed, pro-motility agents such as metoclopramide, erythromycin, and neostigmine can reduce bowel distension and further rises in IAP. The process of IAH/ACS starts with increase in IAP, hence monitoring of this pressure is the best method to detect and treat IAH/ACS early. The accepted method of monitoring IAP is to by bladder pressure measurements [5]. The technique is simple and noninvasive since virtually all patients that undergo complex abdominal wall reconstructions have an indwelling bladder catheter. The setup consists of a three-way stop cock connected to (1) the aspiration port of the urine collection bag tube via pressure tubing and an 18 gauge needle, (2) a 50 ml syringe with sterile saline, and (3) pressure transducer tubing. The actual technique consists of emptying the bladder, clamping the tube of the collection bag distal to the aspiration port, and instilling 25 ml of sterile saline into the bladder. After instillation of the saline, the clamp is briefly loosened to empty the tubing towards the patient’s side of air, and reapplied without loosing the saline. After emptying the air, the pressure within the bladder is measured and recorded. The level of the pubic symphysis is considered 0 mmHg [10]. Studies have shown excellent correlation between the true IAP and the bladder pressure measured by this technique. Like all techniques, however, the accuracy of the measurement depends upon the meticulousness of the technique. The greatest source of error comes from incomplete emptying of the air. Air in the system anywhere from the transducer through the three-way connection into the pressure tubing, urine collection bag tubing, and the bladder catheter can dampen the pressure and give an erroneously low reading. Also in patients with very small bladders or those having bladder spasms the pressure recording maybe falsely high. If the above sources of error are kept in mind and care taken to avoid them, bladder pressure measurement is an excellent technique of monitoring patients for ACS, and is by far the commonest one utilized for this purpose. While bladder pressure monitoring is key for the early detection of IAH/ACS, organ system function monitoring is almost as important. Although the definition of ACS is IAP of >20 mmHg with the development of organ system dysfunction, in reality, organ system dysfunction can result from much lower IAPs as well [11]. The two most sensitive organ systems are the respiratory and renal systems. If the patient is ventilated, changes in the peak pressure (volume controlled ventilation) or tidal volume (pressure controlled ventilation) will be one of the earliest manifestations of IAH/ACS. Decrease in urine output in an euvolemic patient is another early manifestation of the process.

Therapy for Post-operative IAH/ACS

Therapy for post-operative IAH/ACS will depend upon the severity of the syndrome and the rapidity with which IAH is increasing. In the milder form characterized by mild increases in the bladder pressure measurements and/or changes in ventilatory parameters, medical therapy may suffice without the need of surgical decompression. On the other hand, if the IAH is rapidly increasing and there is impending or overt ACS or there has been failure of medical management, surgical decompression will likely be the only therapy that will be effective.

Medical/Minimally Invasive Therapy

Non-operative therapy consists of one or more of: (1) neuromuscular blockade; (2) needle/tube drainage of intra-abdominal fluid; and (3) continuous external negative pressure therapy by special custom made devices.

As stated above, a post-operative patient recuperating from complex abdominal wall reconstruction is most prone to IAH/ACS in the first 48–72 h after surgery due to interstitial edema. In this early post-operative phase, mild elevations of IAP with impending but no overt organ system dysfunction, short term neuromuscular blockade may allow the patient to tide over the inflammatory phase. The blockade is weaned once the patient is past the inflammatory phase with resorption of the interstitial edema and overall decrease in the volume of the intra-abdominal contents [12, 13]. A small proportion of patients develop ACS not due to swelling of the viscera, rather due to accumulation of large volume of fluid and/or blood within the abdominal cavity. Such patients can be treated by placing a needle or small catheter within the peritoneal cavity. In a patient who has recently undergone complex abdominal wall reconstruction, placement of a needle or catheter must be done with extreme caution, lest it injure the viscera or compromise the repair. Case reports of successful management are present in the burn literature [14]. Continuous external negative pressure therapy is performed using custom made devices that surround the abdomen and create a negative pressure outside of the abdominal wall. Such devices have been used successfully in morbidly obese patients with chronic ACS [15, 16]. There application in patients with acute ACS has not been reported but in animal studies of acute ACS they have shown potential [17]. Irrespective of which form of non-operative therapy is utilized, ongoing monitoring is critical, since if the therapy fails, surgical decompression will have to be performed to avoid a disastrous outcome.

Surgical Decompression

In patients with overt ACS or those that have failed attempts at medical management, surgical decompression will be necessary to treat the ACS. The exact technique of decompression will depend on the type of reconstruction that has been performed. In all cases, the increased pressure within the abdominal cavity has to be relieved for success. Once decompression has been achieved, an important decision will have to be made whether the patient can have a revised reconstruction at the same time. The answer will depend upon the reconstructive technique utilized, and if some modification can allow for increasing the size of the abdominal cavity. In any case, it is important to understand that a patient that has had ACS is likely to be in a compromised physiologic state and may not tolerate prolonged and complex surgery. It maybe wise to leave the abdomen open for 1–2 days, optimize the physiologic state, and return for a definitive repair. Even after surgical decompression, ongoing monitoring is critically important since despite having an open musculo-aponeurotic layer, the patient can still develop recurrent ACS—tertiary ACS [2].

Conclusions

IAH/ACS is a dangerous condition that occurs when the space available within the abdominal cavity is less than the combined total volume of the contents leading to increase IAP that in turn causes systemic organ system dysfunction. Any patient undergoing complex abdominal wall reconstruction is prone to develop IAH/ACS. Careful pre-operative evaluation and intra-operative monitoring can provide information that the patient is likely to develop IAH/ACS. Pre-operative preparation and modification of intra-operative technique can prevent the condition from occurring. Post-operative monitoring is critical in early detection and rapid therapy. Mild cases maybe treated with non-operative therapy but for more severe cases, operative decompression with or without subsequent reconstruction has to be performed to prevent poor outcomes.

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The Surgical Nightmare: Dealing with Infected Mesh

23

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Introduction

Currently, several types of prosthetic mesh (both synthetic and biologic) are widely used for repairing abdominal wall defects, however, there is no single ideal mesh used for all hernias and in all patients, and infection rate varies from study population [1–5]. There is a wide range of synthetic meshes currently available with various compositions and textures, potentially leading to chronic infection [6–9].

As described in Chaps. 20 and 21, synthetic mesh can be either permanent or absorbable. Permanent materials are generally composed of polypropylene, polyester, or expanded polytetrafluoroethylene (ePTFE). Each of these materials has its benefits and limitations, and detailed description of these qualities is beyond the scope of this chapter [10]. Polypropylene remains the most commonly used material for hernia repairs. It is well known that synthetic mesh with large pores meshes is more resistant to infection than the firm, smaller pore meshes [11]. Microporous meshes including ePTFE are at higher risk of infection [12].

Although biological meshes are significantly more expensive than synthetic meshes. Although, long-term durability has been questioned [13–14], they are more resistant to infection and high biocompatibility when implanted [15]. A review by Darehzereshki et al. [8] of eight retrospective studies, with a total of 1229 patients comparing biological versus synthetic mesh repair in ventral and incisional hernias demonstrated that biological grafts were associated with significantly fewer wound infections but with no difference in recurrence rate.

Risk Factors and Pathogenesis of Mesh Infection

There are a number of risk factors predisposing mesh to infection that have been described, including high body mass index, chronic obstructive pulmonary disease, prior surgical site infection, use of larger, malnutrition, smoking, steroids use, previous wound infection, microporous, or expanded polytetrafluoroethylene mesh, performance of other procedures via the same incision at the time of repair, longer operative time, lack of tissue coverage of the mesh, enterotomy, and enterocutaneous fistula [16–18]. Recent meta-analysis of six cohort studies has analyzed risk factors for synthetic mesh infection [18]. In this study the crude mesh infection rate was 5%. Statistically significant risk factors were smoking, American Society of Anesthesiologists (ASA) score ≥ 3, and emergency operation. Mesh infections significantly correlated with patient age, and the duration of the hernioplasty. A trend toward higher mesh infection rates was observed in obese patients and in patients operated on by a resident. Mesh infections usually resulted in mesh removal, and common pathogens included *Staphylococcus* spp., *Enterococcus spp.*, and Gram-negative bacteria.

The usual causative micro-organisms associated mesh infection are *Staphylococcus aureus* including methicillin-resistant *Staphylococcus aureus* (MRSA) and *Staphylococcus epidermidis*, group *B Streptococcus*, and Gram-negative bacteria including Enterobacteriaceae [19]. Rarely fungi (*Candida* spp.) can colonize prosthetic wound [20]. *S. aureus*

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is the predominant cause of surgical site infections worldwide with a prevalence rate ranging from 4.6% to 54.4% [21].

Infection with *S. aureus* may be associated with both endogenous source as it is a member of the skin and with contamination from environment, surgical instruments, or from hands of health care workers. Special interest in *S. aureus* surgical site infections is mainly due to the emergence of MRSA strains [22]. The pathogenesis of mesh infection is a complex process involving more factors including [23]: (a) bacterial virulence; (b) surface physicochemical properties of prosthetic; and (c) alterations in host defense mechanisms.

Bacterial adherence and biofilm formation on the surface of synthetic materials are essential steps in the sequence leading to mesh infections. The first stage of mesh infection is bacterial adherence to the prosthesis. In an experimental study Sanders et al. [24] evaluated the relationship between the size of the bacterial inoculum and bacterial adherence to hernia prosthetics. The results demonstrated that even a very low number of bacterial inoculums can result in adherence to hernia biomaterials and that the level of adherence is directly related to the size of the inoculum. These in vitro results provide evidence that the size of the inoculum is important in the colonization of hernia biomaterials and demonstrate the importance of minimizing the bacterial inoculum in the clinical setting.

The result of adherence to hernia prosthetics is the formation of the bacterial biofilm. Several studies have documented in vitro that multiple species of bacteria can attach to prosthetic mesh surfaces and form biofilms including coagulase-negative staphylococci, *S. aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa* [25]. Embedded in self-secreted extracellular polymeric substances, biofilm can provide bacteria an effective barrier against host immune cells and antibiotics [26].

Biofilms have been documented in association with a wide variety of implanted materials such as central venous catheters, urinary catheters, heart valves, orthopedic joint prostheses, and internal fixation devices [27–29] and also in non-absorbable meshes [30].

The nature of biofilm structure makes micro-organisms difficult to eradicate and confer an inherent resistance to antimicrobial agents [30].

Diagnosis of Mesh Infection

Diagnosis of infected mesh is not straightforward and need to be distinguished from superficial incisional surgical site infections. They occur in the early postoperative period and may not be influenced by mesh implantation. The diagnosis of wound infection is clinical with typical symptoms of localized inflammation and pain at the incision site. The usual presentation of infected surgical wound can be characterized by pain, tenderness, warmth, erythema, swelling, and pus formation.

Patients with deep mesh infections, on the other hand, in addition to signs of local inflammation, may tend to be indolent and present chronic signs and symptoms or more systemic signs of infection. Initially they may be initially underestimated, and once they are chronic patients may present with sinus formation (Figs. 23.1 and 23.2) [31].

The diagnosis of chronic mesh infection should be based on its clinical presentation but will require radiological studies, including ultrasound (US), computerized tomography (CT), and on occasion scintigraphy should be useful [19].

In 2011 a study by Zuvela et al. [32] compared the role of detection of late mesh infection following incisional

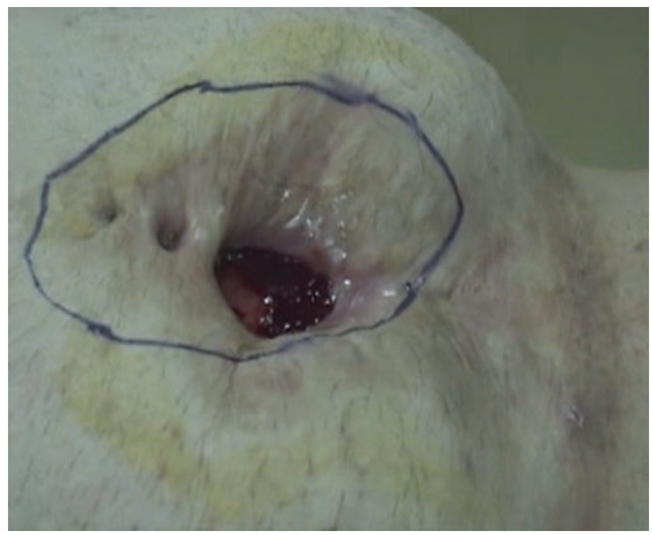

Fig. 23.1 Mesh infection resulted in a chronic sinus

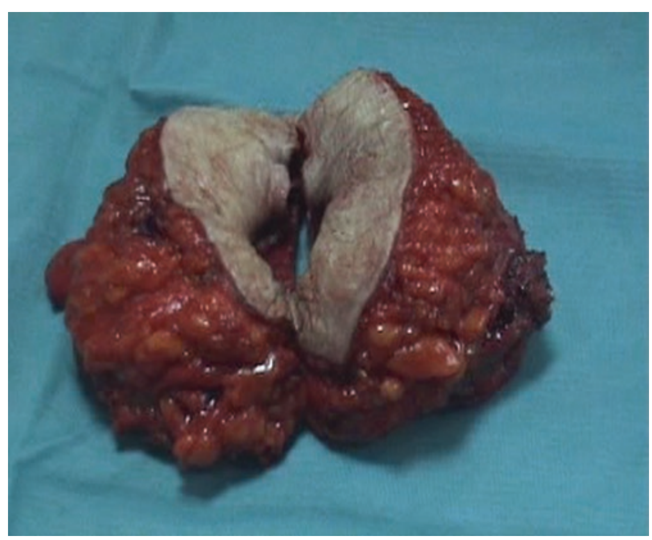

Fig. 23.2 Infected mesh and sinus completely removed with a full-thick abdominal wall resection

hernia repair with US, CT, and scintigraphy with 99mTc-antigranulocyte antibodies.

Among 17 patients investigated, US was positive in 12/17 patients, CT in 13/17 patients, while scintigraphy with antigranulocyte antibodies in 17/17 patients. Therefore, sensitivity of US was 71%, of CT 76% and of scintigraphy 100%. In four patients late mesh infection was confirmed exclusively by 99mTc-antigranulocyte antibody scintigraphy, while US and CT did not indicate the infection.

Management of Mesh Infection

The management of mesh-site infection is challenging and requires an individualized approach combining medical and surgical approaches, as well as respecting well-established surgical principles. Superficial wound infections can be successfully managed without the removal of the mesh, however, this is controversial, and not all surgeons agree with this approach. Although, several studies have shown that in certain instances a conservative approach may be successful for salvaging a contaminated mesh [33–36], in most cases antibiotics and wound drainage are not sufficient to eradicate the infection [37, 38].

There are no recommendations on how long a conservative strategy should be continued. It has been suggested that polypropylene and polyester meshes can be treated conservatively in a higher proportion that a mesh-like ePTFE [39]. If conservative treatment fails, the complete surgical removal of the mesh is mandatory to reduce the risk of infection recurrence or severe complications, such as visceral adhesions that may lead to obstruction and fistulae. Clearly, this depends on where the mesh is placed. Assuming the mesh is placed intra-peritoneally, such as in case of laparoscopic hernia repair, salvaging such mesh without explanting it would be difficult, if not impossible. When there is large wound infection, where the mesh is "floating" in the pus, such mesh needs to be removed at once. A conservative surgical approach including abscess drainage, incomplete sinus excision, or partial mesh excision usually fail and may result in recurrent mesh infections.

The operative strategy, when it is possible, should always include the complete removal of the infected mesh and sinus tract tissues surrounding the mesh [39]. Patients who present with systemic symptoms and signs of wound infection should undergo prompt empiric antibiotic therapy and aggressive surgical debridement to remove infected tissue and the mesh. Infected material should be sent for culture and susceptibility test should be performed to define targeted antimicrobial therapy.

The most serious concern when one removes the infected mesh and surrounding tissue is the defect that is created. How to deal with this new defect, it is a difficult issue. The reconstruction of even simple abdominal wall defects after infected mesh is removed can be challenging. Worse, if there is a large defect created, this represents a real challenge for both surgeon and for the patient. When the defects are contaminated and large, a satisfactory functional reconstruction can be difficult to achieve. In a recent case (performed by RL) an indolent walled off abscess on the left lower chest wall, in a 48-year-old male, post-heart transplant involving 9, 10, 11 ribs that required partial resection of ribs, created a large defect. This was reconstructed using "sandwich" technique with underlay and onlay biological mesh.

While there are three options to deal with the situation after removing the contaminated mesh, the intra-operative options are [39] (a) removing the mesh and do not replace it with a new mesh; (b) re-implantating a new synthetic mesh; and (c) replacement of the infected synthetic with a biological mesh, we clearly do not suggest option b, although there is a literature to support such approach. We suggest native tissue coverage if at all possible. The two viable options are (a) and (c). While, most of us would agree that option (a) is the best, one has to understand that this approach can result in a very high recurrence rate and the second operation should be planned at a later time. This needs to be communicated clearly to the patient.

The basic principle is source control, that is to remove the infected mesh. We suggest that such wounds are treated with negative pressure wound therapy, until is closed completely. If and when so much abdominal wall is resected, that we are unable to reconstruct the wall using native tissue, this becomes more challenging, and advanced surgical procedures such as tissue transfer may be required. Without a functional abdominal wall, the patient has a hernia by definition and requires a second surgical intervention to repair the abdominal wall defect as a planned abdominal reconstruction [40]. It is not clear, when repair of such hernia should take place, however, we suggest individualization of care for each patient. In rare cases, especially in groin region, the removal of the infected mesh may not result in recurrent herniation if sufficient fibrous scarring remains [41].

The second option (or option b above) is to replace the infected polypropylene mesh with a new polypropylene mesh. A retrospective study of short- and long-term results of patients undergoing removal of infected mesh and reconstruction of the abdominal wall with synthetic simultaneous mesh replacement was published in 2015 by Birolini et al. [42]. Simultaneous mesh replacement by standard polypropylene mesh as an onlay graft prevented hernia recurrence and had an acceptable incidence of postoperative acute infection. The study reviewed 41 patients undergoing removal of an infected or exposed mesh and single-staged reconstruction of the abdominal wall with synthetic mesh replacement over a 16-year period retrospectively. The short-term results showed an uneventful postoperative course after mesh replacement in 27 patients; 6 (14.6%) patients developed a minor wound infection and were treated with dressings and antibiotics; 5 (12%) patients had wound infections requiring debridement and one required complete mesh removal. On the long-term follow-up, there were three hernia recurrences, one of which demanded a reoperation for enterocutaneous fistula; 95% of the patients submitted to mesh replacement were considered cured of mesh infection after a mean follow-up of 74 months [42].

The third option (option c above) is to replace the explanted synthetic mesh with a biological mesh [13, 43, 44]. In fact, due to the several limitations of non-absorbable synthetic meshes in infected fields, the use of biological scaffolds has started to be explored in abdominal wall reconstruction [45]. Biological prosthesis (BP) are allogenic or xenogenic collagen mesh. They could be cross-linked or not and for this reason they respectively result to be completely or partially remodeling. The differences in remodeling times should be kept in mind in choosing the kind of materials. BP permit and encourage host tissue ingrowth. The partially remodeling prostheses are also optimal for resisting mechanical stress [44]. They are physically modified with cross-linkages between the collagen fibers to increase the strength of the prosthesis. This process stabilizes the implant by preventing its degradation by human or bacterial collagenase [46, 47].

BP have completely changed the way to face the infected prosthesis dilemma. Their advent introduced the tissue engineering in surgical practice [48, 49]. The implantation leads to new healthy tissue deposition and prosthesis remodeling. It also allows pro-/anti-inflammatory factors, and drugs to reach the infected surgical field during the first phases of healing process. This enhances the effect against contamination/infection [50]. Another factor that should be kept into account in choosing which kind of BP to use is the demonstration that non-cross-linked material exhibits more favorable remodeling characteristics [51]. This has a great importance when BP are used as bridge to cover tissue loss. Discordant data have been published about the use of BP to bridge wide defect. In 2013 a critical review in Medline database to specifically identify review articles relating to biologic mesh in contaminated field was published supported biologic mesh use, in the setting of contaminated fields, but these reviews are limited to case series and case reports with low levels of evidence [52, 53].

To better guide surgeons, prospective, randomized trials should be undertaken to evaluate the short- and long-term outcomes associated with biological meshes under the various surgical wound classifications [53]. The Italian Biological Prosthesis Work Group (IBPWG) proposed a decisional model in the use of BP to facilitate the choice between the different types of BP [50].

The aforementioned decisional model suggests that the decision about which prosthesis utilize should always be a dynamic process mediated by the surgeon decisional capability. The principal variables to keep in mind in deciding the kind of BP to use are infection grade and loss of tissue size.

Infection is divided into three possible grade: (1): potentially contaminated; (2): contaminated; (3): infected. The same three step division is adopted for the tissue loss: (1): no tissue loss; (2): 0–5 cm defect; (3): >5 cm defect. By combining together these variables (multiplication) could be obtained a score which suggest the necessity to use either a cross-linked or a non-cross-linked BP.

When the fascia cannot be primarily re-approximated, rather than bridging a defect with mesh alone and covering this repair with subcutaneous tissue and skin, lateral components separation technique allows for primary fascial closure [13] (Chap. 7). It is unclear the most optimal time of performing the lateral component separation. Often, however, large and complex hernia has been already reconstructed with a combination of mesh placement and component separation. This complicates things more. We suggest, however, that even in cases that some sort of component release has been performed, that you revisit during next definitive reconstruction.

Conclusions and Recommendation

Mesh infection is a great challenge for surgeons and most serious complication for the patient that may have significant consequences. Although mesh is uncommon, mesh infections in most cases require the removal of infected meshes resulting in additional surgery, morbidity, and cost.

The pathogenesis of mesh infection is a complex process involving more factors including bacterial virulence, surface physicochemical properties of prosthesis, and alterations in host defense mechanisms. Mesh infections should be distinguished from superficial incisional surgical site infections (SSIs). SSIs occur in the early postoperative period and are not influenced by mesh implantation. Yet, this is not an easy diagnosis to be made. Frequently, deep mesh infections are indolent and present chronic signs and symptoms. They may be initially underestimated. Typically, patients present with sinus formation. The diagnosis of chronic mesh infection should be based on its clinical presentation. Radiological techniques including ultrasound, computerized tomography, and scintigraphy may be useful for diagnosis in uncertain cases.Treatment of mesh infection should be considered on a case-by-case basis. Although a conservative approach may be attempted, it is well known that the fundamental principle for approaching this problem is to remove the mesh completely and when indicated to replace it. After removing the contaminated mesh, the intra-operative options are: (a) no implant of a new mesh; (b) re-implantation of a new synthetic mesh, and (c) replacement of the infected synthetic with a biological mesh. Although biological meshes are higher in cost than synthetic meshes and the long-term durability may be less favorable, they can confer protective factors such as resistance to infection and high biocompatibility when implanted.

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Abdominal Plastic Surgery and Adjunctive Procedures

24

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Introduction

Patients with large abdominal wall defects often have a large pannus and "extra skin" that needs to be addressed at the time of reconstruction, or often is encountered after the hernia has been repaired. These patients require panniculectomy and other adjunct procedures such as lipoabdominoplasty; miniabdominoplasty; full abdominoplasty; or even superior or reverse abdominoplasty.

The modern approach to abdominoplasty takes advantage of a number of minimally invasive body contouring modalities to optimize the appearance of the abdomen, umbilicus, and waistline via excising skin, suctioning fat, and tightening the abdominal musculature. A thorough evaluation of patient's past medical history, surgical history with details of the operation, weight, physiological function status, diet and tobacco intake, psychological desires, and anatomical concerns such as pre-existing scars to be able to optimize long term outcomes for each individual patient should be performed. The current approaches to abdominoplasty include the following.

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Liposuction

While liposuction is not used frequently as adjunct procedure in patients who undergo complex abdominal wall defects, it is important that the basic principles and techniques are discussed here. It is important to have an extensive pre-operative discussion with the patient and inform them that liposuction "literally means removal of fat only" and at best there is 20–30% contraction of overlying skin which means that the procedure is limited in improving contours of the abdomen where there is genetic pre-disposition of fat storage pockets in the lower abdomen and flanks.

There are currently over a dozen types of liposuction techniques introduced but they essentially involve the same principles. Tumescent technique requires pre-infiltration of a fluid containing 1000 of ringer's lactate with 20–50 cc of 1% lidocaine, and 1 cc ampule of 1:1000 epinephrine. The fluid is usually warmed to make sure to keep the patient normothermic and infiltrated at a rate of 100–300 cc per minute and allowed to take effect for about 10 min to help with pretunneling of the subcutaneous tissues and anesthesia and vasoconstriction of the subnormal vasculature. A number of liposuction techniques are used such as traditional suction assisted lipoplasty (SAL), power assisted lipoplasty (PAL), ultrasound assisted lipoplasty (UAL), laser assisted lipoplasty (LAL), and water assisted liposuction (WAL), but a detailed description of each of these techniques is beyond the scope of this chapter.

Abdominoplasty Techniques

Anterior dermolipectomy with concomitant fascial tightening is an essential defining component of abdominoplasty while variations involve placement and length of the lower abdominal scar. The variation on the magnitude of the operation revolves around whether the surgeon chooses to transpose the umbilicus at the same time.

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Lipoabdominoplasty starts off with deliberate removal of subcutaneous fat via one of the modalities described above to essentially "deflate the anterior truncal and flank fat" prior to fascial plication and skin excision.

The procedure invariably includes the following surgical steps:

The surgical markings in pre-operative area (imperative for the patient to be standing) is done. Liposuction of the abdomen, mons, flanks is carried out using any of the techniques mentioned above. A lower abdominal incision is made and the flap is elevated either floating the umbilicus in the process or incising the umbilicus and stalk and elevating the flap all the way to the typhoid and costal margins bilaterally. Next the artistic input of the surgeon will determine the degree of fascial plication and orientation of each plication that can lead to the tightening and flattening of the abdominal contour. A recent advancement has been the introduction of barbed sutures that allow a "knotless" application of rows of plication sutures that will not be palpable post-operatively.

Pain management plays a prominent role in the outcome of this group of patients. The traditional use of opioids often results in lack of ambulation and post-operative constipation which can potentially lead to paradoxical additional abdominal trauma, nausea, vomiting, and pain. Therefore, upon completion of satisfactory of plication, either a pain pump is introduced to instill small aliquots of 0.25% bupivacaine or more recently we have used liposomal bupivacaine (EXPAREL® by Pacira Pharmaceuticals Inc.) infiltration for intercostal blocks that allow for 3 days of post-operative pain control which is critical for early ambulation and management of the post-operative patient [1]. Sun et al. provided level I evidence in 2008 in a randomized controlled study which showed that patients that received celecoxib for 3 days post-operatively had a significant higher satisfaction rates based on resuming a normal diet, bowl function, and physical activity by 3 days post-operatively as compared with control cohort group [2]. Closure of the abdominal wall has been shown to improve by techniques that employ "progressive tension closure of the dead space." As popularized by Pollack and Pollack, the technique involves tacking of the abdominal scarpa's layer to the rectus fascia with a number of absorbable PDS sutures [3]. Andrades et al. have supported the use of this technique in a level I outcomes study published in 2007 that revealed in a prospective, randomized, double-blinded controlled study, the use of progressive tension sutures or subcutaneous drains resulted in lower incidence of serums as compared to control cohorts. The progressive tension group also were associated with longer operative times but lower drain outputs [4]. Khan et al. reported a level III evidence study in 2008 which showed significant higher level of seroma formation in the non-progressive tension cohort [5].

The final step of the operation includes excision of the excess abdominal skin with the patient in a 45 degree "jack knife position" and reattachment or transposition of the new-umbilicus in its new elected position. The preferred position is usually at the midline plane at the level of the anterior superior iliac spine. Plastic surgery principles dictate use of tension free closure which usually includes a layer in the scrape's followed by dermal and epidermal approximation in total of three layers. Most surgeons employ the use of at least one drain in the subcutaneous space for the first week post-operatively. We use silicone pressure foam dressings and abdominal binders to ensure controlled compression of the final result (Fig. 24.1).

Management of the functionally debilitated abdominal patient requires delaying of the aesthetic procedures mentioned above in favor of enhancing the functional outcome of the abdomen. That means focusing on returning the abdominal domain to its intended boundaries and maintaining the abdominal wall in position with either autologous techniques such as component separation or biological devices and mesh which will be described in other chapters.

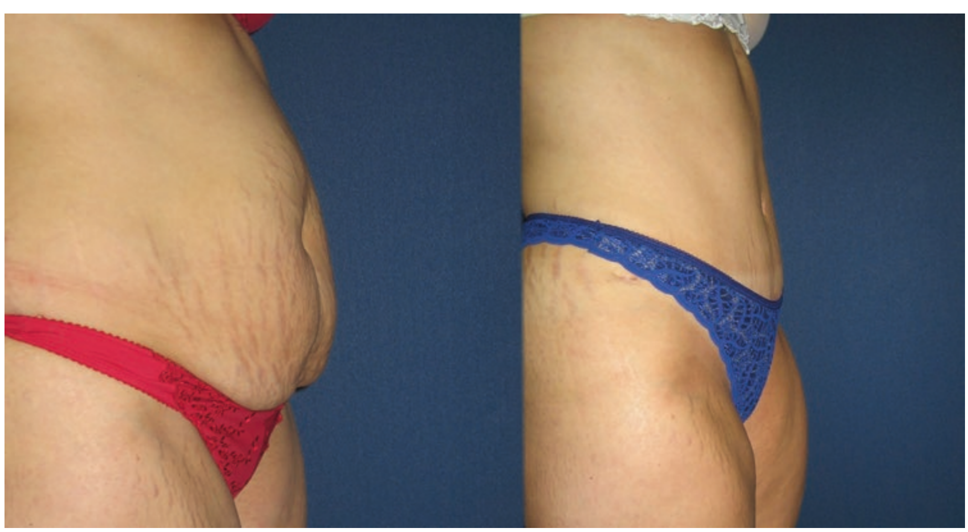

Fig. 24.1 40-year-old patient G5P4 with typical post-partum striae, abdominofascial laxity, and umbilical hernia; 6 months post-operative photo demonstrating the multiplanar approach to improve and define skin, fat, muscle, fascial layers after fixing her umbilical hernia

Long Term Post-operative Outcome Results

The long term results of abdominoplasty patients compare favorably in a number of reports in the literature. Hensel et al. reported an overall complication rate of 32% with only a 1.4% major complication rate. There were 43% surgery revision rates mostly due to aesthetic concerns. 14% of the patients had seroma requiring intervention while 7% had a wound infection. Less than 2% of the patients had a hematoma and as expected, there was a statistical significant difference in patients who smoked tobacco, had diabetes and/or hypertension [6]. Stewart and colleagues published a level IV evidence paper on 278 consecutive abdominoplasty patients where they stratified them according to "early" versus "late" time points and noted an 18% "early" complication rate for the seroma, hematoma, infection, skin or fat necrosis, and delayed wound healing. Approximately 25% of the patients developed "late" complications including dog ears, localized fatty excess, and unsatisfactory scars requiring a revision rate of 24% [7].

Plastic Surgical Management Following Massive Weight Loss Patient

In the USA, obesity is a growing epidemic [8] that can be treated by several medical modalities. Bariatric surgery, aggressive diet, and exercise regimens have become more commonplace [9]. Thus, more patients are experiencing massive weight loss (MWL) defined as an intentional decrease of at least 100 pounds in a patient's body weight in the setting of morbid obesity [10]. While this is life saving, there are a number of consequences of body transformation. The development of loose and overhanging skin in many different parts of the body is expected as patients lose weight; however, the abdomen tends to be a significant area of deformity and concern for many patients. Although abdominal contouring techniques are well established, treating the MWL patient is unique. The abdominal wall has more anatomic variability, and the patients often times have altered nutritional intake [11]. Therefore, the complication rates are higher in the post bariatric surgery patient [12, 13], forcing surgeons to have a different approach to the pre-operative evaluation, intraoperative execution, and post-operative care.

Successful wound healing is predicated on the patient having the necessary nutrition in a stressed state. Concerns for nutritional inadequacy are more likely in MWL patients after gastric surgeries than from diet and exercise. Specifically, gastric bypass patients are of particular concern because the operation limits both nutritional intake and absorption [11]. Therefore, knowing the specific type of bariatric surgery performed in addition to a detailed nutritional history is critical in the pre-operative evaluation. The nutritional history includes several components. The course of weight loss should be well defined: date of bariatric surgery, starting body mass index (BMI) before surgery, lowest BMI after surgery, current BMI, goal BMI, fluctuations over the past 1–3 months. The patient should ideally be stable in their weight for at least 4 months prior to undergoing abdominal contouring procedures. Generally, the weight loss plateau occurs 12–18 months after bariatric surgery [9, 14]. Patients who are still obese after MWL have further increased complication rates, and generally, the lower the BMI the better the aesthetic result. Patients may, therefore, consider additional weight loss. It is important to counsel patients that abdominal contouring does not result in significant weight reduction. A medication list detailing nutritional supplements should be obtained at the initial consultation and should include iron, vitamin B12, calcium, zinc, and a multivitamin. Ideally, a protein intake assessment should be performed, encouraging a peri-operative daily intake of 70–100 gm [11]. A laboratory workup should also be included to objectively define nutritional and metabolic values: hematocrit/hemoglobin, basic metabolic panel, albumin/prealbumin. The patient may need to be referred to a nutritionist to help optimize deficient aspects of the evaluation.

Physical examination of the abdomen in the MWL patient should include close assessment for hernias, prior incisions, and extent of skin laxity. Morbidly obese patients often times have umbilical hernias and patients with open bariatric procedures may have incisional hernias. These hernias may not necessarily be appreciated on exam; however, hernia repair can be safely performed at the same time as the contouring procedure [9, 15]. MWL patients often present with a history of multiple abdominal surgeries, and the location and extent of the prior incisions need to be closely assessed. The skin and soft tissue of the abdominal wall receives its blood supply from perforating vessels from the superior epigastric, inferior epigastric, circumflex iliac, intercostals, and lumbar arcade. The dissection required in many abdominal contouring procedures requires extensive dissection of the abdominal wall up to the costal margin and xiphoid process. As a result, the remainder of the blood supply to the abdominal soft tissue flap is coming laterally from the lumbar arcade and the intercostals [16, 17]. Therefore, prior incisions above the umbilicus of moderate length, such as an open cholecystectomy incision, are the most concerning for potential wound healing problems or skin flap necrosis. The inferior-central part of the abdominal flap is the furthest from the blood supply and the part under the most tension upon closure, making this portion of the incision most at risk for vascular compromise especially in the setting of a prior superior-lateral incision. Additionally, patients should be counseled that prior incisions above the umbilicus will translocate inferiorly and medially with the abdominal contouring procedure, while incisions below the umbilicus will likely be resected along with the pannus. MWL patients also present with excess skin and soft tissue in the cranial-caudal dimension, resulting in one or multiple overhanging pannus that can either be isolated to the abdomen or extend circumferentially. Additionally, excess abdominal tissue can also be present in the side-to-side dimension [18, 19]. Determining the extent of the laxity will determine the optimal abdominal contouring procedure required.

Patient selection and managing expectations is critical in successful abdominal contouring, especially in the MWL patient. Many patients expect minimal downtime, low complications, minimal scarring, flawless results without needing revisions, and no out-of-pocket costs [9, 10, 20]. Patients must understand that abdominal contouring in this setting is a larger operation than the bariatric surgery in the sense that the incisions are longer, the dissection is more extensive, and the duration of the operation may be longer. Therefore, the downtime and the recovery can be more painful, more prolonged, and more likely to have wound healing complications. Abdominal contouring in the MWL patient is more functional than aesthetic with the surgical goal of restoring the dynamics of the abdominal wall with hernia repair, fascial plication, and soft tissue tailoring; therefore, the aesthetic results may not necessarily be the same as a purely cosmetic operation. Patients have to accept that there is a trade-off between contour and scars: improving contour is limited by the size of excision, and thus, the size of the resulting scar. Furthermore, the evolution of the scar and its final appearance is, in part, a function of genetics, ethnicity, anatomic location, and intrinsic/extrinsic biologic factors [21]. Unlike cosmetic abdominal contouring where the goal is to minimize scarring, in the MWL patient, contour is valued higher. Therefore, scarring is inevitable, and several excisions may be necessary to achieve the desired contour.

Operative staging is necessary in many MWL patients especially if several anatomic locations require contouring. The risks of infections, poor wound healing, and thromboembolic events inherent with prolonged operative times means that the surgeon and the patient need to prioritize surgical locations and goals. Often times, the abdomen is the patient's highest priority; and, abdominoplasty can be combined with mastopexy, lower body lift, or brachioplasty in the first stage [22, 23]. However, patient safety is the primary concern and procedures should be divided into as many stages as necessary.

Pre-massive Weight Loss Panniculectomy

Patients may present for excision of a large abdominal pannus before bariatric surgery or significant weight loss or for a repair of large hernia. A large, overhanging abdominal pannus can greatly impede adequate hygiene and ambulation, resulting in intertrigo, recurrent cellulitis, and ulcerations. Furthermore, removing the pannus can aid in surgical access for bariatric, gynecologic, and colorectal procedures. Panniculectomy can sometimes be combined with these procedures; however, combining these procedures can result in high complication rates [24–26], and strong consideration for staging is recommended.

The patient is marked in the standing position to determine the superior and lateral extent of the pannus, which will be obscured in the supine position. The primary goal in panniculectomy is removal of the overhanging pannus with minimal to no undermining of skin flaps and minimal to no tension at the incision line. The size and weight of the pannus can be unwieldy, making dissection without undermining and minimizing blood loss difficult. Furthermore, sterilely preparing the abdominal surgical site with an overhanging pannus is difficult to perform and increases the risk of wound complications in a patient who is already at high risk for wound dehiscence and infection. Therefore, utilizing a pannus suspension system (Hoya crane) during the operation to help lift the pannus off the abdomen can be beneficial. After initial preparation and draping of the surgical site and the suspension system, large penetrating clamps are placed along the pannus and a sterile rope is pasted through the clamps and secured to the suspension system. The pannus can then be lifted for additional sterile preparation and the remainder of the operation.

Dissection is started at the lateral aspect of the pannus and performed straight down to the fascia, avoiding undermining of the inferior and the superior skin flaps. Avoiding skin flap undermining is important to minimize potential space and maximize skin flap vascularity to help prevent post-operative collections and wound dehiscence. Often times, large perforating vessels are encountered during the dissection and require clip application or suture ligation. LigaSure Impact (Covidien Surgical Solutions Group, Boulder, CO) can also be used as an adjunct in the dissection to facilitate speed of the resection without having to identify and dissect the individual intermediate to large sized subcutaneous vessels. The pannus is removed from the abdominal wall at the level of the fascia from lateral to medial and the suspension system can be further elevated to facilitate identifying the proper plane. Often times, the umbilicus is part of the overhanging pannus and will need to be amputated along with the specimen. If the pannus resection does not include the umbilicus, care must be taken to avoid undermining the umbilical stalk and the patient should be warned that the umbilical position will be lower on the abdominal wall upon closure and may possibly appeared tethered. Since occult umbilical hernias may be present, caution should be paid during dissection in the periumbilical region.

The management of the closure in a panniculectomy is varied. The lymphatic vessels in a large pannus are often dysfunctional, contributing to expanding cycle of lymphedematous skin and subcutaneous tissue [27]. The risk of post-operative wound infections, collections, and dehiscence in this setting is significantly high. Additionally, proper sterile preparation of the pannus is difficult. Therefore, some surgeons will opt for an open wound closure method [28]. Large permanent sutures are placed in a wide mattress fashion with skin retention bolsters at 10–15 cm intervals. The knots are placed on the superior skin flap to aid in removal in the office and provide improved comfort for the patient. A saline moist kerlix gauze is used to pack the interval wounds and changed 1–2 times a day until the wound has healed from deep to superficial. The sutures are removed when complete healing is achieved which may take 2–4 weeks. On the other spectrum, some report low complications with a standard layer closure [25]. As a compromise, others have utilized negative pressure wound therapy applied to the open incisions laterally while performing a loose or layered closure centrally. The advantage of negative pressure therapy is a reduction of dressing changes for the patient as well as faster wound closure compared to traditional open wound management. Brown et al. demonstrated that layer closure of massive panniculectomies resulted in a 44% readmission rate and a 33% reoperation rate for wound complications compared to a 0% readmission and reoperation rate in patients treated with open wound management with negative pressure therapy [29].

Post-massive Weight Loss Abdominoplasty

The post-massive weight loss abdominoplasty can be performed in either one of the two patterns of resection. The traditional pattern, as described earlier in the chapter, consists of an elliptical excision of infraumbilical skin laxity and adiposity that spans from hip to hip. This pattern mainly addresses skin laxity in a cranial-caudal direction with mild to moderate improvement of the horizontal laxity through a high lateral tension technique [30] and by the Poisson ratio when the abdominal flap is put on vertical tension. However, MWL patients may present with excessive horizontal skin laxity and adiposity in addition to the overhanging pannus, which cannot be adequately addressed with a traditional resection pattern. A fleur-de-lis pattern may be more appropriate in this setting and is characterized by a midline vertical elliptical resection in addition to the infraumbilical resection. The final resection pattern resembles the stylized French lily symbol to which the pattern is named. The ability of the fleur-de-lis abdominoplasty to provide a superior abdominal contour in the MWL patient has been well described [30–35]. In short, abdominal contour deformity in the setting of massive weight loss can be highly variable and may require additional contouring techniques to achieve the best cosmetic result.

In 2005, Song et al. [18] developed the Pittsburgh Rating Scale: a four-tiered, region-specific classification system for skin laxity and ptosis following bariatric surgery. The abdomen scale consists of grades 0, 1, 2, 3: 0 indicates normal appearance, 1 for moderate adiposity without overhang, 2 for overhanging pannus, and 3 for all multiple roll deformities. The multiple roll deformity was further broken down into sub-grades because the lateral extent and number of rolls had clinical significance on whether a traditional abdominoplasty could be performed. Patients with an upper roll restricted to the panty-girdle line anteriorly were 3a grade, extending to midaxillary line were 3b grade, extending to the back were 3c grade, and triple roll deformities were 3d grade. In a retrospective review of 1006 massive weight loss patients presenting for abdominal contouring procedures, Zammerilla et al. [19] determined that patients with higher deformity grades, crossing into grade 3, were more likely to undergo fleur-de-lis abdominoplasties. Furthermore, patients with larger changes in BMI after massive weight loss were more likely to have higher grade deformities as well as patients who had massive weight loss secondary to bariatric surgery versus diet and exercise. The maximum BMI before weight loss did not significantly differ between the traditional and the fleur-de-lis groups. Therefore, patients that have a large change in BMI after weight loss with high grade deformities are most likely to benefit from adding a vertical component to an abdominoplasty.

The initial surgical approach to abdominoplasty in the MWL patient is similar to the traditional operation described earlier. The inferior incision is marked first in the midline at a point 6–7 cm above the vulvar commissure with the tissues on full stretch. The lateral extent of the hip roll is marked and the midline and lateral points are connected, forming the inferior incision. In the MWL patient, the inferior incision may be inferior to the inguinal ligament; however, upon closure, the final position of the incision is pulled superiorly. If a fleur-de-lis is indicated, a pinch test in the midline is used to approximate the extent of the vertical resection. Dissection through the inferior incision is started first. Lymphatics below the inguinal ligament should be preserved. Therefore, if the marking is below the inguinal ligament laterally, dissection is superficial until superior to the inguinal ligament at which point dissection is deepened to the abdominal wall fascia. The infraumbilical flap is dissected in a plane at the level of the fascia and the umbilicus is detached from the abdominal flap. The superior extent of the resection is determined with the patient in the flexed position and then transverse resection is performed. The transverse incision is then temporarily closed with staples or towel clips in order to address the vertical component of the resection. The vertical markings from the transverse incision to the xiphoid are confirmed with the pinch test, being more conservative with the resection inferiorly. The vertical dissection is then performed down to the abdominal wall fascia. No undermining of the vertical resection is crucial in order to preserve the perforating vessels to the skin flap. The "T" junction can then be adjusted to maximize the vertical and transverse resections to create the best contour. The transverse incision is closed first, starting at the mons pubis. Often times in the MWL patient, there is more thickness of the soft tissue at the mons pubis compared to the abdominal skin flap. Direct fat excision or suction assisted lipectomy can be performed. If the mons is inferiorly displaced, it can be suspended to the anterior abdominal wall. Drains extending laterally and centrally are placed and the incisions are closed in layers. The umbilicus is inset directly into the vertical incision at the level of the anterior superior iliac spine.

Post-operatively, the patient is placed in an abdominal binder and maintained in a flexed position when transferring from the operating table to the stretcher. The patient records the drain output, and the drains are removed when the daily output is less than 30 cc. A compression garment can be applied once the drains are removed. Strenuous activity and exercise is avoided for 4 weeks.

Post-massive Weight Loss Circumferential Lower Truncal Contouring

The lateral and posterior extensions of high grade abdominal contour deformities are not necessarily corrected with an abdominoplasty even if a vertical resection component is included. This set of patients require lateral hip and back dermatolipectomies in addition to the abdominoplasty. Although these procedures can be separated in multiple stages, a circumferential lower truncal contouring procedure can be performed in a single stage. Belt lipectomy and lower body lift are the most commonly described [22, 36, 37]. In a recent study, approximately 50% of surgical patients presenting for body contouring after massive weight loss received a concomitant contouring procedure in addition to abdominoplasty. Most commonly, the additional procedure was a lower body lift [19]. Although there are numerous terms used for circumferential lower truncal procedures, each with slight variation on technique, the principles are generally the same. Anteriorly, the objective is to remove the overhanging pannus and pull down excess skin and adiposity. While posteriorly, the objective is to remove any continuance of the abdominal pannus and pull up the hanging skin and adiposity of the hip and buttock. When a circumferential resection is performed in a single stage, a more aggressive skin resection can be utilized laterally without creating a point of redundancy, often referred to as a dog-ear deformity [38]. There may also be a need for concomitant reinforcement with acellular dermal matrix for fascial integrity (Fig. 24.2).

The belt lipectomy incision is often higher than in lower body lift and better targets waist contouring than posterior-lateral lifting. The lower body lift incision over the buttocks allows for focused gluteal shaping and augmentation, and lifting of the lateral thighs [39]. Circumferential lower truncal procedures must be performed with one or more intraoperative position changes, which require several people to perform in a well-coordinated manner. A two position (prone to supine) sequence is commonly used in the lower body lift; however, a three position (supine to left lateral to right lateral) sequence can be used if focus on the anterior and lateral contour is prioritized over the posterior [36, 37]. Proper padding is crucial when the patient is in the prone or lateral decubitus positions. The anterior component of the operation is performed as described previously for a traditional abdominoplasty or a fleur-de-lis. The posterior dissection can be performed at different depths depending if the buttock is overprojected or underprojected. Generally though, massive weight loss patients present with a ptotic underprojected buttock, while patients with a high BMI present with an overprojected buttock. If overprojected, dissection is performed at the level of the muscle fascia; and if underprojected, dissection is at the level of the superficial fascia in order to leave as much adipose tissue behind. Leaving adipose tissue posteriorly results in autologous augmentation of the gluteal tissue upon closure, stacking the tissues [40–42]. Proper closure of the posterior-lateral dissection results in lifting of the lateral thighs and buttock. Specifically, the soft tissue below the incision can be suspended superiorly by using anchoring sutures to the superficial fascial system (SFS). The SFS is a subcutaneous network of connective tissue that binds skin and adipose tissue to the underlying musculoskeletal structure. In 1991, Lockwood first described the SFS and its utility in lower body lifts [43, 44]. Since then, the principle of SFS suspension has greatly impacted posterior lower truncal contouring by improving long term aesthetic outcomes and minimizing complications [36–38, 45, 46].

Post-operatively, the patient is transferred from the operating table in a flexed position. Over-flexion and underflexion have to be balanced to avoid undue tension on the anterior and posterior incisions. Although patients can be discharged home the same day of surgery, many surgeons will advocate one to two nights of hospitalization to ensure proper pain control and ambulation. The patient records the drain output, and the drains are removed when the daily output is less than 30 cc. A compression garment can be applied once the drains are removed. Strenuous activity and exercise is avoided for 4 weeks.

Complications in Abdominal Plastic Surgery

Despite advancements in peri-operative management, abdominal plastic surgery procedures have been associated with complications, a few of which can be life threatening [47, 48]. The most common complications of abdomino-

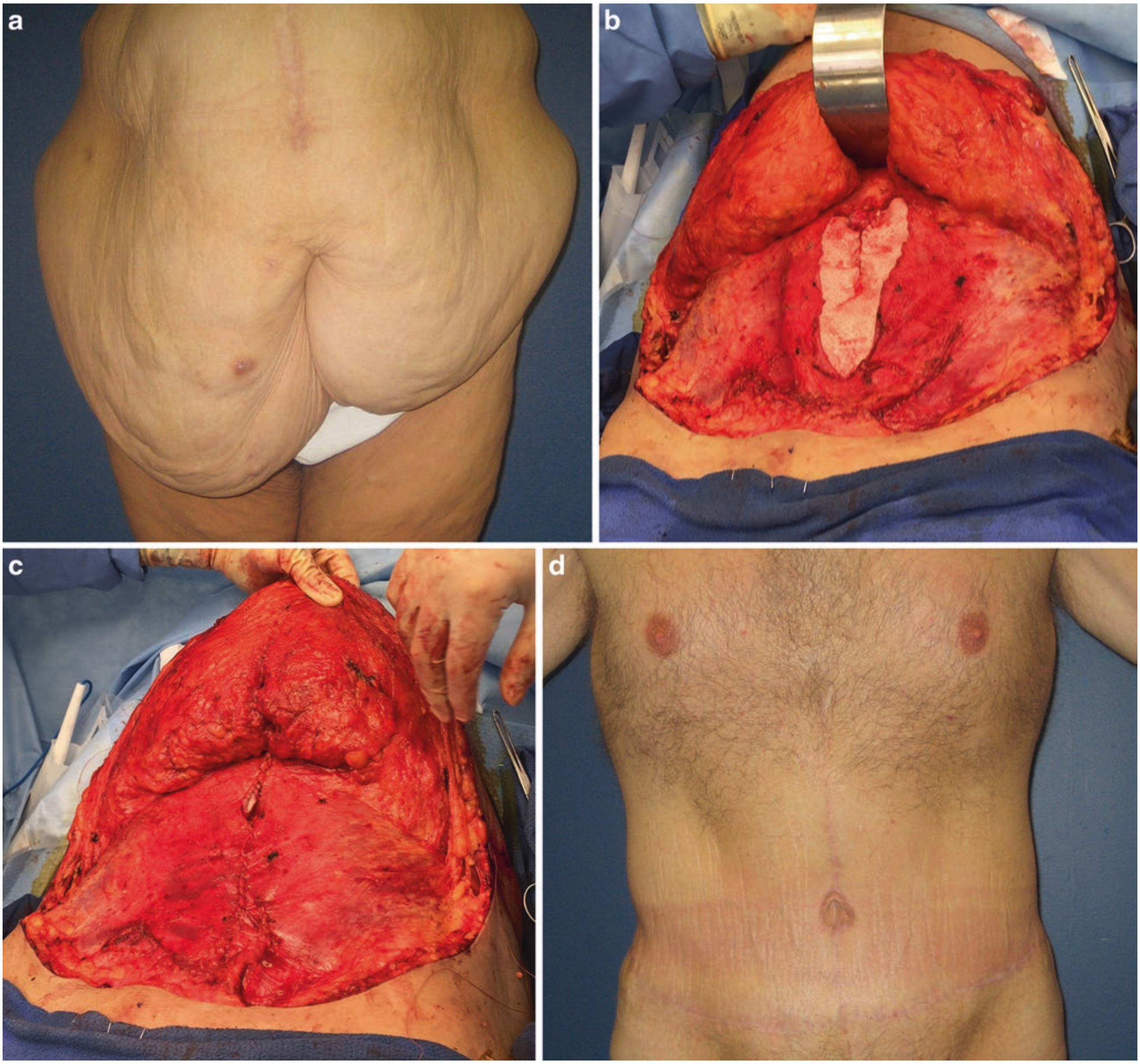

Fig. 24.2 (**a**) 53-year-old male patient after massive weight loss from gastric bypass surgery. (**b**) 53-year-old male patient with s/p massive weight loss with laxity of the anterior and posterior rectus sheath requiring soft tissue reinforcement with acellular dermal matrix. (**c**) Patient after closure of the anterior rectus sheath with plication. (**d**) Patient 6 months after completion of panniculectomy, liposuction, torso lift, and umbilical transposition in two stages. Note the scar placement low on the abdomen and the umbilical placement at the level of the anterior superior iliac spine

plasty include: hematoma, seroma, wound healing problems, infection, and skin flap necrosis [49–51].

Some research studies have shown that abdominoplasty may increase the likelihood of complications if done with other gynecologic or pelvic operations, or bariatric surgery compared to when performed alone [52, 53].

Lievain et al. reported on 238 patients of which 114 were post bariatric patients, and showed that the risk of complications in post bariatric patients is much higher (55.3% vs 26.6%) than patients who have abdominoplasty procedures alone [48]. Obesity, long operative times, and post-operative drainage compromise might be the reasons for increased risk of complications in this group of patients [48]. Another study conducted by Smith et al. looked at 300 patients (of which 75.3% cases were combined surgeries) to find out the increased risk associated with concurrent abdominoplasty and liposuction. They found no increased risk of post-operative complications for these concurrent surgeries as long as the perforator vessels remained intact to keep a consistent blood supply to the central abdomen [53].

Grieco et al. reported 68% overall complication rate with 17/25patients manifesting minor complications, whereas 32% (8/25) patients showed major complications. The complications among all these patients were as follows: seroma in nine patients (36%); wound dehiscence in four patients (16%); 12% [3] patients with hematoma; two patients (8%) showed post-operative bleeding; one patient showed umbilical necrosis; one patient acquired deep venous thrombosis; 12% [3] patients showed infected seroma, and 2 (8%) patients showed wound infection. There was no case of post-operative mortality [52].

Seroma

One of the most common complications of abdominoplasty is the formation of seroma [49, 54, 55]. Seroma is defined as the localized collection of serosanguinous or serous fluid that can be detected clinically or radiologically. The incidence of seroma formation, following the abdominoplasty, ranges from 0% to 38% [55]. This incidence can increase with obesity, wide undermining, thermal injury with cautery, extensive dissection, and undermining such as that performed during lateral component separation, using sharp cannulas for liposuction and with excessive removal of the fat tissues [55–57]. The pathophysiology of seroma formation is believed to be due to the disruption of vascular and lymphatic channels [58]. Others have proposed the potential dead space and shear forces on abdomen as the mechanism. Placing drainage catheters, progressive tension abdominoplasty, preserving the lymphatic channels superior to the fascia layer after removing the fat tissues, and use of tissue glues prevent the seroma formation [58]. The continuous infusion pump of local anesthetics when used during the abdominoplasty could support the possibility of a link between the use of this pump and the seroma formation [54]. But still there is no sufficient evidence to support this correlation [55]. There are several well-established treatments for seroma including drain placement, sclerosis, aspiration, and surgery [59].

Dehiscence

Some studies have reported that post bariatric patients who undergo abdominoplasty usually have greater risk of dehiscence and wound complications compared to non-bariatric patients. Dehiscence usually occurs because of excessive tension on the wound or nutritional deficiencies and requires conservative wound management by maintaining a clean, moist wound environment and optimized nutritional status [60, 61]. A case study has shown that application of medical grade honey in post bariatric patients resulted in appropriate and effective wound healing without the need of surgical revision [60]. Dehiscence in abdominoplasty, with or without skin necrosis, is a difficult reconstructive problem. The use of rapid wound closure with foam suction dressing results (vacuum assisted closure device) in an effective delayed primary closure of the wound with an acceptable aesthetic result [62].

Infection

Inadequate aseptic procedures and protocols, lack of incorporation of mesh or soft tissue reinforcement such as acellular dermal matrix; polybraded non-absorbable sutures, and unattended seroma or hematoma might lead to infections in the susceptible patient [63]. Vastine et al. published a paper on 90 abdominoplasty patients which showed increased risk of wound complications in obese patients compared to non-obese and borderline patients [61]. The authors further concluded that obesity if present at the time of abdominoplasty can have greater risk of wound complications following the abdominoplasty [61]. Great attention to prevent or minimize cautery trauma, tension and dead spaces, desiccation, and tissue trauma can be helpful in this regard. There is no data to support post-operative use of antibiotics to prevent infections, though single dose of IV prophylactic antibiotics prior to surgery is effective to prevent infections [64]. Tissue infection with defect of abdominal wall is a severe complication after abdominoplasty. Management of this complication is antibiotic therapy and multiple step surgery. V.A.C. therapy is used in conjunction with open wound treatment [65].

Hematoma

There is no such evidence that the use of tumescent solution decreases the viability of skin flap or increases the risk for hematomas in abdominoplasty patients [66]. However, it is very crucial to properly clip the lower rectus sheath perforators to decrease the chance of retraction and rectus sheath hematomas later on. The use of super wet infusion during the lipoabdominoplasty might be helpful to prevent hemostasis issues. Rangaswamy used super wet infusion in lipoabdominoplasty for 17 years without significant adverse effects. The hematoma rate was as low as 2% in his studies that involved 200 patients. Hypertension, males, and post weight loss surgery were noted to be risk factors that increase the risk of hematoma [49].

Ischemic Complications

Skin and fat necrosis are the major ischemic complications in the post abdominoplasty setting. They are considered "early" complications and usually appear within 2–4 days after the surgery as blood stained blister or as a darkened area of skin on the edge of the flap. The skin-fat combined necrosis often means the skin component is a tip of the iceberg. This step is quickly followed by the formation of sclerosis in the subcutaneous tissues of the lower abdomen that is an obvious indication of fat necrosis. Flap ischemia is a multifactorial issue. The midline lower flap is at the greatest distance and hence most vulnerable to ischemia. Tight closure of skin can further complicate the ischemia. Decreasing tension during wound closure and minimizing disruption of blood supply to the abdominal skin would be much helpful to prevent flap ischemia [49, 67]. If the ischemic area is small, it can be managed with daily dressing change and waiting for healing from the inside out but large wounds need to be treated with a skin graft in larger cases or usually a skin flap advancement [68].

Deep Venous Thrombosis

The hypercoagulable state is one of the major predisposing factors for deep venous thrombosis. Obesity, surgery that lasts for more than 4 h, advanced age, dehydration, chronic smoking, contraceptive pills, and deep venous incompetence are the other risk factors for deep venous thrombosis [69]. Therefore, it is recommended to stop taking contraceptive pills and stop smoking 3 weeks prior to surgery [69]. Operation time should be minimized and liposuction should not be combined with other lengthy surgical procedures. Proper hydration should be maintained during the surgery. Elastic stocking should be used for all cases under general anesthesia. Anti-DVT pump and sequential stockings should be based on the Caprini scale [69]. Low molecular weight heparin should be given to high risk patients and also to treat DVT. Early mobilization of the patients after the surgery could help to prevent DTV [69]. Treating DVT after surgery prevents local extension and embolizing of thrombus. Anticoagulants are the first choice of therapy in this patients based on ultrasound guidance [70].

Pulmonary Embolism

Massive pulmonary embolism is considered a rare complication of abdominoplasty and can be life threatening [71]. A North America study has reported one death and eight nonfatal cases of pulmonary embolism out of 75,591 patients who received abdominoplasty and liposuction**.** It is assumed that the development of pulmonary embolism may depend on the amount of fat removed (more than 1500 g) and the time of abdominoplasty procedure (more than 140 min) [72]. The use of elastic stockings and intermittent pneumatic compressions of the lower extremities and low molecular heparin could be helpful in the prevention of pulmonary embolism based on the carping scale. PE can be managed with anticoagulant therapy for 3–12 months but in serious complications of PE or DVT with large amounts of clots in legs or pulmonary vessels thrombolytic therapy is indicated [73].

Nerve Problems

Traditional abdominoplasty leads to anesthesia of the hypogastrium for at least 3 months. With selective dissection, the nerve connections from the linea semilunaris, the upper rectus sheath, and perforating branches can be maintained. These nerve fibers go along with vascular perforators. With this careful technique, abdomen can remain sensate [49]. Rarely a neuroma from excessive peri-neural scarring can lead to vexing pain and require surgical reoperation [74].

Abdominal Compartment Syndrome

Abdominal compartment syndrome is defined as the increase in intra-abdominal pressure above 20 mmHg along with increased pulmonary peak pressure and reduced urinary volume [75]. This increased intra-abdominal pressure might be caused by peritonitis, ileus, pelvic, and abdominal trauma. Secondary compartment syndrome usually occurs by the excessively tight closure of the abdominal wall following abdominal surgery which could be exacerbated in patients with pulmonary disease. The classical effects of abdominal compartment syndrome include: pulmonary collapse, decreased cardiac output, decreased intestinal and hepatic perfusion, and oliguria to anuria. Abdominal compartment syndrome is addressed by decompression of the abdominal wall with medical therapies including avoidance of positive fluid balance, use of higher ratio of plasma to red blood cells, and percutaneous catheter drainage but often decompression by opening the abdominal sutures reduces intra-abdominal pressure [76].

Scar Deformity

A careful assessment of the patient's skin type and proper counseling before the surgery could help prevent post-operative scar problems. Surgeons can optimize the scar by putting the tension on the deep fascial closure, atraumatic closure of the skin using fine instruments and suture material, and possibly progressive tension suturing techniques described earlier. A stretched or hypertrophic scar is an indication of improper deep closure and tension at the closure site. Sometimes a scar revision can be really helpful towards the final scar appearance and should be discussed in consultation in the pre-operative assessment.

Conclusion

Abdominal plastic surgical techniques can be performed safely and reliably by paying meticulous attention to patient desires, medical history, anatomical concerns, and a multi-planar operative approach that addresses the skin, fat, and muscle planes to help reinforce, flatten, and tighten the abdominal wall while minimizing the scar burden.

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Short Bowel Syndrome: A Clinical Update

25

Stanley J. Dudrick, Jose M. Pimiento, and Rifat Latifi

Introduction

During the second half of the twentieth century, the basic laboratory development and subsequent successful clinical application of the techniques of total parenteral nutrition have had a transformative effect on the modern practice of medicine, surgery, pediatrics, and many of their subspecialties. Arguably, none of the benefits of this technique have been more fundamental and lifesaving than the resultant developments and advances in the metabolic management, nutritional support, innovative operative procedures, and pathophysiologic understanding of patients with the short bowel syndrome following massive intestinal resection. Furthermore, primarily because of the remarkable salvage of most of these patients with this critically severe life-threatening situation, it has eventually been recognized that an even broader spectrum of disorders of alimentary tract functions could be identified in addition to the dramatic end-game of short bowel syndrome; and that the patients with these various intestinal dysfunctions deserved our special basic and clinical attention, investigations, and attempts to prevent, ameliorate, or cure them. As a result, the concept of intestinal failure inevitably and logically arose, and continues to evolve, as knowledge and experience regarding these often complex alimentary tract problems, and their management, are generated or acquired [1].

Intestinal failure has had a multitude of definitions, which will likely undergo additional revisions as knowledge of this deceptively simple, but tremendously complex and adaptable organ system, and the variations in the types, extents, and degrees of failures of its multiple components, accumulates with further study. Simply stated, intestinal failure is a condition characterized by deficient, inadequate, ineffective, or absent performance of the appropriate and expected intestinal functions essential for the efficacious and optimal absorption of the fluids and nutrients required to maintain the normal physiologic activities of the body cell mass. However, intestinal failure encompasses a broad spectrum of variety and severity of signs, symptoms, presentations, and responses to therapeutic interventions; and its precise definition is difficult, and virtually impossible, to standardize to "one size that fits all" situations. Moreover, its clinical description usually has more practical relevance and usefulness for specific optimal management than does its broad definition. In this regard, intestinal failure is analogous, for example, to cardiac failure, pulmonary failure, renal failure, circulatory failure (shock), and other organ/system failures, in that it can present, advance, respond, and adapt in myriad ways to challenge both the patient, and also the care-givers attempting to ameliorate, manage, and support the patient throughout the various stages of intestinal failure. Attempts to define intestinal failure more precisely by a single, comprehensive, and uniformly accurate statement is, in reality, a futile academic endeavor of limited utility to the practitioner. A summative description of the clinical picture and the relevant laboratory data in each individual patient will ordinarily be of the most value in formulating a management plan specifically best suited for each case. These complex problems are not routine or common, and their management and resolution require persistent, conscientious, dedicated, intensive attention to detail, together with skill, knowledge, experience, judgment, wisdom, and resilience if optimal outcomes are to be achieved [1].

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Short bowel syndrome (SBS) is a form of intestinal failure usually consisting of an inadequate length of intestine which results following massive bowel resection. SBS is a clinical entity characterized primarily by intractable diarrhea, steatorrhea, dehydration, malnutrition, weight loss, and malabsorption of fats, minerals, and other macronutrients and micronutrients, and not a situation merely defined anatomically by a specific length of remaining functioning small intestine. Subsequent adverse consequences of short bowel syndrome include hypovolemia, hypoalbuminemia, hypokalemia, hypocalcemia, hypomagnesemia, hypozincemia, hypocupricemia, essential fatty acid and vitamin deficiencies, anemias, hyperoxaluria, and metabolic acidosis. The formation of kidney stones and/or gallstones can also often accompany SBS. The actual clinical presentation and progression of the patient with SBS depends on several factors, including:

1. the extent of the bowel resection;
2. the site(s) of the resection(s);
3. the presence or absence of the ileocecal valve;
4. the residual function of the remaining small bowel, stomach, pancreas, biliary tree, and colon;
5. the capacity or potential of the intestinal remnant for adaptation;
6. the primary nature and status of the disease, disorder, or trauma that precipitated the loss of the small bowel;
7. the type, extent, location, and activity of any residual disease in the intestinal remnant;
8. the general condition of the organ systems and body cell mass of the patient [2–8].

The minimum length of small bowel sufficient for adequate digestion and absorption is controversial. Standardization of the adaptive potential of the residual bowel is difficult because of the variable absorptive capacity of the remaining remnants, the wide variation in the length of the normal small intestine, and the difficulty in obtaining reproducible measurements of the length of the remaining bowel following massive resection. The nutritional and metabolic status, overall general health and function, and the age of the patient are important collateral factors. Depending upon the state of contraction or relaxation of the intestinal musculature, intraoperative estimates of the length of the normal, intact, small intestine in the adult vary from 260 to 800 cm (approximately 8–26 feet). On the other hand, the mean length of normal small intestine measured during life is 350 cm (11–12 feet), and post-mortem is 600 cm (20 feet) [6]. Because of this large variability, it is virtually impossible to determine the exact initial length of the remaining small bowel, and it is very difficult to estimate the percentage of the total length of small bowel represented by the segment remaining following massive intestinal resection. Moreover, many surgeons often only measure the length of the resected small bowel, rather than also measuring the length of the remaining intestinal segment, which is the critically important functional and prognostic measurement. Additionally, they then often fail to describe accurately the nature, condition, and extent of the remaining small bowel in the patient's medical record for future reference. Furthermore, since inflamed intestine generally shortens after operation, the absorptive functions following massive small bowel resection often do not correlate well with the original intraoperative estimated or measured length of the remaining intestine [6, 8].

Because of the rather ample functional reserve capacity of the small bowel, short segmental resections of the small intestine usually do not result in significant problems with digestion and absorption [9, 10]. Indeed, resection of as much as 40% of the small intestine is usually well tolerated, provided that the duodenum, the distal half of the ileum, and the ileocecal valve are spared [11]. On the other hand, resection of 50% or more of the small intestine usually results in significant malabsorption initially, but can be tolerated eventually without extraordinary pharmacological and/or parenteral or enteral nutritional support. However, resection of 75% or more of the small intestine usually leaves the patient with 70–100 cm (2–3 feet) of remaining intestine, resulting in a degree of short bowel syndrome which can significantly impair the ability of the patient to maintain normal nutrition and metabolism. Such patients will likely require special nutritional management on a long-term or permanent basis, especially with the loss of the terminal ileum and the ileocecal valve, if normal body cell mass and function are to be preserved or restored [7].

The severity of symptoms and signs following massive small bowel resection is related both to the extent of the resection and the specific anatomic site(s) of the resected small bowel [12]. However, the minimal residual small intestinal absorptive surface required to sustain life without permanent parenteral nutritional support appears to vary somewhat with each patient [13, 14]. Development of effective total parenteral nutrition has revolutionized the treatment of the short bowel syndrome by allowing maintenance of adequate nutrition indefinitely or until the remaining bowel can adapt maximally to oral and/or enteral feeding, thus reducing the morbidity and mortality significantly [15–20]. Prolonged survival has now been achieved in a number of patients having only an intact duodenum and 15 cm (6 in.) of residual jejunum, with or without all or part of the colon [4, 10, 21]. If approximately 60 cm (2 feet) of jejunum or ileum remain functional, in addition to the entire duodenum, survival has been the rule rather than the exception [21].

Preservation of the ileocecal valve is of paramount importance during massive small bowel resection, and by significantly increasing the duration of the intestinal transit time allows a longer exposure time of the intestinal chyme to the residual absorptive surface of the mucosa. Salvage of the ileocecal valve, whenever possible, has the clearly beneficial effect of increasing the absorptive capacity of the remaining small bowel to approximately twice that anticipated for the same length of comparable small bowel without an intact ileocecal valve. Primarily as a result of mucosal hyperplasia and villous hypertrophy, absorption by the residual intestinal segments of patients with short bowel syndrome can increase as much as fourfold. Therefore, in a patient with an intact ileocecal valve, the total cumulative absorptive capability of the remaining bowel potentially can be increased maximally about eightfold. This amount of adaptive absorptive recovery function often approaches normal intestinal capacity [7, 21].

The most common clinical conditions which precipitate massive small bowel resections are those which compromise the vascular supply of the small intestine [22–24]. These include venous thrombosis and arterial occlusion as a consequence of primary vascular disease, heart failure with attendant mesenteric low flow state, various coagulopathies, volvulus, malrotation of the gut, and internal or external herniation of the bowel with strangulation. Short bowel syndrome can also occur as a result of necrotizing enterocolitis or massive atresia of the small intestine in newborn infants, at times associated with gastroschisis or omphalocele. Inflammatory bowel disease involving large segments of the small bowel, or recurrent exacerbations of inflammatory bowel disease over a long period of time, can eventually result in the short bowel syndrome secondary to massive or multiple intestinal resections. Excision of retroperitoneal malignancies which involve the celiac and/or superior mesenteric vessels can mandate secondary resection of most, or all, of the small bowel in order to accomplish palliation or cure. Major abdominal blunt or sharp trauma involving transection, disruption, or avulsion of the mesenteric vasculature can also result in ischemic necrosis of large segments of the small bowel, resulting in short bowel syndrome. Post-irradiation or postoperative complications such as extensive severe radiation enteritis, multiple small bowel fistulas, multiple bowel obstruction procedures, and intestinal gangrene can also result in irreversible short bowel syndrome.

Some of these conditions or situations are accompanied by, result in, or result from, complex abdominal wall defects. For example, in neonates, gastroschisis is a congenital anomaly which not only is comprised of a defect in the closure of the abdominal wall, but also is frequently associated with other developmental intestinal deformities such as extensive or multiple small bowel atresias, and/or mesenteric vascular abnormalities which result in the "apple peel" or "Christmas tree" mesentery anomalies. Omphaloceles, sometimes ruptured during the birthing process, are accompanied not only by an underdeveloped and contracted peritoneal cavity causing a "loss of domain" of the extraabdominal small intestine, but also by atretic segments of bowel, and an abdominal wall defect in the region of the umbilical cord. Surgical correction of these problems is obviously required, and the extent and nature of the procedure or procedures varies with the magnitude and complexity of each individual situation, ranging from simple closure of the abdominal wall defect, with or without resection of an accompanying atretic segment of bowel, to a compound or composite operative and non-operative management plan of a multifaceted or variegated nature, in order to restore both the integrity of the abdominal wall and the anatomical and functional continuity of the intestinal tract. The most difficult or complex of these conglomerate situations can pose formidable challenges to the neonatology and pediatric surgery teams, but can also represent the highest level of personal and professional accomplishment when optimal outcomes result from their combined skills, efforts, and acumen. Obviously, nutritional and metabolic management and support must be intricately and masterfully interwoven judiciously with surgical operative talent, ingenuity, and timing; and continued, persistently and conscientiously, throughout the recovery and rehabilitative periods until optimal organ, system, and body cell mass functions are achieved or restored for the patient.

In adults, the recent era of abdominal compartment syndrome and the treatment or decompression of intraperitoneal hypertension by "open abdomen" measures and/or temporary intestinal coverage by various reconstructive operative techniques, using native tissues or various artificial or despeciated substitute products for abdominal closure, have been accompanied by a significant incidence of fistula formation, bowel obstructions, herniations, recurrent operations, etc. At times, the prolonged treatment periods necessary to salvage and rehabilitate these patients, together with the multiple associated complications, have challenged surgeons not only technically in order to restore abdominal wall integrity, but also has required their understanding of the physiologic and metabolic states of the patients, that will enable them to restore and maintain intestinal continuity and function, while dealing with multiple enteroatmospheric fistulas ("the surgeon's nightmare"), multiple intestinal resections, functional and/or anatomical intestinal failure, or short bowel syndrome, combined with the ever present need to maintain optimal nutritional status to promote immunocompetence, combat infection, heal anastomoses and wounds, support normal organ, system, and body cell mass functions, and preserve life itself [25, 26]. Most such patients result from acute major traumatic injuries, in which portions of the abdominal wall may be lost, destroyed, or devitalized, in addition to injuries to other organ systems. However, these complex abdominal wall/short bowel syndrome catastrophic situations can also arise following non-traumatic gastrointestinal tract perforations secondary to a variety of inflammatory or neoplastic disorders, mesenteric infarctions of the intestine, anastomotic leaks, various intraperitoneal abscesses, abdominal wound disruptions, et cetera, often coupled with, or compounded by, hypoproteinemic malnutrition either as a contributing, precipitating factor, as a comorbidity, or as a secondary complication of short bowel syndrome or other intestinal failure [26].

Pathophysiology of Short Bowel Syndrome

The intestinal absorption of water, electrolytes, and other specific nutrients is dependent primarily upon the extent and site of the small bowel resection. The intestinal phase of digestion occurs initially in the duodenum, where pancreatic enzymes and bile acids promote digestion of all nutrients and enhance fat absorption. It is highly uncommon for the duodenum to be resected together with extensive segments of the small bowel, primarily because of the differences in blood supply, however, total duodenectomy, when it occurs, leads to malabsorption of calcium, folic acid, and iron [2]. Proteins, carbohydrates, and fats are absorbed virtually completely in the 150 cm of the jejunum, therefore, only small quantities of these nutrients or their derivatives ordinarily reach the ileum [27].

The small intestine acquires and handles a total of about 8 L of fluid daily, including dietary ingestion and endogenous secretions. Normally, approximately 80% of the intraluminal water transported is absorbed in the small bowel, leaving approximately 1.5 L of fluid to traverse the colon. The colon usually absorbs about 1–2 L of fluid, having maximal absorptive capacity of approximately 6 L of fluid per day [28]. Since the ileum and colon have a large capacity for absorbing excess fluid and electrolytes, proximal small bowel (jejunal) resections only rarely result in diarrhea. On the other hand, extensive or total resection of the ileum results in a much greater potential for malabsorption and resultant diarrhea. Not only will such resections increase the volume of fluid reaching the colon, but depending upon the length of ileum resected, bile salt diarrhea (cholorrhea), or steatorrhea may ensue, with subsequent losses of essential fatty acids and fat-soluble vitamins. If the ileocecal valve has been resected, transit time is likely to decrease, and bacterial colonization of the small bowel will eventually be more likely to occur, further aggravating cholorrhea and steatorrhea. As the length of ileal or colonic resections increases, essential absorptive surface area is lost, resulting in proportionally increased dehydration, hypovolemia, and electrolyte derangements. If the colon remains in continuity with the remaining small bowel following massive intestinal resection, malabsorbed bile salts can be deconjugated by colonic bacteria, stimulating increased colonic fluid secretion and further compounding existing diarrhea. Following extensive ileal resection, the enterohepatic circulation is interrupted, and irreversible loss of bile salts results with or without the colon in continuity. Although the excess fecal losses stimulate hepatic synthesis of bile salts, a higher incidence of cholelithiasis occurs in these patients. Because the transit time in the ileum is usually slower than in the jejunum, residual intestinal transit is slowed, and fecal output is diminished as the length of remaining ileum increases.

Following extensive small bowel resections, intestinal lactase activity may be decreased, resulting in lactose intolerance [29]. The presence of unhydrolyzed lactose causes increased hyperosmolality in the intestinal lumen. Moreover, fermentation of lactose by colonic bacteria produces a large amount of lactic acid that can further aggravate osmotic diarrhea [2]. The water soluble vitamins (vitamin B-complex and C) and minerals (Ca^{2+}, Fe^{3+}, Cu^{2+}) are absorbed in the proximal small intestine, whereas magnesium diffuses passively throughout the entire small bowel [2]. On the other hand, the ileum is the only absorption site for vitamin B_{12} and bile salts. Resection of the jejunum with preservation of the ileum produces no permanent impairments of protein, carbohydrate, and electrolyte absorption [30]. The ileum can compensate for most absorptive functions, but not for the secretion of jejunal enterohormones. Following jejunal resections, diminished secretions of cholecystokinin and secretin decrease gallbladder contraction and emptying, and decrease pancreatic exocrine secretions. Additionally, after jejunal resection, gastric hypersecretion is greater than after ileal resection. This results from the loss of inhibitory hormones such as gastric inhibitory polypeptide (GIP) and vasoactive intestinal polypeptide (VIP), which are secreted in the jejunum, thus causing gastrin levels to rise, and stimulating gastric hypersecretion [31]. Significant gastric hypersecretion can be documented within 24 h postoperatively, and the gastric and small bowel mucosa can be injured by the accentuated high gastric acid output, causing gastritis, ulceration, and bleeding. Subsequently, the high salt and acid load secreted by the stomach, together with the inactivation of digestive enzymes by the inordinately low intraluminal intestinal pH, serves to compound the other causes of diarrhea associated with short bowel syndrome.

Ordinarily, the colon is a major site of water and electrolyte absorption, and as the ileal effluent increases, the colon may increase its absorptive capacity to three to five times normal [32]. Moreover, the colon has a moderate capacity to absorb other nutrients, and concomitant colon resections can adversely affect the symptomatic and nutritional courses of patients with massive small bowel resections. Malabsorbed carbohydrates which reach the colon are fermented there by indigenous bacteria to yield short chain fatty acids, principally acetate, butyrate, and propionate [33, 34]. These short chain fatty acids can be absorbed by the colon in quantities representing up to 500 calories/day and can enter the portal circulation to serve as a fuel source [35, 36]. Although retention of the colon is highly desirable during massive bowel resections, its presence can be associated with potential complications. In addition to cholorrheic diarrhea, a patient with a massive small bowel resection and an intact colon often develops hyperoxaluria and a tendency to form calcium oxalate renal stones. These result from the increased absorption of dietary oxalate, which is normally rendered insoluble by binding with calcium in the intestinal lumen and, therefore, is ordinarily unabsorbable. However, in patients with short bowel syndrome and steatorrhea, intestinal calcium ion is bound preferentially to the increased quantities of unabsorbed fatty acids, leading to decreased binding, and thus an increased colonic absorption of unbound oxalate [12].

Finally, preservation of the ileocecal valve is important in preventing abnormal metabolic sequelae because the ileocecal valve not only slows intestinal transit and passage of chyme into the colon, but to a large extent, prevents bacterial reflux and passage from the colon into the small bowel. Nutrients which reach the colonic lumen, especially vitamin B_{12}, become substrates for bacterial metabolism rather than being absorbed into the circulation by the mucosa [2]. Furthermore, bacterial overgrowth in the small bowel in patients with short bowel syndrome appears to increase the incidence of liver dysfunction [37].

Nutritional and Metabolic Management of Short Bowel Syndrome

In the metabolic and nutritional management of patients with the short bowel syndrome, three different, but overlapping, therapeutic periods having rather distinctive characteristics can be designated arbitrarily (Table 25.1) [38]. During the first two months (immediate and early postoperative period), the clinical picture and course are dominated by problems related to fluid and electrolyte balance, adjustments of organ blood flow patterns, especially the portal venous flow, and other effects of the major operative insult and its accompanying specific and general complications. During the second period, from about two months up to 2 years postoperatively (bowel adaptation period), efforts are directed toward defining maximum oral feeding tolerances for various nutrient substrates, encouraging and maximizing intestinal and bowel adaptation, and determining and formulating the most effective patient-specific feeding regimens. Usually within 2 years, 90–95% of the bowel adaptation potential has been accomplished, and only 5–10% further improvement in absorption and bowel adaptation can be anticipated. The third period (long-term management period) constitutes the period after 2 years, when nutritional and metabolic stability have ordinarily occurred. By this time, the patient has either adapted maximally so that nutrition and metabolic homeostasis can be achieved entirely with oral feeding, or the patient is committed to receiving specialized supplemental or complete nutritional support for the remaining life-span, either by ambulatory home TPN and/or specially prepared enteral or oral feedings [7].

Table 25.1 Synopsis of short bowel syndrome management [7, 21, 38]

Immediate postoperative period (First 2 months)	**Bowel adaptation period (First 2 years)**
Fluid and electrolyte replacement	*Enteral supplementation*
Lactated Ringer's solution	Coconut oil 30 mL po tid
Dextrose 5% in water	Safflower oil 30 mL po tid
Human serum albumin (low salt)	Multiple vitamins 1 mL bid
K^+, Ca^{++}, Mg^{++} supplementation	Ferrous sulfate 1 mL tid
Strict intake and output	Ca gluconate 6–8 g/day
Daily body weight	Na bicarbonate 8–12 g/day
Graduated metabolic monitoring	*Parenteral supplementation*
Antacid therapy (optional prn)	Electrolytes, trace elements
Mylanta liquid	Divalent cations (Mg, Zn, Cu, Se)
Camalox suspension	Vit B_{12}, Vit K, Folic acid
Amphogel suspension	Albumin, packed red cells
Gelusil liquid (30–60 mL via N–G tube q 2 h clamp N–G tube 20 min)	Fat emulsion
Antisecretory/antimotility therapy	*Antisecretory/antimotility*
Cimetidine 300 mg IV q 6 h	Famotidine 20 mg po q 12 h
Ranitidine 150 mg IV q 12 h	ProBanthine 15 mg po q 4–6 h
Famotidine 20 mg IV q 12 h	Dicyclomine 20 mg po q 6 h
Pantoprazole 40 mg IV daily	Omeprazole 20 mg po q day
Codeine 60 mg IM q 4 h	Deodorized tincture of opium
Loperamide 4–16 mg po daily	10–30 gtts q 4 h
Lomotil 20 mg po q 6 h	Codeine 30–60 mg po q 4 h
Hyoscyamine sulfate 0.125 mg	Paregoric 5–10 mL po q 4 h
sc q 4 h	[Refer to column one for additional agents]
Cholestyramine 4 g po q 8 h	
Total parenteral nutrition	*Growth hormone/glutamine* [54, 55]
One liter on second postop day	**Long-term management (After 2 years)**
Gradually increase dosage as tolerated	*Apply previous principles*
Supplemental fluids, electrolytes, and colloids as needed	As indicated individually
	Ambulatory home TPN
	Supplemental or total continuous, cyclic or intermittent
Bowel adaptation period (First 2 years)	*Surgical management*
Progression of oral diet	Treat operative complications
Water, tea, broth	Drain abscesses
Simple salt solutions	Resect fistulas
Simple sugar solutions	Lyse adhesions
Combined salt/sugar solutions	Reduce obstructions
Dilute chemically defined diets	Restore bowel continuity
High carbohydrate, high protein	Probable cholecystectomy
Modified fiber, low fat diet	*Intestinal lengthening* [70–75]
Near-normal, normal diet	*Intestinal transplantation* [77–81]

Immediate Postoperative Period

During the immediate postoperative period, for up to two months, virtually all nutrients, including water, electrolytes, fats, proteins, carbohydrates, and all vitamins and trace elements are absorbed from the gastrointestinal (GI) tract poorly, unpredictably, or not at all [38]. Fluid losses via the GI tract are greatest during the first few days following massive small intestinal resection, and anal or stomal effluent frequently reaches volumes in excess of 5 L per 24 h. In order to minimize life-threatening dehydration, hypovolemia, hypotension, electrolyte imbalances, and other related potential problems, vigorous fluid and electrolyte replacement therapy must be instituted promptly and judiciously. Frequent measurements of vital signs, fluid intake and output, and central venous pressure, together with regular determinations of hematologic and biochemical indices, are mandatory in monitoring the patient during this period of rapid metabolic change and instability. All patients with short bowel syndrome exhibit some abnormalities in their liver profiles, and the vast majority of them experience at least transient hyperbilirubinemia [38]. This has been advocated by some to be secondary to the translocation of microorganisms and/or their toxins through the ischemic or gangrenous intestinal mucosa into the portal vein and thence to the liver [39, 40]. Others attribute the hyperbilirubinemia to impaired blood flow to the liver through the portal vein by as much as 50% as a result of greatly diminished mesenteric venous return secondary to the massive small bowel resection [41]. Still others attribute this phenomenon to a combination of both factors and/or other etiologies [42]. Broad spectrum anaerobic and aerobic antibiotic therapy should be instituted empirically and maintained for several days to one week following massive intestinal resection.

Typical patient management efforts during this period are directed toward achievement of four primary goals: fluid and electrolyte replacement, antisecretory/antimotility therapy, antacid therapy, and total parenteral nutrition. During the first 24–48 h, replacement therapy usually consists of 5% dextrose in lactated Ringer's solution administered intravenously concomitantly with appropriate amounts of potassium chloride and/or acetate, calcium chloride and/or gluconate, magnesium sulfate, and fat- and water-soluble vitamins. If there is no evidence of sepsis, low salt human albumin (12.5–25 g) usually is added exogenously to the intravenous regimen every 8 h for the first 24–48 h postoperatively in order to maintain normal plasma albumin concentrations and normal plasma colloid oncotic pressure. It is the authors' opinion and experience that maintenance of optimal intravascular colloid osmotic pressure with normal albumin and erythrocyte concentrations reduces intestinal mucosal edema and enhances fluid and nutrient absorption, while reducing losses as diarrhea. In patients with severe diarrhea, zinc losses can increase to as much as 15 mg/day, and appropriate aggressive, parenteral replacement is required [43].

Anti-acid therapy can reduce the increased tendency for peptic ulceration, which commonly occurs following massive small bowel resection. Antacids are given through a nasogastric tube, if one is in place, every 2 h in doses of 30–60 mL, and the tube is then clamped for 20 min before reapplying suction. Alternatively, or concomitantly, liquid sucralfate can be given by mouth or via the nasogastric tube in a dose of one gram every 6 h, clamping the tube for 20 min after each dose. To counteract the hypergastrinemia and associated gastric hypersecretion which follows massive small bowel resection in the majority of patients, an H_2 receptor blocker is infused intravenously [44]. The intravenous administration of 300–600 mg of cimetidine every 6 h can have a profound effect on reducing gastric acid and intestinal fluid production. Alternatively, ranitidine 150 mg can be given I.V. every 12 h, famotidine 20 mg can be given I.V. every 12 h, or an intravenous form of a proton pump inhibitor, pantoprazole, can be given daily in 40 mg doses. In selected short bowel patients, somatostatin analog (octreotide) has reduced fecal losses when administered in a dosage of 50–150 mcg I.V. or subcutaneously every 6 h [45, 46]. If the diarrhea persists despite these measures, an opiate can be prescribed. Preferably, codeine is given intramuscularly in doses of 60 mg every 4 h. Improvement in fluid and electrolyte management can also be achieved in selected patients with stomal access to a distal defunctionalized bowel loop by reinfusing the chyme from the proximal stoma into the distal bowel segment [47]. Later in the course of the postoperative period, when the patient is tolerating liquids by mouth, antimotility therapy can be achieved by giving loperamide 4–16 mg orally in divided doses daily, cholestyramine 4 g every four to 8 h, and/or diphenoxylate 20 mg every 6 h. Codeine 30–60 mg, paregoric 5–10 mL, or deodorized tincture of opium (DTO) 10–30 drops every 4 h orally can be used to impede bowel motility. The major advantages of DTO are that it is readily absorbed by the upper alimentary tract and that the patient's bowel hypermotility and diarrhea can be titrated to tolerable therapeutic levels by adjusting the dosage up or down a few drops at a time to optimize dose effectiveness and to minimize undesirable side effects [7, 21].

By the second or third postoperative day, the patient's cardiovascular and pulmonary status has usually stabilized sufficiently to allow TPN to be initiated [7, 21]. The average adult patient can usually tolerate 2 L of TPN solution daily administered by central vein. By titrating levels of plasma glucose and glycosuria, the daily nutrient intake can be increased gradually to desired levels or to patient tolerance. In a patient with diabetes mellitus, or in one who is glucose intolerant, crystalline regular human insulin is added to the TPN solution in dosages up to 60 units per 1000 calories as needed. Following an operation of the magnitude of massive small bowel resection, patients may require up to 3000 mL of TPN solution (about 3000 calories) per day initially for a few days to maintain nutritional and metabolic homeostasis. Supplemental fluid and electrolyte infusions may be necessary for several days or weeks to replace excessive losses as diarrhea. The patient is offered a clear liquid diet as soon as the postoperative condition is stabilized, and fecal output is controlled with antidiarrheal medications. It may take several days to several weeks before the patient is able to discontinue TPN support in favor of oral or enteral feedings. It is essential to provide adequate nutritional supplementation with TPN for as long as the patient requires such support to maintain optimal nutritional status. The TPN ration is reduced gradually in an equivalent reciprocal manner as oral intakes and intestinal absorption of required nutrients are increased. The patient's diet is advanced slowly and gradually to a low lactose, low fat, high protein, high carbohydrate composition according to individual tolerances to the nutrient substrates and to the water volume and osmolality of the dietary regimen [7, 21, 48].

Bowel Adaptation Period

During the period of bowel adaptation from two months to 2 years postoperatively, the patient is allowed to consume increasing amounts of water, simple salt solutions, and simple carbohydrates [7, 21]. Various fruit and other flavorings can be added to 5% dextrose in lactated Ringer's solution as a relatively inexpensive and practical oral nutrient and fluid replacement solution. Gradually, dilute solutions of chemically defined diets containing simple amino acids and short chain peptides are given as tolerated in increasing volumes and concentrations as bowel adaptation progresses toward a normal or near normal diet consisting of high carbohydrate, high protein, and low fat, and comprised of food most preferred by the patient as the next stage of nutritional rehabilitation. Alternatively, the major nutrients can be provided as required in commercially prepared modular feedings tailored to the needs of individual patients until ordinary food is well tolerated. All essential vitamins, trace elements, essential fatty acids, and minerals are initially supplied in the patient's balanced intravenous nutrient ration. Subsequently, the oral diet may be supplemented most economically by short- and medium-chain triglycerides in the form of coconut oil, 30 mL two or three times daily; essential fatty acids as safflower oil, 30 mL two or three times daily; multiple fat- and water-soluble vitamins in pediatric liquid form, 1 mL twice daily; vitamin B_{12}, 1 mg intramuscularly every four weeks; folic acid, 15 mg intramuscularly weekly; and vitamin K, 10 mg intramuscularly weekly. Some patients may require supplemental iron, which can be administered initially by deep intramuscular injection as iron-dextran according to the recommended patient-specific dosages schedule, or as an I.V. infusion after testing the patient for sensitivity [7, 21]. Alternatively, an oral liquid iron preparation can be given one to three times daily, while closely monitoring iron indices and liver function tests.

A strong tendency for patients with short bowel syndrome to develop metabolic acidosis usually requires the use of sodium bicarbonate tablets, powder, wafers, or liquid in doses of 8–12 g/day for as long as 18–24 months, but usually not for fewer than six months [7, 21]. It is often helpful to alternate the form of sodium bicarbonate prescribed in order to encourage maximal patient compliance. Because of the difficulty in absorbing adequate dietary calcium, supplemental calcium gluconate should also be prescribed as tablets, wafers, powder, or liquid in doses of 6–8 g/day. As bowel adaptation progresses, the doses of sodium bicarbonate and calcium gluconate can be decreased concomitantly or discontinued as restorative goals are attained. However, such oral supplements may be necessary for as long as two years or more in some patients in order to maintain homeostasis. Occasionally, on the other hand, a patient may become severely acidotic (pH 7.0–7.2) as a result of obviously copious diarrhea, but sometimes more subtly, and may require urgent or emergency intravenous infusion of sodium bicarbonate. Usually the patient responds promptly to the therapy within a few hours and without untoward sequelae. Rarely, calcium gluconate must be given intravenously as a supplement to correct recalcitrant hypocalcemia (<8.0 mg/dL). It is important to maintain normal serum albumin levels in patients with hypocalcemia. Dietary advancement and nutrient supplementation must obviously be individualized for each patient, and an effective nutrition support team can be very helpful in maintaining and monitoring these complex patients. When solid foods are given, they should be dry and followed 1 h later with isotonic fluids, rather than giving solids and liquids together at the same time. This practice is followed to minimize diarrhea and to improve nutrient absorption. Lactose intolerance should be anticipated and treated as required with a low lactose diet and/or lactase, 125–250 mg by mouth. Clearly, milk products should be avoided as much as possible if intolerance persists [7, 21].

As progress occurs during the bowel adaptation period of management of the short bowel syndrome, fat can be increased in the diet as tolerated, and supplementation with short- and medium-chain triglycerides and essential fatty acids may no longer be necessary [7, 21]. Serum-free fatty acid levels and triene:tetraene ratios are monitored periodically to determine the efficacy of treatment and the need for supplementation. Contrary to early reports, high fat diets apparently are comparable to high carbohydrate diets when evaluated in reference to calories absorbed, blood chemistries, stool or stomal output, urine output, and electrolyte excretions [47]. However, it has been suggested that enteral intake of fat should approach 50–100% greater than expected goals to compensate for malabsorbed nutrients [43]. Patients who cannot tolerate or utilize a normal oral diet should be given a trial of continuous administration of enteral formula. Low residue, polymeric, chemically defined, or elemental diets offer the putative advantage of high absorbability in the short bowel patient. However, some investigators have recently shown no differences in caloric absorption, stomal output, or electrolyte loss among elemental, polymeric, and normal diets in patients with short bowel syndrome [7, 21, 49–51].

Depending upon the results of periodic hematologic and biochemical studies, adjustments are made in the patient's intake of sodium, potassium, chloride, and calcium [52]. Additionally, intermittent supplemental infusions of solutions containing magnesium, zinc, copper, and selenium may be required. As malabsorption and diarrhea become less troublesome, the vitamin and trace element requirements may be satisfied by multivitamin capsules, tablets, or chewable tablets containing therapeutic doses of vitamins or minerals, one dose twice daily. Relatively large amounts of magnesium, zinc, vitamin C, and vitamin B-complex can be administered in the form of several commercially available therapeutic vitamin and mineral preparations [7, 21, 38]. It is especially important to avoid thiamine deficiency (Wernicke's syndrome).

In some patients, it may be necessary periodically to correct individual nutrient substrate deficiencies intramuscularly or intravenously for prolonged periods of time. Intermittent infusions of human serum albumin and packed erythrocytes may be required to treat recalcitrant hypoalbuminemia and anemia and to restore the plasma albumin level and the hematocrit to normal. Cholestyramine can be administered to counteract bile salt diarrhea if indicated, but intraluminal cholestyramine itself can cause or aggravate diarrhea. Fatty acid, electrolyte, trace element, vitamin, and acid–base imbalances must be promptly corrected enterally or parenterally as required when manifested clinically or by laboratory assessment. Serum vitamin B_{12} levels must be monitored and its deficiency corrected immediately. Hyperoxaluria should be assessed regularly, and if documented, foods containing high levels of oxalate such as chocolate, spinach, celery, carrots, tea, and colas should be restricted [7, 21].

In patients with severe forms of short bowel syndrome, in whom little or no small intestine is present distal to the duodenum, or in whom the remaining small intestine has residual disease, hypermotility and recalcitrant or intractable diarrhea may require continuous long-term antimotility/antisecretory treatment with oral and/or parenteral forms and dosages of the previously described pharmaceutical agents. Additional oral medications which have been helpful in selected patients include omeprazole, 20 mg daily; propantheline bromide, 15 mg every 4–6 h; dicyclomine hydrochloride, 20–40 mg every 6 h; hyoscyamine sulfate, 0.125–0.250 mg every 4–6 h as needed [7, 21].

Long-Term Management Period

Long-term management of the short bowel syndrome can be accomplished successfully in most patients by conscientious attention to the principles and practices outlined previously. However, in a few patients who have undergone massive small bowel resection, total or supplemental parenteral nutrition must be provided in a continuous or cyclic manner for extended periods of time, and sometimes for life. The metabolic management and nutritional therapy of patients with the short bowel syndrome must be tailored specifically to each patient, and the clinical responses following massive intestinal resections depend upon many and varied factors. Patients with the short bowel syndrome pass through several stages of nutritional and metabolic support during their recovery, convalescence, and rehabilitation. Most of them can ultimately be maintained on a normal or near normal diet. However, depending upon the adaptability of their remaining bowel, they may have to settle for receiving their nutritional requirements by one or more of the following options:

1. a modified oral diet;
2. an oral diet supplemented with intravenous fluid and/or electrolytes;
3. an oral diet supplemented with enteral feedings;
4. an enteral diet entirely;
5. an oral diet supplemented with enteral feedings and parenteral nutrition;
6. an enteral diet supplemented with oral feedings;
7. an oral diet supplemented with parenteral nutrition;
8. an enteral diet supplemented with parenteral nutrition;
9. an enteral diet supplemented with parenteral nutrition and oral feedings;
10. a primarily parenteral nutrition regimen supplemented with variable oral and/or enteral diets;
11. total parenteral nutrition virtually entirely, but with trophic oral feedings as tolerated to stimulate intestinal adaptation and immunocompetence.

Almost every patient with the short bowel syndrome eventually develops gallstones, most usually requiring cholecystectomy within two years following massive intestinal resection if the gallbladder had not been previously removed. Indeed, the high propensity of patients who have undergone massive intestinal resection to develop stones in their gallbladders has stimulated some physicians to advocate cholecystectomy prophylactically at the time of bowel resection [53]. However, gallstone formation in the common bile duct and elsewhere in the biliary tree is also increased in these patients even after cholecystectomy. Therefore, long-term surveillance with periodic abdominal ultrasonography may be useful in identifying and monitoring echogenic changes in the gallbladder and biliary tree in short bowel patients [7, 21].

Finally, some otherwise stable patients occasionally develop recalcitrant diarrhea secondary to colonization or bacterial overgrowth of the residual small bowel segment, requiring periodic stool culture and bacterial antigen studies followed by parenteral treatment with appropriate antibiotics [7, 21].

Experience with the Growth Hormone, Glutamine, and Modified Diet Regimen

A rather extensive study was carried out initially to determine if growth hormone or nutrients, given alone or together, could enhance absorption from the small bowel after massive intestinal resection, especially in patients who continued to experience malabsorption and require long-term parenteral nutrition [54]. The effects of high carbohydrate, low fat diet, administered alone, or in combination with the amino acid, glutamine, and growth hormone were studied in 47 adult patients with short bowel syndrome, who had been dependent on TPN to some extent for an average of 6 years. The mean age of the patient was 46 years, and the mean residual small bowel length was 50 cm in those with all, or a portion, of the colon remaining, and 102 cm in those with no colon remaining. During the 28-day trial of therapy using this regimen, recombinant growth hormone was given by subcutaneous injection at a dose ranging from 0.03 to 0.14 mg/kg/day (average dose 0.11 mg/kg/day). Supplemental glutamine was provided by both the parenteral and enteral routes. The parenteral glutamine dosage averaged 0.6 g/kg/day, whereas a standard daily dose of 30 g glutamine was administered orally in six equal portions of 5 g mixed within a hypotonic cold beverage. In addition to the growth hormone and glutamine, all patients underwent extensive diet modification and nutritional education, the details of which have been reported extensively elsewhere [55]. Growth hormone was discontinued at the end of the four week protocol, and the patients were discharged home receiving only oral glutamine, 30 g/day, and the modified oral diet [7, 21].

The initial balance studies indicated improvement in absorption of protein by 39%, accompanied by a 33% decrease in stool volume output during the 28-day trial. In evaluation of the long-term results, averaging one year and extending as long as five years, 40% of those studied remained free of TPN; an additional 40% had demonstrated a reduction in their TPN requirements; and TPN requirements were unchanged in the remaining 20%. These changes had occurred in a subset of patients that had previously failed to adapt to the provision of enteral nutrients, and this therapy may offer an alternative to long-term dependence on TPN for some patients with severe short bowel syndrome. Subsequently, a more comprehensive clinical study of greater than 300 patients has been reported by the same group of investigators [56, 57]. However, growth hormone alone has not been shown to be beneficial consistently in other randomized, blinded, placebo-controlled, crossover studies, and the Bryne et al. study results have not been able to be reproduced by other investigators [58–60]. These conflicting data emphasize the need for further clinical studies to evaluate the effects of trophic agents in promoting, enabling, and/or enhancing intestinal adaptation [61]. Both growth hormone and glutamine are available for clinical use, but growth hormone generally is not used routinely or very often in attempts to enhance intestinal adaptation in patients with short bowel syndrome, primarily because of its high cost, untoward side effects, and questionable efficacy, which have supported both the cautious approaches among many clinicians, and the scrutiny and conservative attitudes by the Federal Food and Drug Administration related to the use of growth hormone for this purpose [58, 62–64]. The use of growth hormone has been limited largely because of concerns related to efficacy and the fact that only short-term use has been approved. Moreover, the effects of growth hormone on intestinal absorption in human beings are still unknown, whereas it appears to increase reabsorption of sodium in the distal nephrons, preventing pressure natriuresis and increasing extracellular volume [65]. On the other hand, it has been shown that patients with acromegaly have an increased risk of developing colonic neoplasia and adenomas although no increase in malignancy has been reported [66].

Growth Factors and Intestinal Adaptation in Short Bowel Syndrome

A multitude of growth factors other than growth hormone may be involved in the complex and multifactorial process of intestinal adaptation in patients with SBS following massive resections. Some of them include vascular endothelial growth factor (VEGF), hepatocyte growth factor, transforming growth factor-ß, epidermal growth factor, keratinocyte growth factor (KGF), insulin-like growth factor-1(IGF-1), cholecystokinin, gastrin, insulin, neurotensin, and glucagon-like peptide-2 (GLP-2) [63, 67]. GLP-2 is among the first of these factors to be evaluated in human beings with short bowel syndrome/intestinal failure (SBS/IF). GLP-2 is released from cells in the distal small bowel and the colon in response to ingestion of food, but this response is severely diminished in patients with SBS/IF, especially with ileal resection [68]. However, in patients with preserved colon, the meal-stimulated release of GLP-2 is enhanced. GLP-2 promotes intestinal epithelial growth by increased hyperplasia which may be further enhanced by increasing mesenteric blood flow [69]. GLP-2 also increases gastrointestinal transit time, which may be one of the mechanisms by which it decreases diarrhea [70]. Although native GLP-2 has resulted in less chronic dehydration and associated nephropathy together with a beneficial effect on bone health [71–73], these actions are limited by a very short half-life. Accordingly, a longer acting GLP-2 analog (Teduglutide) was created by substituting a glycine residue for alanine, which resulted in increased resistance to rapid enzymatic degradation [63].

About five years ago, a review article on the management options in the short bowel syndrome reported that administration of glucagon-like peptide-2 (GLP-2) to patients following major small bowel resection improved intestinal adaptation and nutrient absorption [74]. Based on data derived from multiple clinical studies in patients with SBS/IF, Teduglutide, an enzyme-resistant GLP-2 analog, had shown promise in preventing intestinal injury, restoring mucosal integrity, increasing villous height, enhancing intestinal absorptive function, reducing gastric emptying and secretion, and increasing lean body mass [75–80]. A prospective, multi-institutional, multi-national collaborative study was undertaken to determine if the parenteral nutritional support in patients with SBS/IF could be reduced by adding Teduglutide to the treatment regimen [77]. However, further studies and the completion of ongoing phase III trials were deemed necessary to determine the appropriate dosage (high vs. low) and length of treatment required for these patients to gain optimal benefits from the administration of this novel growth factor [74, 75]. In a subsequent 24-week, extremely complex, multi-national study of a very complicated group of 86 patients with SBS/IF (in fact, the largest prospective study ever carried out in this patient population), subcutaneous Teduglutide was shown to be safe and well tolerated; it facilitated reduction in the required volumes of parenteral nutrition; and it allowed patients to have some days free of parenteral nutrition [81]. Furthermore, Teduglutide administration could reduce malabsorption-related consequences (diarrhea, large stomal output, stomal problems, fecal incontinence, meteorism, abdominal pain), parenteral nutrition-related inconveniences (time spent connected to parenteral nutrition apparatus, social isolation, disturbed sleep, altered body image), and potentially life-threatening complications (catheter-related sepsis, central venous thrombosis, and SBS/IF-associated liver disease). Based on the findings of this study, Teduglutide could positively add to the limited treatment armamentarium of SBS/IF [81]. Teduglutide allows the clinician an additional option for patient management as an incremental improvement in the care of patients with SBS/IF [63]. It also has the potential to improve quality of life for patients with SBS/IF although a fully validated measure of quality of life in these patients remains to be developed. Finally, the development of longer acting analogs, as well as other growth factors, such as HGF and KGF, provides promises of future therapeutic advances in this vitally important area of SBS treatment and management [63].

Other Factors Affecting Intestinal Adaptation and Outcomes in SBS

A recent study has shown that the fecal microbiome of patients with SBS is significantly different from that of healthy controls when analyzed by metagenomics, and such changes in the intestinal microbiome of patients with SBS are thought to affect clinical outcomes significantly [82]. The changes may not only interfere with, or delay the advancement of, enteral diet, but may also predispose patients to bacterial translocation, bacteremia, and liver disease. SBS patients are thought to be more susceptible to changes in gut microbial compositions due to intestinal dysmotility and/or lack of adequate anatomic safeguards, such as the ileocecal valve. In a small study, the fecal microbiome of nine children with SBS was different from that of eight healthy control children. Stool from the SBS patients had significantly greater abundance of Gammaproteobacteria and Bacilli, and decreased abundance of Ruminococcus. Differences in the composition and function of intestinal microbiomes in children with SBS may affect bowel physiology and these findings may provide new prospects for opportunities for intestinal rehabilitation and clinical management. Future studies including whole-genome "shotgun" metagenomics of fecal samples and longitudinal sampling of children with SBS are also likely to provide additional insights into the potential role of the microbiome in intestinal adaptation and barrier function, such as bacterial translocation, in children with SBS [82].

In another study of eleven children with SBS diagnosed in the neonatal period, compared with seven of their healthy siblings, the composition of the intestinal microbiota seemed to be a major important factor in determining the clinical outcome in the children with SBS, defined as independence from parenteral nutrition treatment, and intestinal adaptation [83]. Alterations in the microbiota may result in serious complications such as small bowel bacterial overgrowth (SBBO) and intestinal mucosal inflammation that lead to long dependency on parenteral nutrition and subsequently to increased risks of liver failure and sepsis. This was the first report on the microbial profile in children with SBS, and the overall decreased bacterial diversity shown was consistent with intestinal microbiome mappings in inflammatory bowel diseases (Crohn's disease) and necrotizing enterocolitis (NEC) in pre-term infants. A pronounced microbial dysbiosis was demonstrated in children with SBS, who were receiving parenteral nutrition, compared with children weaned from parenteral nutrition, with an increased relative abundance of proteobacteria despite having been treated with long-term antibiotics. The conclusion derived from the study was that intestinal dysbiosis which occurs in children with SBS is associated with prolonged dependency on parenteral nutrition and impaired outcomes. Future studies were recommended to develop new strategies to treat dysbiosis in children with SBS [83].

A recent, parallel case report described the successful use of fecal transplantation in the treatment of recurrent, recalcitrant D-lactic acidosis in a 15-year-old male with SBS, dependent upon gastrostomy tube feeding since age three years [84]. The acidosis occurs when excessive malabsorbed carbohydrate enters the colon and is metabolized by colonic bacteria to D-lactate, which can be absorbed systemically. The increased serum levels which result are associated with central nervous system toxicity manifested by confusion, ataxia, and slurred speech. Current therapy, usually consisting of suppressing intestinal bacterial overgrowth and limiting ingested carbohydrate, is not always successful. Although the exact mechanism of action is unknown, it is surmised that the alteration of the intestinal microbiome, in addition to the reintroduction of potentially beneficial microbes, helps mediate the disease, and the case was presented to report a SBS child with recurrent debilitating D-lactic acidosis successfully treated with fecal transplantation. The technique is offered as a consideration for recurrent D-lactic acidosis resistant to current therapies [84]. The value of the use of probiotic and prebiotic regimens in the management of the SBS patients discussed in this section remains to be determined, although studies in this area of clinical investigation are already underway, and results will likely be reported in the near future.

Management of Liver Disease in SBS/IF Patients Dependent on Parenteral Nutrition

A most feared, unintended consequence of the success of parenteral nutrition in salvaging the lives of neonates and infants with short bowel syndrome has been the subsequent development of progressive liver failure which often results in the death of the patient [85]. This life-threatening complication, known as Intestinal Failure Associated Liver Disease (IFALD) or Parenteral Nutrition Associated Liver Disease (PNALD), has no standardized definition to date, and there is no consensus of agreement upon clinical thresholds by which to establish the diagnosis. A recent A.S.P.E.N. Clinical Guidelines has resulted from an attempt to develop recommendations for the care of children with IFALD or PNALD and with the potential to prevent or improve treatment of this onerous condition [85]. Because a comprehensive presentation and discussion of this broad topic is beyond the scope of this chapter, the reader is referred to the Clinical Guidelines cited above. Since liver failure is the most common cause of death in patients with IFALD or PNALD, the goal of therapy has been to optimize intestinal function and promote adequate intestinal adaptation before development of irreversible liver disease. By controlling liver dysfunction, patients can be allowed a prolonged period of time to allow maximal intestinal adaptation to occur; and much of the improvement in patient outcomes during the past decade is related to controlling the progression of the liver failure. The Clinical Guidelines [85] focus on four therapeutic interventions in the care of patients with intestinal failure and present an overwhelming amount of information derived from the literature and evaluated by the expert authors. Four Questions and Recommendations were developed to be addressed by the Clinical Guidelines: (1) Is ethanol lock effective in preventing bloodstream infection and catheter removal in children at risk of PNALD/IFALD? *Recommendation*: A suggestion is made to use ethanol lock to prevent CLABSI and to reduce catheter replacements in children at risk of PNALD/IFALD; (2) What fat emulsion strategies can be used in pediatric patients with intestinal failure to reduce the risk of, or treat, PNALD/IFALD? *Recommendation*: Since the only I.V. fat emulsion available for use in the United States is SOE (Soybean Oil Emulsion), a suggestion is made to reduce the dose of SOE to <1 g/kg/d to treat cholestasis in children with PNALD/IFALD. The quality of evidence supporting this recommendation is very low. Most studies are small observational studies. The desirable effect of reduction of liver indices has to be considered in light of the unknown effects of poor growth and development when lipids are restricted. *Rationale*: This is an emerging area of study; until larger RCTs (Randomized Controlled Trials) with indicators of cholestasis are reported, strong recommendations are difficult to make; (3) Can enteral ursodeoxycholic acid (UDCA) improve the treatment of PNALD/IFALD in pediatric patients with intestinal failure? *Recommendation*: A suggestion is made to use UDCA for the treatment of elevated liver enzymes in children with PNALD/IFALD. The evidence is of very low quality and confounded with the presence of enteral feeding in conjunction with treatment with UDCA. In addition, the patients studied tend to be premature infants with an intact intestinal tract; therefore, the efficacy of UDCA may not be generalizable to patients with established intestinal failure. In the included studies, no harm from this treatment was reported. The desirable effect of the reduction of liver indices has to be weighed against the unknown efficacy of the treatment and the fact that in most cases the study participants did not have primary intestinal pathology; (4) Are PNALD/IFALD outcomes improved when patients are managed by a multidisciplinary intestinal rehabilitation team? *Recommendation*: A suggestion is made to refer patients with parenteral nutrition-dependent intestinal failure to multidisciplinary intestinal rehabilitation programs. The evidence on this topic is of very low quality, but the improvement in survival is compelling, and the risk to the child with treatment with multidisciplinary practice is not increased. These A.S.P.E.N. Clinical Guidelines closed with the comment that, "Now that mortality risk has diminished with establishment of intestinal rehabilitation programs, future research should address the impact of other comorbidities on outcome, long-term neurodevelopmental outcomes, quality of life of patients receiving chronic parenteral nutrition and after intestinal transplantation, and economic evaluation of intestinal rehabilitation programs" [85].

Surgical Considerations

Total parenteral nutrition is the mainstay of early, and sometimes late, management of the short bowel syndrome [56]. Prior to the widespread use of TPN, patients often survived the initial surgical insult of massive small bowel resection and its early complications only to die ultimately of fluid, electrolyte, and nutritional imbalances. Today, however, patients can usually be managed successfully, and often rehabilitated, with the judicious use of TPN. In this regard the surgeon is required to insert, maintain, and supervise a temporary and subsequently a permanent indwelling central venous catheter or catheter port for administration of TPN solutions [7, 21].

Massive small bowel resection is associated with a prompt and inordinate increase in the secretion of gastrin and gastric acid. The resulting hypersecretion can readily cause or aggravate existing gastritis, ulceration, bleeding, diarrhea, and fluid and electrolyte depletion. Because the hypersecretion is thought to be mediated hormonally, truncal vagotomy and pyloroplasty have been performed in the past in human beings, with good results [2]. Now that effective H_2 receptor blockers and proton pump inhibitors have been developed for clinical use, the surgical treatment of hypersecretion is seldom indicated or required. Currently, vagotomy or other acid-reducing operations should be reserved only for those short bowel syndrome patients who develop complicated peptic ulceration problems resistant to conservative medical therapy. Partial or total gastric resections in patients with SBS/IF should be avoided assiduously because of the high subsequent potential for compounding the malabsorption, or leading to more catastrophic results in an already severely compromised alimentary tract.

In patients with the short bowel syndrome following massive intestinal resection, parenteral nutrition should be given for at least 6–12 months to assure that optimal bowel adaptation has occurred, or reached a plateau, before contemplating the use of any surgical procedures to increase absorption of nutrients [39]. In fact, in most short bowel syndrome patients, sufficient bowel adaptation occurs during the first year following massive intestinal resection so that parenteral nutrition can be discontinued, and contemplated surgical interventions can be avoided [7, 21].

Thompson has recently reviewed his extensive operative experience with adjunctive management of SBS/IF patients [58]. He posits that if an adult with SBS develops intestinal dilatation, it usually is secondary to obstruction, either secondary to recurrent intraabdominal adhesions, or at the site of a previous anastomosis. Bacterial overgrowth often develops in dilated, relatively hypotonic bowel, and compounds the malabsorption secondary to SBS/IF. Although conservative management is preferable initially, surgery is usually required to relieve intestinal obstruction, which may include lysis of adhesions, stricturoplasty, or minimal segmental resections only as absolutely necessary [58, 86]. Dilatation of the intestinal remnant occurs more frequently in children than in adults and appears to have a basis which is more adaptive in nature rather than pathologic [58, 87]. In patients with adequate bowel length, longitudinal taper enteroplasties have been used to restore the dilated lumen diameter toward normal. Tapering enteroplasties may be either resective or imbricating, with no significant differences reported between either approach [58, 87]. Lengthening procedures are not performed on obstructed bowel in an effort to "create length," but rather to relieve the functional obstruction and to allow the bowel transit to return toward normal. To restore luminal diameter, Thompson and others have found the "so called" intestinal lengthening procedures to be the optimal treatment [58, 87]. Although easiest to describe as lengthening, Thompson states that these procedures actually, more truly, represent an attempt to optimize the small intestinal volume to surface area ratio (volume: mucosal surface area) of the intestine to improve contact time between luminal contents and the absorption surface area. [58] The initial operative approach was longitudinal lengthening via the Bianchi procedure which involves meticulous dissection of the mesentery of the bowel segment to allocate terminal blood vessels anatomically to either side of the bowel wall [58, 87, 88]. Longitudinal transection of the bowel is then performed, usually with a stapling device, which creates two parallel vascularized limbs of a smaller caliber, which can then be anastomosed effectively to lengthen the intestinal remnant through which the chyme must flow [58, 87, 88]. More than 100 cases have been reported, mostly in children, with achievement of overall improved nutrition in approximately 80% of patients [58, 87]. Complications have been reported after 20% of procedures, which, not surprisingly, include ischemia, anastomotic leaks, and recurrent dilatation [58, 87]. However, follow-up for up to 10 years suggests that long-term benefits occurred in 50%

of patients, while 10% ultimately underwent intestinal transplantation [58, 87].

More recently, an alternative method of lengthening, Serial Transverse EnteroPlasty (STEP), has been introduced, consisting of repeated applications of a linear stapling device from opposite directions in a zigzag fashion, which divides the bowel about fifty percent of its diameter alternately from either the mesenteric or anti-mesenteric sides transversely [58, 89]. Thompson believes that ideally this procedure initially involves complete release of adhesions from the duodenum to the colon, and then a combination of tapering enteroplasties and/or STEP enteroplasties to restore a uniform bowel lumen appropriate for the size of the patient. He typically requires a bowel diameter of at least 4 cm before performing a STEP enteroplasty, in order to maintain a subsequent lumen diameter of about 2 cm [58]. Motility can be somewhat slow to return, and in general, the full benefit of a STEP taper procedure is not often realized until 8–12 weeks after the surgery [58]. More than 70 cases of STEP have been reported in the literature, with clinical improvement in 80% of patients, while 5% have undergone subsequent intestinal transplantation [87].

Thompson summarizes his experience with these procedures as follows: "Our experience with the STEP technique has been quite favorable, and it has now become our procedure of choice [58, 90, 91]. We found that 58% of 64 patients undergoing either the Bianchi procedure or STEP were able to discontinue Parenteral Nutrition (PN). This correlated with the length gained and total length after the procedure. Overall clinical outcome is similar with STEP and Bianchi procedures [90]. STEP avoids the difficult dissection along the mesenteric border required of the Bianchi procedure and the end to end anastomosis. While bowel may have to be more dilated to use this technique, it is more feasible in challenging areas such as near the ligament of Treitz. There are no prohibitions to performing either repeat STEP procedures or tapering enteroplasties at later operations" [58].

Attempts to ameliorate the untoward effects of the short bowel syndrome surgically by interposing isoperistaltic or antiperistaltic bowel segments, intestinal valves, or recirculating loops; pacing the intestine electrically; growing new intestinal mucosa; and transplanting small intestine have been of limited additional value to date [92]. Therefore, no operative procedure for adjunctive management of the short bowel syndrome currently is sufficiently safe and effective to recommend its routine use [58, 90]. Long-term parenteral nutrition remains the cornerstone of successful management of short bowel syndrome, and its judicious use is recommended in appropriate amounts and formulations for as long as needed, not only to insure maximal gastrointestinal adaptation and nutritional rehabilitation of the patient, but also to support the optimal size and function of the body cell mass [7].

Intestinal Transplantation in Short Bowel Syndrome Patients

Recently, especially during the past decade, intestinal transplantation has been increasingly applied as a rescue therapy for patients with life-threatening complications of SBS and other forms of intestinal failure [74]. When the complications include portal hypertension and/or progressive liver failure, SBS patients become candidates for combined liver/small intestine transplantation [58, 93]. The generally accepted indications for intestinal transplantation include recurrent sepsis, loss of central venous access, and development of progressive liver disease. Intestinal transplants have also been used following extensive resection of retroperitoneal neoplasms such as desmoids, fibromas, and neuroendocrine tumors, during which the superior mesenteric artery and its dependent bowel are sacrificed in deference to potential cure [58].

Some unsuccessful attempts at intestinal transplantation were made in the 1960s, but it was not until the late 1980s when the first successful isolated cases of intestinal transplantation in humans were reported [94–96]. When Tacrolimus became available in the 1990s, intestinal transplantation advanced rapidly to become a practical means of treating intestinal failure in patients who developed serious complications of parenteral nutrition or who were not able to maintain a good quality of life [97–99]. Since then, more than 2880 intestinal transplants have been performed in the United States, approximately 75% of which have been in recipients under 18 years of age [58, 93, 94]. One-year graft survival rates are currently as high as 89% in adults aged 18–34, and as low as 64% in children under 1 year of age [58, 93]. Graft survival drops at 5 years with published rates ranging as low as 31% in children under 1 year of age to as high as 69% in children aged 6–10 years of age [58, 93]. Patient survival rates are similar at 1 and 5 years after transplant [58, 93, 100, 101]. Chronic rejection and infectious complications remain important determinants of survival, and improvements in outcomes over the past two decades have in large part been related to improved pediatric critical care and to judicious management of immunosuppression to reduce the incidence of opportunistic infections and post-transplant lymphoproliferative disorder [58, 101]. Overall, it is increasingly being recognized that the treatment of intestinal failure involves both nutritional and metabolic rehabilitation and transplantation, and that these approaches are complementary rather than competitive or contradictory [58].

Information regarding long-term nutritional outcome and quality of life (QOL) is continually emerging [58, 93, 102, 103]. Approximately one third of patients undergoing intestinal transplantation require PN at discharge, however, at 1 year, 90% are independent of PN [58, 93]. Quality of life

(QOL) has been improved in almost all areas, but particularly related to digestive function, vocational abilities, medical compliance, optimism, and energy [58, 102]. On the other hand, this should be interpreted cautiously in view of more recent studies suggesting that QOL in SBS transplant patients remains lower than in non-transplant controls [58, 103].

Of all of the surgical approaches to SBS, intestinal transplantation has the greatest potential for treating selected SBS patients, both in terms of the number of patients who might benefit and also the functional improvement achieved [58]. With greater experience and improved results, it is hoped that this therapy can be extended to a larger number of patients with SBS [58, 73]. Parenteral nutrition remains the main therapeutic resource in the management of intestinal failure. Recent advances in care of parenteral nutrition-dependent patients have improved survival and quality of life, with higher rates of enteral autonomy achieved, and lower rate and later onset of complications. Accordingly, the number of transplants performed per year in the past few years has actually declined [94]. However, 20–25% of these patients still develop complications that force referral of the patient to an intestinal rehabilitation unit for evaluation. These complications are well defined, and they can establish the indication(s) for intestinal transplant [104, 105]. Thompson recommends that patients with high risk complications of intestinal failure be referred early to a center specializing in intestinal transplantation so that patients may be carefully managed and monitored by an experienced team, and if needed, listed for transplant prior to development of complications that preclude the operation [58]. Intestinal transplant has become a reasonable therapeutic option in those SBS patients with intestinal failure who develop complications while receiving parenteral nutrition. The use of induction therapy has improved patient and graft survival, and current survival rates of intestinal transplantation are now similar to other solid organ transplants. However, there remain some challenging issues such as the causes of, and the therapeutic options in, chronic rejection or early noninvasive detection of acute rejection that require continuing future investigations [94].

The Future of Management of Short Bowel Syndrome

Despite the multiple advancements in the various aspects of clinical management of patients with the short bowel syndrome, even the current sophistication of intestinal transplantation represents a bridge at best. The ultimate goal in the future is the development of a truly artificial, or artificially grown and harvested, small intestine. This has been the dream of basic investigators for more than a century since the first attempt at intestinal transplantation in animals was performed in 1901 by Carrell [106]. Significant advances have occurred in this area, but the ultimate development of a practical and functional artificial small intestine remains elusive. Even a functioning small intestine capable of absorbing nutrients for delivery to the circulation of a SBS/IF patient constructed on a biotechnologically produced platform using the patient's own stem cells remains distant from clinical reality at this time [63]. In the meantime, the multiple measures currently available to clinicians who treat patients with SBS/IF presented in this chapter may be helpful and will likely continue to advance in sophistication and usefulness for the benefit of some of the clinicians and their patients with SBS/IF.

Summary and Conclusions

Short bowel syndrome (SBS) is a form of intestinal failure following massive intestinal resection for a variety of conditions, in which the remaining length of small bowel has inadequate capabilities for the absorption of the required water, macronutrients, and micronutrients to support optimal health, functions, and performance of the body cell mass. Some of these conditions or situations are accompanied by, result in, or result from, complex abdominal wall defects. Notably are the clinical scenarios which often accompany the treatment of abdominal compartment syndrome by the various "open abdomen" techniques. The complex pathophysiology of SBS is summarized together with its clinical consequences. Nutritional and metabolic management of SBS can be characterized arbitrarily by three overlapping periods of therapy which are discussed in some detail and have withstood the tests of time for a few decades. This is followed by a summation of the more recent efforts to enhance intestinal absorption by incorporating the use of growth hormone, Teduglutide, glutamine, and other nutraceuticals, in combination with dietary modifications, in attempts to reduce or obviate the use of long-term parenteral nutrition in selected patients, while promoting maximal adaptation of the intestine. Multiple other growth factors are also being studied to determine their potential usefulness in improving intestinal adaptation and absorption in patients with SBS/IF. Surgical considerations in the adjunctive management of SBS/IF are discussed as potential means of enhancing intestinal absorption. Increasing the exposure of the intestinal chyme to the mucosal enterocytes by decreasing intestinal transit and overcoming functional bowel obstructions with a variety of specialized surgical procedures has been helpful in appropriate patients. Of all of the surgical approaches to SBS management, intestinal transplantation may well have the greatest promise in terms of restoring gastrointestinal tract function to normal as this field of endeavor continues to advance and improve its long-term outcomes. Possibilities for development of artificial intestinal mucosal absorptive surfaces using the patient's own stem cells on biocompatible support platforms are already being explored and may well result in an effective, novel means to treat SBS/IF in the future. Finally, parenteral nutrition has been, and remains, the cornerstone of optimally successful management of short bowel syndrome, and its judicious use and monitoring by expert, experienced, dedicated nutrition support teams can insure safe, effective, and maximal gastrointestinal adaptation and nutritional rehabilitation of the patient, while maintaining the optimal size and function of the body cell mass.

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Minimizing Postoperative Complications by Preoperative Optimization

26

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Introduction

In the quest to provide the best care for patients undergoing major abdominal wall reconstruction, a multidisciplinary and systematic approach should be undertaken by all members involved in the operative management of the patients. Since the 1980s, we have seen significant advances in the management of medical and surgical conditions of critically injured patients; these advances have led to improved survival and reduced morbidity. However, the practicing surgeon when faced with the management of the open abdomen and large abdominal wall defects that require major abdominal wall reconstruction needs to be able to provide preoperative care that would ensure optimal operative outcomes. The reconstruction of a large abdominal wall defect poses a major burden to patients who are already unconditioned physiologically and psychologically. This chapter focuses on the multidisciplinary approach and measures to be taken into consideration in the preoperative optimization of complex surgical cases, which are frequently associated with complications and mortality.

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Preoperative Evaluation

All patients undergoing a major abdominal wall reconstruction (AWR) procedure should receive a systematic preoperative evaluation and objective assessment of their risk through validated methods such as those of the American Society of Anesthesiologists (ASA) Physical Status Classification System, the Goldman Cardiac Risk Index, and the like. Obtaining preoperative information can lead to better preparation of the patient for a major surgical procedure and modification of the intraoperative strategy, management, and postoperative care, all of which will result in better outcomes and patient satisfaction. Adopting the concurrent guidelines of preoperative evaluation of complex surgical cases will facilitate the entire process. We should take into consideration, however, that "one size does not fit all"; frequently, such complicated patients during their preoperative evaluation might require deviations from the already-established guidelines, due to the emergency nature of the required procedure. Other considerations to be addressed during this period include the following: patient and family expectations and that of the expertise of the operating team (i.e., attending surgeon and anesthesiologist, intensive care unit nurses, and other healthcare providers involved in the medical care from admission to discharge, including rehabilitation).

Getting ready for a long and complex reconstructive procedure requires more time and preparation to achieve optimization of the patient. The main goal of the preoperative evaluation is to achieve the best possible optimization of the patient, and this might require the postponement of the definitive closure or repair and the establishment of a temporary closure in the acute setting or during the resuscitative phase (damage control concept).

The preoperative evaluation process should be undertaken in a location where all healthcare providers are active participants in the process. Our experience and contemporary literature confirm that when a multidisciplinary team works together and is efficient, reduces the

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chance of errors, reduces the cost, and decreases operating room cancellations.

The evaluation process starts with a thorough history and physical examination and should be performed by a multidisciplinary team. The anesthesiologist, intensivist, and surgeon involved in the procedure should be part of the evaluating team and ideally should communicate the indications and risk of the procedure to the patient and close relatives in the same setting.

Assessing the Perioperative Risk

Assessing the risk in a systematic fashion is imperative and should focus on evaluating the capacity of the patient to withstand the acute physiological stress resulting from prolonged operative procedures and general anesthesia that extends well into the recovery and rehabilitation phases. Furthermore, team should be able to treat major life-threatening conditions, such as hypoxia, hypoglycemia, major fluid and electrolyte imbalances, sepsis, coagulopathy, and other major organ impairment, and estimate if the patient can meet the increased oxygen demand caused by the stress response to surgery and anesthesia. By zeroing in on the neurological, cardiovascular, respiratory, and renal systems, a better grasp of the short and long-term functional outcome of those patients would be attained.

Neurological System Evaluation

A significant number of patients have a history of major injuries, including traumatic brain injury, major abdominal vascular injury, and devastating surgical catastrophic conditions requiring prolonged hospitalization. Furthermore, delirium is a common condition in these patients and is associated with increased length of stay, morbidity, and mortality.

Patients with recent history of traumatic brain injury, spinal cord injury, and cerebrovascular accident or patients with high index of clinical suspicion or recent neurological deterioration might require neuroimaging studies and monitoring prior to the procedure. If the major abdominal wall reconstruction will be performed during the acute traumatic brain injury phase, an intracranial pressure (ICP) monitoring device might be indicated as per The Brain Trauma Foundation: Guidelines for the Management of Severe Traumatic Brain Injury.

Patients with a spinal cord injury may present unique challenges in the management of the intraoperative, acute postoperative, and rehabilitation phases depending on the level of the cord injury. Patients with high spinal cord injuries might require a secure airway, prolonged ventilator support, and prolonged rehabilitation care in specialized centers.

Cardiovascular System Evaluation

Patients undergoing major abdominal wall reconstruction are at risk of major perioperative cardiac events. According to the American College of Cardiology/American Heart Association (ACC/AHA), intraperitoneal surgery carries intermediate risk with a reported risk of cardiac death or nonfatal myocardial infarction (MI) of 1–5%. There are numerous guidelines used in the evaluation of the cardiovascular risk. Some patients, however, arrive with devastating neurological and orthopedic injuries or are elderly, which makes the process of obtaining an accurate functional status almost impossible, partly because of their limited mobility or altered mental status. It is also pertinent to mention that there are important limitations of some of the cardiovascular risk indexes. For example, the Lee index is a practical way to assess the cardiac risk in stable old patients, but it does not take into consideration emergency surgery and the increasing number of elderly patients undergoing surgical procedures today. In addition, it is important to delineate that currently many of the multiple procedures included in such risk indexes are performed in a minimally invasive fashion.

Lee index comprises of six questions that evaluate patients for high-risk surgery (i.e., intraperitoneal) or not, having coronary artery disease (CAD) or not, having congestive heart failure or not, having insulin-dependent diabetes mellitus or not, having cerebrovascular accident or not, and finally having serum creatinine level >2 mg/dL or less. This risk index needs to be used in the context of the contemporary ACC/AHA guidelines on perioperative cardiovascular evaluation and care for non-cardiac surgery.

Summary of the 2014 ACC/AHA Guidelines

According to the ACC/AHA guideline, the incidence of cardiac morbidity after non-cardiac surgery depends on the definition of CAD, which ranges from only rising of cardiac biomarkers to the more classic clinical ischemic heart disease (IHD) spectrum. Few studies showed that merely elevated serum troponin post-abdominal surgery is associated with a considerable 30-day mortality rate. The stability and timing of a recent MI have great impact on the incidence of perioperative morbidity and mortality. Data showed very higher morbidity and mortality rates in patients with unstable IHD than those who had stable angina. However, this risk could be modified by the presence and type of coronary revascularization in terms of coronary artery bypass grafting (CABG) or percutaneous coronary interventions (PCI) that was done at the time of the acute coronary event.

Previous data showed that ≥60 days should be allowed after a MI before non-cardiac surgery in the absence of a coronary intervention. A recent MI (i.e., within 6 months of non-cardiac surgery) was reported as an independent risk factor for perioperative stroke, which was associated with an eightfold increase in the perioperative death rate.

Patient age has a great impact on the postoperative outcome. Patients (>65 years old) undergoing non-cardiac surgery have a higher incidence of acute ischemic stroke than for those who were ≤65 years of age. Furthermore, age > 62 years is an independent risk factor for perioperative stroke.

Clinically, the presence of preoperative third heart sound and jugular venous distention are useful signs that indicate the presence of heart failure (HF) and have the strongest association with perioperative major adverse cardiac event (MACE). Patients with HF who undergo major surgical procedures have substantially higher risks of operative death and hospital readmission than do other patients. Moreover, data showed that patients with HF and preserved left ventricular ejection fraction (LVEF) had a lower all-cause mortality rate than did of those with HF and reduced LVEF. The risk of death did not increase notably until echocardiogram showed a decrease of LVEF below 40%.

Generally, routine preoperative coronary angiography is not recommended due to lack of data to support the use of coronary angiography in all patients as a routine testing, including patients undergoing any specific high-risk surgery. The indications for preoperative coronary angiography are similar to those identified for the non-operative setting. Coronary computerized tomography angiography may be safer but, again, data on its indication are limited as a perioperative screening tool.

After perioperative evaluation before elective non-cardiac procedures, if the results indicate the need for CABG surgery, coronary revascularization should be performed before a high-risk surgical intervention.

The indications of PCI before non-cardiac surgery should be limited to patients with left main coronary artery disease whose comorbidities preclude CABG without undue risk and patients with unstable IHD who would be appropriate candidates for emergency or urgent revascularization. Patients with acute MI benefit from early invasive management. However, if the non-cardiac surgery is time sensitive despite an increased risk in the perioperative period, a strategy of balloon angioplasty or bare-metal stent (BMS) implantation should be the plan.

There are no prospective randomized clinical trials data to support the use of coronary revascularizations before non-cardiac surgery aiming to decrease the intraoperative and postoperative cardiac events.

Elective non-cardiac surgery should be delayed 2 weeks after balloon angioplasty (*Level of Evidence: C*) and 1 month after BMS implantation (*Level of Evidence: B*). Elective non-cardiac surgery should optimally be delayed 1 year after drug-eluting stent (DES) implantation (*Level of Evidence: B*).

In patients in whom non-cardiac surgery is required, a consensus decision among treating clinicians as to the relative risks of surgery and discontinuation or continuation of antiplatelet therapy can be useful (*Level of Evidence: C*).

PCI should not be performed as a prerequisite in patients who need non-cardiac surgery unless it is clearly indicated for high-risk coronary anatomy (e.g., left main disease), unstable angina, MI, or life-threatening arrhythmias due to active ischemia amenable to PCI.

If PCI is necessary, then the urgency of the non-cardiac surgery and the risk of bleeding and ischemic events, including stent thrombosis, associated with the surgery in a patient taking dual antiplatelet therapy (DAPT) need to be considered.

If there is little risk of bleeding or if the non-cardiac surgery can be delayed ≥12 months, then PCI with DES and prolonged aspirin and $P2Y_{12}$ platelet receptor–inhibitor therapy is an option.

If the elective non-cardiac surgery is likely to occur within 1–12 months, then a strategy of BMS and 4–6 weeks of aspirin and $P2Y_{12}$ platelet receptor–inhibitor therapy with continuation of aspirin perioperatively may be an appropriate option.

If the non-cardiac surgery is time sensitive (within 2–6 weeks) or the risk of bleeding is high, then consideration should be given to balloon angioplasty with provisional BMS implantation.

If the non-cardiac surgery is urgent or an emergency, then the risks of ischemia and bleeding, and the long-term benefit of coronary revascularization must be weighed. If coronary revascularization is absolutely necessary, CABG combined with the non-cardiac surgery may be considered.

In patients undergoing urgent non-cardiac surgery during the first 4–6 weeks after BMS or DES implantation, DAPT should be continued unless the relative risk of bleeding outweighs the benefit of the prevention of stent thrombosis (*Level of Evidence: C*).

In patients who have received coronary stents and must undergo surgical procedures that mandate the discontinuation of $P2Y_{12}$ platelet receptor–inhibitor therapy, it is recommended that aspirin be continued if possible and the $P2Y_{12}$ platelet receptor–inhibitor be restarted as soon as possible after surgery (*Level of Evidence: C*).

Management of the perioperative antiplatelet therapy should be determined by a consensus of the surgeon, anaesthesiologist, cardiologist, and patient, who should weigh the relative risk of bleeding with that of stent thrombosis (*Level of Evidence: C*).

Emergency non-cardiac surgery may occur in the presence of uncorrected significant valvular heart disease. The risk of non-cardiac surgery can be minimized by having an accurate diagnosis of the type and severity of valvular heart disease, choosing an anesthetic approach appropriate to the valvular heart disease, and considering a higher level of perioperative monitoring as well as managing the patient postoperatively in an intensive care unit setting.

Severe aortic stenosis (AS) is associated with a perioperative mortality rate of 13%, compared with 1.6% in patients without AS in previous data. The mechanism of MACE in patients with AS likely arises from the anesthetic agents and surgical stress that lead to an unfavorable hemodynamic state in terms of hypotension and tachycardia during surgery; the latter two changes are the main drivers for worse outcome and death in those patients.

Patients with moderate-to-severe valvular regurgitation undergoing non-cardiac surgery had a higher in-hospital mortality rate, postoperative MI, stroke, pulmonary edema, prolonged intubation, and major cardiac arrhythmia. Predictors of in-hospital death are LVEF <55%, renal dysfunction, high surgical risk, and lack of preoperative cardiac medications.

Patients with moderate-to-severe valvular regurgitation undergoing non-cardiac surgery should be monitored with invasive hemodynamics and echocardiography and admitted postoperatively to an intensive care unit setting when undergoing surgical procedures with elevated risk.

Patients with prosthetic valves taking vitamin K antagonists may require bridging therapy with either unfractionated heparin or low-molecular-weight heparin, depending on the location of the prosthetic valve and associated risk factors for thrombotic and thromboembolic events. For patients with a mechanical mitral valve, regardless of the absence of additional risk factors for thromboembolism, or patients with an aortic valve and ≥1 additional risk factor (such as AF, previous thromboembolism, LV dysfunction, hypercoagulable condition, or an older-generation prosthetic aortic valve), bridging anticoagulation may be appropriate when interruption of anticoagulation for perioperative procedures is required and control of hemostasis is essential.

Atrial fibrillation (AF) is the most common sustained tachyarrhythmia, particularly in older patients who are likely to be undergoing surgical procedures. Patients with a preoperative history of AF who are clinically stable generally do not require modification of medical management or special evaluation in the perioperative period, other than adjustment of anticoagulation.

Renal System Evaluation

Acute and chronic kidney derangements are frequent in this population of patients because, in the majority of cases, the etiology of the large abdominal wall defects is from major trauma or catastrophic general surgery and abdominal vascular conditions. In severely injured patients, despite advances in resuscitation, acute kidney injury (AKI) is still a frequent occurrence and remains an important predictor of multiorgan failure and mortality.

There are few perioperative measures to take into consideration in the management of such complex patients: prevention of contrast-induced nephropathy with acetylcysteine and fluid management, control of diabetes mellitus and hypertension, optimization of the fluid status of the patient, and close monitoring of aminoglycoside administration.

In the acute setting, AKI can be associated in severely burned and polytrauma patients as a result of increased intraabdominal pressure and development of the abdominal compartment syndrome (ACS), which should be recognized in a timely manner and the abdomen promptly decompressed to reverse the renal dysfunction. The use of nonsteroidal anti-inflammatory drugs (NSAIDs) should be avoided in the setting of hypoperfusion and renal dysfunction.

Another condition that is associated with AKI is rhabdomyolysis. The management of rhabdomyolysis is to focus on the correction of the underlying cause (i.e., compartment syndrome, etc.) and undertake prompt and vigorous volume replacement. Compartment syndrome in the extremities is a clinical diagnosis, and fasciotomy of the affected limb should be performed as soon as it is recognized. The most common method used in evaluation and monitoring of renal function deterioration is measurement of the serum creatinine and blood urea nitrogen levels. Measures of glomerular filtration rate and creatinine clearance are also commonly employed. Control of urea levels can prevent platelet dysfunction and mental status changes. Optimizations of renal function in patients with AKI and chronic kidney conditions might require renal replacement therapies to obtain a good control of uremia, electrolyte disturbance such as hyperkalemia and acidosis, and fluid status.

Gastrointestinal System Evaluation

Evaluation and optimization of the entire gastrointestinal (GI) system is of major importance because derangement of GI tract continuity is a frequent complication in patients requiring abdominal wall reconstruction because of major abdominal wall defect.

Disruption in the continuity of the intestine will affect the course of management in the acute and elective reconstruction settings. Enterocutaneous fistulas remain among the most challenging complications associated with patients with open abdomen and major abdominal trauma requiring abdominal wall reconstruction. In patients undergoing major surgery, goal-directed hemodynamic therapy (GDT), by maintaining adequate systemic oxygenation, can protect organs particularly at risk of perioperative hypoperfusion and is effective in reducing GI complications as described by a recent meta-analysis.

The effort of the multidisciplinary team is to reestablish continuity of the GI tract, enabling prompt use of oral or enteral feeding to optimize the patient's nutritional status. The authors recommended a nine-step treatment strategy in abdominal wall reconstruction in patients with an open abdomen and enterocutaneous fistulas; and this is further described in Chap. 7 of this book.

Endocrine System Evaluation

Endocrine disorders are common in critically ill patients and have a global effect on the patient's well-being. A systematic approach to the evaluation and management of common endocrinological conditions should be under taken during the preoperative period. Examples of common endocrinological derangements observed in critically ill patients include sodium-level abnormalities, thyroid dysfunction, relative adrenal insufficiency, and abnormal glucose level, among others.

Hematologic and Coagulation Evaluation

Patients might have a history of hematological disorder or have become coagulopathic during the course of management of the severe clinical condition or injury, partly because of the acute major trauma insult, sepsis, acidosis, hypothermia, or iatrogenic effects caused by heparin-induced thrombocytopenia or chronic use of antiplatelet medications. Patient also might have a history of a hypercoagulable state, and the condition could be exacerbated during the hospitalization.

Infections

Infections are frequent in patients with an open abdomen, and source control should be obtained before embarking on abdominal reconstruction. Goal-directed therapies have improved outcomes in patients with severe sepsis and septic shock and are part of our standard of care.

Nutritional Evaluation and Optimization

The nutritional status of the patient should be considered early in the course of the management of complex conditions. Evaluation and optimization of the nutritional status should be performed prior to major surgical procedures (See Chap. 4). Methods include evaluation of serum albumin level, prealbumin level, and indirect calorimeter measurements, depending on the availability of the measure at your institution. We strongly recommend early aggressive nutritional support through the initiation of enteral feeding unless a patient's condition dictates otherwise. Our second option is the optimization of nutritional status through initiation and maintenance of parenteral nutrition. Elective abdominal wall reconstruction should be postponed in patients with a history of recent weight loss of 15% or more, along with an albumin level less than 3 g/dL. There is a strong association reported between postoperative albumin level and morbidity and mortality. Consideration should be given to addressing chronic conditions, such as chronic malnutrition; chronic alcoholism, which is associated with multivitamin deficiencies (thiamine and folate deficiency); and electrolyte abnormalities in sodium, magnesium, phosphorus, potassium, and calcium. In our practice, we prefer to give patients extra supplements of vitamin C, vitamin E, micronutrients such as zinc and selenium, and if clinically indicated, vitamin A.

Control of Premorbid Conditions

As previously detailed in this chapter, all chronic conditions should be addressed and optimized per current published clinical practice guidelines. These conditions include diabetes, hypertension, heart problems, thyroid disease, obesity (when possible), and those involving the kidney and pulmonary system.

Social and Addiction Issues

Patients who have suffered and survived major injuries and undergoing emergency general surgery and vascular procedures requiring damage control have an associated decreased quality of life. A significant number of patients have a history of chronic complications of alcohol or drug abuse, such as financial instability, homelessness, abusive behaviors, chronic and acute legal problems, and prescription drug abuse, which might require addiction and psychiatry evaluation and management before undergoing major abdominal wall reconstruction. Patients should be enrolled in a smoking cessation program prior to the surgical reconstruction.

Prevention Strategies

For all patients undergoing major abdominal surgery, some conditions can be prevented with a systematic approach: (1) thromboembolic complications by implementing deep venous thrombosis prophylaxis (mechanical and pharmacological treatment if not contraindicated); (2) prevention of surgical site infections by timely administration of perioperative antibiotics; (3) prevention of GI bleeding in high-risk patients, and implementation of various published critical care bundles practiced in your institution.

Summary

Preoperative evaluation and optimization are parts of a multidisciplinary process associated with improved outcomes in patients undergoing major abdominal reconstruction procedures. The most frequent method of optimization in the acute setting is fluid management. Surgery of complex abdominal wall defects could be a major undertaking for any surgeon and is associated with frequent complications. Planned, systematic evaluation; perioperative risk assessment; and appropriate timing are essential for providing the best functional outcome.

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The Final Word on a Complex Problem

27

Rifat Latifi

Throughout this book, the reader will find answers to a number of questions dealing with difficult defects of the abdominal wall such as fistulas, short gut syndrome, complex tissue transfer, and the techniques of complex surgery to address these issues. These complex and challenging problems can be organized into two segments: the acute phase of catastrophic infection(s) and or injury management of surgical problems, that is dealing with closure of the abdominal wall in the acute phase, and segment two, management of the patient that has survived the acute phase and the consequences of acute phase management. In both phases the goals are the same: restore the functionality of the abdominal wall and return the patients to their standard way of living.

In the acute phase, when damage control surgery (DCS) is performed, temporary abdominal closure (TAC) is used. Depending on clinical indication for DCS, the surgeon has several options, most notably an intestinal bag, wound vacuum-assisted closure (VAC), or a moist gauze that serves as the "poor man's wound VAC". However, if the patient has enough skin and subcutaneous tissue, then closing the skin offers the best temporary closure. I avoid temporary closure of the fascia out of fear of injuring the edges of the fascia and subsequently creating a hernia and dehiscence. If the wound VAC is used, just enough pressure should be applied to maintain closure; pressures higher than 70 mmHg must clearly be avoided, especially for long periods of time. High pressures may risk creation of new fistulas in patients with an open abdomen. If at all possible, final and definitive closure of the abdomen should be performed within 12–24 h after temporary closure. If not, one should attempt sequential closure that has been described by many authors in details. However, performing DCS does not mean that you have committed the patient to long-term open abdomen management, and every attempt should be made to close the fascia primarily. If and only when you are unable to definitively close the abdomen, you have to consider long-term management with eventual closure. Although numerous studies have shown that DCS is life saving, the consequences of DCS have been elucidated in recent years.

Using sequential fascial closure, Burlew et al. were able to achieve 100% fascial approximation as well as reducing the morbidity of the open abdomen and the cost of complex abdominal reconstruction or biologic mesh insertion [1]. Another important question in the management of patients undergoing DCS or damage control laparotomy (DCL), in particular, is when to use mesh repair and when to use lateral component separation (LCS). To answer this question, Sharrock et al. [2] conducted a systematic review and meta-analysis of studies that compared methods of restoration of fascial continuity when primary closure was not possible following DCL for trauma. In their analysis, they included randomized controlled trials (RCTs), cohort studies, and case series that reported temporary abdominal closure (TAC) and early definitive closure methods in trauma patients undergoing DCL. After reviewing 26 studies, with mortality, days to fascial closure, hospital length of stay, abdominal complications, and delayed ventral herniation as outcomes they concluded that component separation or mesh repair may be valid alternatives to delayed primary closure following a trauma DCL [2]. Others have used various modifications of VAC [3] to facilitate primary fascial closure and reduce morbidity in patients who had severe abdominal sepsis. Pliakos et al. [3] concluded that sequential fascial closure can begin once abdominal sepsis is controlled. Additionally, Cothren et al. [4] performed a modification of the vacuum-assisted closure (VAC) technique that provided constant fascial tension in order to achieve a higher rate of primary fascial closure and achieved 100% fascial approximation. Other techniques have been described as well [5, 6], to achieve closure.

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Looking into the Future: Will Tissue Engineering Be the Next Answer?

We have all become acutely aware of the need to close the abdomen as soon as possible. However, if and when one cannot use native tissue to close the defect or they are in need to use reinforcement of the repair with mesh, use of tissue engineering (TE), which aims to create and substitute failing or severely injured organs, by replacing them both anatomically and functionally as close as possible or entirely substituting the healthy organ, is in order. TE has contributed more advancements to general and trauma surgery than any other field currently. As general and trauma surgeons or acute care surgeons we are presented daily with large defects of the abdomen as well as other parts of the body that must be sealed off with newly created tissue that eventually will become part of the body and mimic fascia. This tissue has been called "biologic" and is being used to restore the functionality of abdomen. Other clinical indications have emerged also and vary from creating better cosmetics results in breast reconstruction, reconstruction after major cranioplasties, facial reconstruction or skin coverage after major burns, or other musculocutaneous defects.

The process of TE is beyond the scope of this chapter, but suffice it to say that it has undergone time development starting in the early 1900s through the present day and involves cells (differentiated adult cells to undifferentiated progenitor cells and stem cells), use of scaffolds material, vascularization), and bio-fabrication [7–13]. What I believe is needed, is that clinicians become part of the research of various tissues and conduct multi-institutional clinical trials. However, the clinical applications of TE need to be framed ethical questions such as when to conduct clinical trials, how to regulate such trials, when and how to responsibly introduce these strategies into clinical practice, and how to maintain a positive public perception of the tissue-engineering field. These questions have been raised and many more will develop in the future as tissue engineering advances. It is likely that this issue will continue to be debated in the future as well, but we surgeons must lead this process and work together with other scientists interested in this complex issue.

In summary, biologic meshes are derived from human dermis, porcine dermis, porcine small intestine submucosa, bovine dermis, or bovine pericardium. Their individual use has been rationalized by many and there are strong arguments on each side. While their benefit has been demonstrated, although no randomized clinical trials have been conducted in the infected field, there are a number of issues with all biologic meshes. First, they are extremely expensive and their application have high recurrence rate of hernia.

Furthermore, the biology of interaction with a host is still being studied, with particular attention being paid to mediators and the mechanism of controlling inflammatory and immune response. Nonetheless, these meshes are here to stay, and it will be up to surgeons to further study, modify, learn more about, and finally create a product that will eventually be cheaper and more effective and will become integrated fully by the scaffold through cellular and fibrovascular ingrowth tissue remodeling. Finally, the AWR using biologic mesh has advanced this field significantly; however, the biggest challenging issue that continues to plague abdominal wall reconstruction using bioengineered materials is the extraordinary cost that simply renders it impossible to be used in the majority of the countries in the world. Hopefully, what has happened with the expansion of biologic mesh will be followed by other organs as well. My hope is that readers will find inspiration in this book. Even if this book helps to care for one patient alone, the work that so many authors and I have done in this book will be worth the contribution.

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Index

A
Abdominal compartment syndrome (ACS), 11, 17, 77, 78, 115, 162, 201, 221
intra-operative considerations, 202–203
loss of domain, 202
patient selection, 202
post-operative, 204
post-operative care/monitoring, 203–204
post-operative considerations, 203–204
pro-inflammatory stimulus, 201
size of defect, 202
Abdominal contour deformities, 218
Abdominal hernia, 157, 188
ACS, 201
generalized effects, 201
organ system dysfunction, 201
vena-caval pressure, 201
Abdominal reconstructive procedures, 93
Abdominal trauma index (ATI), 81
Abdominal wall closure, 11, 12, 146, 163
Abdominal wall defect repair timing, 89–90
Abdominal wall defects, 102, 103
Abdominal wall distensibility, 11–13
Abdominal wall reconstruction, 98, 116, 125, 243
abdominal cavity, 112
adhesion formation, 106
anti-adhesive characteristics, 106
biologic mesh, 71, 72
bioprosthetic meshes, 106
component separation technique, 65
composite materials, 106
costovertebral margin, 59
ECFs/ECAs, 55
epigastric region, 62
fistula resection, 63
immunologic response, 106
intercostals, 59
intraabdominal complications, 111
lateral component separation, 65
mesh-musculofascia, 112
musculofascial layer, 105
musculofascial replacement, 112
myocutaneous flap, 65
negative pressure, 112
optimization of nutrition, 57
patient factors, 105
postoperative care, 70
postoperative fistulas, 56–57
principles, 107–109
rectus abdominis, 65
refistulization, 61
sepsis control and eradication, 57
seromas, 57
surgery procedures, 105
surgical approach, 61–70
suture repair, 105
synthetic mesh reinforcement, 105
TAM, 68
VAC therapy, 58
wound care, 58
Abdominal wall reconstruction, pediatric population
abdominal wall defects, 141
anesthesia, 142
delayed closure, 146
general anesthesia, 144
hernia sac, 149
herniated bowel, 142
intestinal atresia, 144
intestines, 145
obstructing bands and adhesions, 143
povidone-iodine, 147
primary reduction and operative fascial closure, 142
rectus abdominus muscles, 143
staged closure, 146
staged reduction and closure, 143
sutureless closure, 143–144
umbilical vessels, 142
viscera, 143
visceroabdominal disproportion, 142
volvulus and ischemia, 142
Abdominoplasty, 213–218
Absorbable mesh, 9
Absorbable synthetic polymers, 190
ABThera (TM), 116
Acellular dermal matrix (ADM), 68
Adhesiolysis, 62–63
American College of Cardiology/American Heart Association (ACC/AHA), 244
bleeding, 245
guideline, 244
hemodynamic state, 246
IHD, 244
non-cardiac surgery, 245
$P2Y_{12}$ platelet receptor–inhibitor therapy, 245
patient age, 245
PCI, 245
perioperative antiplatelet therapy, 245
preoperative coronary angiography, 245
valvular regurgitation, 246
vitamin K antagonists, 246
American College of Surgeons National Surgical Quality Improvement Program, 9
American Society of Anesthesiologists (ASA), 243

R. Latifi (ed.), *Surgery of Complex Abdominal Wall Defects*, DOI 10.1007/978-3-319-55868-4

Anatomy and physiology of the abdominal wall
abdominal hernia, 14
abdominal wall hernia, 14
anterior abdominal wall, 12
fascia, 11
musculofascial structure, 12
viscera, 11
Anemia, 32
Annals of Surgery, 7
Anterior abdominal wall, 116, 117
Anterior component separation (ACS), 67, 127, 136
Anterior rectus turnover flap, 120
Anteromedial portion, 102
Antibiotics
dressings, 210
host immune cells, 208
and wound drainage, 209
Aortic stenosis (AS), 246
Aponeurosis, 118
Arteriovenous (AV) loop, 102, 103
Atrial fibrillation (AF), 246
Aulus Cornelius Celsius in Rome, 141

B
Barker's vacuum-packing technique, 116
Biologic mesh, 193
Biologic prosthetics
classification, 188
Biologic prosthetics (Grafts), 190
Biologic tissue matrix, 163
Bioprosthetic mesh
animal and clinical studies, 106
bacterial contamination, 110
clinical experience, 106
fascial closure technique, 106
fascial defect, 108
fistulization, 106
incisional hernia repair, 106
indications, 106
initial musculofascial replacement, 112
musculofascial edge, 107
musculofascial reconstruction, 106, 107
patient selection, 107
primary fascial closure, 108
rectus muscle, 109
regeneration, 106
synthetic mesh, 106
Bioprosthetic meshes, 106
Blind Veress needle, 175
Bowel adaptation, 229, 231, 232
Bridge mesh placement, 194, 196
Butler's MICS technique, 110

C
Calcineurin inhibitors (CNI), 160
Cardiovascular system evaluation, 244–246
Catastrophic intra-abdominal sepsis, 96
Cheatle–Henry approach, 171
Chemical component sepration, 134–135
Child-Turcotte-Pugh score, 159
Chronic anemia, 97
Chronic liver disease, 155, 158–159
Chronic obstructive pulmonary disease (COPD), 133
Comparing anterior component separation techniques, 129
Complex abdominal wall (CAW), 60
Complex abdominal wall defect (CAWD), 55
complications, 187
isolation, 187
management, 187
Complex abdominal wall reconstruction
abdominal cavity, 30
abdominal wall, 30
age, 32
anemia, 32
biologic and mechanical pathways, 30
biomaterials, 29
causes, 27–31
collagen, 31
DC/OA surgery, 29
diabetes, 32
Fibroblasts and myofibroblasts, 31
growth factors, 31
hematomas, 32
infections, 32
inflammation, 31
irradiation, 32
laparotomy wound healing, 31
maturing adhesions, 33
nutrition, 32
OA, 27
obesity, 33
sutures, 32
tissue type, 32
wound infection, 28
wound management, 27
Complex surgical procedures, 3
Complications in abdominal plastic surgery, 218–220
Component separation, 67, 109, 110, 116, 118, 149
Butler's MICS technique, 110
fascial edges, 110
fasciocutaneous flaps, 111
healing scenarios, 110
linea semilunaris, 109
medialization, 109
microporous foam, 110
midline skin incision, 110
oblique aponeuroses, 109
pedicled flap, 111
recipient vessels, 111
revascularized mesh, 110
subcutaneous access tunnels, 109
subcutaneous skin flaps, 109
"U" stitches, 110
Conservative treatment
surgical removal, 209
Continuous ambulatory peritoneal dialysis (CAPD), 159
Coronary artery bypass grafting (CABG), 244
Cortisone, 160
Cosmetic outcome, 150
Crohn's disease, 88

D
Damage control (DC) laparotomy, 29
Damage control laparotomy (DCL), 87, 249
Damage control surgery (DCS), 4, 17, 18, 77, 249
Decision-making algorithms, 158
Decision-making process (DMP), 3

Definitive reconstructive surgery
  biologic mesh, 90
  clinical presentation, 88
  DCL, 87
  ECFs, 87
  enterocutaneous fistulas, 89
  inflammation, 89
  optimization, 87
  perioperative morbidity, 87
  prosthetic mesh, 89
  traditional teaching, 88
  waiting period, 89
Dehiscence, 220
Dense and fibrotic adhesions, 93
Diabetes, 32
Diet Regimen, 233
D-lactic acidosis, 235
DMP model, 4
Double mesh, 170–171
Double prosthetic repair, 171
During damage control surgery (DCS), 77

E
Ehlers–Danlos syndrome, 13
End stage liver disease (ESLD), 156
End stage organ disease (ESOD), 155, 157–158
End stage renal disease (ESRD), 159, 163
Endocrine disorders, 247
End-organ dysfunction, 17
Enteral nutrition (EN), 18
Enteroatmospheric fistulas (EAFs), 55, 82, 87
Enterocutaneous fistula (ECF), 20, 88
  classification, 21
  pysiology, 21–22
Enterocutaneous fistulas (ECFs), 21, 55, 93
Expanded polytetrafluoroethylene (ePTFE), 105, 188–189, 207

F
Fascial repair, 103
Fascial tensioning device, 81
Fasciocutaneous flap advancement, 111
Fatal aggressive fibromatosis, 30
Fibrin sealant, 190
Flank complex hernia
  bone edges, 169
  classification, 167–168
  clinical and diagnosis, 168–169
  double mesh, 170–171
  factors, 167
  incisional hernias, 167
  intramuscular mesh, 169
  intraperitoneal mesh, 170
  medial ventral hernias, 169
  open technique, 169
  preperitoneal mesh, 170
  suprafascial mesh, 169
  surgical and social problem, 167
  topographic anatomy, 168
Fluid collection, 47
Free flap
  locoregional flap, 111
  pedicled regional flap, 110
  soft tissue coverage, 111
Full abdominoplasty, 213

G
Gastroesophageal (GE) junction, 98
Gastrointestinal (GI) tract, 17
Gastrointestinal fistula, 22
Gastrointestinal quality of life (GIQLI), 179
Gastrointestinal system evaluation, 246–247
Gastroschisis, 141, 144
Giant omphaloceles, 146
Glutamine, 233
Growth factors, 233–234
Growth hormone, 233

H
Harris–Benedict equation, 19
Heart failure (HF), 245
Hematologic and coagulation evaluation, 247
Hematoma, 32, 220
Hernia
  bacterial adherence, 208
  biological grafts, 207
  biomaterials, 208
  definition, 209
  infection rate, 207
  laparoscopic repair, 209
  material, 207
  repair, 209
Hernia classification, 157
Hernia grading system, 83, 157
Hernia recurrence rates, 149
Hernia repair, 158, 159
Hernias
  abdominal wall hernias, 193
  contaminated, 193
  fistulas, 193
Herniation, 45
History of abdominal wall repair
  abdominal wall, 7
  absorbable mesh, 9
  laparotomy, 7
  local tissue approach, 8
  nonabsorbable mesh, 8–9
  prosthetic materials, 8
History of abdominal wall repair, 7–9
Hostile abdomen, 96
  abdominal wall, 97
  GI tract, 98
  intra-operative decisions, 98
  patients, 94
  planning reconstruction, 97
  preoperative conditions, 93–94
  timing of the operation, 97
Human Acellular Dermal Matrix (HADM), 162
Hypovolemia, 97

I
Iliac hernia, 171
Incisional abdominal wall hernia repair, 83
Incisional hernia, 27–28
  long-term complication, 179
  multiple laparotomies, 179
  operations, 179
  recurrence, 183
  treatment, 184

Incisional hernias, 155
Infected mesh
 diagnosis, 208–209
 infection rate, 207
 management, 209–210
 microporous meshes, 207
 pathogenesis, 207–208
 risk factors, 207–208
Intensive care unit (ICU), 5, 18
Interposition, 196
Intestinal adaptation, 233–235
Intestinal anastomosis, 63–64
Intestinal failure
 analogous, 225
 definitions, 225
 SBS, 226
Intestinal Failure Associated Liver Disease (IFALD), 235
Intestinal lengthening, 236
Intestinal transplantation, 237–238
Intra-abdominal hypertension (IAH)
 abdominal cavity, 201
 abdominal compartment syndrome, 201
 and ACS, 201
 and organ system dysfunction, 201
 patient selection, 202
 post-operative, 204
Intra-abdominal pressure (IAP), 201
Intra-abdominal sepsis, 94
Intraperitoneal mesh, 170
Ischemic complications, 220–221
Ischemic heart disease (IHD) spectrum, 244

J
Jaundice, 33

K
Kinetic Concepts Inc. (KCI), 80

L
Laparoscopic access
 advantages, 177
 bowel loops/mesenteric vessels, 175
 carbon dioxide, 175
 incisional hernia repair, 175
 injuries, 175
 patient selection, 175
 surgical technique, 176–177
Laparoscopic component separation, 68
Laparoscopic hernia repair
 abdominal wall defects, 179
 complications, 183–184
 equipment, 179–180
 intra-abdominal adhesions, 179
 long-term complication, 179
 in men and women, 179
 mesh repair, 179
 patient preparation, 179–180
 postoperative care, 183
 surgical technique, 181–182
Laparoscopic incisional hernia, 162
Laparoscopic repair, 9
Laparoscopic ventral hernia, 126
Laparoscopic ventral hernia repair (LVHR), 161
Laparoscopy
 in hernia repair, 171–173
Laparotomy, 161
Laparotomy wound healing, 31
Laplace effect, 13
Lateral hernia
 classification, 168
 double prosthetic repair, 171
 double-mesh technique, 170
 outpatient treatment, 173
 preperitoneal area, 169
 surgical and social problem, 167
Left ventricular ejection fraction (LVEF), 245
Linea semilunaris, 117–118
Lipoabdominoplasty, 213, 214, 220
Liposuction, 213
Liver disease, 235–237
Liver transplantation, 164
Living donor liver transplant (LDLT), 156, 164
Long term post-operative, 215
Long-term management, 232, 233

M
Major adverse cardiac event (MACE), 245
Malnutrition, 17
Massive fluid resuscitation, 115
Massive hernias, 125, 126
Massive weight loss (MWL), 215, 216
Medical/minimally invasive therapy, 204
MELD score, 159
Mental model, 4
Mesh
 abdominal hernias, 193
 abdominal wall hernias, 193
 choice, 193
 management, 193
 placement technique, 194
 “single-staged” approach, 193
 synthetic grafts, 193
Mesh graft selection, 68–69
Mesh placement, 69–70
Micronutrients, 23
Microporous meshes, 105–106
Miniabdominoplasty, 213
Minimally invasive anterior component, 128
Minimally invasive component separation (MICS), 108, 109
 abdominal wall defects, 125
 abdominal wall reconstruction, 133
 AWR surgeon, 125
 complex abdominal reconstruction, 126
 contamination, 130
 fascial closure, 108
 functional abdominal wall reconstruction, 126
 IPOM procedure, 133
 laparoscopic procedure, 132
 nutritional status, 129
 pre-operative care, 129–133
 pre-operative/intra-operative measures, 126
 risk factors, 130
 skin graft, 129
 subcutaneous access tunnel, 110
 TAR, 125
Model for end stage liver disease (MELD), 159
Musculofasciocutaneous flap, 102

N
Negative pressure wound therapy (NPWT), 79
Negative pressure wound vacuum therapy, 147
Nerve problems, 221
Neurological system evaluation, 244
Nonabsorbable Mesh, 8–9
Nutritional consideration
  biochemical measurements, 17
  C-reactive protein, 19
  crystalloid/colloid, 18
  ECF formation, 20, 21
  fistula output, 23
  lethal triad, 18
  malnutrition, 17
  open abdomen, 17–19
  parenteral vs. enteral nutrition, 22–23
  recommendations, 20
Nutritional evaluation, 247
Nutritional optimization, 93
Nutritional status, 22

O
Ochsner's comment, 120
Omphalocele, 145, 148
Onlay mesh placement, 194
Open abdomen, 29, 227, 238, 249
Open abdominal (OA) wounds, 27
Open access
  abdomen, 176
Open component separation, 65–67
Orthotopic liver transplantation (OLT), 155

P
Panniculectomy, 216–217
Panniculectomy incisions, 111
Paramedian skin, 111
Parenteral nutrition associated liver disease (PNALD), 235
Parietex™, 8
Pedicled flap, 111
Pedicled thigh-based flaps, 111
Percutaneous coronary interventions (PCI), 244
Perioperative radiologic evaluation
  abdominal wall defect, 46
  abdominal wall hernia, 38
  adynamic mesh, 44
  bowel loops, 39
  component separation, 50
  CT, 39
  diagnosis, 37–38
  intraoperative guidance, 43–46
  MRI, 40
  parastomal hernia, 45
  postoperative complications, 46
  proinflammatory milieu, 37
  recurrence, 47
  ultrasonography, 38
Pinch test, 89
Planned hernia, 101, 103
Planned ventral hernia, 126, 129, 134
Polydioxanone (PDS) suture, 149
Polyester, 188
Polypropylene, 188
Polypropylene mesh, 189
Post bariatric plastic surgery
  abdominoplasty, 213
  extra skin, 213
Post-massive weight loss, 216–218
Premorbid conditions, 247
Preoperative testing
  abdominal wall reconstruction, 243
  healthcare providers, 243
  operating team, 243
  preoperative care, 243
  reconstructive procedure, 243
  risk, 244
  surgical procedure, 243
Prosthetic materials
  CAWD, 187
  hernia surgery, 187
  long-term strength, 188
  material, 188
  mesh repair, 188
  surgical repair, 187
  ventral hernia repair, 188
Prosthetic mesh, 162
Pulmonary embolism, 221

R
Reapproximation, 40
Recognition-primed decision-making, 4
Rectus sheath turnover, 121
Recurrence
  complications, 209
  hernia, 209
  second operation, 209
Recurrent incisional hernia, 28
Removal of infected mesh, 209, 210
Renal system evaluation, 246
Retention sutures, 79
Retentions sutured sequential fascial closure (RSSFC) procedure, 79
Retrorectus fluid collections, 48
Rives–Stoppa mesh placement technique, 195
Rives-Stoppa–Wantz, 126

S
Scar deformity, 221
Semielemental formulas, 23
Seroma, 220
Short bowel syndrome (SBS)
  abdominal compartment syndrome, 227
  bowel adaptation, 231–232
  bowel resections, 227
  catastrophic situations, 227
  clinical description, 225
  enterocolitis/massive atresia, 227
  factors, 226
  gastroschisis, 227
  hypoproteinemic malnutrition, 228
  ileocecal valve, 226
  intestinal failure, 225, 226
  kidney stones, 226
  laboratory development, 225
  long-term management, 232, 233
  management, 238
  metabolic management, 225
  nutritional and metabolic management, 229–230
  nutritional and metabolic status, 226

Short bowel syndrome (SBS) (*cont.*)
  pathophysiology, 228–229
  pediatric surgery teams, 227
  postoperative period, 230–231
  small intestine, 226
  standardization, 226
  surgical considerations, 236–237
  surgical correction, 227
  symptoms, 226
  synopsis, 229
  variability, 226
Short-gut syndrome, 96
Silo contents, 146
Silver sulfadiazine, 141, 147
Simultaneous liver and kidney transplantation (SLKT), 156
Sirolimus, 160
Skin and subcutaneous tissue, 78
Skin graft closure, 102
Skin management
  deficiency, 111
  redundancy, 111
Small seroma anterior, 50
Small-bowel follow-through study, 39
Social and addiction issues, 247
Somatostatin, 23
Southern Surgical Association, 8
SOWATS, 56
Spacemaker™, 131
Split-thickness skin graft (STSG), 62
Staged abdominal wall reconstruction
  maturation period, 101
  planned ventral hernia, 101
  rectus muscles, 101
  single-stage reconstructive solution, 102
  TAC, 101
  TFL, 102, 103
  type I and II defect, 103
Steroids, 32
Stomas, 135–136
Strangulated hernias, 162
Strattice™, 68
Subcostal hernia, 173
Superior/reverse abdominoplasty, 213
Suprafascial mesh, 169
Surgeons' intraoperative decisions, 3–4
Surgical decompression, 204
Surgical site occurrence (SSO), 72
Sutureless closure, 143–144
Synthetic mesh, 82
Synthetic non-absorbable polymers
  composites, 190
  polyester, 188
  polypropylene, 188

T
Temporary abdominal closure (TAC), 5, 77, 79, 101, 249
Tensor fascia latae (TFL), 102, 103
Thoracic epidural analgesia, 130
Tight double-mesh technique, 171
Tissue engineering (TE), 250
Tissue transfer
  abdominal compartment syndrome, 115
  abdominal contents, 116
  acute abdominal wall, 116
  dissection proceeds, 118
  heterogeneity, 116
  laparotomy, 119
  neurovascular plane, 116
  standard fascial closure, 119
  trauma patients, 121
Total enteral nutrition (TEN), 18, 58
Total parenteral nutrition (TPN), 18, 95
Towel Clip Closure, 78
Transplantation and immunosuppressive therapy, 159
Transversus abdominal release (TAR), 125
Transversus abdominus muscle (TAM), 68
Transversus abdominus release (TAR), 67
Traumatic lumbar hernia, 42

U
Ultrasonography, 38, 46
Underlay mesh placement, 194–195
Upper gastrointestinal (UGI) series, 59
Uremia, 33

V
Vacuum-assisted closure (VAC), 58, 79, 97, 196, 249
Vacuum-assisted wound closure, 79–80
Vacuum-packed dressing, 115
Valsalva maneuver, 38
Vascularized flaps, 102
Venous thrombosis, 221
Ventral hernia, 7, 9, 187, 188
  in men and women, 179
  prevalence, 183
  recurrence rate, 179
Ventral hernia repair, 162
  hospital stay, 105
  Rives-Stoppa ventral hernia repair technique, 109
Ventral Hernia Working Group (VHWG), 83, 106, 157
Vicryl®, 80
Vicryl™, 63
Video-Assisted Anterior Component Separation Technique, 128–129
Viscero-abdominal disproportion, 148

W
Water assisted liposuction (WAL), 213
Wittmann Patch®, 115
World Society of Emergency Surgery guideline, 164

Y
Yale New Haven Transplantation Center, 159