Options in the Management of the Open Abdomen

Firas G. Madbak
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Editors

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ISBN 978-1-4939-1826-3 ISBN 978-1-4939-1827-0 (eBook)
DOI 10.1007/978-1-4939-1827-0
Springer New York Heidelberg Dordrecht London

Library of Congress Control Number: 2014947682

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

DEDICATION

IN MEMORIAM

George Elias Madbak
October 21, 1948–July 12, 2013

“For my father—the epitome of unconditional love, support and sacrifice. Your eloquence, wisdom and sense of humor are deeply missed” *—FM*

Rita Dangleben
April 22, 1947–May 13, 2013

“For my mother, the woman who pushed me to always believe in myself” *—DD*

Foreword

Like many things in medicine and surgery, the use of the open abdomen following severe trauma and other life-treating intra-abdominal conditions is not a new concept and has been utilized episodically since before World War II. However it was "rediscovered" in earnest beginning in the early 1980s when it was combined with the concepts of damage control trauma care and marked improvements in modern critical care. These improvements in care counteracted many of the problems associated with the technique that plagued previous generations and the open abdomen has now become a mainstay of treatment for many patients who would have previously died. Most importantly, the use of the open abdomen has transcended the trauma patient population and is being utilized by almost every other surgical discipline. In fact, it is likely that the primary reason for an open abdomen today is severe intra-abdominal sepsis rather than trauma. Like many new techniques that improve survival, they do so at the expense of complications which were rarely observed previously. There is no doubt that complicated issues in the loss of domain or the development of enteroatmospheric fistulae are directly related to the technique and thus understanding the management and eventual reconstruction of these challenging patients is a must for all general surgeons and surgical subspecialists. This book by Madbak and Dangleben has collated lot of information that has been presented and published in many disparate arenas into a single easy to read source. In an area where there is more experience and "favorite techniques" than true evidence based answers, they provide a wealth of information along with outstanding photographic support that makes this an excellent resource for all surgeons caring for this population. Similar to many things in life, when treating patients with the open abdomen one size or methodology does not fit all and this book will assuredly contain at least one possible answer to your patient's problem.

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Preface

Advances in trauma care have resulted in improved survival of many severely injured patients. These advances include “damage control surgery” or “abbreviated laparotomy” with abdominal packing as well as the recognition of the abdominal compartment syndrome. As part of damage control surgery, and for the treatment of the abdominal compartment syndrome, the abdomen is frequently left open. Damage control has been extended to the management of life-threatening intra-abdominal bleeding and severe intra-abdominal sepsis, resulting in an increase in the prevalence of the open abdomen among emergency surgery cases. The historical background and pathophysiologic mechanisms at play are outlined in the three chapters.

Although the numbers of “open abdomens” are decreasing due to changes in resuscitation and transfusion practices, it still represents a complex complication that can be challenging to deal with. This ambitious textbook on the management of the open abdomen provides a practical approach for addressing this complex problem.

One of the more unique aspects of this textbook is its detailed “How to” approach for the wide variety of techniques utilized in the management of the open abdomen, most notably in Chap. 4. While there may be no consensus as to what constitutes the optimal management of the open abdomen, this book articulates a number of options and their advantages. Most importantly, it provides high quality photographs that enhance the step by step “How to” approach of the text. More recent developments including using biologic mesh, implementing complex abdominal wall reconstruction and utilizing minimally invasive endoscopic techniques are described in detail (Chaps. 5–7). An important chapter about complications concludes the text.

This is an extremely well written book that articulates a variety of well thought out options for open abdomen management. This book is not only appropriate for all practicing surgeons that deal with this complex issue, but is also relevant for residents and fellows who are just getting their first exposure to open abdomens.

I congratulate the authors on taking a complex and controversial subject and making it easy to follow, informative, and most importantly; enjoyable to read.

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Acknowledgements

We are genuinely indebted to the contributing authors to this work.

Dr. David Livingston a great mentor and surely one of America's finest physicians, went through this work with a constructively critical eye. Dr. Ali Salim, another brilliant champion of surgical education is to be commended for his support.

To Elise M. Paxson the developmental editor at Springer must go a prize for seeing this work through from start to finish.

We also would like to thank Dr. Christine M. Blaine who provided many invaluable photographs to embellish the text.

It is difficult to overstate our gratitude to our families who bore with us through several months of work on the manuscript. For their unconditional support and sacrifice, we are profoundly grateful. We dedicate this book to them and to all our patients.

Firas G. Madbak
Dale A. Dangleben

Disclaimer

Medicine is an ever changing science. As new research and clinical experience broadens our knowledge changes in treatment and drug therapy are required. The authors and the publisher have checked with sources believed to be reliable in their efforts to provide information that is complete and generally in accord with the standards accepted at the time of publication. However, in view of the possibility of human error or changes in medical sciences, neither the authors nor the publisher nor any other party who has been involved in the preparation or publication of this work warrants that the information contained herein is in every respect accurate or complete, and they are not responsible for any errors or omissions or for the results obtained from the use of such information. Readers are encouraged to confirm the information contained herein with other sources.

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Chapter 1
Historical Perspective

Firas G. Madbak and Ryan A. Lawless

Introduction

Few advances have had a major impact on acute care and trauma surgery as much as current management of the open abdomen. Sometimes called "laparostomy," the concept of leaving an abdomen open after surgery is not new. E. C. Wendt noted the reduced urinary flow in the presence of abdominal hypertension as early as 1876. When surgeons of yesteryear operated on peritoneal patients, they often were concerned about the "enormous pressure increase that often precluded abdominal closure." Marey in 1863 and Henricus in 1890 commented on the adverse effects of increased intra-abdominal pressure (IAP). In 1911, Emerson introduced his readers to a series of elegant experiments with the statement that "pressure conditions which exist within the peritoneal cavity had received insufficient attention." Baggot, an Irish anesthetist, suggested that forcing distended bowel back into the abdominal cavity of limited size might kill the patient from abdominal wound dehiscence ("abdominal blowout") and coined the term *acute tension pneumoperitoneum* in 1951 [1–2]. Despite all these condemnations of closing an abdomen under tension, the practice continued well into the late twentieth century [28].

IAP was since studied extensively, and since 1959, numerous authors have described the negative effects of abdominal hypertension on the function of almost every organ system. Deleterious impact on cardiovascular, pulmonary, hepatic, renal, and even central nervous system function were described. These effects of elevated IAP were recognized by pediatric surgeons in the 1960s, particularly following

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F. G. Madbak, D. A. Dangleben (eds.), *Options in the Management of the Open Abdomen,* DOI 10.1007/978-1-4939-1827-0_1

repair of diaphragmatic hernias and omphaloceles. Since that time, the concepts of intra-abdominal hypertension (IAH) and the ensuing abdominal compartment syndrome (ACS) have been emphasized, neglected, resurrected, and forgotten again. Further laboratory investigations into the pathophysiology of increased IAP continued well into the 1970s. Sporadic clinical and laboratory reports documenting the pathophysiology of increased IAP began to appear in the 1980s, the decade during which early reporting of the benefits of abdominal decompression ensued [29]. However, the term *abdominal compartment syndrome* was not coined until 1989 by Fietsam et al. [11]. Since then, considerable investigation has been directed at defining an otherwise elusive and controversial clinical pathophysiology [5–6].

Historically used as a naval term in World War II, the concept of damage control (see Chap. 2) was used in the early 1990s as a method to treat the surgical equivalent of a sinking warship. Accepting that definitive surgical management would not be achieved at the first operation, abbreviated laparotomy was pursued. As a consequence of the development of trauma systems with high-volume level I trauma centers that have improved survival of the catastrophically injured patient, undesirable (yet still frequent) empiric administration of isotonic crystalloids in the early management of injured patients, the strategy of damage control was embraced, and open abdomen cases became the norm, not the exception in the trauma and surgical intensive care unit. Understanding the need for restoring physiology, reversing coagulopathy, correcting acidosis and hypothermia, and the crucial need for ongoing resuscitation have thrusted management of the open abdomen into the forefront as its use has drastically increased [26–27, 30]. Moreover, although initially described for catastrophic penetrating intra-abdominal injuries, the principles of damage control surgery have been applied to almost any trauma operation in other body cavities, including thoracotomies, peripheral vascular explorations, and orthopedic procedures as well as being adopted as a widely recognized clinical approach in emergency general surgery where intra-abdominal sepsis and massive resuscitation for nontraumatic pathology may lead to ACS [24–25].

With its evolution came the promulgation of significant variability in the management and support of the patient with an open abdomen. In 2006 and 2007, the World Society of Abdominal Compartment Syndrome (WSACS) published expert consensus for the diagnosis and management of IAH and ACS. They also defined the terminology, thus providing a basis for improved communication and comparison of current and future work.

The notable variations in the management of the open abdomen following damage control or decompressive laparotomies are based mainly on personal preference, institutional biases, or the patient population. Techniques include: (1) vacuum-assisted closure techniques such as the commercial wound vacuum-assisted closure (VAC®, Kinetic Concepts, San Antonio, TX) and the noncommercial vacuum pack ("Vac Pack") technique described by Barker et al. in 1995; (2) "zipper" closures, including the Wittmann artificial burr patch (StarSurgical, Burlington, WI) as well as other mesh with zipper mechanism techniques as originally described by Leguit in 1982 [20]; (3) placement of temporary absorbable or nonabsorbable mesh; (4) the plastic silo technique (Bogotá bag); and (5) temporary skin closure with towel clips or sutures, all of which are described in this volume. Choosing one technique over another based on the current literature remains challenging; the use of such techniques is based on a heterogeneous patient population, and there is significant practice variation among various authors. It is imperative to recognize that ACS can and does still occur with any temporary abdominal closure technique, and we recommend routine monitoring of IAP during ongoing resuscitation. The decision concerning timing of the second laparotomy is based on the indications of the first operation and the overall physiologic status of the patient [15–16].

Methods of temporary abdominal closure have evolved from a skin-only closure using towel clips for rapid completion of a damage control procedure to devices that control intra-abdominal contents, such as the Bogotá bag, to systems that allow for treatment of the underlying physiologic state as seen with the VAC® system with a specialized abdominal dressing as described in the synopsis below. Controlling physiologic causes could increase the rate of early closure and reduce the overall complications seen in patients with open abdomens [31–32].

Skin-Only and Towel-Clip Closure

Now all but abandoned, an early, inexpensive method of rapid temporary abdominal closure utilized continuous skin-only nonabsorbable monofilament suture reapproximation. Alternatively, use of sequential penetrating towel clips placed a centimeter apart achieved the same outcome in a straightforward and expeditious manner as it obviated suturing (Fig. 1.1). After reapproximation, an iodophore-impregnated plastic sheet would be placed on the abdomen completing the closure. Both methods allowed easy access to the abdominal cavity for reexploration; however, drainage was not possible and hence the incidence of abdominal compartment syndrome (Chap. 3) was unacceptably high. While the abdominal viscera were protected and domain was maintained, there was a high risk of evisceration [10, 17].

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Esmarch Closure

Originally described by Cohn et al. in 1995 [7], an Esmarch bandage (latex or latex free) was first used to span the gap across the abdominal wall defect. The lateral aspect of each sheet was stapled to the skin and the medial aspects were brought together in the midline. The edges were then turned in and stapled, creating a silo. They were then folded down resulting in a tension-free closure. An iodophore-impregnated plastic sheet was then placed over the abdominal wall. Advantages included nonadherence to the bowel, cost-effectiveness, and feasibility. However, abdominal drainage did not occur with this closure either.

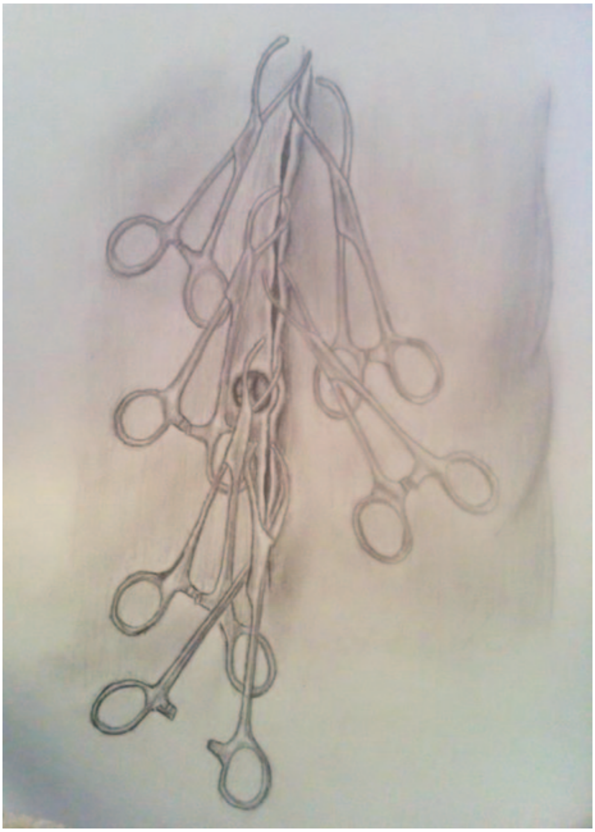

Fig. 1.1 Artist rendition of towel-clip, skin-only closure. (Used with permission K. Dangleben)

Temporary Silos (Bogotá Bag, Sterile X-Ray Cassette Cover)

The concept of covering the abdominal contents with a silastic/plastic bag was developed in 1987 in Bogotá, Colombia by Borraez. He used a 3-L intravenous fluid bag as an abdominal covering. A time-honored method, its advantages include reduction in the rate of intra-abdominal infections seen with the previous use of sterile OR towels. This closure enabled bedside inspection of the abdominal contents through a clear, biologically inert dressing when refractory ischemia or bleeding was a concern. With resolving bowel edema, the abdominal viscera slowly reduced back into the abdominal cavity and the bag was truncated and resecured with metal clips to maintain domain [12, 18, 19].

Synthetic Mesh

A diverse assortment of synthetic mesh has been used to cover the bowel to manage the open abdomen. Marlex polypropylene mesh (Davol Inc, Providence, RI) is a porous material that allows drainage of intra-abdominal fluid. The rate of intestinal fistula formation ranges from 35 to 75 % with its use. Additionally, polypropylene mesh is difficult to remove at the time of primary closure. Knitted Dexon polyglycolic acid mesh (Davis and Geck, Inc., Danbury, CT) is an absorbable similarly porous synthetic mesh that has been used in cases of intra-abdominal sepsis. However, Dexon will frequently stretch under tension allowing for loss of domain and subsequent large ventral hernia defects. Goretex (W. L. Gore & Associates, Elkton, MD) is a soft, flexible, compliant counterpart that is desirable since it does not stretch while achieving abdominal coverage, but could also lead to ventral hernia formation.

Zipper Closure

Obtained at a local retailer, autoclaved, and attached to Marlex mesh then sutured to the fascia, a nylon zipper was described by Bose et al. [3] as a new closure method. This was then covered with saline-soaked or iodine-soaked gauze and surgical pads. Shortly thereafter, medical device manufactures began producing their own form of the nylon zipper. Ethizip (Ethicon, Somerville, NJ) is one commercially available abdominal zipper device. Zipper closure allowed easy reexploration and access for repeated lavages without fascial or mesh disruption while avoiding repetitive tissue trauma from suturing [3, 4, 8, 13, 14, 20].

The Wittmann Patch

Management of the open abdomen with a burr-like material has been described throughout the literature. Wittmann and Aprahamian et al. [33] described suturing the material to the fascial edges to protect the bowel and placing roller gauze over the burr. The patient was then returned to the operating room 24–48 h later for relaparotomy. The benefits of relaparotomy were recognition of continued hemorrhage, anastomotic dehisicence or leakage, and intestinal ischemia which were all treated at relaparotomy.

Following this, Wittmann described the tensile strength of the burr-like device noting that the device was unaffected until the fifth relaparotomy. In patients requiring multiple abdominal explorations, resuturing the fascia leads to necrotic edges, which is avoidable with the burr. The rate of abdominal closure was found to be comparable to other modalities.

The Vacuum Pack (Barker Vac Pack)

In 1995, Brock and Barker et al. described a rapid, simple, and cost-effective method of temporarily covering the open abdomen. A fenestrated piece of polyethylene was placed over the abdominal viscera, beneath the parietal peritoneum and fascia. A moist laparotomy pad was placed between the open edges of fascia on top of the polyethylene sheet. Two sump drains were then placed over the moist laparotomy pad followed by application of an adhesive-backed drape over the entire wound and well onto the abdominal wall. The drains were placed to suction creating rigid compression of the dressing layers facilitating drainage of the abdomen. This method was modified in 1998 with the addition of an iodophore-impregnated adhesive plastic and the use of spray adhesive to facilitate adhesion of the outer sheet to the abdominal wall. The authors recommend at least 10 cm of abdominal wall overlap of the plastic sheet. This method protects the abdominal viscera from desiccation and heat loss as well as decreases the rate abdominal compartment syndrome. It could be applied in a matter of minutes as it avoids any suturing, allows for rapid reentry, and is cost-effective. Note that evisceration can still occur with increasing intra-abdominal pressure as the strength of plastic adhesive is less than that of fascial sutures [21–23].

Summary

Many advances have taken place in the management of the open abdomen as it has become more customary in the treatment of the critically ill. Better-defined criteria that include patients with massive solid organ injury, bowel edema, abdominal wall resection, and multiple planned relaparotomies ("second looks") have come to the forefront.

While there is no accepted gold standard for management of the open abdomen, the improvements in trauma care have led to a dramatic rise in the incidence of these cases that have made establishing defined guidelines and algorithms a compelling endeavor. The optimal temporary closure approach provides protection of the intraperitoneal contents, prevents evisceration, preserves fascia, minimizes damage to the viscera by desiccation, quantifies third space fluid losses, permits selective tamponade, minimizes the loss of domain, reduces infection risk, and keeps the patient dry until definitive closure.

Many options are available for management of the abdomen that will not close or that should not be closed. Open abdomen management has proven benefits. Its disadvantages and pitfalls are being resolved through the development of modern principles and techniques. Application of these principles is highly recommended for clinicians taking care of these desperately ill patients.

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Chapter 2
Damage Control

Rona E. Altaras, Firas G. Madbak and Dale A. Dangleben

History

Originally a naval term, damage control (DC) is a simple and useful idea referring to the ability of a battleship to absorb adversarial fire while maintaining mission integrity. After rapid assessment, the vessel is basically compartmentalized, eventually sacrificing the damaged areas in order to save the ship as a whole. The goal is minimal repair of devastating damage to facilitate return to a safe harbor.

Building on the foundations led by Burch and Stone in the 1980s, Rotondo and Schwab described DC in 1993. Since then, DC has become the standard of care for the management of severely injured trauma patients. Recently, its application has also been extrapolated to other surgical specialties. Today, it is relatively common to see DC applied to general surgical, vascular, thoracic, as well as orthopedic patients [5, 6]. The guiding principle behind surgical DC is immediate and abbreviated management of severe and life-threatening conditions with definitive surgical management deferred to a period after physiologic stabilization.

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F. G. Madbak, D. A. Dangleben (eds.), *Options in the Management of the Open Abdomen,* DOI 10.1007/978-1-4939-1827-0_2

Fig. 2.1 Damage control for intra-abdominal sepsis from acute bowel ischemia

Indications

While its utilization has been the cornerstone of severe blunt and penetrating abdominal trauma care in the past two decades, it is not without morbidity. There is increased risk for gastrointestinal fistulas, infections, abscesses, and multiple-organ dysfunction syndrome (MODS). Therefore, it is vital not to use DC indiscriminately, but to have some selection criteria. For this purpose, the three parameters (intraoperative pH < 7.2, temperature < 93 °F, blood loss > 10 units of packed red blood cells) as defined by Asensio et al. can be useful. Common indications for damage control in trauma are multisystem injuries with competing treatment priorities, multicavitary injuries with shock, major abdominal vascular injuries, complex hepatic injuries, hypothermia, metabolic acidosis, coagulopathic state, and exsanguinating patients. It is important to recognize the clinical picture early on to initiate a DC operation without delay. In severely injured patients, the lethal triad of hypothermia, acidosis, and coagulopathy will inevitably develop, reinforcing each other's negative effects and causing the so-called vicious cycle. Early intervention with combining aggressive hemorrhage and contamination control with resuscitation and rewarming measures will ameliorate the effects of the lethal triad.

Ideally, one should stay well ahead of the operation and consider the physiology, injury pattern, trauma burden, as well as resources at hand even before the operation begins. All these factors will go into play as one makes the decision between definitive repair versus damage control. The earlier the decision is made, the more effective the team can rally to get the patient off the table alive (Figs. 2.1, 2.2).

Technique

Damage control uses a multiphasic approach and can be divided into four different stages. Management of each of these stages requires coordination, communication, and leadership. A decision to proceed with damage control has to be taken early on before the occurrence of physiologic exhaustion.

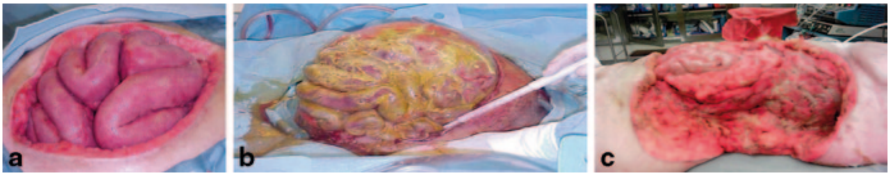

Fig. 2.2 **a** Abdomen left open secondary to significant bowel edema. **b, c** Necrotizing soft tissue infection of abdominal wall with resulting peritoneal defect

Stage 0: Prehospital and Preoperative Phase

Prehospital resuscitation with limited crystalloid of the trauma patient in extremis begins until arrival to the trauma bay, where damage control resuscitation with a 1:1:1 ratio of blood component therapy is initiated. Hypothermia has to be prevented with external rewarming measures. Communication with the anesthesia team about the operative plan and the ongoing resuscitation efforts is crucial.

Stage I: Operative Phase

An abbreviated laparotomy, with the primary goals of controlling hemorrhage and then intestinal spillage is performed. To achieve rapid hemostasis, large vessels can be repaired or shunted, small vessels ligated, liver packed, large wound tracts tamponaded with a balloon catheter, injured solid organs such as the spleen and kidney removed. Intestinal spillage should be managed with suture closure of smaller and stapling of larger injuries leaving the gastrointestinal tract in discontinuity. At the end of the procedure, the abdomen should be left open in order to prevent the development of abdominal compartment syndrome (ACS) while enabling easy reentry into the abdomen. Currently, the most widely used temporary abdominal closure techniques are the commercially available Abthera (KCI, San Antonio, TX) and the Barker wound vacuum pack (see Chaps. 1 and 4). Both of them are vacuum-assisted devices that provide the benefit of visceral protection, control of drainage, and preservation of fascia for latter definite closure. As previously mentioned, more antiquated techniques like the Bogotá bag, towel-clip and skin-only closure are generally slower, can provide neither adequate effluent control nor preservation of fascia. In case of severe liver bleeding with multiple packs in the right upper quadrant, the skin-only and towel-clip closure techniques may occasionally provide a desirable tamponade effect.

Stage II: Resuscitative Phase in the Intensive Care Unit

The goal of this phase is restoration of patient's physiologic state. Each individual component of the lethal triad (acidosis, hypothermia, coagulopathy) is corrected.

The resuscitation is completed using established end points. A concerted effort is made to prevent under and over resuscitation; the former being associated with an increased incidence of MODS, the latter with secondary ACS and difficulty achieving primary fascial closure. A vigilant reassessment is performed in the intensive care unit (ICU) to monitor the patient for the early development of secondary ACS which is possible notwithstanding an open abdomen with temporary closure. When recognized, this condition mandates immediate decompression and reexploration at the bedside if necessary. Other indications for early reexploration are worsening acidosis despite adequate resuscitation and continuous bleeding despite normothermia and correction of the coagulopathic state. Otherwise, following normalization of physiology, most patients are returned to the operating room in 48–72 h for re-exploration.

Recently, direct peritoneal resuscitation (DPR) was evaluated as a resuscitation strategy in severely injured trauma patients with hemorrhagic shock requiring damage control surgery, and the impact on time to definitive fascial closure was among the end point studied. Twenty patients undergoing standardized wound closure and adjunctive DPR were identified and matched to 40 controls by Injury Severity Score (ISS), age, gender, and mechanism of injury. The DPR technique consists of suffusing the peritoneal cavity with a hypertonic glucose-based peritoneal dialysis solution. Previously, animal studies have shown this treatment to cause microvascular vasodilation and increase visceral and hepatic blood flow; reversal of endothelial cell dysfunction; improve of survival and downregulation of the inflammatory response; reversal of established microvascular constriction; normalization of capillary perfusion density; and normalization of systemic water compartments.

Patients receiving adjunctive DPR in this small study were closed in 4.4 ± 1.7 days compared to 7.0 ± 3.4 days in the control patients. The percentage of patients undergoing primary fascial closure was also considerably increased in the group of patients receiving adjunctive peritoneal resuscitation. The odds ratio for primary fascial closure was 10.7:1 for those undergoing DPR ($p = 0.01$), as opposed to traditional management [7].

Although further study is needed, the addition of adjunctive DPR to the damage control strategy appears to be a promising adjunct that shortens the interval to definitive fascial closure without affecting overall resuscitation volumes.

Another novel intervention hypothesized to improve early primary fascial closure rates is administration of hypertonic (3 %) saline which reduces resuscitation-induced intestinal edema in animals. This was demonstrated in a small study by Harvin and colleagues who used this method in conjunction with normal saline as an adjunct to facilitate early closure [1].

Stage III: Reoperative Phase

Formal exploration is performed in the operating room. As the patient's physiologic state has been restored, standard operating times can now be applied. The goal at this stage is to identify any missed injuries, definitively repair injured viscera and vascular structures, and possibly restoring intestinal continuity versus exteriorization of bowel segments. Packs are carefully removed and a thorough washout with crystalloid irrigation solution is performed. If possible, primary closure of the fascia is achieved. If the abdomen cannot be closed at this stage because more procedures are needed (e.g., if the bowel is too edematous for anastomotic creation or because of increased tension), then a temporary closure is employed.

A retrospective review from the University of Texas showed that 34 % of DC laparotomies could be closed at the first take back. Their data demonstrated that vacuum-assisted closure at initial laparotomy was an independent predictor of closure at the first reexploration. However, postoperative intra-abdominal pressure (IAP) and postoperative elevated INR were predictive of closure failure at this stage [2].

Stage IV: Definitive Abdominal Closure Phase

A significant number of patients will require multiple return trips to the operating room for regular washouts and repeated attempts to close the fascia primarily in a delayed fashion. Overall, definitive fascial closure is achieved in 85 % of the cases as demonstrated in a prospective observational study by University of Southern California investigators. With the application of biologic mesh, some authors have reported an improvement in this rate. A systematic review by van Hensbroek [3] demonstrated that the sequential closure techniques using the Wittmann Patch (90 %), or the dynamic retention sutures (85 %) have the highest primary closure rate. The wound VAC showed a rate of 60 %, which can be increased to more than 80 % with application of interrupted fascial sutures at the wound apices at each subsequent VAC change. Generally, achieving primary fascial closure beyond 10 days becomes less likely. During this time, maintaining a negative fluid balance may facilitate earlier closure. Closure of the fascia will significantly reduce the rate of enteroatmospheric fistula, which is a feared complication of the open abdomen. Other common complications are intra-abdominal abscess, sepsis, and pneumonia (see Chap. 8). In an abdomen that will not close, a viable option is interval treatment of a planned ventral hernia. For this purpose, the fascial defect can be bridged with mesh (biologic or synthetic) and covered with a split-thickness skin graft after granulation is formed, usually after 5 days.

Summary

Damage control techniques and preventive measures to avoid the development of ACS are now standards of care in the management of traumatic shock [4]. Complications can then be avoided by not attempting to close the fascia under excessive tension and maintaining abdominal domain during the recovery phase. Multiple attempts at fascial closure can then be safely performed either primarily or with the use of biologic material to bridge the fascial gap during initial hospitalization. It is no longer acceptable to commit the posttrauma open-abdomen patient to a large ventral hernia and delayed reconstruction except for unusual circumstances where a prolonged inflammatory response precludes early fascial approximation. The surgeon needs to be aware of unique challenges presenting in each of the individual stages to assure the desirable outcome.

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Chapter 3
Abdominal Compartment Syndrome

Rona E. Altaras and Firas G. Madbak

The abdomen is a functional compartment with limited compliance. Increased sustained pressure in this compartment potentially leads to deleterious effects on several organ systems. The impairment to the cardiac, respiratory, and gastrointestinal and central nervous systems (CNS) can often result in multiple organ dysfunction syndrome (MODS) and death.

The establishment of damage control techniques with aggressive resuscitation requirements since the 1990s has led to the awareness of the abdominal compartment syndrome (ACS) especially among trauma surgeons and surgical intensivists. Historically, however, surgeons have been aware of the effects of intra-abdominal hypertension (IAH) since the mid-nineteenth century. As discussed briefly in Chap. 1, Fietsam coined the term abdominal compartment syndrome in 1989 in a paper outlining complications after repair of a ruptured abdominal aortic aneurysm repair.

Definitions

The increased recognition of IAH and ACS in the past decade has led to significant research and also to two separate consensus statements by the international experts of the World Congress on Abdominal Compartment Syndrome (WCACS). The WCACS established definitions and also issued recommendations on management of ACS and IAH.

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F. G. Madbak, D. A. Dangleben (eds.), *Options in the Management of the Open Abdomen,* DOI 10.1007/978-1-4939-1827-0_3

Intra-abdominal pressure (IAP) is the steady-state pressure concealed in the abdominal cavity. The reference standard for intermittent IAP measurement is the transvesical method described below. Normal IAP is about 5–7 mm Hg in critically ill patients. IAH is a sustained or repeated elevation in IAP to greater than 12 mm Hg. IAH is graded as follows: grade I: IAP 12–15 mm Hg, grade II: IAP 16–20 mm Hg, grade III: IAP 21–25 mm Hg, and grade IV: IAP>25 mm Hg.

Definition 1	IAP is the steady-state pressure concealed within the abdominal cavity
Definition 2	APP=MAP−IAP
Definition 3	FG=GFP−PTP=MAP−2*IAP
Definition 4	IAP should be expressed in mm Hg and measured at end-expiration in the complete supine position after ensuring that abdominal muscle contractions are absent and with the transducer zeroed at the level of the mid-axillary line
Definition 5	The reference standard for intermittent IAP measurement is via the bladder with a maximal instillation volume of 25 mL of sterile saline
Definition 6	Normal IAP is approximately 5–7 mm Hg in critically ill adults
Definition 7	IAH is defined by a sustained or repeated pathologic elevation of IAP>12 mm Hg
Definition S	IAH is graded as follows: Grade 1: IAP 12–15 mm Hg Grade II: IAP 16–20 mm Hg Grade III: IAP 21–25 mm Hg Grade IV: IAP 25 mm Hg
Definition 9	ACS is defined as a sustained IAP>20 mm Hg (with or without an APP<60 mm Hg) that is associated with new organ dysfunction/failure
Definition 10	Primary ACS is a condition associated with injury or disease in the abdomino-pelvie region that frequently requires earlv surgical or interventional radiological intervention
Definition 11	Secondary ACS refers to eoiulilions that do not originate from the abdomiito-pelvie region
Definition 12	Recurrent ACS refers to the condition ill which ACS redevelops following previous surgical or medical treatment of primary or secondary ACS

Adapted from Malbrain et al [13]

ACS abdominal compartment syndrome, *APP* abdominal perfusion pressure, *FG* filtration gradient, *GFP* glomerular filtration pressure, *IAH* intra-abdominal hypertension, *IAP* intra-abdominal pressure, *MAP* mean arterial pressure, *PTP* proximal tubular pressure

Abdominal compartment pressure is defined as a sustained IAP>20 mm Hg that is associated with new organ failure or dysfunction. ACS can be further subdivided into primary, secondary, and recurrent ACS. Primary ACS is a condition associated with injury or disease in the abdominopelvic area. Secondary ACS refers to conditions which do not originate from the abdominopelvic area. Recurrent ACS is the redevelopment of ACS following previous surgical or medical treatment of primary or secondary ACS.

Etiology

IAH has been established as an independent risk factor for development of organ failure and mortality. A high index of suspicion is crucial to early recognition and prompt treatment in order to avoid the consequences. McNelis et al [14] noted daily fluid balance and peak airway pressure trends in general surgical patients as independent predictors for the subsequent development of ACS [4, 9, 11].

There are four different mechanisms of IAH:

1. Reduced abdominal wall compliance (due to abdominal wall hematoma, burn eschar, or pneumoperitoneum)
2. Increase of intestinal (intraluminal) content (due to small bowel or colonic ileus, Ogilvie's syndrome, gastroparesis, or volvulus)
3. Increase of intra-abdominal content (due to retroperitoneal bleeding, ascites, abscess, masses, severe acute pancreatitis, or hemoperitoneum)
4. Massive resuscitation in conjunction with capillary leak (due to sepsis, extensive burn injuries, polytrauma, or systemic inflammatory response syndrome

Pathophysiology

Sustained IAH will, through direct or indirect pathophysiological mechanisms, have adverse effects on virtually every organ system, as outlined below [12, 15–17].

Central Nervous System

Increased intracranial pressure (ICP) with secondary reduction in cerebral perfusion pressure.

Respiratory

Increased intrathoracic pressure secondary due to diaphragmatic and direct transmission of the elevated IAP. Reduction in pulmonary and chest wall compliance, increased peak inspiratory pressure (PIP), hypoxia, and hypercapnea.

Cardiovascular

Reduction in venous return, cardiac output, and hypotension; increased systemic vascular resistance; and paradoxical elevation of central venous pressure.

Renal

Decreased renal blood flow and decreased glomerular filtration rate (GFR), with resulting oliguria.

Gastrointestinal

Splanchnic hypoperfusion, mucosal ischemia, and reduced hepatic blood flow with secondary impairment of lactate clearance.

Abdominal Wall

Reduction in compliance and rectus blood flow.

Clinical Presentation

As patients with developing IAH are initially asymptomatic, early clinical monitoring of high-risk patients, with standardized measurement of IAP, may prevent development of ACS.

Risk factors for IAH/ACS include undergoing a damage control laparotomy, massive transfusion (> 10 U PRBC in 24 h), or massive fluid resuscitation (> 5 L in 24 h) and presence of hemoperitoneum, extensive burns, acute pancreatitis, ascites, and large incisional hernia repair with loss of domain, large intra-abdominal fluid collections, or abscesses.

Once ACS develops, patients may have a tense and distended abdomen on physical examination. High peak airway pressures with hypercapnea, hypoxia, oliguria, and cardiovascular dysfunction with hypotension may also be present and should raise the index suspicion and prompt rapid therapy [1–3].

Diagnosis

Physical examination is notoriously unreliable and correlates poorly with levels of IAP. Currently, the measurement of bladder pressure is the gold standard. It is an indirect method, which has been proven to be reliable at a minimal cost. First described in 1984 and validated in animal studies in 1987, the technique utilizes a Foley catheter with a pressure transducer system by injecting 25 mL of sterile normal saline into the empty bladder and recording the measured pressure at the midaxillary line (Fig. 3.1).

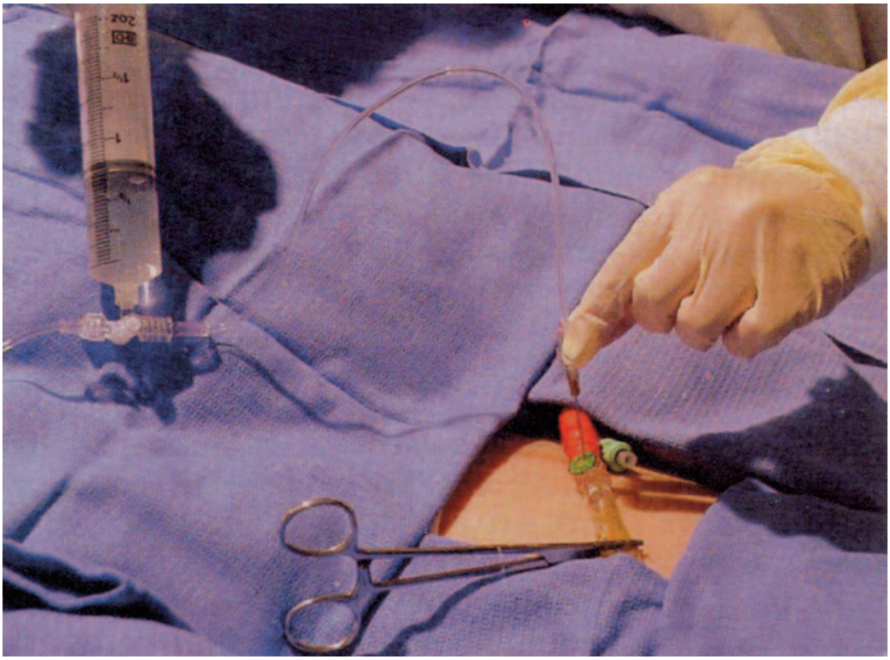

Fig. 3.1 Transvesical method of IAP measurement

Less commonly, intragastric pressures could be measured by attaching a nasogastric or gastrostomy tube to a saline manometer or a pressure transducer. In this method, 50–100 mL of saline are instilled into the stomach via the nasogastric or gastrostomy tube. The manometer or transducer is zeroed at the midaxillary line and the pressure is measured at end-expiration.

Used occasionally in laparoscopy, a direct measurement of IAP can be obtained by directly placing a catheter into the peritoneal cavity and connecting it to a saline manometer or pressure transducer. Another, even more invasive direct measurement involves the placement of a catheter directly into the vena cava. Direct measurement methods have largely been supplanted by the less invasive indirect approaches described above, which utilize pressure measurements that are recorded in abdominal organs such as the stomach and bladder. Both of these methods are predicated on the fact that the stomach and bladder are intra-abdominal organs that can be distended and compressed, making them subject to the transmission of IAP.

Management

Increased clinical awareness especially among trauma surgeons and understanding of the disease process has led to improved management strategies over the last decade. Total fascial decompression remains the mainstay in unstable patients with a diagnosis of ACS. The management of the open abdomen that will not close or should not be closed is diverse and should be individualized, as described elsewhere in this volume. Diligent care is critical in order to prevent the development of ACS and ensuing organ failure.

Prevention

Damage control resuscitation (1:1:1 administration of blood products) with the implementation of massive transfusion protocols has resulted in decreased utilization of crystalloids, which are the main culprit of iatrogenic secondary ACS. This novel resuscitation approach, combined with leaving the abdomen open in high-risk patients, has led to decreased incidence of ACS after trauma. Although most of the evidence is retrospective and based on small sample size of victims of penetrating trauma, damage control resuscitation has been extrapolated to all exsanguinating patients. The following nonoperative management techniques could also play a role in the prevention of IAH/ACS.

Nonoperative Management

Initial and subsequent intermittent measurements (every 4–6 h) of IAP in high-risk patients guide selective nonoperative management. Cheatham identified five therapeutic interventions each consisting of several steps.

1. Reduce volume of intraluminal contents with nasogastric and rectal tube decompression as necessary. Prokinetic agents can be used if needed.

Early enteral nutrition is encouraged in patients with an open abdomen with no effect on abdominal closure rate. In addition, the reduction in pneumonia associated with immediate enteral nutrition suggests a tangible benefit [5, 6, 8].

2. Evacuate intra-abdominal space occupying lesions with image-guided percutaneous or surgical drainage.
3. Improve abdominal wall compliance with adequate sedation and analgesia and, if necessary, neuromuscular blockade.
4. Optimize fluid management. Avoid excessive crystalloid infusion and judiciously use diuretics to achieve zero to negative fluid balance by the third postoperative day.
5. Optimize systemic perfusion. Hemodynamic monitoring and goal directed fluid management.

Nonoperative management is not a substitute for surgical decompression. Increased IAH with development of organ failure should prompt urgent abdominal decompression.

Operative Management

The decompressive midline laparotomy is the long established standard therapy for the definitive treatment of ACS. Unstable patients can be decompressed in the ICU, with a temporary abdominal closure applied at the bedside. The improvement in hemodynamic and ventilator parameters is usually dramatic with almost immediate decline in IAP, PIP, and ICP and immediate increase in blood pressure and, later, improved urine output. The surgeon has to be prepared for potential consequences of reperfusion injury with a massive systemic inflammatory response. A more stable patient who can be transported should be optimized and decompressed in the more controlled environment of the operating room.

Alternatively, a bilateral transverse subcostal (Chevron) laparotomy can be performed. This technique could be utilized if extensive adhesions are expected in the midline or, as proposed by Leppaniemi, for treatment of ACS associated with severe acute pancreatitis [7, 10].

Another alternative technique described by the same author is the subcutaneous linea alba fasciotomy (SLAF). With this technique, three transverse 2–4-cm-long incisions are placed 10 cm below the xiphoid and 5 cm both above and below the umbilicus. The linea alba is divided in the midline, leaving the peritoneum intact. The author was able to create a fascial opening of 8–10 cm with a reduction of IAP of 10–15 mm Hg. Fifty percent of the patients with SLAF avoided full decompressive laparotomy. Cheatham modified this technique for a morbidly obese trauma patient placing two 4-cm-long horizontal midline incisions, one between the xiphoid and the umbilicus and the other between the umbilicus and pubis. The fascial incisions were further extended superiorly and inferiorly leaving the skin intact. The total reduction in IAP was 16 mm Hg and patient improved clinically. SLAF is a less invasive form of abdominal decompression suitable for more stable patients with mild forms of IAH/ACS. Patients also have to be closely monitored during and after the procedure. In cases of unsuccessful decompression with this technique, the procedure clearly has to be converted to a formal decompressive laparotomy. Potential benefits of SLAF are lower rates of enterocutaneous fistualization, fewer infections, better visceral protection, and a less invasive repair of the resulting incisional hernia defect. SLAF is a promising new alternative technique that may play a role in the comprehensive management of ACS/IAH, but long-term data are still lacking.

Summary

ACS is a condition with a high incidence of morbidity and mortality. Clinical recognition of high-risk patients and understanding the pathophysiology that may lead to ACS/IAH is of paramount importance. Proactive management utilizing the abovementioned preventive and nonoperative as well as decompressive techniques clearly saves lives and returns patients to their normal function.

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Chapter 4
Types of Closure

Dale A. Dangleben, Andrew Dennis and Firas G. Madbak

The "Vac Pack"

Equipment

- Chlorohexidine sponges to cleanse perincisional skin
- Sterile blue towel
- Pediatric drape
- Poole tip suction
- Suction tubing
- Suction canister
- Pulse versus sterile saline irrigation
- Four sterile laparotomy pads
- Suture removal kit
- 10–10 nonadherent polyethylene drape (3M, St. Paul, MN) or sterile X-ray cassette cover
- Benzoin (PDI, Orangeburg, NY) or Mastisol (Eloquest, Ferndale, MI)
- Large iodoform-impregnated (Ioban, 3M, St. Paul, MN) dressing
- Two Jackson-Pratt (*Baxter*, Deerfield, *IL*) drains (or nasogastric tubes)

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F. G. Madbak, D. A. Dangleben (eds.), *Options in the Management of the Open Abdomen,* DOI 10.1007/978-1-4939-1827-0_4

Fig. 4.1 Barker Vac Pack

This is the simplest dressing being utilized in the management of the open abdomen. Barker et al. [1–3] retrospectively described a 7-year experience of its use. The "Vac Pack" consists of a sterile 10 × 10 Steri-Drape, two large surgical sponges, two 10-French flat Jackson-Pratt (JP) drains or NG tubes, topped with a sterile towel followed by Ioban drape (Fig. 4.1). Some surgeons choose to forgo the sponges and sterile towel to allow for postoperative bowel edema as well as allow inspection in cases where worsening bowel ischemia is a concern.

Scissors are used to create fenestrations in the 10 × 10 drape to allow for outward egress of fluids. The Steri-Drape is then placed circumferentially under the fascia 2–3 in. from its edge, taking care to cover the abdominal viscera as an interface layer prior to placing overlying laparotomy sponges. The two laparotomy sponges are placed over the drape, taking care to cover the cut edges of skin and subcutaneous tissues to prevent desiccation. Two JP drains with their tips oriented in a caudad direction. A sterile towel is shaped to fit over the entire wound. The abdominal wall should then be cleaned and dried, and an adhesive such as Mastisol or Benzoin is generously applied to the skin surrounding the wound. Following this, an Ioban dressing is placed over the entire abdomen. Care must be taken to ensure a good seal of the Ioban dressing to the skin, particularly, in the problematic contours of the suprapubic and inguinal regions, because an inadequate seal in these areas will result in leaking of intra-abdominal fluid and failure of the vacuum dressing. A "mesentery" is created at the top of the vac pack for each JP drain by "tubulizing" the Ioban drape around each drain as the drape is secured. The JP drains are then placed to 100–125 mm Hg continuous wall suction creating a negative pressure system that serves to minimize fascial retraction and loss of abdominal domain [5]. The obvious advantage of using this method is that it is easy and quick to apply, especially in the damage control setting. The most common complications (see Chap. 8) are fistula formation (5–7 %), intra-abdominal abscesses (4–6 %), and delayed small bowel obstruction (4 %). Mean closure times are between 6–10 days with reported primary fascial closure rates of 70–80 %. One criticism of this method is the lack of consistent measured applied negative pressure which tends to be much less than the set pressure of 100–125 mm Hg.

The Wittmann Patch

The Wittmann Patch (StarSurgical Inc, Burlington, WI) is a simple tool composed of two sheets (40 × 20 cm) of Velcro®-like prosthetic biocompatible material (propylene). The two sheets adhere to each other when pressed together and provide a secure temporary closure of the abdominal wall. The softer "loop" sheet is then sutured to the right-sided fascia with running #1 monofilament nonabsorbable suture. Sutures should be placed 2 cm into the fascia and 2 cm apart and 1–2 cm into the patch to avoid tissue strangulation between bites. Special care should be taken to ensure that the softer "loop" sheet is sutured to the fascia in the proper configuration with its smooth portion facing the intra-abdominal contents and its "fuzzy" portion, containing the loops, facing outwards. The softer loop sheet is then pushed underneath the fascia on the opposite side of the wound (left) taking care to cover the intra-abdominal contents.

The harder "hook" sheet is then similarly sutured to the left fascia, taking care to orient the sheet so that the hooks (scratchy) face inwards. The hooks are gently pressed into the loops of the loop sheet. The hook sheet is then trimmed to fit into the abdominal wound. Access to the abdominal cavity is achieved by simply unfastening the two adhering sheets. Management of the Wittmann Patch requires bedside abdominal washouts every 24–48 h with tightening and trimming of the excess Velcro®-like layers sequentially [8].

The major advantage of this approach is the ability to apply tension to the midline fascia, which prevents lateral retraction of the aponeurotic edges and facilitates definitive delayed primary closure. The Wittmann Patch also allows for easy successive access for packing removal, peritoneal washouts, assessment of bowel viability, tissue debridement, and ultimately abdominal closure. Disadvantages of the Wittmann Patch include poor control of third-space fluid, some damage to the fascial edges where the Wittmann Patch is sutured (which may require debridement), adherence of bowel to the abdominal wall, and potential for fistula formation (Fig. 4.2).

Wittmann Patch in Conjunction with the Wound VAC

Once the Wittmann Patch is sutured to the fascia, a wet to dry dressing may be applied. It is our preference to apply a KCI Wound VAC above the patch as it controls fluid and maintains subcutaneous and skin approximation closer to the midline.

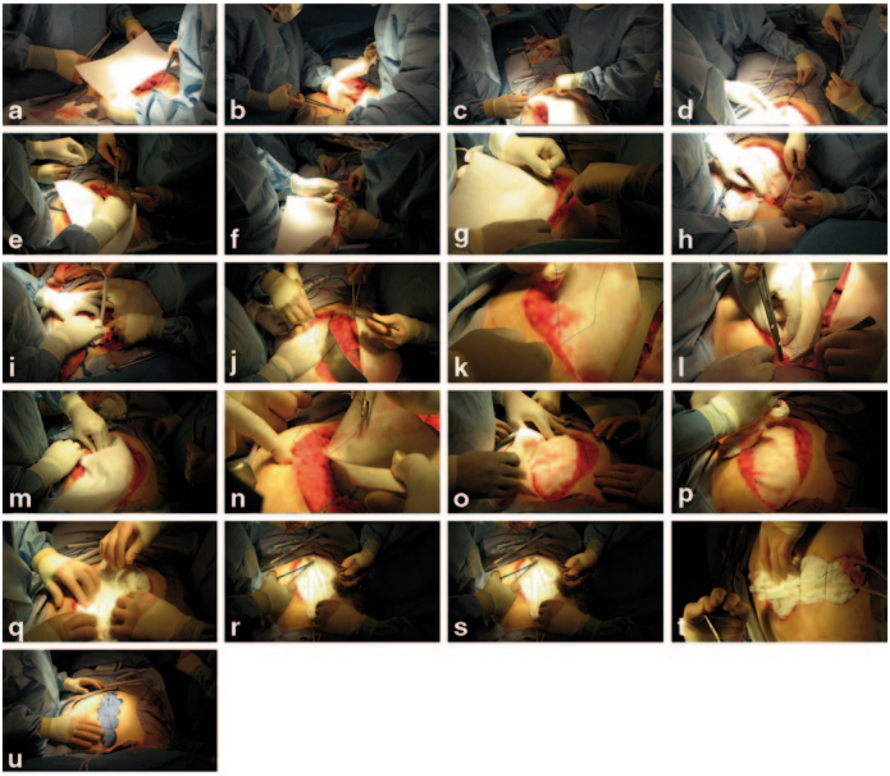

Fig. 4.2 Wittmann Patch application

Wittmann Patch in Conjunction with the Wound VAC and Sutures

In addition to the method outlined above, some surgeons add skin sutures over the wound vac. We discourage this practice as it may cause unnecessary trauma to the skin edges that may affect final closure. However, as edema diminishes, it is sometimes considered as it ultimately allows for better reapproximation (Figs. 4.3 and 4.4) [7–9].

Absorbable Mesh

Absorbable mesh has been used in the management of the open abdomen for the last 25 years. Synthetic absorbable meshes such as polyglactin (Vicryl; Ethicon, Somerville, NJ) and polyglycolic acid (Dexon; Covidien, Mansfield, MA) are the

Fig. 4.3 Wittmann Patch in conjunction with Wound VAC

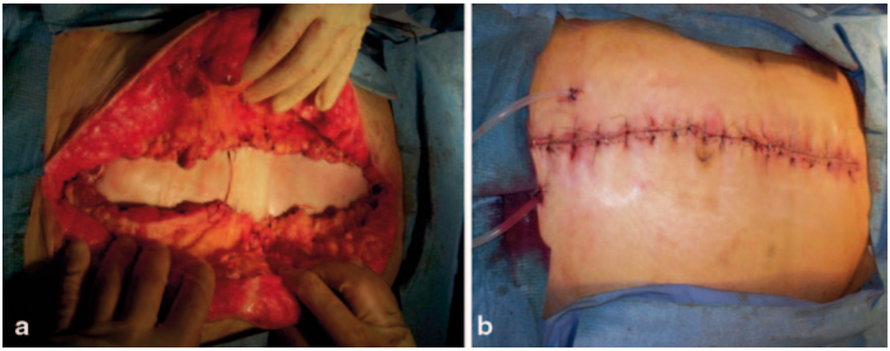

Fig. 4.4 **a** Wittmann Patch tightening at patient's bedside. **b** Same patient after skin closure after achievement of primary fascial closure

meshes most frequently used (Fig. 4.5). This is a viable option in the abdomens that cannot be closed. This method should be employed when abdominal re-exploration is unlikely to be required. However, if re-exploration becomes necessary, the mesh can be incised in its mid-portion and re-approximated with suture.

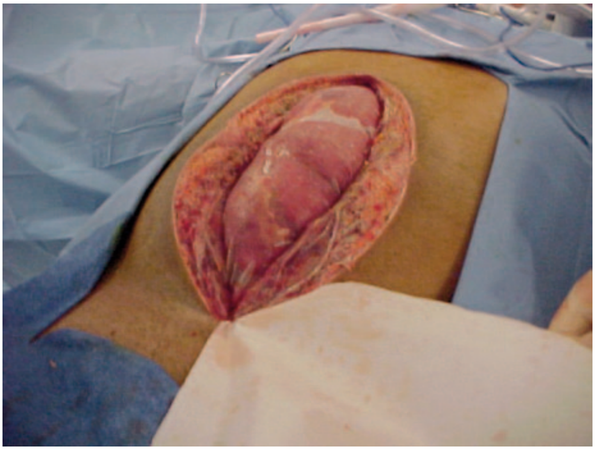

Fig. 4.5 Vicryl mesh application

Generally, the mesh is loosely applied over the abdominal contents and secured to the fascia with either interrupted or continuous suture. The mesh can also be doubled back upon itself prior to suturing it to the fascia for increased strength. The bowel and intra-abdominal contents should be within the abdominal cavity, beneath the absorbable mesh. A Vac Pack or KCI Wound VAC can then be placed over the mesh or alternatively the mesh can be covered with a wet to dry dressing changed every 6 h. In our opinion, it is strongly advisable to place a layer of nonadherent dressings in between the vac sponge and the absorbable mesh in order to reduce the risk of fistulization [5].

If bowel edema resolves within 3–5 days, the mesh can be progressively pleated by the bedside and delayed fascial closure may be possible. If there is persistent bowel edema, the absorbable mesh can either be left in place to granulate typically taking 2–3 weeks after placement, as long as sufficient granulation tissue on the bowel has formed and fixation of the abdominal viscera has taken place. Alternatively, the mesh can be completely removed after 5 days and the wound can be managed with a skin graft directly on the viscera. One of us prefers this latter approach. In either case, a planned ventral hernia is then created by either placing the split-thickness skin graft over the granulation tissue or performing a full thickness skin closure over the granulated viscera (Fig. 4.6). A delayed abdominal wall reconstruction can then be performed 6–12 months later [6].

It is important to allow sufficient time for resolution of inflammation and dense adhesions between the mesh or fascia and viscera. An indication that adequate remodeling has occurred is the so called “pinch test”; the ability to pinch and separate the skin from the underlying mesh in the area of the abdominal defect (Fig. 4.7). The skin should then be assessed prior to definitive repair. If complex rearrangement of tissue is required, preoperative placement of tissue expanders with the help of a plastic surgeon may be required. During the reconstruction, the skin graft must be excised and completely removed from the previously placed mesh, if present. The

Fig. 4.6 **a** Vicryl mesh in situ at the time of reexploration. **b** Immediately after split-thickness skin graft application. **c** 5 months after split-thickness skin graft application

underlying viscera must then be completely lysed from the overlying fascia. The abdominal wall defect is then reapproximated with either the creation of skin flaps, component separation (see Chaps. 6 and 7), the use of mesh, or a combination of all the aforementioned. Drains can then be placed to help eliminate any dead space.

Advantages of the use of absorbable mesh in temporary abdominal closure include its relatively low cost and the ability to apply it directly over the bowel and drain intra-abdominal fluid through it. The main drawbacks include damage to the fascial edges, risk of fistula, and its rapid loss of tensile strength, especially in the setting of infection, which may lead to a large, delayed ventral hernia.

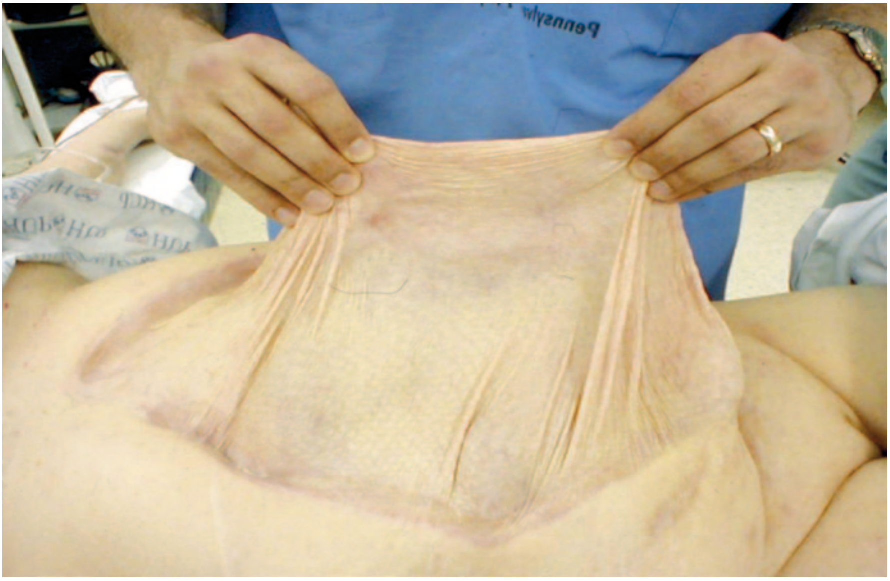

Fig. 4.7 The "pinch" test to assess readiness for definitive abdominal wall reconstruction after planned ventral hernia 1 year after split-thickness skin graft application

Fig. 4.8 Sure-Closure device

Sure-Closure Device

One of the authors has used the Sure-Closure device (Figs. 4.8 and 4.9) to attempt skin closure over the open abdominal viscera or over Vicryl mesh. The main drawback is the labor-intensive time-consuming process that requires tightening twice a day by the surgical team. This is purely experimental without long-term data.

ABThera

Kinetic Concepts Inc (San Antonio, Texas) officially launched the ABThera™ open abdomen negative pressure therapy system, the latest addition to its Negative Pressure Technology Platform (NPTP) in September 2009. The system consists of

Fig. 4.9 Sure-Closure removal and reapproximation with suture

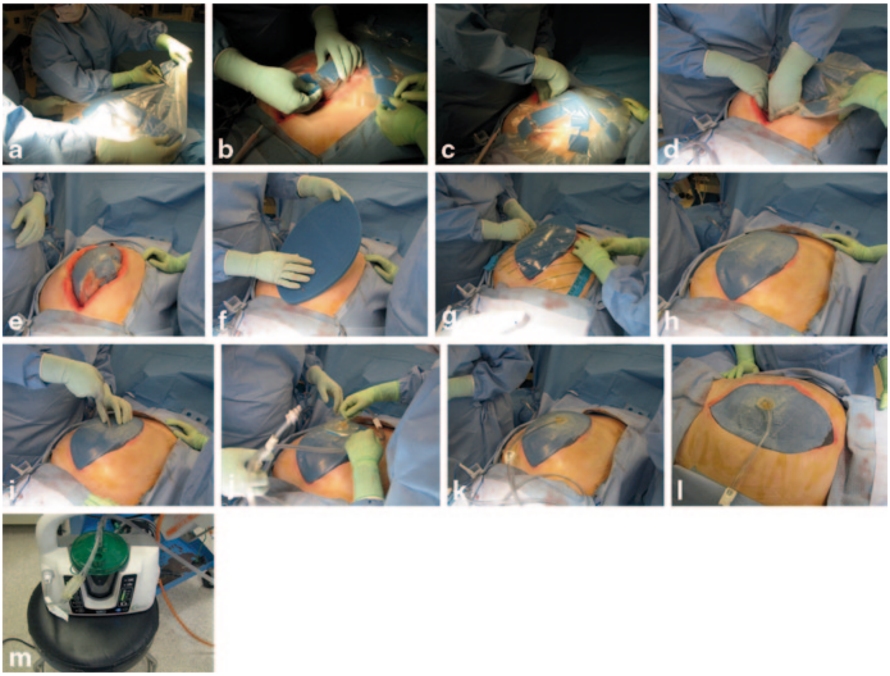

Fig. 4.10 a–m ABThera placement

perforated polyurethane foam encased in a visceral protective layer covered by a drape that is then attached to a negative pressure therapy unit with a 1 L canister and audible alarms. There are three pressure settings (Fig. 4.10).

Unlike the Barker Vac Pack, the suction is readily quantifiable and this actively removes fluid and helps reduce edema thus providing medial tension which helps minimize fascial retraction and loss of domain. Other advantages are its simplicity; it can be placed rapidly and allows quick access for re-entry, and fixity; the dressing stays in place more reliably. The foam allows for easy sizing and no sutures are required for placement. Surgeons familiar with the KCI Wound VAC system in use for many years for coverage of wounds, flaps, and grafts will be accustomed to the application of this device since the concept is the same. Long-term studies are still pending.

Trans-Abdominal Wall Traction (TAWT)

Trans-abdominal wall traction (TAWT) is a technique developed at the Cook County Trauma Unit and used in patients with both acute and chronic defects [4]. An enhancement of the dynamic retention method originally described by Koniaris and colleagues at the University of Rochester has reminded surgeons of the problematic irreversibility of domain loss, and its use emphasizes reversing the process of muscle contraction and muscle fiber shortening that results in the subsequent lateralization of the abdominal wall and hernia formation. The primary muscles affected are the internal and external obliques, the latissimus dorsi, and the transversus abdominis muscles. Instead of accepting the abdominal wall lateralization as an inevitable outcome, TAWT is underscored by the simple use of sustained traction. Borrowed from physiatrists, the concept of managing muscle contractures with a technique of constant countertraction to the affected muscle groups, to restore muscles to neutral length and normal function is the underlying principle of the TAWT closure. Over time, the contractures release and the muscles lengthen. The device is gradually tightened over days which allows for a nonsurgical advancement of the lateral abdominal wall back to midline. Such success is attributed to a concept known as myofascial release which occurs at the level of the muscle fibers and allows for lengthening of the overall muscle group. In doing so, surgeons are able to restore natural anatomy to the abdominal wall without component separation, bridging meshes, or other prosthetics. In our experience, the success of TAWT is predicated upon the timing of device insertion and the understanding that it is critical to keep the abdominal wall independent from the underlying viscera; despite adherence of bowel loops, it is essential to prevent abdominal wall adhesion to the bowel. By keeping the abdominal wall separate, closure could be attempted several days to weeks later. In some cases, abdominal wall fusion to bowel occurs and the success of contracture release using TAWT is reduced, and the patient will likely be remanded to a skin graft. The same holds true for chronic complex abdominal reconstruction patients for whom the surgeon chooses to use TAWT. These patients often require a long, tedious operative procedure to release adhesions, take down ostomies and excise skin grafts. In these patients, depending on the degree of resuscitation required, it might be prudent to stage the repair by placing a negative pressure dressing the first day and come back for the placement of TAWT after edema subsides. In order to accomplish the above, we couple the use of TAWT with an open abdomen protocol that focuses on timing of TAWT insertion, timing of tightening, and the use of way points that are based on patient volume status, degree of edema, physiologic steady state, and nutrition. In order to keep the viscera free from adhering to the peritoneal surface of the abdomen, we insert a plastic visceral protective barrier that sits in the abdomen over the abdominal contents. This barrier is fenestrated and can be a sterile x-ray cassette cover or a commercial version as is found in negative pressure abdominal wound dressings [5].

TAWT Technique

The TAWT device consists of two hook and loop sheets (Wittmann Patch ™, Star Surgical, Burlington, WI), four padded plastic, pre-drilled bolsters, #5 Ethibond™ polyester suture (Ethicon, Somerville, NJ), a fenestrated plastic sheet (to cover viscera), and several $8' \times 8'$ pieces of adherent hydrocolloid dressing.

Based on the associated open abdomen protocol, once the patient is considered "near dry weight," the TAWT device is inserted. The anterior abdominal wall skin is covered by adherent hydrocolloid dressings. On each side of the oval-shaped abdominal defect, two 1′ × 9′ semi-rigid, padded bolsters are placed over the hydrocolloid dressing. These bolsters are placed at the lateral side of the rectus muscles, on both sides of the wound. Care is taken to stay lateral to avoid the vascular perforators within the muscle. A set of hook/loop sheets 30 × 10 cm are placed into the abdomen as an underlay abutting the peritoneal underside of the abdominal wall. The loop sheet is placed facing up and the hook sheet is placed facing down. The hook and loop sheets are fixed to the underside of the abdominal wall by #5 polyester sutures running parallel to the vascular bundle at the lateral edge of the rectus sheath. The sutures penetrate all layers of the abdominal wall, effectively sandwiching it between the overlying bolsters. A thin, fenestrated plastic barrier is placed into the abdomen over the abdominal viscera to provide protection to the viscera and inhibit fusion of the viscera to the underside of the abdominal wall. The external lateral abdominal wall is manually pushed to the midline with a medially directed force applied to the external, lateral abdominal wall. Simultaneously, medial traction is applied to the abdominal wall via the hook and loop sheets as the hook sheet is lifted medially and anteriorly and the loop sheet is pressed medially and posteriorly. They are then adhered to each other to fix the position of the abdomen. A negative pressure dressing is then applied to the midline wound over the hook and loop sheets. The TAWT system applies isometric traction for a period of 48 h, allowing for myofascial release and subsequent relaxation and lengthening of the oblique muscles and surrounding connective tissue. The patient is then returned to the operating room and under general anesthesia, the hook and loop sheets are opened. The abdomen is then washed out as necessary, the visceral protective barrier is rinsed or replaced, and the TAWT device is again medially tightened in the manner described above. Patients are extubated between operations when possible [4].

Myofascial Release as the Probable Mechanism for TAWT Success

The concept of myofascial release is the basis for TAWT. In theory, TAWT creates traction to maintain the abdominal wall in line with the oblique muscle fibers and maintains a constant stretch, which opposes contracture.

Several studies have demonstrated that connective tissue exhibits a slow, progressive shortening over a period of days if it is not resisted by an equal or greater force. The term "domain loss" describes this concept when it is applied to the lateral contractures of the abdominal wall. Prevention of contractures by the simple addition of constant tension tends to be more feasible than correcting the shortening after it has developed. TAWT is capable of both. From a histological perspective, areolar connective tissue in regions of contracture gradually reorganizes to become much more dense. Once this occurs, motion in that area is restricted. This

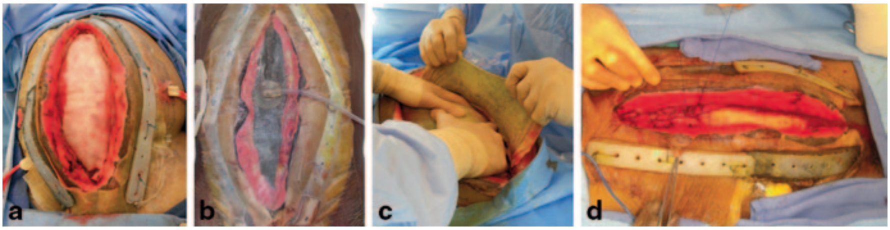

Fig. 4.11 The TAWT system is applying isometric traction for a period of 48 h, allowing for myofascial release and subsequent relaxation and lengthening of the oblique muscles and surrounding connective tissue. The patient is then returned to the operating room, paralyzed, intubated, and the hook and loop sheets are opened. The abdomen is then washed out as necessary, the visceral protective barrier is rinsed or replaced, and the TAWT device is again medially tightened

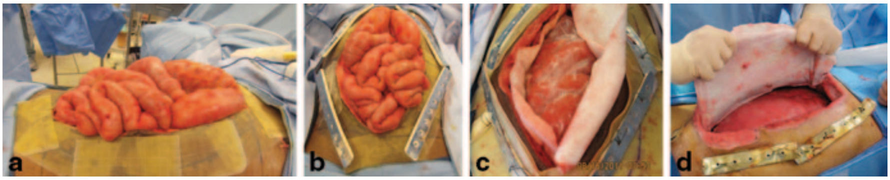

Fig. 4.12 TAWT device

shortening of connective tissue has been attributed to changes in the length of the collagen fibers to the metabolic response of fibroblasts.

When an abdomen is left open, each side of the abdominal wall lateralizes due to shortening and contracture from lack of opposing forces. TAWT capitalizes on that concept by placing each side of the contracted abdominal wall under prolonged, dynamic tension, allowing plastic elongation of connective tissue fibers. Such elongation has been attributed to the separation of the attachments at points of contact between the adjacent collagen fibers in the connective tissue meshwork (Figs. 4.11 and 4.12).

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Chapter 5
The Biologics Explosion Era

Dale A. Dangleben and Firas G. Madbak

The application of nonsynthetic or natural tissue mesh in the reconstruction of the open abdominal wall after damage control had become rapidly widespread in the early twenty-first century. Despite their popularity, there are no compelling data comparing the effectiveness of these natural tissue alternatives with that of synthetic mesh repairs.

Categorized based on source material (e.g., human, porcine, bovine) as well as postharvesting processing techniques (e.g., cross-linked, non-cross-linked) and sterilization techniques (e.g., gamma radiation, ethylene oxide gas sterilization, nonsterilized), numerous products are available as listed in Table 5.1. These products are largely composed of acellular collagen and may provide a matrix for neovascularization and native collagen deposition. Cross-linked mesh has slowly fallen out of favor because of the tendency to become encapsulated. In infected or contaminated cases where synthetic mesh is thought to be contraindicated, these properties theoretically provide distinct advantages including prevention of bowel desiccation and fistula formation, providing better integrity of the abdominal wall, accelerating angiogenesis and wound repair, achieving a biologic barrier to bacterial invasion, and allowing easier access to the peritoneal cavity for tentative abdominal wall reconstruction at a later time. Since the open abdomen is technically colonized from the outset, synthetic mesh is generally not recommended because of the high rate of mesh infections. Ideal placement techniques are yet to be defined for these relatively new products; however, some general principles apply. These products function best when used as a fascial reinforcement. An underlay (intraperitoneal),

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F. G. Madbak, D. A. Dangleben (eds.), *Options in the Management of the Open Abdomen,* DOI 10.1007/978-1-4939-1827-0_5

Table 5.1 Categories of biologics

Product	Source	Cross-linked	Sterilization method
Alloderm (Lifecell, Branchburg, NJ)	Human dermis	No	Ionic
Allomax (Davol, Warwick, RI)	Human dermis	No	E beam
Flex HD (Ethicon, Sommerville, NJ)	Human dermis	No	Ethanol
Strattice (Lifecell, Branchburg, NJ)	Porcine dermis	No	Gamma irradiation
Permacol (Covidien, Norwalk, CT)	Porcine dermis	Yes	Ethanol
Collamend (Davol, Warwick, RI)	Porcine dermis	Yes	Ethanol
Xenmatrix (Davol, Warwick, RI)	Porcine dermis	No	Gamma irradiation
Surgimend (TEI Biosciences, Boston, MA)	Bovine fetal dermis	No	Ethanol
Veritas (Synovis, St. Paul, MN)	Bovine pericardium	No	
Periguard (Synovis, St. Paul, MN)	Bovine pericardium	Yes	
Surgisis (Cook, Bloomfield, IN)	Porcine intestine	No	Ethanol

onlay or inlay (retrorectus) placement could be utilized rather than as a bridge or interposition repair. Unfortunately, the long-term durability of biologic mesh is currently unknown [4].

Quilting

The use of biologic mesh has been used more frequently, especially with the predominant use of acellular dermal matrix (ACM). Historically, individual pieces were small and therefore had to be quilted together. Initially, it was felt that the acellular dermal matrix quilts could be sutured to the fascial edge with acceptable outcomes (Figs. 5.1 and 5.2a–d). This concept was inconsistent with general principles learned with synthetic mesh experiences [1–3, 6].

Bridging the Gap

During that era, with the rising prominence of ACM use, even the smallest fascial gaps were bridged with the biologics. This resulted in what we called "bridging the gap." As seen in the case below, the fascial edge is about 5 cm apart and with a myocutaneous and myofascial flap; this could have been closed primarily. Preference was given to attempts at stimulating fascial regenerating by dermal matrix implantation with the bridging technique. The immediate results were good and led to a reduction of ICU and hospital length of stay as the patients were discharged sooner (Fig. 5.3a–g).

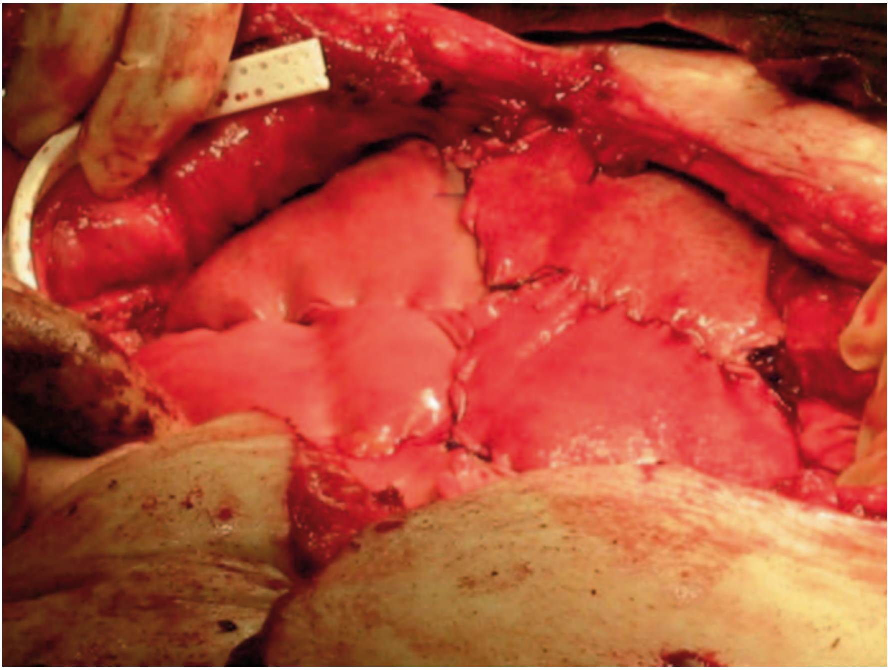

Fig. 5.1 One of the very first reported cases in which the acellular matrix was used in 2001. It illustrates the quilting of the small pieces of ACM to each other and to the fascial edge

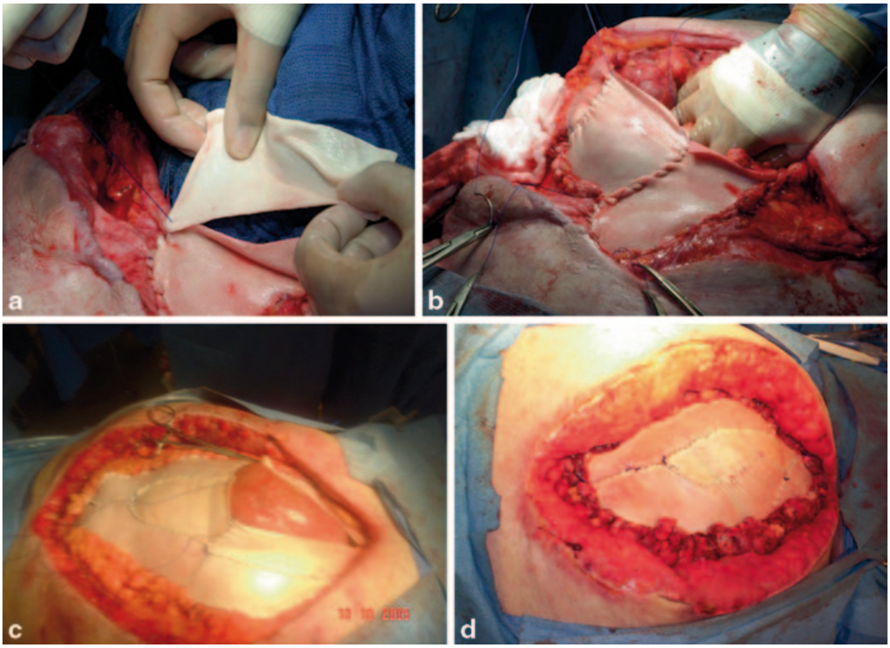

Fig. 5.2 a–d Quilting and suturing to fascial edge

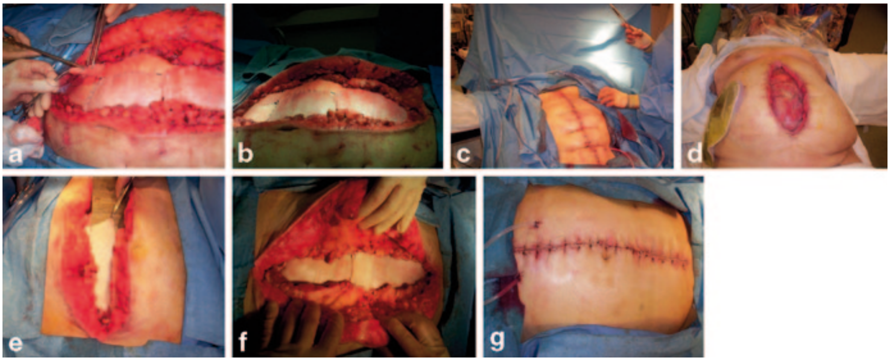

Fig. 5.3 a–g Bridging the gap with quilted mesh

Larger Biologics

With the increased utilization of the smaller biologic meshes, there was a demand for larger pieces. Industry responded with newer allografts that were longer but not wider. Xenografts (porcine, bovine) were introduced and larger pieces were marketed. The large pieces of xenograft allowed for inner fascial overlap. In many cases, there was not enough tissue to close over the graft but the concept of tissues regeneration did not allow for component separation with lateral release (Fig. 5.4a–g) [4, 5].

Sequelae of the Biologic Era

In one author's experience, outpatient follow-up of patients treated with the bridging the gap technique consisted of returns to the office with complaints of abdomi-

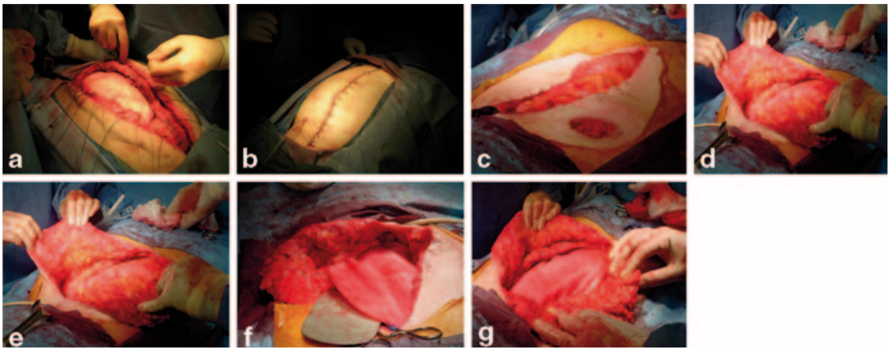

Fig. 5.4 a–g A large piece of xenograft bridging the fascial gap. Note the distance of the fascial edge

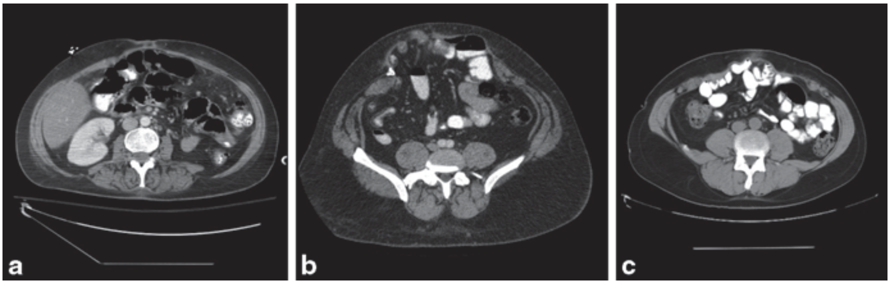

Fig. 5.5 a–c Failure of bridging the gap postoperative: computed tomography (CT) scans of different patients managed with acellular dermal matrix during the biologic era (a) 1 month, (b) 6 months, (c) 2 years

nal bulging, typically within 6 months to a year. This is particularly problematic when human tissue biologics are used, thus more surgeons prefer porcine or bovine products. Physical exam findings demonstrated what appeared to be ventral hernias. On imaging, these "hernias" were more precisely eventration due to extreme stretching and laxity of the biologic material (Fig. 5.5a–c). Clearly, there was no incorporation and transformation of the adjacent tissue. Another main drawback is the eventual weakening and dissolution of the mesh material which is sometimes observed at reoperation (Fig. 5.6).

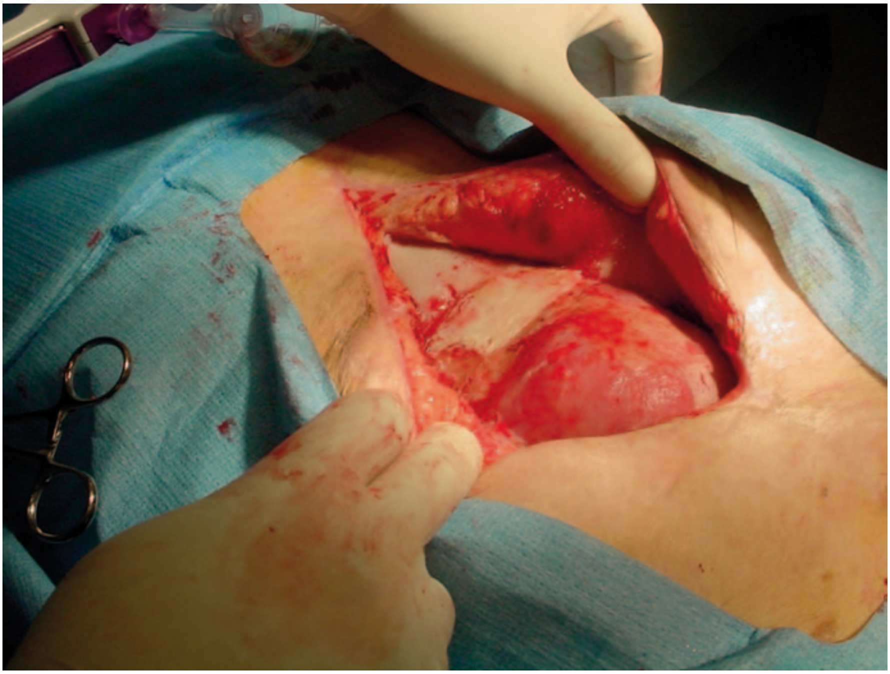

Fig. 5.6 Some of the ACM showing partial disintegration with a portion unchanged 5 months after surgery

While preferentially used in the contaminated or infected field, the unbridled use of biologic mesh may warrant a closer look and more rigorous investigation as it may represent adoption of an unproven approach with significant expense and a suboptimal outcome.

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Chapter 6
Considerations in Abdominal Wall Reconstruction

Joshua M Adkinson, Ramon Garza III, M. Shuja Shafqat and Marshall G Miles

Defects of the abdominal wall have many etiologies, ranging from congenital malformations, trauma, burns, and radiation to those caused by surgical intervention for a variety of disease processes. The resultant defects can be broadly classified into partial thickness and full thickness defects depending on the components involved. Furthermore, the acuity of the wound could influence reconstruction options. Based on extent of the wound and involvement of adjacent structures, reconstructive maneuvers may range from simple primary closure to microsurgical free tissue transfer. For complex reconstructions, a collaborative approach between acute care, trauma, and plastic surgeons may yield the most durable, functional, and aesthetic outcomes.

Reconstruction of the abdominal wall requires a thorough understanding of the anatomy and function of the involved structures. The anatomic layers of the abdominal wall include the skin, subcutaneous tissue, superficial and deep fascia, muscle, extraperitoneal fascia, and peritoneum. The main muscles of the abdominal wall include the external oblique, internal oblique, transversus abdominis, and rectus

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F. G. Madbak, D. A. Dangleben (eds.), *Options in the Management of the Open Abdomen,* DOI 10.1007/978-1-4939-1827-0_6

abdominis muscles. These muscles serve to provide protection of the abdominal viscera and stabilization of the torso, while also playing a key role in movement and posture. The arterial supply to the abdominal wall consists of the superior and inferior epigastrics, superficial and deep circumflex iliacs, superficial external pudendals, intercostals, and lumbar vessels. Innervation to the abdominal wall is from the ventral rami of T7 through L4, the iliohypogastric, and ilioinguinal nerves.

Prior to embarking on any attempt at abdominal wall reconstruction, an initial thorough review of the patient's history is mandatory. Particularly, the surgeon should elicit comorbidities, past surgical history, tobacco use, previous radiation, and medications. The examination should focus on which noting structures are absent, whether the defect is midline or lateral, as well as the presence of any surrounding scars that may compromise attempts at local flap reconstruction. Vascularity of adjacent tissues should be assessed as this is especially important when using underlying prosthetic materials. Additional attention during the preoperative evaluation should focus on the presence of an enterostomy, enterocutaneous fistula, contamination, or infection.

Ideally, closure should be tension-free in an effort to prevent tissue necrosis or fascial dehiscence. However, when this is not possible, the interpositional use of biologic materials is recommended. Introduced in Chap. 5 and discussed in more detail below, these adjuncts are significantly easier to salvage when exposed or infected in contradistinction to prosthetic agents. Management of the open abdominal wound presents numerous challenges: bowel edema, continued sepsis, and loss of abdominal domain. Skin grafting and tissue expansion should be avoided, when possible, as they require multiple operative procedures, with their inherent associated morbidity.

Details of the techniques for management of the complex abdominal wall defect are discussed in other chapters. However, a collaborative approach to abdominal wall reconstruction is typically most effective. Plastic surgeons may offer alternatives such as local, regional, or free flap reconstruction. In some situations, these options may be unavailable, secondary to either limited familiarity with these techniques or unavailability of the requisite equipment. In these settings, a broad range of relatively simpler options exist to successfully manage abdominal wounds in one or multiple stages.

Prosthetics and Adjuncts in Abdominal Wall Reconstruction

The word prosthetic is derived from the Greek word *prostithenai* (from *pros* "add to" and *tithenai* "to put/place"). In modern times, it is defined as "an artificial device to replace or augment a missing or impaired part of the body." Originally, prostheses for abdominal wall reconstruction were meshes created from various types of wire. In the 1940s and 1950s, tantalum mesh and stainless steel were both described for use as prosthetics in abdominal wall reconstruction but quickly abandoned because of numerous complications. Nylon, fiberglass, and Teflon are all examples of other materials that have been used. The development of plastic in the twentieth century allowed for creation of meshes which were lighter and more flexible. These later became the prosthetics of choice [1–3].

To reconstruct the abdominal wall, one can refer to the "reconstructive ladder"—a series of options for wound closure, ranked from the least to most invasive. Autologous tissue, however, is typically described as the "gold standard" for abdominal wall reconstruction, as it is associated with fewer of the common complications seen with implantable prostheses such as infection, hematoma, seroma, fistula, and extrusion. Synthetic meshes are prone to infection in grossly contaminated fields, thus precluding their use. The advent of biologic mesh has reduced the infectious complications seen with synthetics based on the premise that they can safely be used in contaminated wounds.

Synthetic Mesh

Synthetic meshes were the first prostheses used in abdominal wall reconstruction, and have continued to develop since their introduction in the mid-twentieth century. Although there have been many advances in mesh materials, there is no "one-size-fits-all" mesh. Ideally, a synthetic mesh should be nontoxic, resistant to infection, and immunologically inert [1]. Currently, there is no prosthetic mesh that exhibits all of these properties. However, most synthetic meshes are strong and pliable, making them useful for abdominal wall reconstruction in clean cases.

Most meshes have a tensile strength that is twice that necessary for the average abdominal repair; paradoxically, hernias still recur. True breakdown of these repairs most commonly occurs at the tissue–mesh interface. Thus, the material, the quality of the fascia to which the mesh is fixated, and the strength of the interface are some of the most important qualities in an abdominal wall reconstruction.

There are many intrinsic properties that can determine the success of a mesh repair (Table 6.1). Porosity is frequently noted as one of the most important intrinsic properties of synthetic meshes. Macroporous meshes ($>75\ \mu$) allow for macrophage and neutrophil infiltration, better vascular ingrowth, and collagen deposition and incorporation. Macroporous meshes are also lighter and more flexible, which inevitably improves quality of life postoperatively. Meshes with smaller pores ($<10\ \mu$) have decreased incidence of bowel adhesions and injury; however, they allow bacteria to enter the prosthetic and prevent inflammatory cells from entering, thus inhibiting the immune response. This can lead to a higher incidence of infection [4].

Polypropylene material is one of the most commonly used synthetic meshes. It is nonabsorbable and popular for its macroporous structure. It is advantageous because of better fibrovascular ingrowth and immune cell penetration. It also leads to stronger scar formation, creating a more durable apposition with the fascial edge [5]. These meshes create a stiff scar due to the lack of pliability. This can be useful to cover large defects of the abdominal wall where there is little support. The

Table 6.1 Classification of prosthetic mesh based on pore size

Type	Porous structure	Examples
Type I	Macroporous (>75 μ)	Marlex[a], Prolene[b] Trelex[c]
Type II	Microporous (<10 μ in at least one direction)	ePTFE, Dual-Mesh[d]
Type III	Macro and microporous	PTFE[d], Mersilene[b] Surgipro[e]
Type IV	Submicronic pore size	Silastic sheeting, Celgard[f]

[a] Bard, Murray Hill, NJ
[b] Ethicon, Somerville, NJ
[c] Boston Scientific, Natick, MA
[d] Gore, Newark, DE
[e] Covidien, Mansfield, MA
[f] Polypore, Charlotte, NC

macroporous structure also allows for neutrophil and macrophage migration into the mesh, thereby allowing clearance of bacteria [1, 4]. More common complications include mesh extrusion or erosion into bowel.

PTFE/ePTFE (Gore-Tex, W.L. Gore, Newark, DE) is another nonabsorbable mesh. It is stronger than polypropylene but also flexible. The expansion process of PTFE creates a material that is relatively inert when implanted. The small pore size accounts for a minimal foreign body reaction compared to polypropylene and accounts for its advantages and disadvantages [5]. There is less risk of the mesh erosion through the skin or viscera due to its microporous structure and can be placed directly over the exposed bowel. The small pore size does predispose this implant to seroma formation, as this fluid cannot adequately egress through the mesh. Similarly, formation of fluid can increase the risk of abdominal compartment syndrome [6]. It also allows smaller bacteria (1 μ in size) to migrate into the mesh but does not allow entry of inflammatory cells, such as macrophages (greater than 50 μ). This, along with the lack of fibrovascular ingrowth, predisposes the implant to infection, which would ultimately mandate mesh removal.

Alternative options include polyglactin-based meshes (e.g., Vicryl, Ethicon; Dexon, Davis & Geck, Sugarland, TX) which are absorbable. Their primary advantage is use as a temporary solution in grossly contaminated wounds. Polyglactin-based options retain their strength in the short term, have a decreased risk of fistula formation, and allow fluid drainage. They are usually not used for long-term or permanent reinforcement as a result of progressive loss in tensile strength over time.

Composite meshes (e.g., Vypro I/II, Ultrapro, Proceed, Ethicon, Somerville, NJ; Sepramesh and Composix, Bard, Murray Hill, NJ) are also available for repair of abdominal wall defects. The primary advantage of composite meshes is that one side of the mesh prevents adhesions to adjacent bowel, while the other provides strength and support to the abdominal wall. These meshes offer a great option for the abdominal wound with exposed viscera; however, the anti-adhesive layer can develop marginal breakdown, leading to adhesions. Also, the permanent materials in these prostheses can become infected if bacterial seeding occurs.

The major drawbacks to the use of synthetic mesh are infection and seroma formation. Seroma formation is common and is usually the result of extensive dissection and creation of dead space. Seromas of the abdominal wall are typically managed with observation; however, if drainage is necessary, it is imperative to obtain a fluid culture. Observed in large series of laparoscopic ventral hernia repair experience, aspiration of seromas has the risk of introducing bacteria, resulting in infection and the recurrence of the hernia. Usually, expectant management is all that is required. Hematomas can also occur and are treated in the same fashion. Hematomas require treatment if actively bleeding, expanding, or infected.

Infection is the most feared complication and usually necessitates prosthetic explantation. This is most commonly due to surgical wound infection that tracks the underlying mesh, resulting ultimately in mesh extrusion. Every attempt should be made to cover the mesh with well-vascularized tissue to decrease the incidence of these complications.

Biologic Mesh

Biologic mesh materials are derived from human or animal tissue. Human dura, dermis, muscle, fascia, small intestine submucosa, porcine dermis, amniotic membranes, and pericardium have all been used in the past as a biologic mesh prosthetic. Chemical treatments are used to minimize associated foreign body reaction. They are incorporated into native tissue by the host inflammatory cascade and continue to undergo remodeling over time. Less concern for complications has been noted even when placing these materials in infected fields or with inadvertent enterotomies or serosal injury. As previously mentioned, routine use of biologic mesh is still difficult to justify, given their high cost and the lack of long-term data. Still, they are an excellent option in complicated abdominal wall defects.

AlloDerm (Lifecell, Branchburg, NJ) and Allomax (Bard, Murray Hill, NJ) are two of the most popular biologic regenerative tissue matrices which consist of non-cross-linked human dermal collagen matrices. The dermal matrix is treated with sodium chloride and sodium deoxycholate to remove living cells, leaving behind extracellular matrix. Acellular human dermis has numerous applications, ranging from incisional and ventral hernia repairs to abdominal and chest wall reconstruction. It is advantageous because of its rapid vascularization, allowing complete incorporation to occur in as little as 4 weeks. Additionally, the large pore size allows fluid to flow freely, consequently decreasing the risk of seroma or increasing intra-abdominal pressure.

Compared to other biologic prostheses, acellular dermal matrix has been shown to have lower rates of hernia recurrence, seroma, and wound infection. Local wound care resolves most cases of dermal matrix exposure and wounds usually heal by secondary intention. FlexHD (Ethicon, Somerville, NJ), a less commonly used acellular dermal matrix, is another available product. In contrast to early versions of Alloderm and Allomax, FlexHD does not require refrigeration and is readily available for instant use.

Surgisis (Cook Medical, Bloomington, IN) is made of porcine small intestinal submucosa. Historically, it was used for arterial bypass, ACL repair, and bladder slings. It is available in a perforated and non-perforated form. The perforated version facilitates vascular ingrowth, but is also more adhesiogenic as compared to the non-perforated alternative. Surgisis has a tensile strength greater than two times the strength of native tissue and has been shown to have almost five times the strength 2 years after repair [7]. Other studies did show higher rates of infection when it was used in highly contaminated wounds or in critically ill patients. Surgisis is an excellent choice in clean-contaminated cases where surgeons would prefer to avoid a synthetic mesh.

Permacol (Covidien Surgical, Mansfield, MA) is an acellular porcine dermis which is decellularized and chemically cross-linked to inhibit breakdown of the collagen matrix. It creates less foreign body reaction than Surgisis and the collagen is resistant to degradation. Small case series supports its use in infected areas with contamination; however, there is little long-term outcome data. XenMatrix (Bard, Murray Hill, NJ) is another porcine dermis-derived biologic mesh and is not cross-linked (Bard Davol). The lack of cross-linking may contribute to the high rates of infiltration and remodeling in this material when compared to Permacol. In contrast to human-derived dermis options, Permacol appears relatively more rigid.

Technique

Options for the placement of mesh include an underlay, an inlay, or an onlay technique. Though several approaches are feasible, evidence has shown that technique is one of the primary factors driving hernia recurrence. While intraperitoneal placement has been described, it is preferable to avoid mesh contact with bowel if possible.

The underlay technique is defined as an intraperitoneal placement of the prosthesis (Fig. 6.1). This is the preferable method of placement because intra-abdominal pressure will push the prosthetic against the rectus abdominis and its overlying fascia. In addition, there is a large amount of surface area in contact between the mesh and the fascia [8]. As a result, we believe the underlay technique has the lowest incidence of recurrent herniation. It also has the lowest rate of infection and wound breakdown due to the greater soft tissue protection from skin flora and environmental contaminants.

Inlay placement is defined as a bridge of prosthetic mesh between the edges of the rectus fascia (retrorectus and preperitoneal). This method usually has an unacceptably high incidence of recurrent hernia (up to 75 %) [9]. This is likely due to a small total contact area between the mesh and fascia, which leads to a weaker repair.

Onlay is placement of the mesh superficial to the fascial repair. There is less fibrovascular infiltration of the mesh in this position, and it is closer to the skin, making this method the most likely to have wound complications. The onlay technique requires dissection in the subcutaneous plane which may lead to seroma formation (Fig. 6.2). Furthermore, division of blood supply to the overlying skin can lead to

Fig. 6.1 Underlay placement of dermal matrix

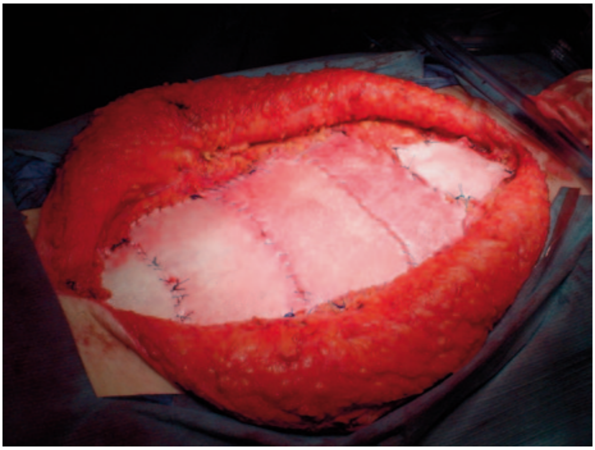

Fig. 6.2 Onlay placement of dermal matrix

skin necrosis, breakdown, and subsequent prosthetic infection. However, the onlay technique does avoid the risk of visceral adhesion formation or more importantly bowel erosion and fistula formation.

Vacuum-Assisted Closure

Vacuum-assisted closure (VAC) or negative pressure wound therapy (NPWT) is a commonly used technique in the management of open abdominal wounds. Negative pressure is applied to a wound through a sponge system usually at a pressure of −125 mmHg. The VAC has great success if infection is controlled, necrotic tissue is debrided, and bacterial counts are minimized. Gross infection, presence of necrotic tissue, and residual neoplasia are contraindications to the use of VAC therapy.

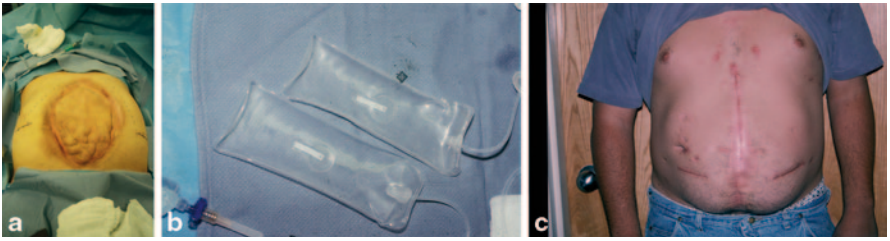

Fig. 6.3 **a–c** Use of tissue expansion in the closure of an abdominal wall defect. Final result is shown in **c**

The VAC can remove a large amount of fluid in a short period of time. This allows for faster and improved wound healing as tissue edema decreases and soft tissue perfusion increases. Research has shown stimulation of granulation tissue and fibrovascular ingrowth allowing for better wound healing and a favorable wound bed, should a skin graft be needed for wound coverage. Bacterial counts are significantly decreased with VAC therapy, which greatly assists wound closure. VAC therapy also limits repeated operative interventions and allows wounds to be temporized, while optimizing patients for definitive surgery [10].

Tissue Expansion

In the presence of significantly large soft tissue defects in the abdominal wall, tissue expanders are a viable option for reconstruction (Fig. 6.3). Hollow prosthetics are implanted into soft tissue and gradually filled with saline to produce tissue recruitment and growth overlying the expander. They help recruit and provide autologous tissue that is well vascularized and has adequate innervation, which is ideal for abdominal wall reconstruction.

The major drawback to tissue expansion is the long period of time required for expansion and patient discomfort during the expansion period. Additionally, it is frequently inconvenient, as the expander must be placed overlying firm areas such as the chest wall, the iliac crest, or the lumbar fascia. Furthermore, expanders have a propensity to become infected, especially in an already compromised abdominal wound. This technique is not frequently used and should be considered only when options are limited or tissue defects are substantial [11].

Autologous Options for Abdominal Wall Reconstruction

The use of autologous tissue is always preferable to the use of foreign materials in wound healing. This holds especially true in wounds from trauma or surgical wounds complicated by infection or radiation. As mentioned, abdominal wall reconstruction by non-autologous means has higher incidences of fistula formation, extrusion, and infectious complications (see Chap. 8) [12–13]. Undoubtedly, the ideal closure for any type of wound, including the open abdominal wound, is primary closure. When primary fascial closure is not possible, there are several strategies that can be used in this scenario to achieve wound closure without the use of foreign materials. Each of these options has distinct advantages and disadvantages.

Skin Grafting

Skin grafting has a limited role in the reconstruction of the anterior abdominal wall due to poor cosmesis and lack of structural support. It can, however, be used as a temporizing measure to provide reliable coverage of abdominal wall defects and assist in wound healing. Ultimately, patients who undergo skin grafting will require a subsequent staged procedure to reestablish abdominal wall integrity.

Skin grafting should be performed on healthy, noninfected tissue with an adequate wound bed (i.e., healthy granulation tissue). A skin graft can be placed directly on viscera or on omentum, if necessary [14]. Skin grafts should not, however, be applied to exposed prosthetic mesh. The recipient wound bed should have less than 10^5 bacterial colonies per gram of tissue for a skin graft to survive [15]. Split thickness skin grafts (STSG) should be meshed before placement on the wound to both maximize the size of the STSG and increase chance of "take." STSG are usually harvested from an inconspicuous location such as the upper lateral thigh, the buttock, and/or the hair-bearing scalp. In the first 24 h postoperatively, skin grafts survive by imbibition, but for the following 2–10 days, inosculation and new vascular ingrowth will provide permanent vascular support to the skin graft.

Component Separation

Described in more detail in the previous chapter, [16, 17] abdominal component separation is currently one of the most common methods employed by surgeons to achieve reliable abdominal closure with autologous tissue. First described by Ramirez in 1990, this method not only provides reliable abdominal closure but also helps recreate a functional and dynamic anterior abdominal wall by using innervated myofascial flaps. Some believe that a dynamic reconstructed abdominal wall is better able to resist strain and redistribute tension forces evenly throughout the abdominal wall, yielding a lower rate of hernia recurrence and limiting poor functional sequelae.

The original technique described by Ramirez has since undergone many modifications, with each modification improving upon the original description. The cornerstone concept of any component separation is creation of the rectus abdominis-internal oblique-transverses abdominis muscle complex. Creation of this complex is the essential maneuver that allows for a tension-free abdominal closure. Generally, component separation can provide approximately 5 cm of mobility from each fascial edge at the costal margin, 10 cm of mobility from each fascial edge at the waistline, and 3 cm of mobility from each fascial edge at the suprapubic region. This yields bilateral advancement of 10 cm at the costal margin, 20 cm at the waistline, and 6 cm at the suprapubic region [12, 16, 17].

Drawbacks to the use of component separation include a relatively high rate of hernia recurrence (between 10 and 30 %), high rate of infection, potential skin and subcutaneous tissue loss from extensive undermining of skin flaps [12, 18] (approximately 20 %), and interference with enterostomies when advancing muscle under skin flaps. The high rate of hernia recurrence has been attributed to the complexity of the hernias that are reconstructed using this technique as well as field contamination at the time of surgery. In patients requiring abdominal wall reconstruction that have concurrent enterostomies, it is our practice to do a staged procedure consisting of ostomy reversal and reestablishment of gastrointestinal continuity prior to embarking on definitive separation of components after several months. In patients that have inflammatory bowel disease that predispose them to fistula formation (e.g., Crohn's disease), one may choose to use biologic mesh for reconstruction because of the risk of seeding, should a fistula develop. Endoscopic techniques (see Chap. 6) continue to evolve and have shown promising results thus far.

Moreover, whereas it is acceptable to use synthetic mesh in open component separation reconstruction, some surgeons utilize biologic mesh empirically because of the high infection rate. One promising option to curtail the high cost of biologics is utilizing Phasix, a new mesh available from Bard Davol. This is a fully absorbable mesh designed to limit seroma formation and avoid permanent foreign material implantation, while providing a strong, durable repair. Constructed from monofilament poly-4-hydroxybutyrate, it has handling properties similar to that of polypropylene and is designed to retain higher strength for a longer period of time than some other fully resorbable materials based on preclinical data. Long-term studies are pending.

Technique

The defect must be completely defined initially and the hernia sac should be excised. Once the fascial edges are cleared of adhesions, skin flaps are elevated from the anterior abdominal musculature to the level of the anterior axillary line. A vertical incision is made parallel to and 2–3 cm lateral to the linea semilunaris, releasing the external oblique from the underlying internal oblique and the transverses abdominis muscle. This vertical incision extends from the level of the inguinal ligament to the costal margin. The plane beneath external oblique is developed towards the midaxillary line. Though this plane is avascular, one must be careful not to violate the internal oblique muscle so as to not disrupt the neurovascular bundles that supply the rectus abdominis muscle and sensory branches of the abdomen that run in the plane between the internal oblique and the transverses abdominis muscle. Next, the rectus abdominis muscle is dissected away from the posterior rectus sheath, starting at the medial border of the muscle and working laterally to the edge of the rectus muscle. Once this is accomplished, the rectus abdominis-internal oblique-transverse abdominis muscle complex is created.

The midline defect could then be closed by approximating the two edges of the rectus abdominis muscle with its anterior rectus sheath en masse. The skin flaps are then closed in a multilayer technique with placement of closed suction drains between the skin flaps and the external oblique muscles. An abdominal binder is usually applied for comfort and to minimize seroma formation. The drains can be discontinued after output is less than 20–30 ml of fluid over a 24-h period.

Local and Distant Muscle and Fascial Flaps

Local and distant muscle flaps provide autologous tissue for wound closure. This is beneficial with respect to dynamic support, coverage in contaminated fields, or coverage of exposed mesh. Local flaps could be principally useful for the reconstruction of lateral abdominal wall defects. The workhorse flap for these defects is the rectus abdominis muscle. With a dual dominant vessel blood supply, the rectus abdominis muscle can be based off of either an inferior pedicle from the deep inferior epigastric artery or from a superior pedicle from the superior epigastric artery. For defects located in the upper lateral abdomen, the rectus abdominis muscle should be based off of the superior epigastric artery. Similarly, the deep inferior epigastric artery is used as the pedicle for lower lateral abdominal wall defects.

Less commonly utilized local flaps include the external oblique muscle and the internal oblique muscle. The external oblique muscle is preferably used in the upper abdomen. However, this is not an ideal local flap due to the tenuous segmental blood supply from the posterior intercostal arteries. The internal oblique muscle can be used to reconstruct the lower abdomen and groin area. The blood supply to the internal oblique arises from segmental branches of the intercostal arteries and from the ascending branch from the deep circumflex iliac artery.

Distant muscle flaps can also be used when local tissue is not adequate for a local muscle flap or if the local flap has limited reach. For lower abdominal wall reconstruction, one of the most commonly used flaps is the tensor fascia lata (TFL) flap. This muscle, which is supplied by the lateral femoral circumflex artery, spans from the anterior superior iliac spine to the lateral aspect of the knee. Additionally, an overlying skin paddle can be included with the flap to provide skin and subcutaneous tissue to an area lacking adequate skin for closure. This skin paddle can measure up to 15×40 cm in dimension. Drawbacks to using this muscle flap include distal tip necrosis of the flap and donor site morbidity with wound infection and dehiscence.

Another reliable option for lower abdominal wall defects is the rectus femoris flap. It can be harvested with fascia and skin. The blood supply to the rectus femoris muscle is the lateral femoral circumflex vessels. This muscle originates from the anterior superior iliac spine and inserts into the patellar tendon. Reapproximation of the quadriceps tendons is necessary to maintain the terminal 15° of knee extension [14].

The main distant muscle flap used for upper abdominal wall defects is the latissimus dorsi muscle flap. This muscle has a reliable vascular anatomy and is supplied by the thoracodorsal artery. A skin paddle can also be included with this muscle to fill soft tissue voids. Limitations of this muscle flap are little fascial support for the prevention of hernia and donor site morbidity from the loss of latissimus dorsi, a powerful arm adductor. However, unless the patient is a competitive athlete, most will not be significantly affected from loss of the latissimus dorsi muscle [14].

Alternatively, fascial flaps have been utilized for abdominal wall reconstruction, most commonly the pedicled anterior lateral thigh (ALT) flap. This flap is based on the descending branch of the lateral circumflex femoral artery which is a branch of the superficial femoral artery. Perforators from the descending branch of the lateral femoral circumflex artery are dissected out through a septum between the rectus femoris and vastus lateralis. Sometimes these vessels traverse through the substance of the vastus lateralis creating a more difficult dissection of the perforators. The skin paddle can measure up to 8×20 cm; however, skin grafting is often required to cover the donor site when large skin paddles are harvested. Additionally, portions of the vastus lateralis and the investing fascia of the thigh can be included to provide fascia for closing abdominal wall defects deficient in fascia. Mesh can also be used in an underlay fashion to provide extra reinforcement to the abdominal wall in clean/non-contaminated cases.

Aside from the cosmetic defect, the donor site causes minimal morbidity due to the fact that the muscle is spared. The flap is most useful in reconstruction of the lower third of the abdomen based on the arc of rotation from the origin of the pedicle just inferior to the inguinal ligament. In some instances, bilateral ALT flaps are needed to provide enough soft tissue coverage for significant abdominal wall defects.

Free Flaps

The use of free flaps in the reconstruction of abdominal wall defects is recommended for abdominal wall defects complicated by extensive size, infection, radiation, and defects that cross the midline. A free flap is often selected because of inadequate local flaps whose blood supply has been compromised by previous abdominal surgeries. One distinctive advantage of free muscle transfer over pedicled muscle transfer is the ability to orient the muscle fibers to the vector of force. Additionally, skin and subcutaneous tissues can be included with the free muscle transfer, thereby facilitating closure of complex abdominal wounds. Furthermore, free flaps can aid in the closure of the abdomen as a one-stage procedure due to the addition of tissue to an abdomen that has lost domain. The addition of tissue results in less risk of developing abdominal compartment syndrome. The major drawbacks to using free flaps for abdominal wall reconstruction include a longer procedure time, potential donor site morbidity, atrophy of denervated muscle included in the free flap, and donor site cosmesis.

Since its first description in 1983, the TFL has become the most commonly used free flap for reconstruction of the lower abdomen. The vascular supply is derived from the lateral femoral circumflex artery. The motor branch of the femoral nerve can be included with the TFL to create a dynamic repair. The anatomy of this flap is reliable and makes for a consistent dissection. Skin and subcutaneous tissue can be included if there is a soft tissue defect requiring skin coverage. Skin paddles can measure up to 28 × 22 cm. It is important to orient the muscle and fascia perpendicular to the fibers of the rectus abdominis muscle. This assists in providing adequate tensile strength. Major concerns with this muscle flap include distal tip necrosis and donor site morbidity from wound infection and dehiscence from excessive tension. Skin grafting of the donor site, when necessary, may prevent wound dehiscence [19].

The rectus femoris free flap is also a good option when reconstructing the lower abdominal wall. If the rectus femoris motor nerve is preserved and coapted to one of the motor nerves of the abdominal wall, the dynamic properties of the abdominal wall will be reestablished and add to the strength of the reconstruction. Additionally, some advocate using this muscle in conjunction with TFL, utilizing the TFL for fascial strength and the rectus femoris for functional muscle. This method creates an anatomic repair similar to the native rectus abdominis/rectus sheath. The vascular supply of the rectus femoris is the lateral femoral circumflex artery. Once harvested, the vastus medialis and vastus lateralis should be approximated to avoid problems with terminal extension of the knee. Additionally, donor site cosmesis may be a limitation to the use of this flap.

The latissimus dorsi muscle free flap is considered a workhorse muscle flap in many realms of plastic and reconstructive surgery. Similarly, the reliable anatomy of this muscle flap makes for a reproducible dissection. This muscle flap also has the capability of being transferred as a functional muscle. Most surgeons would recommend using a prosthetic mesh under the muscle flap to aid with fascial support. Limitations of this muscle flap are similar to the limitations when used as a pedicled muscle flap.

The ALT perforator free flap is useful for abdominal wall reconstruction in that it has a reliable blood supply and a large skin paddle that can be used to cover large abdominal wall defects (Fig. 6.4). This flap is a fasciocutaneous flap containing only fascia, subcutaneous tissue, and skin. No muscle is included in this flap, thus conferring less morbidity. As an alternative, this flap can be transferred in conjunction with the TFL or the investing fascia of the thigh which will provide strength to the repair.

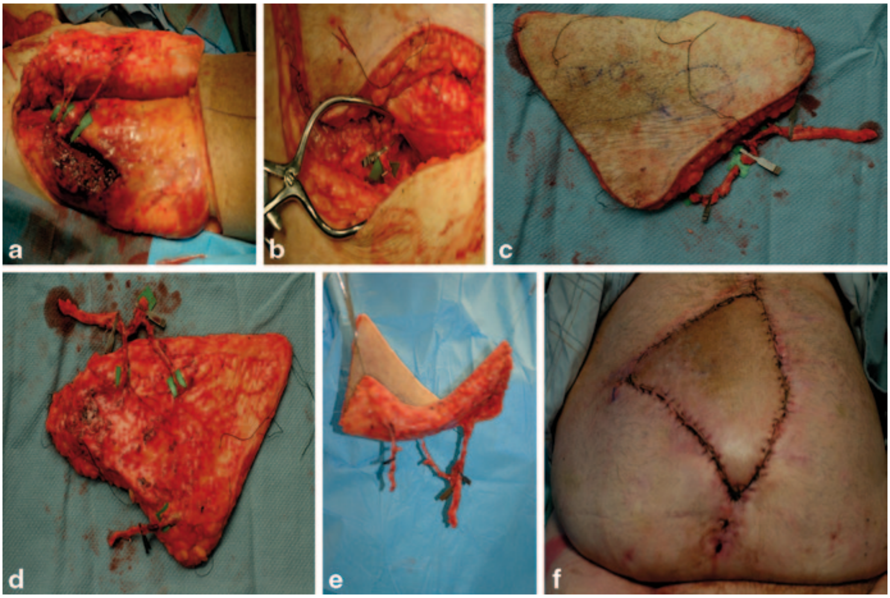

Fig. 6.4 a–e Free anterolateral thigh flap after measurement, dissection and elevation. **f** Free anterolateral thigh flap inset for reconstruction of an abdominal wall defect

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Chapter 7
Endoscopic Component Separation for Ventral Hernia Repair

Jennifer W. Harris and John Scott Roth

Introduction

Incisional hernias are chronic post-incisional abdominal wall defects which result in the protrusion of abdominal contents through the incisional opening. These defects, which Jean Rives initially referred to as a "disease process," are a serious complication of abdominal surgery and primarily contribute to chronic pain, bowel obstruction, strangulation, incarceration, while secondarily resulting in a reduction in quality of life and employment [27, 38, 49]. Ramirez et al. first described their component separation technique for complex abdominal wall hernia repairs, which utilized a technique that separated individual muscle components of the abdominal wall. This allowed greater mobilization of each unit over a greater distance, facilitating tension-free abdominal wall closure for patients with very large and complex incisional hernias [35]. However, this technique resulted in significant morbidity and postoperative complications due to the mobilization of large undermining skin flaps, seroma formation under Gallaudet's fascia, and skin necrosis. These complications hastened the development of less invasive techniques, such as the subcutaneous endoscopic component separation technique, in an effort to reduce morbidity secondary to wound complications [23]. Technical challenges associated with a subcutaneous approach to endoscopic component separation led to the "inter-oblique" technique for endoscopic component separation whereby the space between the external and internal oblique muscles is dissected. Advantages of endoscopic component separation techniques are related to the reduced morbidity

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F. G. Madbak, D. A. Dangleben (eds.), *Options in the Management of the Open Abdomen,* DOI 10.1007/978-1-4939-1827-0_7

by minimizing subcutaneous dissection and undermining skin flaps which have been demonstrated to increase wound morbidity [20]. The treatment of incisional hernia is a complex problem plagued with complications and recurrences and often requires a multidisciplinary approach, including the expertise of general and plastic surgeons, primary care providers, medical specialists, nutritionists, and wound care specialists, to address the complex needs of patients with disease process.

Review of Abdominal Wall Physiology

In order to understand the techniques used in ventral hernia repair, the surgeon must have a comprehensive understanding of the anatomy and physiology of the abdominal wall musculature and its contributing vasculature and innervation.

Abdominal Wall Musculature

The abdominal wall consists of four major muscle groups: rectus abdominis, external oblique, internal oblique, and transversus abdominis muscles (Fig. 7.1). These muscle groups collectively function to provide support and movement of the trunk, spine, and pelvis, as well as compression and containment of the abdominal viscera [34]. The rectus muscle extends from the xiphoid process of the sternum and the fifth, sixth, and seventh costal cartilages to the pubic crest, and the muscles are enclosed in the rectus sheath. The rectus contributes to both trunk flexion and rotation. The external oblique arises from the lower eight ribs and inserts into the anterior superior iliac spine and pubic tubercle to form the inguinal ligament. Its fibers run downward and forward to form its aponeurosis anteriorly, and it contributes to trunk rotation, lateral spine flexion, and upright spine stabilization [9]. The internal oblique arises from the lumbar fascia, iliac crest, and the lateral two thirds of the inguinal ligament and runs upward and forward to form its aponeurosis. It inserts inferiorly into the pubic symphysis and fuses with the transversus abdominis to form the conjoint tendon. The internal oblique contributes to trunk rotation, lateral spine flexion, and trunk flexion. The transversus abdominis arises from the lower six costal cartilages, the lumbar fascia, and the iliac crest and is important in upright spine stabilization [3]. The arcuate line plays an important role as it demarcates the lower limit of the posterior layer of the rectus sheath and is also where the inferior epigastric vessels perforate the rectus abdominis (Fig. 7.2). Above the arcuate line, the rectus abdominis is surrounded by an anterior layer of the rectus sheath as well as a posterior layer. The anterior layer is formed from the external oblique aponeurosis and the anterior lamina of the internal oblique aponeurosis. The posterior layer comprises posterior lamina of the internal oblique aponeurosis and the transversus abdominis aponeurosis. Inferior to the arcuate line, all three muscle aponeuroses make up the rectus sheath, and the rectus abdominis lies directly on the transversalis

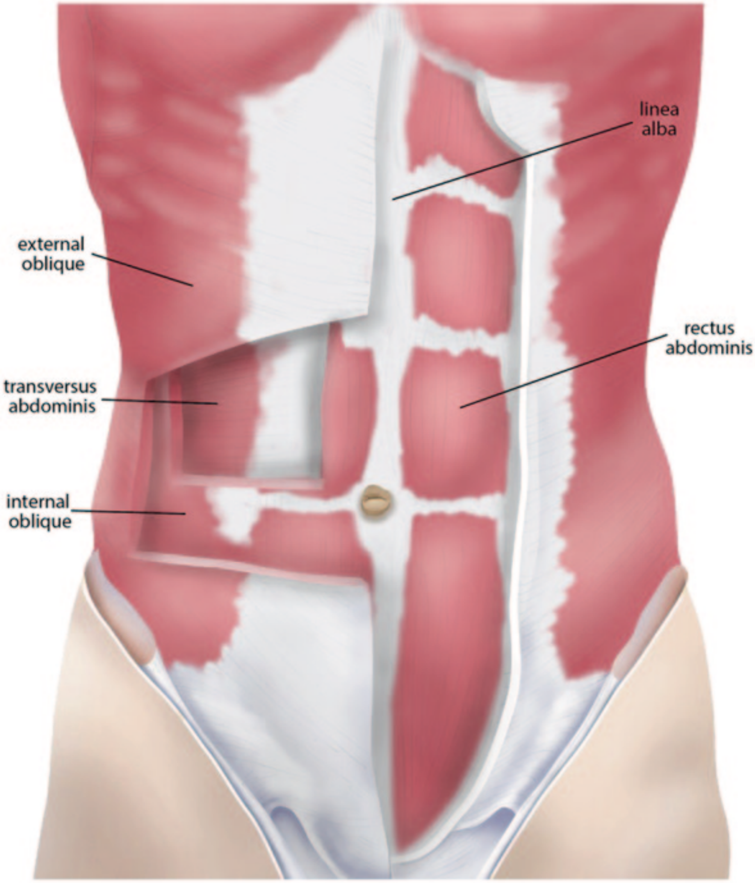

Fig. 7.1 Abdominal wall musculature. The abdominal wall comprises four major muscle groups: rectus abdominis, external oblique, internal oblique, and transversus abdominis muscles

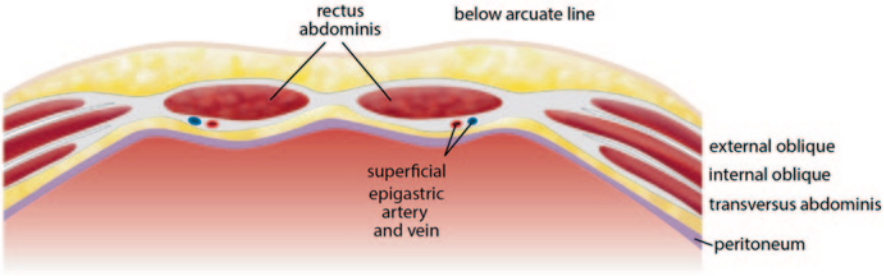

Fig. 7.2 Cross-sectional view of the abdominal anatomy. The arcuate line plays an important role as it demarcates the lower limit of the posterior layer of the rectus sheath and is also where the inferior epigastric vessels perforate the rectus abdominis

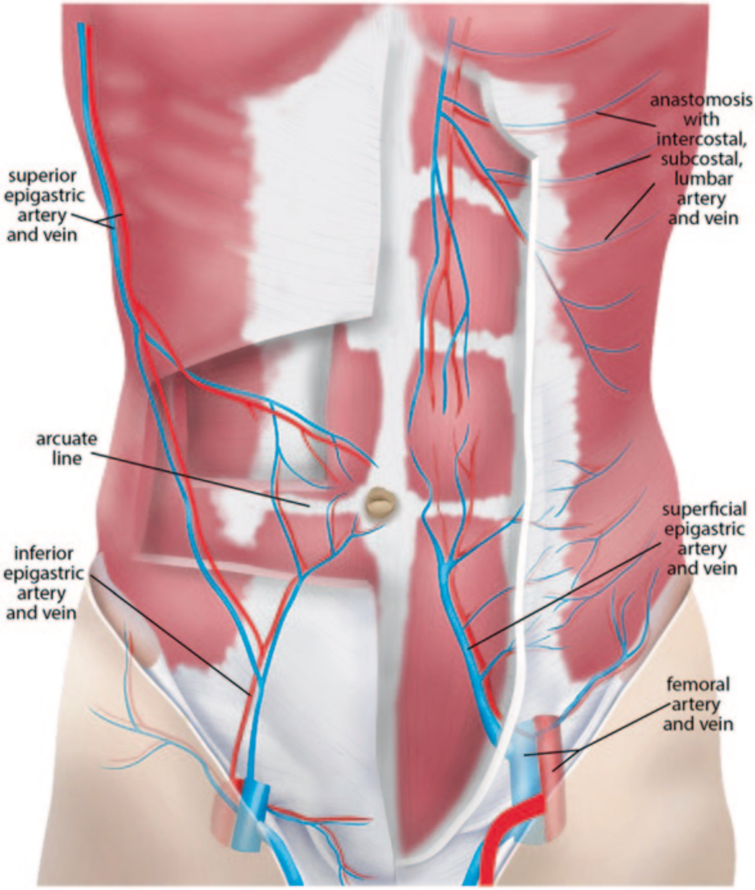

Fig. 7.3 The vasculature of the abdominal wall is made up of a complex collateral system

fascia. Weaknesses inferior and lateral to the arcuate line are at the highest risk for hernia development. All four major muscle groups participate in increasing intra-abdominal pressure during Valsalva and compressing abdominal contents into the cavity. When the integrity of the functional capacity of these muscles is compromised, there is an increased risk for the development of weakness or hernias of the abdominal wall.

Abdominal Wall Vasculature

The vasculature of the abdominal wall is made up of a complex collateral system (Fig. 7.3). The inferior deep epigastric artery branches from the external iliac artery and is the dominant vascular supply to the anterior abdominal wall. It ascends

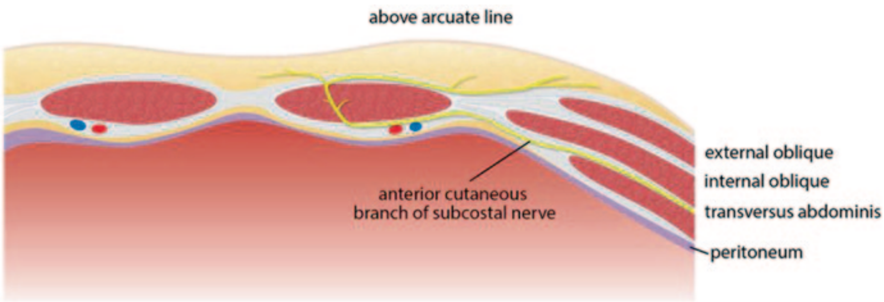

Fig. 7.4 Anterior abdominal wall innervation. The thoracoabdominal nerves (T7–T11), subcostal nerves (T12), ilioinguinal nerves (L1), and iliohypogastric nerves (L1) all travel between the internal oblique and transversus abdominis muscles

superficially to the transversalis fascia and crosses the lateral border of the rectus muscle at the arcuate line where it enters the posterior rectus sheath. It then branches extensively and develops a collateral system with the superior deep epigastric artery, which is a terminal branch of the internal thoracic artery. The inferior deep epigastric vessels are bounded only by loose areolar tissue below the arcuate line and are susceptible to avulsion and hematoma during hernia surgery [33]. The musculocutaneous perforating vessels of the inferior deep epigastric artery reach and supply deeper tissue as well as the integument of the anterior abdominal wall. These perforators are particularly relevant in reconstructive surgery as an important supply for abdominal tissue flaps used [29]. The number, location, and course of these perforators are highly variable. The venous supply of the anterior abdominal wall tends to be more variable than arterial pathways, but veins typically follow the course of arteries. Above the umbilicus, veins tend to drain to the subclavian vessels, and below the umbilicus, they drain to the external iliac vessels. Veins may be dilated in patients with chronic liver disease, portal hypertension, and renovascular disease. Special consideration and careful preoperative planning must be engaged to avoid complications in these patients [31].

Abdominal Wall Innervation

Knowledge of the innervation of the abdominal wall is paramount as denervation of these muscles can compromise their function and place the patient at increased risk of incisional hernia and complications secondary to herniosis. The thoracoabdominal nerves (T7–T11), subcostal nerves (T12), ilioinguinal nerves (L1), and iliohypogastric nerves (L1) all travel between the internal oblique and transversus abdominis muscles (Fig. 7.4). Careful attention must be given to the dissection around these structures during both open and endoscopic component separation approaches to hernia repair in order to protect the viability of the innervation, and therefore the function of the muscles involved in the integrity of the abdominal wall. Avoidance of the space between the internal oblique muscles and the transversus abdominis muscle will help to minimize denervating injuries to the abdominal wall during abdominal wall surgery.

Impact of Abdominal Wall Hernia on Abdominal Wall Mechanics

Jean Rives, one of the first surgeons to acknowledge the complex pathophysiology hernias, noted that the abdominal wall loses synergy with the diaphragm with resultant protrusion of the viscera with respirations. This subsequently leads to the development of lumbar lordosis as a compensatory mechanism for patients to maintain their center of gravity and later results in lower back pain. The lack of counterbalance to the back muscles causes the lateral abdominal wall muscles to retract and fibrose, thus worsening the protrusion of the abdominal contents [36, 38]. Dermatologic changes such as ischemic ulcers of skin are frequently late-stage events in the disease process of herniosis, especially when they occur in combination with other comorbid conditions such as decompensated cirrhosis, smoking, or uncontrolled diabetes mellitus [2, 4, 17, 31].

Open Hernia Repairs and Components Separation Techniques

Primary Hernia Repair

The incidence of incisional hernia after midline laparotomies ranges from 10 to 20 %, while the recurrence rate following hernia repair with primary suture closure techniques varies from 25 to 52 % [47]. In one study of abdominal closure rates with mesh after trauma laparotomy and damage control, the hernia development rate at 4 years was 67 % for the total, 13 % for patients with delayed fascial closure, and 80 % for patients requiring other closure techniques. Vacuum-assisted closure seems to reduce the incidence in other trials.

The increased incidence in recurrence relative to the incidence of initial incisional hernia formation suggests that factors beyond technique impact hernia formation. Approaches to hernia repair aim to reattach tendons of the lateral abdominal muscles in an effort to reconstruct the abdominal [6, 36]. Relaxing incisions such as the Gibson or Clotteau–Premont may facilitate a tension-free repair, although patient outcomes were disappointing [37, 43]. Stoppa popularized a technique for hernia repair in which an unsutured Dacron patch was placed between the peritoneum and the muscular layers due to his belief that relaxing incisions induce unnecessary parietal damage and increase the likelihood of hernia recurrence despite

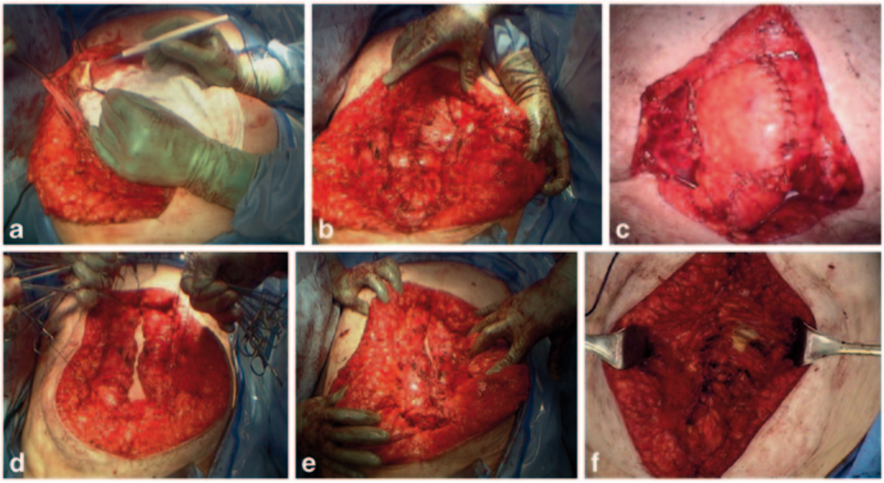

Fig. 7.5 Retro-rectus hernia repair. The retro-rectus hernia repair or Rives–Stoppa repair involves dissection of the posterior rectus sheath from the rectus abdominis muscles. The posterior sheath is dissected from the rectus abdominis muscles in an avascular plane (**a**). The posterior rectus sheath and peritoneum are closed (**b**). In the event the peritoneum is unable to be closed, an absorbable mesh is sutured as an inlay to the posterior sheath (**c**). Mesh is placed in the retro-rectus space sutured circumferentially (**d**), resulting in opposition of the midline fascia (**e**). Closed suction drains are placed in the preperitoneal space prior to midline closure (**f**)

attempts to reduce tension (Fig. 7.5) [7, 44]. The procedure initially described by Stoppa remains a commonly utilized technique for ventral hernia repair and is often considered the gold standard for hernia repair. Contemporary studies clearly demonstrate improvements in recurrence rates with the utilization of prosthetic mesh during incisional hernia repair [16]. However, due to risk of infection, previous mesh infections, or contaminated spaces such as chronic wounds of fistulas, not all patients are candidates for synthetic mesh placement [22, 32, 33, 45]. An additional drawback of a mesh hernia repair may be the loss of abdominal wall function, particularly when utilized to bridge hernia defects. Bridging mesh has been found to reduce overall abdominal wall torque relative to a suture-based primary closure of the abdominal wall musculature [11], although the clinical relevance of these findings remains unproven.

Component Separation Techniques

Complex hernias XE "Hernia:repairs:Stoppa's technique:complex" frequently necessitate reconstructive procedures due to challenges associated with contamination, infection, defect size, loss of abdominal wall tissue, prior or existing stomas, and previous surgical procedures. Tissue transfer by means of rotational and free flaps may be utilized for soft tissue coverage (Fig. 7.6). These flaps are often

Fig. 7.6 Free tissue transfer for non-healing anterior abdominal wound. The patient shown in this figure required soft tissue coverage after wound healing complications in conjunction with a complex abdominal wall hernia. Tissue transfer by both rotational and free flaps may be utilized for soft tissue coverage in patients with complex hernias and loss of domain (see Chap. 6). These flaps are often reserved for patients with the most complex hernias due to the morbidity associated with these techniques

reserved for patients with the most complex hernias due to the morbidity associated with these techniques. In an attempt to close abdominal wall defects without remote tissue transfer, Ramirez et al. described a technique based on the premise that separation of the muscular components of the abdominal wall would allow mobilization of each unit over a greater distance than possible by mobilization of the entire abdominal wall as a block [35]. Their technique required separation of the posterior rectus sheath from the rectus abdominis muscle, elevation of the skin and subcutaneous tissues from the anterior abdominal wall to the linea semilunaris, and division of the external oblique aponeurosis with separation of the external and internal oblique muscles. The compound flap of the rectus muscle, with its attached internal oblique–transversus abdominis muscle, can be advanced 10 cm around the waistline and up to 20 cm bilaterally (Fig. 7.7). Their study suggested that large abdominal wall defects might be reconstructed with functional transfer of abdominal wall components without the need for resorting to distant transposition of free muscle flaps. Other authors developed similar techniques for components separation, although the Ramirez technique is the most widely popularized [12, 13, 18, 19, 24, 26, 42, 48]. The elevation of large undermining skin flaps and division of the perforating musculocutaneous vessels of the abdominal wall skin resulted in significant wound complications, including seroma and skin necrosis [10, 28]. Some

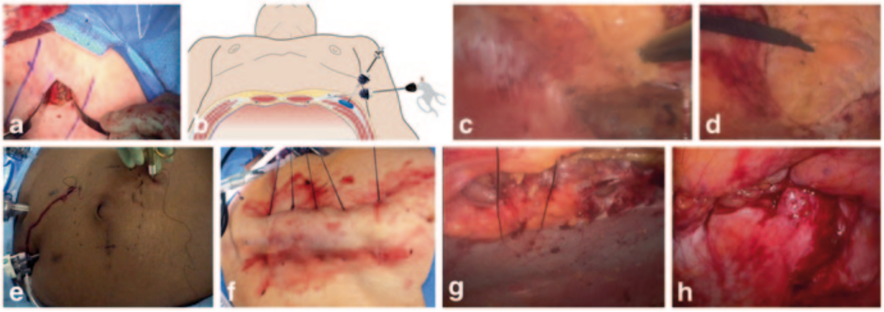

Fig. 7.7 Endoscopic components separation technique/laparoscopic ventral hernia repair. The endoscopic technique for component separation is performed to minimize wound morbidity associated with the Ramirez component separation technique. A 2-cm transverse incision is made at the anterior axillary line (lateral to the linea semilunaris) approximately 5 cm cephalad to the costal margin. Dissection is performed until the inferomedially oriented fibers of the external oblique muscle are identified (**a**). The external oblique fibers are subsequently separated bluntly to expose the underlying internal oblique aponeurosis. A balloon dissector is then inserted into the inter-oblique space parallel to the linea semilunaris and insufflated to dissect the potential space between the internal and external oblique muscles (**b**). An additional 5-mm trocar is inserted laterally to divide the external oblique aponeurosis from above the costal margin inferiorly to the inguinal ligament (**c**). Dissection into the subcutaneous adipose tissues to the level of the subcutaneous fascia maximizes advancement (**d**). Endoscopic component separation may be utilized as an adjunct to laparoscopic ventral hernia repair to facilitate hernia defect closure with transcutaneously placed horizontal mattress sutures (**e**). Pneumoperitoneum is reduced while tying sutures externally (**f**) to allow for a tension-free defect closure (**g, h**)

studies have reported major wound morbidity in up to 40% of patients, prompting the development of perforator-preserving component separation in the repair of incisional hernias [15]. These perforator-preserving component separations may be performed through a midline incision, incisions on the lateral abdominal wall, or utilizing endoscopic techniques. Although the technical details of each of these procedures vary, the preservation of the blood supply to the abdominal wall skin originating from the epigastric arteries is their common objective as this is crucial for reducing wound morbidity and improving outcomes.

Subcutaneous Endoscopic Component Separation Technique

The initial descriptions of an endoscopic component separation technique were developed in order to minimize operative injury to the vasculature of the abdominal wall and decrease postoperative wound dehiscence by utilizing subcutaneous balloon dissection to develop the operative space [23]. Balloon dissectors, frequently used in laparoscopic extraperitoneal inguinal hernia repairs, were placed in the subcutaneous space of the anterior abdominal wall lateral to the linea semilunaris. Following balloon dissection, additional ports were placed into the abdominal wall in order to enable division of the external oblique aponeurosis from the inguinal ligament to the costal margin or above. This technical advance mimicked the Ramirez component separation technique while eliminating the need for undermining skin flaps. The endoscopic component separation technique reduced the incidence of wound infection, ischemia, and dehiscence without impacting hernia recurrence rates. In 2013, Daes et al. refined this technique by developing an alternative method in which preoperative skin marking of the semilunar line under ultrasonic guidance precedes creation of a subcutaneous space with a balloon trocar and division with undermining of the external oblique aponeurosis. This ultrasound guidance enables clear identification of anatomic landmarks [8]. Recognition of the linea semilunaris represents one of the most important facets of component separation procedures, as inadvertent division of the linea semilunaris may predispose patients to lateral abdominal wall hernia formation.

Endoscopic Component Separation: "Inter-Oblique" Techniques

Initial descriptions of endoscopic component separation were described as a more feasible alternative to the subcutaneous component separation technique. The initial description by Maas et al. involved a midline laparotomy for adhesiolysis followed by a 2–4-cm incision placed on the lateral abdominal wall bilaterally lateral to the rectus abdominis muscle [25].

A balloon dissector is then used to create a space between the external and internal oblique by insufflation under video-endoscopic guidance, thus dissecting the "inter-oblique" space. Following removal of the dissecting balloon, the external oblique is retracted through this small incision and a 30° laparoscope is utilized to visualize and divide the external oblique aponeurosis, thus creating a compound flap while taking care not to shift the skin from the rectus muscle. Their proposed technique is attractive for the repair of large midline incisional hernias without the use of prosthetic material. The use of the distention balloon and video-endoscope minimizes tissue trauma and preserves the blood supply of the skin through the epigastric perforators. This is a major benefit in patients in whom the reconstruction is performed in a contaminated environment. Further work led to the development of less invasive techniques that are comparable in safety and acceptability.

Subsequent descriptions of laparoscopic component separation techniques were built upon the initial descriptions by Maas et al. [15, 40]. The laparoscopic component separation technique involves placement of a low anterior costal incision, dissection between the external and internal oblique muscles, and placement of a balloon dissector to create a space between the muscular structures. Subsequently, two additional ports are placed into the lateral abdominal wall which may be utilized to divide the external oblique aponeurosis, allowing for the medialization of the rectus abdominis muscle toward the midline. In this initial description of seven patients involving the single-stage treatment of patients with infected mesh, only one superficial wound complication occurred, suggesting a benefit to this minimally invasive approach.

Giurgius et al. further expanded upon the techniques described by Rosen et al. to more closely mimic the component separation initially described by Ramirez which extended from the inguinal ligament to a distance 5 cm above the costal margin. Initially, a 2-cm transverse incision is made at the anterior axillary line (lateral to the linea semilunaris) at 5 cm above the costal margin. Dissection is performed until the inferomedially oriented fibers of the external oblique muscle is identified. The external oblique fibers are subsequently separated bluntly to expose the underlying internal oblique aponeurosis. A balloon dissector is then inserted into the inter-oblique space parallel to the linea semilunaris. The balloon is insufflated under direct laparoscopic visualization, thus dissecting the potential space in the lateral abdominal wall between the internal and external oblique muscles. The newly created space is bounded by the external oblique muscle as the roof, while the internal oblique muscle creates the floor of the cavity. An additional 5-mm trocar is inserted lateral to the initial port and is utilized to divide the external oblique aponeurosis from above the costal margin inferiorly to the inguinal ligament. Dissection is extended beyond the external oblique aponeurosis into the subcutaneous tissues and subcutaneous fascial layers to obtain maximal advancement. The linea semilunaris is easily visualized in the medial most aspect of the lateral abdominal cavity, and dissection of the external oblique muscle is performed 2–3 cm lateral to avoid the division of internal oblique fibers as they course into the anterior rectus sheath.

We believe this technical modification has several advantages over other techniques for endoscopic components separation. First, identification of the inter-oblique space is facilitated cephalad to the costal margin by the muscular fibers of the external oblique muscle. Inferiorly, the external oblique muscles become increasingly aponeurotic, which may make identification of the space more challenging. The external oblique muscle is reliably muscular cephalad to the costal margin, and the inferomedially oriented fibers are readily identified and separated. Second, the thoracic cage facilitates dissection through the external oblique by providing counter-resistance to the dissection of the muscular fibers. Third, the placement of the ports cephalad allow for a unidirectional division of the external oblique fibers beginning cephalad and continuing caudally toward the inguinal ligament. This unidirectional dissection avoids the need for additional trocars and the potential for operating toward the camera, which can be challenging due to mirror-imaging effects. Most importantly, this technique allows for the division of the external oblique fibers comparably to the Ramirez component separation, originating 5 cm above the costal margin and extending caudal to the inguinal ligament [1, 14].

The benefits of endoscopic component separation relative to the open component separation are compelling. The overall incidence of wound complications has been demonstrated to be reduced when utilizing the less invasive techniques, with wound complications occurring in 6–27 % of those patients undergoing laparoscopic components separation and up to 57 % of those patients undergoing open component separations [14, 15]. Furthermore, there does not appear to be any difference in the recurrence rate among patients undergoing repairs by either method, suggesting that an endoscopic component procedure may be the procedure of choice for patients requiring myofascial advancement.

Although wound complications occur less commonly with laparoscopic and endoscopic component separation techniques, largely as a result of the avoidance of undermining skin flaps and preservation of the perforating vessels to the skin, a potential drawback may be the reduction in advancement of the abdominal wall musculature. While not all hernia defects will require maximal advancement, the absolute advancement of the midline is reduced with the less invasive procedures. In a porcine study of laparoscopic component separation, the degree of advancement obtained was only 86 % of that which was obtained with an open approach [22]. In a study by Milburn et al., a laparoscopic component separation procedure was compared to open component separation in a cadaveric model [28]. In this study, the technique for laparoscopic component separation consisting of division of both the posterior rectus sheath and transversus abdominis muscles was compared to traditional open component separation techniques as initially described by Ramirez. This study demonstrated comparable advancement of the abdominal wall with both techniques, thus ultimately paving the way for entirely laparoscopic hernia repairs, including both laparoscopic component separation and laparoscopic ventral hernia repair. Additionally, this study demonstrated and quantified the degree of advancement of the abdominal wall as a result of raising skin flaps from the abdominal wall musculature. Although advancement was on average less than 1 cm per side, there were outliers in up to 3 cm of abdominal wall advancement which was obtained as a result of skin and subcutaneous dissection. It is difficult to predict which patients will obtain the greatest benefit from the creation of the undermining skin flaps, but the risk of increased wound complications should be balanced against the potential benefit of increased abdominal wall advancement when determining the optimal technique. For the majority of hernias, a laparoscopic or endoscopic approach will provide adequate advancement, and in the event of excess tension, subsequent conversion to an open component separation technique may be performed to maximize mobilization of the abdominal wall.

Laparoscopic incisional hernia repair offers many advantages as it lessens wound complications, has lower recurrence rates than previous component separation techniques, and has shorter hospital stays and improved recovery and return to physical work [39]. This method of repair also allows for a more complete adhesiolysis and detection of defects that may not be obvious during an open repair [41, 46]. The laparoscopic method of ventral hernia repair most commonly utilizes the placement of a composite mesh underlay to cover the defect(s) which is secured with either transfascial sutures and/or tacks [7]. The laparoscopic method has a few potential drawbacks resulting from a bridging mesh that include seroma formation, mesh eventration, recurrence, poor cosmetic results, and lower patient satisfaction [20, 21]. There has been a trend toward closing hernia defects with transfascial sutures or endoscopic suturing to decrease the likelihood of these adverse outcomes, although some authors suggest there can be an increased infection rate with transfascial sutures [5, 30].

Combining the techniques for laparoscopic or endoscopic components separation with the techniques for laparoscopic ventral hernia repair allow for a minimally invasive abdominal wall reconstruction. Primary opposition of large fascial defects may not be feasible during a laparoscopic ventral hernia repair without the adjunct of a myofascial release. Performing an endoscopic component separation procedure with a laparoscopic ventral hernia repair will allow for a tension-free midline closure prior to securing a mesh, thus minimizing the risk for mesh eventration which may be seen with a bridging mesh. Although not widely adopted, small series have demonstrated the feasibility of this combined approach. Reservations regarding this approach include limitations to width of defect closure, the requirement of diffusion of carbon dioxide between the peritoneal cavity and lateral abdominal wall, and cosmetic concerns such as scar revision, excision of excessive skin, and panniculectomy. However, this approach allows for primary closure of midline defects without tension by approximating rectus muscles and potentially augments abdominal wall function by off-loading midline tension with the component separation technique.

Conclusions

Options for the surgical management of hernias continue to evolve. Patient goals and preferences, comorbid conditions, and physiologic and anatomic restraints should be considered in determining the optimal surgical strategy. Consideration of minimally invasive approaches when feasible will facilitate enhanced recovery, reduced perioperative morbidity, and excellent long-term outcomes. Component separation techniques are a useful adjunct to facilitate the midline closure of complex hernias. Endoscopic component separation techniques may be utilized as an adjunct to both open and laparoscopic hernia repair. Endoscopic and laparoscopic component separation techniques allow for comparable abdominal wall advancement, reduced postoperative wound morbidity, and equivalent hernia recurrence rates compared to open component separation techniques.

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Chapter 8
Complications

Firas G. Madbak

Fistulae, Wound Infections, Abscesses

Management of the open abdomen presents numerous challenges in order to contain the significant loss of protein and fluid, loss of bowel function, and loss of domain. The complication rate with an open abdomen can be as high as 50%, and this is attributable to attempts at closing the fascia primarily excessive tension or awaiting the formation of granulation tissue or using synthetic material for bridge closure which predisposes the patient to serious wound infections.

In the multiply injured, malnourished, and immunocompromised septic patient, wound infections and intra-abdominal abscesses are quite common. They are consequences of prolonged atmospheric exposure of abdominal viscera, intestinal ischemia from abdominal compartment syndrome, and/or delayed resuscitation. However, the most morbid complication associated with the management of the open abdomen is intestinal fistulization [1, 2].

In some series, the fistula rate has been reported to be between 7 and 50% when prosthetic mesh material is used for acute management. In a study by Miller et al. [19] from Vanderbilt, 32 of 276 (11.5%) patients developed fistulae. When vacuum-assisted closure (VAC) pack dressings were compared to polyglactin 910 mesh closures, the fistula rate in the VAC pack group was 21% but not statistically different from the 5% rate for the mesh group [4]. Foy et al.'s [11] study, using silicone as a temporary coverage, only 7 of 83 (8.5%) patients formed fistulae. Using polyglactin 910 woven mesh, Jernigan [16] reported an 8.4% fistula rate (14 of 167) in survivors of the open abdomen. All 14 developed the fistulae through the open wound, and the duration of mesh application before coverage of the granulating

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F. G. Madbak, D. A. Dangleben (eds.), *Options in the Management of the Open Abdomen,* DOI 10.1007/978-1-4939-1827-0_8

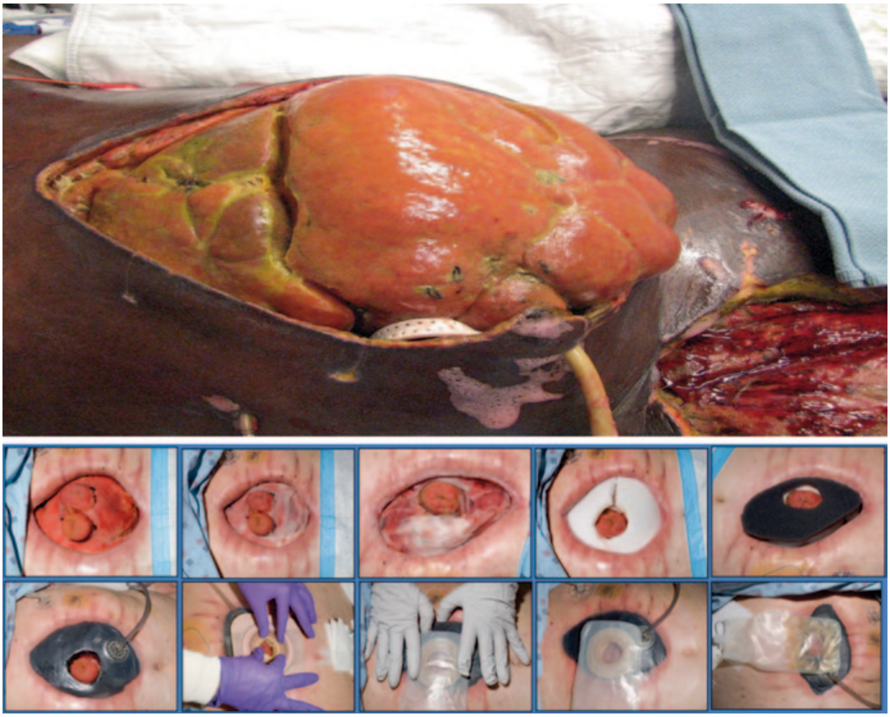

Fig. 8.1 Enteroatmospheric fistula treated with tube cannulation in a patient with an open abdomen

wound appeared to contribute to the development of the intestinal fistulae. Barker et al. [3] exclusively used the vacuum pack technique and had a very low fistula rate of 5 in 92 survivors (5.5 %).

The reported rate of exposed fistula, also called enteroatmospheric fistulae, is approximately 4.5 %. This is a serious complication which is often very challenging to manage. By definition, it is defined as an intestinal fistula with bowel mucosa at the level of an open abdominal wound. These frequently occur at an anastomotic site or at the site of injured bowel. Even uninjured exposed bowel can become traumatized to the point of developing a fistula in the absence of any overlying soft tissue coverage, leading to a very sick patient and a frustrated surgeon. Once a fistula forms, the adjacent viscera must be protected and the effluent controlled. Unfortunately, authors frequently do not distinguish between superficial and exposed fistulas. The former is merely a laborious wound management problem while the latter is a life-threatening emergency. Superficial fistulas are an extraperitoneal process that are often a result of a defect in the bowel wall, usually iatrogenic that could be managed by protection of the skin by a close and cover technique or conversion to an ostomy. Additionally, optimizing nutritional and fluid status is essential. Early enteral feeding (within 4 days) has been associated with early successful abdominal fascia closure and decreased fistula formation. Generally, if the fascia cannot be primarily closed by day 8, decisions about abdominal visceral coverage must be considered (Fig. 8.1) [5–9, 12, 13].

Deep exposed fistulae evolve into a complex pathology that lead to tremendous metabolic drain from uncontrolled peritonitis. Levy and colleagues, [17] a group that pioneered open management of severe abdominal infection, reported 120 cases from their referral center in Paris in 1986 and coined the term *exposed fistula* to denote an enteroatmospheric fistula in an open (or dehisced) abdomen. The first report in the English literature was by Schein and Decker [23] from Johannesburg, who described the entity in detail and reported a 60 % mortality rate, despite adherence to modern principles of fistula management. This is an intraperitoneal process with unbridled egress of intestinal effluent in the abdominal cavity. The underlying principle that guides management is conversion of this process to a wound management problem.

Negative pressure dressings showed early promise, but have anecdotally shown to result in more fistulization when placed directly on granulating abdominal viscera and therefore should be avoided. In fact, an alert issued by the Food and Drug Administration (FDA) in November 2009 warned against the use of these dressings on exposed enteric fistulas because of serious complications [10]. In a frozen abdomen, inserting tubes and catheters in fistulae is again ill-advised as these methods only make the defect larger and prevent healing. It is also inadvisable to repair this type of fistula acutely in the inflamed surgical field and in a malnourished patient. Elective repair of the fistula should be delayed for several months when the fistula can be resected in conjunction with a delayed abdominal wall reconstruction. A planned ventral hernia with control of the effluent is usually the safest option. Intubation of the fistula through a protective wound VAC, the so-called tube VAC devised by George Al-Khoury in 2007 while working with the Hirschberg group, has been described to be successful in several select cases [14, 15].

Schein [22] from South Africa described simple measures for management of enteroatmospheric fistulae by exteriorizing a leaking segment or proximal diversion if possible. Another elegant technique was described by Hirschberg et al. in 2002 [24]. They proposed using a Bogota bag (sterile IV fluid bag used in temporary closures in the 1990s), suturing it to the skin and a making hole over the fistula. This serves as a physical barrier that protects the peritoneum. An ostomy bag can then be placed while granulation continues underneath.

Morbidity associated with wound complication from the open abdomen remains high (25 %) and is associated with the timing and method of closure and transfusion volume, but is independent of injury severity. Delayed primary fascial closure before 8 days is associated with the best outcomes at the least charges. However, attempts at fascial closure under undue tension are fraught with significant morbidity and mortality [18–21].

Abscesses are frequently a result of undrained cytokine-rich collections in the dependent recesses of the abdomen. Timely take backs to the operating room for abdominal washouts as well as effective temporary abdominal closure with quantifiable suction to remove this toxic fluid is essential for prevention. Abscess rates between the two groups were similar. At each VAC re-exploration, very few intra-abdominal abscesses were found. Most of the abscesses were diagnosed well after polyglactin mesh placement in both groups. As expected, those patients who had hollow viscus injury or gauze packing placed were more likely to develop abdominal abscesses.

The key is prevention by utilizing early closure, limiting fluids, utilizing an effective temporary closure, and selective use of biologic materials.

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F. G. Madbak, D. A. Dangleben (eds.), *Options in the Management of the Open Abdomen,* DOI 10.1007/978-1-4939-1827-0