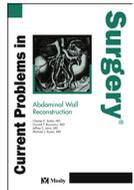




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Abdominal wall reconstruction

Introduction

Hernias can result from genetically impaired collagen formation, deposition, organization, or degradation; from wound-healing deficiencies; and from injury, failed laparotomy closures, or failed hernia repairs.^{1–3} Decades ago, it was suggested that both primary and recurrent hernias resulted from abnormal collagen metabolism.^{4,5} Original proposed risk factors for the development of hernias included tobacco use and a strong family history of hernia, which suggests a genetic predisposition. Subsequently, ratios of type I and type III collagen and tissue metalloprotease expression in patients with inguinal and incisional hernias were studied in an attempt to isolate an etiology.⁶ Further studies suggested that mechanical strain on load-bearing tissues can induce secondary changes in tissue fibroblast function that in turn can result in failure of abdominal wall repairs.⁷ Although more studies are needed, it is evident that some primary hernias are the result of a genetic predisposition, whereas the rest may be due to acquired structural collagen abnormalities from mechanical strain, with or without associated predisposing risk factors, such as tobacco use, diabetes, and obesity.⁸

Evolution of abdominal wall reconstruction

Advances in abdominal wall reconstruction over the 2 decades have eclipsed those over the past 2 centuries. Three key developments in abdominal wall reconstruction have redefined the field. The first came from the realization that direct suture repair of ventral hernia defects results in an extremely high rate of recurrence compared with mesh reinforcement of repairs. This realization drove innovation in both surgical technique and next-generation mesh materials. The second development was the landmark work done by Ramirez and colleagues⁹ defining the surgical technique of component separation (CS), which facilitates medialization of the rectus musculofascia, and thus midline abdominal closure by releasing the external oblique aponeuroses and posterior rectus sheath bilaterally. The third development was the introduction and improvement of bioprosthetic meshes as an alternative to synthetic meshes. Bioprosthetic mesh materials themselves have undergone an evolution based on donor tissue (allograft vs xenograft), as well as their different (and proprietary) methods of processing and sterilization, and will continue to evolve until the ideal bioprosthetic is developed. These developments are synergistic in that the combined use of CS and bioprosthetic mesh has enabled surgeons to achieve superior outcomes in complex abdominal wall reconstruction than is typically achieved with primary repair alone. The durability of these procedures and the resiliency of these bioprosthetic meshes have provided surgical options for a whole cohort of multiply morbid

patients who otherwise may not have been considered candidates for elective ventral hernia repair.

Classification of ventral hernias

Several classification systems exist that categorize ventral hernias based on whether they are spontaneous or acquired or by their location on the abdominal wall. Acquired hernias typically occur after surgical incisions and thus are commonly referred to as incisional hernias. Epigastric hernias occur from the xiphoid process to the umbilicus, umbilical hernias occur at the umbilicus, and hypogastric hernias occur below the umbilicus in the midline.

Although not a true hernia, diastasis recti can present clinically as a bulge in the midline. In this condition, the linea alba is stretched, resulting in bulging at the medial margins of the rectus abdominis muscles. There is no fascial ring or hernia sac. Unless significantly symptomatic, diastasis recti does not need to be corrected surgically.

This monograph focuses primarily on the repair of incisional hernias.

Epidemiology and etiology of hernias

As a result of the almost 4 million laparotomies performed annually in the United States and the 2%–30% incidence of incisional hernia, 150,000–250,000 ventral hernia repairs are performed each year.⁵ Ventral hernia repair is the fifth most common procedure listed by surgeons applying for American Board of Surgery recertification and carries with it an annual estimated cost of \$2 billion.

Several patient-related and technical factors have been linked to the occurrence of incisional hernias. Patient-related factors linked to ventral hernia formation include obesity, older age, male sex, sleep apnea, and prostatism. The factors associated with destruction of the collagen in the lung in chronic obstructive pulmonary disease and emphysema likely result in poor wound healing and increased hernia formation in patients with these diseases. Wound infection is also clearly associated with hernia formation.¹⁰

It has been suggested that the type of suture used during the primary operation affects incisional hernia formation, but there is no conclusive evidence to support this notion.³ Whether the type of abdominal incision used in the primary surgery influences the occurrence of incisional hernias also remains controversial. A 1995 analysis of 11 publications examining the incidence of ventral hernia formation after various types of abdominal incisions concluded that the risk was 10.5% for midline, 7.5% for transverse, and 2.5% for paramedian incisions.¹ A more recent prospective, randomized trial reported no difference in hernia formation after 1 year when comparing midline and transverse incisions but did note a higher wound infection rate with transverse incisions.⁵ Given the likely similar rates of incisional hernia formation after transverse and midline incisions, surgeons should plan incisions based solely on the operative exposure desired to safely complete procedures.

A factor known to be linked to incisional hernia formation is the manner in which the initial midline myofascial incision is closed. Specifically, animal and human trials have shown that a 4:1 suture to wound length ratio is optimal to reduce wound-related morbidity and incisional hernia formation.^{4,6} This suture strategy is often misunderstood; for clarification, it typically involves 5–7-mm fascia bites and 3–4 mm of travel. This “small-stitch” approach results in improved healing and reduced rates of wound infections.

Indications for hernia repair

There are 3 general indications to repair an incisional hernia: the hernia is symptomatic, causing pain or alterations in the bowel habits; the hernia results in a significant protrusion that

affects the patient's quality of life; and the hernia poses a significant risk of bowel obstruction (such as a large hernia with a narrow neck). However, the likely slow continued growth of incisional hernias due to intra-abdominal pressure should also be taken into consideration. In a young patient with a moderate-sized hernia, an initial nonoperative approach can result in the need for a more complex reconstruction in the future if the hernia becomes larger and symptomatic. Therefore, most surgeons recommend that these hernias be repaired electively when discovered.

Goals of ventral hernia repair

The goals of ventral hernia repair, regardless of the etiology of the defect, are to reestablish the integrity of the myofascial layer and provide durable cutaneous coverage while minimizing the risk of hernia recurrence (ie, to restore form and function). Although it is impossible to restore the abdominal wall to its native state after surgical wounding or to cure patients with hernia of their intrinsic collagenopathies, strategies can be employed to maximize the possibility of a successful outcome in abdominal wall reconstruction. Restoring the layered nature of the abdominal myofascia, the native location of key muscle groups, and the tone and contour of the abdominal wall is often achievable with contemporary surgical maneuvers. The importance of a meticulous dual-layered repair, centralizing the rectus abdominis muscle complexes, and reinforcing the repair with mesh, especially for hernias larger than 4 cm in greatest dimension, cannot be overemphasized.¹¹

Although CS will often allow for midline fascial reapproximation, which is the optimal situation, occasionally this will not be possible, particularly for larger hernias; and the myofascial edges will need to be bridged with mesh. Data have shown that defect size reduction, especially if less than 150 cm², will lead to the lowest recurrence rates.¹² All attempts should be made to avoid a bridged mesh repair because there is a clear trend toward higher recurrence rates compared with when the fascia can be reapproximated over a mesh repair.¹³ There are several other theoretic advantages to reapproximating the linea alba. If one considers the linea alba as the tendinous insertion of the rectus and oblique muscles and borrows from the concepts of tendon repair, then it seems logical that the physiological tension of the abdominal wall should be restored during ventral incisional hernia repair. Some authors have evaluated the functional improvement in patients in whom the midline fascia was restored and noted a 40% improvement in the abdominal wall function after repair.¹⁴ Although every attempt to reestablish the midline is advisable, accomplishing that goal is not always feasible, and not all patients can tolerate the intraperitoneal compression required (which can result in intraperitoneal hypertension, pulmonary compromise, or abdominal compartment syndrome). Understanding all of the approaches for abdominal wall reconstruction and particularly myofascial advancement flaps is critically important to determine the least invasive procedure to provide a long-lasting repair with an excellent functional outcome for the patient.

In the repair of abdominal wall defects, the surgeon must consider a multitude of factors to identify the appropriate surgical technique to accomplish the reconstructive goals. An individualized approach is required and must take into account the patient's age, comorbidities, physiological status, defect size, available local tissue, and presence of contamination. An understanding of the available reconstructive techniques and an honest assessment of his or her ability to perform each of these techniques should also guide the surgeon in establishing the most appropriate repair for the patient.

Anterior abdominal wall anatomy

The lateral abdominal wall musculature is composed of 3 layers, with the fascicles of each muscle directed obliquely at different angles to create a strong envelope for the abdominal contents. Each of the muscles forms an aponeurosis that inserts into the linea alba, a midline

structure joining the 2 sides of the abdominal wall. The external oblique muscle is the most superficial muscle of the lateral abdominal wall. Deep to the external oblique muscle lies the internal oblique muscle. The fibers of the external oblique muscle course from superiolateral to inferomedial (as hands in pockets), and those of the internal oblique muscle run perpendicular to the external oblique muscle's fibers. The deepest muscular layer of the abdominal wall is the transversus abdominis muscle; its fibers course horizontally. These 3 lateral muscles give rise to aponeurotic layers lateral to the rectus abdominis muscle, which contribute to the anterior and posterior layers of the rectus sheath. It is noteworthy that in contradistinction to what is stated in most anatomy books, the transversus abdominis muscle does not insert into the linea semilunaris medially; instead, the transversus abdominis aponeurosis actually forms the posterior rectus sheath and continues as a muscular component laterally in the upper abdomen. This feature is important when considering the technical aspects of a posterior CS.

The medial extension of the external oblique aponeurosis forms the anterior layer of the rectus sheath. At the midline, the 2 anterior rectus sheaths form the tendinous linea alba. On either side of the linea alba is a rectus abdominis muscle, the fibers of which course vertically and run the length of the anterior abdominal wall. The width of these muscles averages 5–7 cm in men. Below each rectus muscle lies the posterior layer of the rectus sheath, which also contributes to the linea alba.

Another important anatomical structure of the anterior abdominal wall is the arcuate line, which is located 3–6 cm below the umbilicus and delineates the point below which the posterior rectus sheath is absent. The arcuate line is composed of the transversalis fascia and peritoneum. Above the arcuate line, the aponeurosis of the internal oblique muscle contributes to both the anterior and posterior rectus sheaths, and the aponeurosis of the transversus abdominis muscle passes posterior to the rectus abdominis muscle to form the posterior rectus sheath as described previously. Below the arcuate line, the internal oblique and transversus abdominis aponeuroses pass completely anterior to the rectus muscle.

The abdominal wall receives the majority of its innervation from the 7th to 12th intercostal nerves and the first and second lumbar nerves. These rami provide innervation to the lateral abdominal muscles, the rectus abdominis muscles, and the overlying skin. The nerves traverse the lateral abdominal wall between the transversus abdominis and internal oblique muscles and penetrate the posterior rectus sheath just medial to the linea semilunaris.

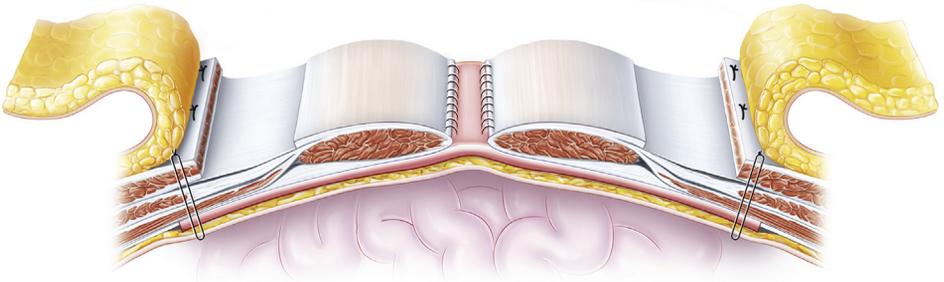
The lateral abdominal muscles receive their blood supply from the lower 3 or 4 intercostal arteries, the deep circumflex iliac artery, and the lumbar arteries. The rectus abdominis muscles have a more complex blood supply derived from the superior epigastric artery (a terminal branch of the internal mammary artery), the inferior epigastric artery (a branch of the external iliac artery), and the lower intercostal arteries. The superior and inferior epigastric arteries anastomose near the umbilicus. The periumbilical area provides critical myocutaneous perforator vessels that, if preserved, can decrease skin flap necrosis from skin undermining.¹⁵

Mesh

Mesh use is advised for hernia defects larger than 74 cm² even when the myofascia can be closed without tension. Randomized prospective studies have shown significantly lower early and late hernia recurrence rates when mesh is used.^{11,16}

Mesh placement

Mesh materials can be placed in several different configurations: interpositional (mesh edge to fascial edge), inlay [or sublay] (dorsal to the rectus muscles), or onlay (ventral to the rectus muscles). The interpositional technique has been largely abandoned by most surgeons owing to an unacceptably high hernia recurrence rate. Options for inlay mesh placement include retrorectus (between the rectus abdominis muscles and posterior rectus sheath), preperitoneal (between the posterior rectus sheath and preperitoneal fat), or intraperitoneal.

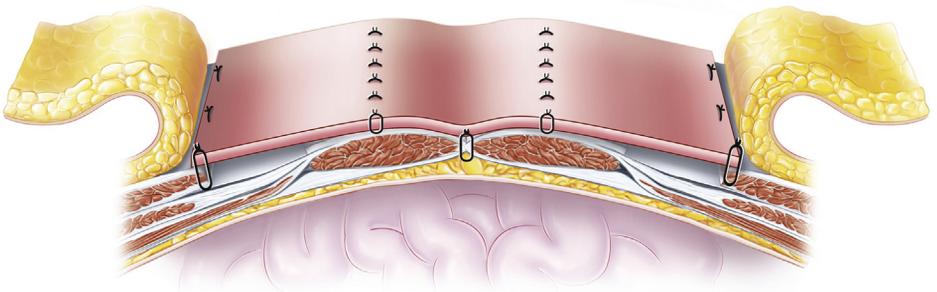


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Fig. 1. Bridging inlay mesh placement. The mesh is interposed between the medial edges of the rectus abdominis muscle complexes. (Adapted with permission from Losken A, Janis JE. *Advances in Abdominal Wall Reconstruction*. St. Louis: Quality Medical Publishing, 2012.) (Color version of figure is available online.)

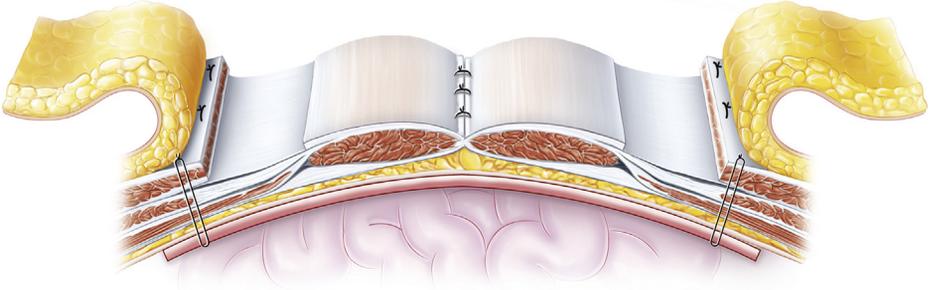
The location of mesh placement plays a critical role in optimizing outcomes. Bridging inlay repairs (Fig 1), in which the mesh edges are sutured to the medial fascial edges of the defect without midline reapproximation, give the poorest outcomes.^{13,14,16,17} The location on the abdominal wall to which the mesh is sutured varies between surgeons. Figure 1 and subsequent figures depict the mesh being anchored to the lateral aspect of the released external oblique, internal oblique, and transversus muscles. Many surgeons (including the senior author and C.E.B.) prefer to anchor the mesh to the lateral aspect of the rectus abdominis musculofascial sheath at the semilunar line. The theoretic advantage is that the semilunar line or lateral rectus sheath is a strong aponeurotic buttress and may reduce the risk of suture pull-through. An advantage of suturing the mesh through the lateral musculature is that there is a greater amount of mesh surface area peripheral to the defect often referred to as a “wide mesh underlay.” However, no studies have directly compared these techniques.

Onlay repairs (Fig 2) place the mesh superficial to the anterior rectus sheath and external oblique aponeurosis and reapproximate the fascia over the mesh. The major advantage of this approach is that the mesh is placed outside the abdominal cavity, avoiding direct contact with the abdominal viscera. However, the technique has several disadvantages: a large subcutaneous dissection is required to inset the mesh; there is an increased potential likelihood of seroma formation; the superficial location of the mesh places it in jeopardy of contamination if the incision becomes infected; and a skin wound dehiscence can result in direct external exposure of



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Fig. 2. Onlay mesh placement. The mesh is placed superficial to the anterior rectus sheath and the external oblique aponeurosis. (Adapted with permission from Losken A, Janis JE. *Advances in Abdominal Wall Reconstruction*. St. Louis: Quality Medical Publishing, 2012.) (Color version of figure is available online.)

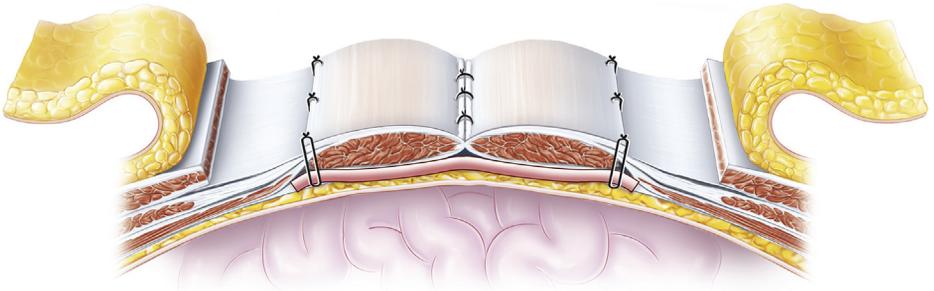


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Fig. 3. Intraperitoneal inlay mesh placement. The mesh is placed within the peritoneal cavity deep to the posterior rectus sheath and transversalis fascia laterally. The mesh is anchored laterally and the anterior rectus sheaths are closed in the midline. (Adapted with permission from Losken A, Janis JE. *Advances in Abdominal Wall Reconstruction*. St. Louis: Quality Medical Publishing, 2012.) (Color version of figure is available online.)

the mesh. Onlay mesh is usually placed after the fascia is closed in the midline and therefore has little ability to “offload” the fascial tension. In contrast, an inlay mesh inset can be placed with the appropriate physiological tension to facilitate midline fascial reapproximation as a reinforced, rather than a bridged repair. In addition, if the midline fascia separates in the early postoperative period, the mesh is often exposed to abdominal viscera. No prospective studies of this technique are available, but a retrospective review reported hernia recurrence rates of 28% with mesh onlay.^{9,18}

Most herniologists, in both Europe and America, favor inlay mesh repairs because the intra-abdominal pressure is distributed against the mesh itself so that tension is spread across the abdominal wall. Inlay mesh placement can be performed in any of 3 tissue planes: intraperitoneal (Fig 3), retrorectus (Fig 4), and preperitoneal. Notice that the mesh is sutured to the lateral rectus sheath and semilunar line in Figure 4. This location of suture placement can also be used for onlay and inlay techniques. The advantage of the intraperitoneal approach is the avoidance of injury to the posterior sheath and rectus muscle, as well as the fact that concomitant procedures are often performed in the same space (eg, ostomy takedown or fistula resection). The retrorectus approach has the advantages of being relatively easy to develop (assuming no prior disruptions of this plane) and insulating mesh from the intraperitoneal



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Fig. 4. Retrorectus inlay mesh placement. The mesh is placed within the posterior rectus sheath deep to the rectus abdominis muscle. The mesh is anchored to the linea semilunaris, and the anterior rectus sheaths are closed in the midline. (Adapted with permission from Losken A, Janis JE. *Advances in Abdominal Wall Reconstruction*. St. Louis: Quality Medical Publishing, 2012.) (Color version of figure is available online.)

contents, where adhesions may form; this approach also has the theoretical advantage of providing a broad muscle interface with the mesh to facilitate revascularization.^{19,20} The preperitoneal approach is a sound option for patients who have a well-developed preperitoneal fat pad; this puts the mesh in direct contact with the posterior sheath.

Regardless of the plane of mesh placement, appropriate tension must be established across the mesh repair. The key is to recreate the physiological tension across the repair that correlates with the tone of the abdominal wall in a resting state while standing. If excessive tension is placed on the mesh-myofascia suture line, this interface will attenuate and lead to peripheral failure of the mesh repair. Critical clinical judgment must be exercised to establish proper physiological tension in each patient. The techniques of mesh placement are described in detail in the section “Operative Repair of Ventral Hernias.”

Types of mesh

Synthetic mesh

When selecting the appropriate mesh for a patient, the surgeon must consider whether the mesh will be in direct contact with the viscera and whether infection is present or likely. A variety of synthetic mesh products are available for ventral hernia repair. The ideal mesh has not yet been developed but would cause minimal or no inflammatory reaction and be chemically inert, resistant to mechanical stress, sterilizable, noncarcinogenic, hypoallergenic, and reasonably priced. Each of the commercially available synthetic meshes has some but not all of these properties.

Synthetic mesh materials are classified based on the weight of the material (weight per surface area), pore size, and water angle (hydrophobic or hydrophilic), and whether they include an antiadhesive barrier. When mesh is placed extraperitoneally and there is negligible risk of bowel erosion, a macroporous mesh without an antiadhesive barrier layer is appropriate. Both polypropylene and polyester mesh have been placed successfully in the extraperitoneal position.

Polypropylene mesh is a semirigid, hydrophobic, macroporous mesh that allows for ingrowth of native fibroblasts and incorporation into the surrounding fascia. Placing polypropylene mesh in an intraperitoneal position directly against the bowel should be avoided because of bowel adhesions to mesh and unacceptable rates of enterocutaneous fistula formation.⁷ Recently, lighter-weight polypropylene mesh has been introduced to address some of the long-term complications of heavyweight polypropylene mesh, particularly adhesions to bowel. The definition of lightweight polypropylene mesh was arbitrarily set at less than 50 g/m², with heavyweight mesh weighing greater than 80 g/m². Lightweight mesh products often have an absorbable component that provides initial handling stability; this material is typically composed of Vicryl or Monocryl (Ethicon, Inc, Somerville, NJ). Whether lightweight, rather than heavyweight mesh results in improved patient outcomes is controversial. Two prospective randomized trials evaluating the incidence of postoperative pain after open inguinal hernia repair showed mixed results.^{21,22} In a randomized controlled trial evaluating lightweight vs heavyweight polypropylene mesh for ventral hernia repair, the recurrence rate was more than 2 times greater in the lightweight mesh group (17% vs 7% for heavyweight mesh; $P = 0.052$).¹⁰ The use of lightweight polypropylene mesh in the setting of contamination has received renewed interest as a more cost-effective approach than bioprosthetic mesh. Several authors have demonstrated that lightweight polypropylene mesh is relatively resistant to bacterial colonization in experimental models, and small case series have demonstrated safety when utilized in clean-contaminated colorectal cases.^{11,23–25}

Polyester mesh is composed of polyethylene terephthalate and is a heavyweight, hydrophilic, macroporous mesh. Polyester mesh has several different configurations: a 2-dimensional flat screen-like mesh, a 3-dimensional multifilament weave, and more recently, a monofilamentous mesh. Unprotected polyester mesh should not be placed directly on the viscera because unacceptable rates of erosion and bowel obstruction have been reported.⁷ When polyester mesh is placed in the preperitoneal position in complex ventral hernia repairs, complication rates are low.^{13,26}

When mesh is to be placed in an intraperitoneal position, several options are available. A laminar sheet of mesh with different porosities at different sites and a composite mesh with 1 side designed to promote tissue ingrowth and the other to resist adhesion formation are available. Laminar mesh is composed of expanded polytetrafluoroethylene (ePTFE). It has a visceral side that is microporous ($3\ \mu\text{m}$) to resist adhesion formation and an abdominal wall side that is macroporous ($17\text{--}22\ \mu\text{m}$) to promote tissue ingrowth. This product differs from other synthetic meshes in that it is flexible and smooth. Some fibroblast proliferation occurs through the pores, but ePTFE has limited fluid permeability. Unlike polypropylene, ePTFE is not incorporated into the native tissue. Encapsulation occurs slowly, and infection can occur during the encapsulation process. When infected, ePTFE mesh almost always requires removal.

To promote better tissue integration, composite meshes were developed. These products combine the attributes of both polypropylene and ePTFE by layering the 2 substances. The ePTFE surface serves as a permanent protective interface against the bowel, and the polypropylene side faces the abdominal wall and is macroporous to promote incorporation into the native fascial tissue. These materials have different rates of contraction that can result in buckling of the mesh and lead to mesh exposure to the viscera.

Recently, other composite meshes have been developed that combine a macroporous mesh with a temporary absorbable antiadhesive barrier. These mesh materials are made of heavyweight or lightweight polypropylene or polyester and an absorbable barrier typically composed of oxidized regenerated cellulose, hyaluronic acid, omega-3 fatty acids, or collagen hydrogels. Studies in small animals have validated the antiadhesive properties of these barriers, but currently no human trials exist evaluating the ability of these composite materials to resist adhesion formation.

Bioprosthetic mesh

Bioprosthetic meshes are reported to have certain advantages over synthetic meshes because of their potential ability to resist infection and remodel over time, leaving behind host cells and native regenerated collagen. Animal studies have demonstrated a marked reduction in the strength and surface area of adhesions with the use of acellular dermal matrices (ADMs) compared with polypropylene mesh.^{27–29} Animal studies have also demonstrated rapid host cell and vascular infiltration into ADMs used for hernia repair. These properties are believed to reduce the risk of bacterial infection and potentially allow ADMs to be used in contaminated hernia repairs with a lower risk of infection.³⁰ One experiment systematically evaluated the performance of various bioprosthetic meshes in an animal model after exposure to *Staphylococcus aureus*.¹⁴ There was a broad range of bacterial clearance for the different materials, which might ultimately affect clinical performance.

Several bioprosthetic meshes are commercially available for abdominal wall reconstruction (Table 1). These products can be categorized based on the source material (human, porcine, or bovine), processing technique (cross-linked or non-cross-linked), and sterilization technique (gamma radiation, ethylene oxide gas sterilization, or nonsterilized). These products are composed mostly of acellular collagen and theoretically provide a matrix for neovascularization and native collagen deposition.

Ideal placement techniques have yet to be defined for these products; however, some general principles apply. Bioprosthetic meshes function best when utilized as a fascial reinforcement rather than a bridge or interposition graft.¹⁶ Furthermore, a clear understanding of advanced reconstructive techniques is important to achieve optimal outcomes with these materials. A recent prospective multicenter trial evaluated outcomes with various bioprosthetic mesh positions in abdominal wall repair.¹⁷ The investigators noted a 3-fold lower recurrence rate when the bioprosthetic mesh was placed in the retrorectus position vs the intraperitoneal position in contaminated abdominal wall reconstruction. They postulated that this advantage might be due to the improved local blood supply afforded by the retrorectus position; however, larger studies are necessary to confirm these findings.

Table 1

Commercially available bioprosthetic meshes for abdominal wall reconstruction

Product	Source	Cross-linked?	Sterilization technique
Alloderm, LifeCell, (Branchburg, NJ)	Human dermis	No	Ionic
Allomax, Bard Davol, Inc (Warwick, RI)	Human dermis	No	Electron beam immouduction
Flex HD, Ethicon Endo-Surgery, Inc (Edison, NJ)	Human dermis	No	Ethanol
Strattice, LifeCell (Branchburg, NJ)	Porcine dermis	No	Gamma irradiation
Permacol, Covidien (Mansfield, MA)	Porcine dermis	Yes	Ethanol
Xenmatrix, Bard Davol, Inc (Warwick, RI)	Porcine dermis	No	Gamma irradiation
Surgimend, TEI Inc (Boston, MA)	Bovine fetal dermis	No	Ethanol
Veritas, Synovis, Inc (Deerfield, IL)	Bovine pericardium	No	Electron beam immouduction
Biodesign, Cook Surgical (Bloomington, IN)	Porcine small intestine submucosa	No	Ethanol

Few data are currently available to assess the long-term durability of bioprosthetic meshes, and no randomized trials have been performed to compare the performance of different bioprosthetic meshes. Furthermore, no data exist comparing the outcomes of bioprosthetic mesh vs synthetic mesh in a clean or clean-contaminated field.

In summary, the best practices for bioprosthetic mesh placement are not completely elucidated. Use of bioprosthetic materials is a relatively new area in hernia surgery, and further animal and clinical studies are needed to answer many important questions. Currently, these grafts appear to tolerate placement in a clean-contaminated field, but their long-term durability and role in hernia recurrence are largely unknown. Although bioprosthetic meshes are much more expensive than synthetic meshes, the long-term cost-effectiveness of these materials, particularly in contaminated cases, may be better.

More recently, newer bioabsorbable synthetic meshes that do not biodegrade for several months (unlike polylactic acid-based mesh) have been introduced and proposed as less costly alternatives to bioprosthetic meshes. However, further studies are required before the exact place of these new materials in the armamentarium of the abdominal wall hernia surgeon can be determined.

Operative repair of ventral hernias

Intraperitoneal mesh placement

Several composite meshes with antiadhesive barriers (absorbable and permanent) are available to place in the intraperitoneal position. Once the previous incision (if present) is reopened and adhesiolysis is complete, the fascial edges are clearly defined. The mesh is sized to extend at least 4 cm peripheral to the myofascial defect edge and is secured to the musculofascia with interrupted mattress sutures. Intraperitoneal mesh placement may be in direct contact with the abdominal contents if insufficient greater omentum is available to interpose between the mesh and viscera. It is therefore important to place the sutures close together to prevent entrapment of a loop of intestines between sutures. Another technical challenge with this approach is to avoid buckling of the mesh once the midline fascia is approximated. If the midline is going to be closed, the surgeon can measure the amount of fascial overlap on both sides and inset the mesh appropriately. Ideally, once the mesh is inserted peripherally the midline fascia will be reapproximated, and the mesh will bear the majority of the tension.

The laparoscopic approach for intraperitoneal mesh placement relies on the same principles as the open technique. Trocars are placed as far laterally as feasible based on the size and location of the hernia. The hernia contents are reduced, and adhesions are lysed. The defect is

measured intraperitoneally, and an appropriately sized piece of barrier-coated mesh is fashioned with at least 4 cm of overlap around the defect. The mesh is rolled, placed into the abdomen, and deployed. It is secured to the anterior abdominal wall with preplaced mattress sutures that are passed through separate incisions, and tacking staples are placed between these sutures to secure the mesh 4 cm beyond the defect. The laparoscopic approach offers a significant reduction in postoperative wound morbidity by avoiding subcutaneous tissue dissection. Postoperative pain, however, is often similar to that with an open procedure, and in thin patients a perceptible postoperative bulge can be present.

Myofascial advancement flaps

For defects that are too wide to close without undue tension, myofascial release and advancement can be performed. These concepts were originally described by Stoppa and Ramirez, and several modifications have been reported.¹⁸ Myofascial advancement techniques take advantage of the laminar nature of the abdominal wall and the ability to release 1 muscular or fascial layer to enable medial advancement of another.

There are few comparative data to suggest the superiority of 1 myofascial advancement approach over another, and likely each has a role in abdominal wall reconstruction. The least invasive is the standard retromuscular approach as described by Stoppa.¹⁸ If the lateral abdominal compartment must be released, release can be done by open or minimally invasive CS. A minimally invasive CS can be performed various ways, but all of the techniques (to a certain degree) maintain the blood supply to the skin from the underlying rectus abdominis muscles. CS variations are described in detail later in the article. Examples of a minimally invasive CS that is described later include an endoscopic CS, with an inlay of bioprosthetic mesh, periumbilical perforator-sparing technique, and a posterior CS.

Retromuscular mesh placement

Mesh can be placed extraperitoneally in either the preperitoneal space or retrorectus position (Fig 5). This technique was initially described by Rives and Stoppa.^{20,26} A large piece of mesh is placed ventral to the posterior rectus sheath or peritoneum. This space must first be dissected laterally on both sides of the linea alba to the linea semilunaris. The linea semilunaris is identified by the presence of the intercostal nerves perforating the lateral border of the rectus muscle, as well as the lateral reflection of the posterior sheath as it transitions to the anterior sheath. These neurovascular bundles must be maintained as they provide segmental innervation to the rectus complex. The mesh extends 5–6 cm beyond the superior and inferior borders of the defect. The mesh is secured laterally with several sutures. These sutures should be placed under physiological tension to help medialize the rectus abdominis muscles and prevent buckling of the mesh during midline fascial reapproximation. This approach avoids contact between the mesh and the abdominal viscera and has been shown in long-term studies to have a respectable hernia recurrence rate of 14% for large incisional hernias.^{20,26} A retrospective review from the Mayo Clinic with a median follow-up of 5 years documented a 5% overall hernia recurrence rate in 254 patients undergoing complex ventral hernia repair over a 13-year period.¹⁹

Component separation

Open CS

Open CS is performed by raising large subcutaneous flaps to expose the external oblique fascia. The cutaneous perforators emerging from the anterior rectus sheath are ligated and divided to facilitate exposure of the linea semilunaris in its entirety. These flaps are carried

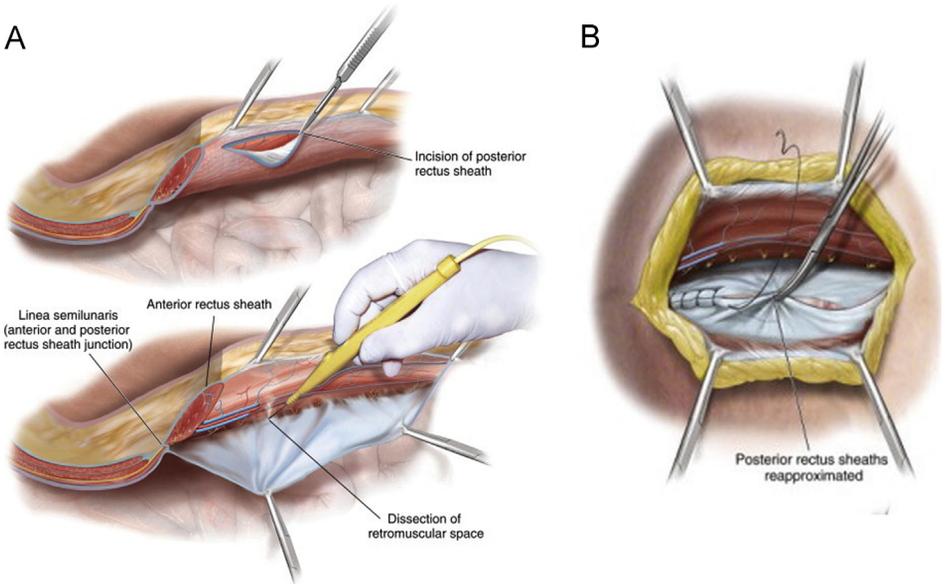


Fig. 5. Rectorectus extraperitoneal mesh placement. (A) Access to the retrorectus space is gained by releasing the medial edge of the posterior rectus sheath. Dissection in an areolar plane is carried out to separate the rectus abdominis muscle from the posterior sheath to create a space for inlay mesh placement. (B) The posterior rectus sheaths are then reapproximated in the midline before mesh placement. This maneuver excludes the mesh material from the peritoneal cavity. (Adapted with permission from Rosen M. *Atlas of Abdominal Wall Reconstruction*, pp. 15-195, Copyright Elsevier, 2012.) (Color version of figure is available online.)

laterally past the linea semilunaris. This subcutaneous dissection itself can provide some medial advancement of the abdominal wall skin (Fig 6).

An anatomically precise external oblique aponeurotomy is made 1-2 cm lateral to the linea semilunaris on the lateral aspect of the external oblique aponeurosis from several centimeters above the costal margin to the pubis. It is important to confirm that the incision is not carried through the linea semilunaris, as this would result in a full-thickness defect of the lateral abdominal wall, which is very challenging to repair. The external oblique aponeurosis is then bluntly separated in the avascular plane away from the internal oblique aponeurosis to the midaxillary line, allowing the internal oblique and transversus abdominis muscles with the rectus abdominis muscle or fascia to advance medially as a unit. The use of additional relaxing incisions in the aponeurotic layers of the internal oblique or transversus abdominis muscles has been described, but this practice can result in problematic lateral bulges or herniation and is not recommended. If needed, additional release can be safely achieved by incising the posterior rectus sheath. These techniques, when performed bilaterally, can yield up to 20 cm of mobilization in the midabdomen.

Once the mesh inset and fascial closure are performed, the subcutaneous skin flaps are advanced and closed at the midline. To reduce subcutaneous dead space, Butler and colleagues³¹ described the use of interrupted quilting sutures between the Scarpa fascia and musculofascial repair. Janis recently reported a technique to improve complication rates in the open CS approach with a cosmetic surgery concept originally described by Pollock and Pollock for use in drainless cosmetic abdominoplasties—progressive tension sutures.^{32,33} This concept differs from traditional quilting sutures in that the sutures are “offset,” with the down bite being more medial on the fascia and the up bite being more lateral on the undersurface of the skin flap, engaging a small amount of Scarpa fascia. The use of multiple progressive tension sutures (usually 5 vertical rows) of 2-0 Vicryl—originally interrupted sutures but recently modified to a running barbed suture—minimizes

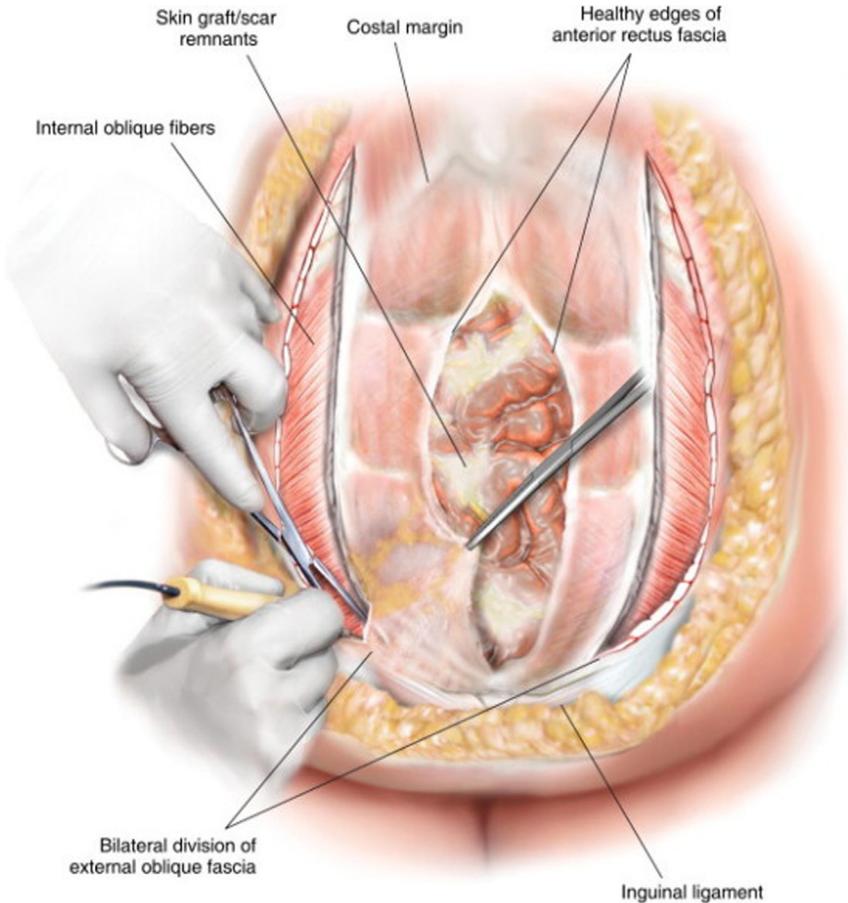


Fig. 6. Open component separation. Subcutaneous flaps are elevated off the anterior rectus sheath to expose the external oblique aponeurosis. The external oblique aponeurosis is released from the inguinal ligament inferiorly to above the costal margin superiorly. This allows exposure of the internal oblique muscle fibers once the external aponeurosis is incised. (Adapted with permission from Rosen M. *Atlas of Abdominal Wall Reconstruction*, pp. 15–195, Copyright Elsevier, 2012.) (Color version of figure is available online.)

subcutaneous dead space and repositions the skin flaps to the myofascia of the abdominal wall. This technique also decreases shear stress, which is thought to contribute to postoperative seroma formation, and has been shown statistically to significantly decrease the total drain output, allowing the surgeon to place fewer drains and leave them in for a shorter period. It also allows for tension-free skin reapproximation. Care must be taken to avoid excessive medial tension on the skin flaps to avoid vascular compromise. After paramedian skin perfusion is critically assessed, a vertical panniculectomy is performed so that the skin is reapproximated in the midline without redundancy.

Open CS often allows tension-free closure of large defects, and recurrence rates as low as 20% have been reported with the use of open CS and mesh reinforcement in large hernias.¹⁵ Recognizing the high recurrence rates with CS alone, several authors have reported series of bioprosthetic or synthetic mesh reinforcement of these repairs, although to date, no randomized controlled trials have demonstrated lower hernia recurrence rates with a specific mesh type. If bioprosthetic mesh is placed, it can be secured in either an underlay or onlay technique; no comparative data exist demonstrating the superiority of either technique.³⁴

Laparoscopic CS

A major limitation of open CS is the wound morbidity associated with the large skin flaps necessary to access the lateral abdominal wall. To avoid this morbidity, several authors have described innovative minimally invasive approaches to CS.^{32,33,35,36} These approaches are designed to gain direct access to the lateral abdominal wall without creating large skin flaps, creating dead space, or interrupting the primary blood supply to the central abdominal skin by ligation of the rectus abdominis perforator vessels.

Laparoscopically, CS is performed through a 1-cm incision below the tip of the 11th rib overlying the external oblique muscle (Fig 7). The external oblique muscle is split in the direction of its fibers, and a standard bilateral inguinal hernia balloon dissector is placed between the external and internal oblique muscles and directed toward the pubis. Three laparoscopic trocars are placed in the space created, and the dissection is carried from the pubis

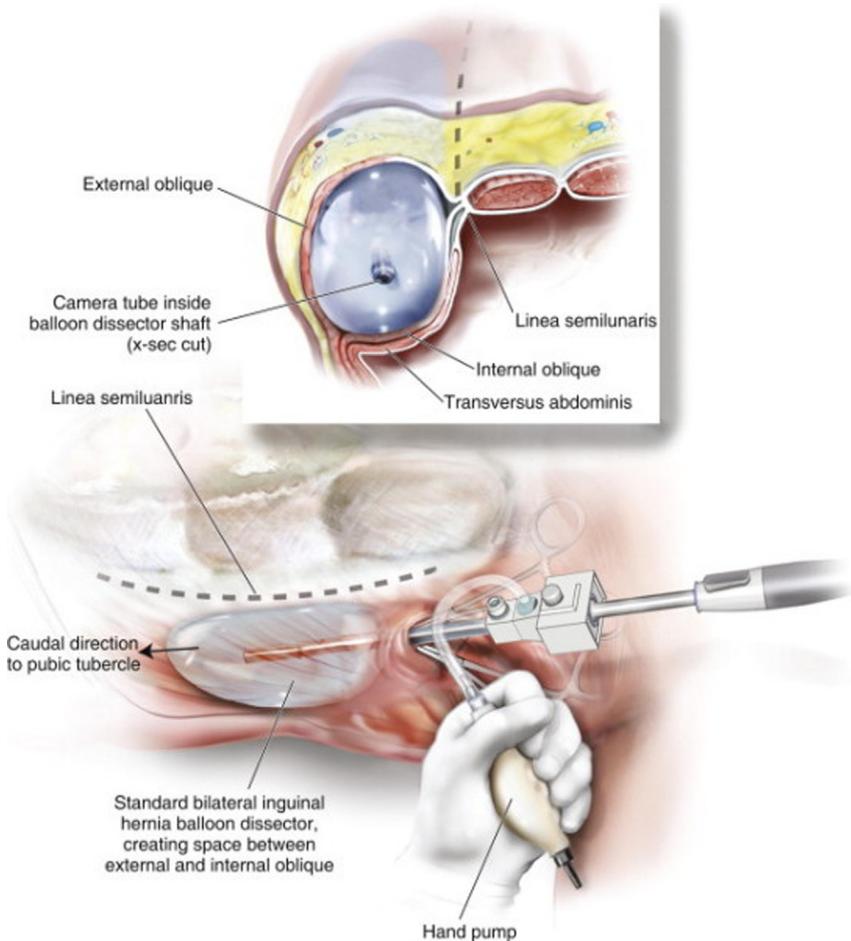


Fig. 7. Endoscopic component separation. Access to the external oblique aponeurosis is achieved through a small incision at the costal margin through which a balloon dissector is placed. The external oblique aponeurosis is then divided from the pubis to above the costal margin. This minimally invasive approach preserves the attachments of the subcutaneous tissue (including myocutaneous perforators) to the anterior rectus sheath throughout its course. (Adapted with permission from Rosen M. *Atlas of Abdominal Wall Reconstruction*, pp. 15-195, Copyright Elsevier, 2012.) (Color version of figure is available online.)

to several centimeters above the costal margin. The linea semilunaris is carefully identified, and the external oblique aponeurosis is incised from beneath the external oblique muscle at least 2 cm lateral to the linea semilunaris. The muscle is released from the pubis to several centimeters above the costal margin. This procedure is performed bilaterally. Comparative data have shown laparoscopic CS to result in a lower rate of wound morbidity than open CS.³⁷

Periumbilical perforator-sparing CS

The rationale for the periumbilical perforator-sparing technique of CS is that the blood supply to the anterior abdominal wall skin near the midline is based primarily on perforator vessels from the deep inferior epigastric vessels. Cadaver dissections and radiographic studies have confirmed that the majority of these vessels are located within 3 cm of the umbilicus.³⁸ With preservation of these vessels, ischemic complications involving the subcutaneous flaps are significantly reduced.³⁹

To avoid injury to the periumbilical perforator vessels, a line is marked no less than 3 cm cephalad and 3 cm caudal to the umbilicus. The periumbilical perforator tunnels are begun at the epigastric and suprapubic regions. Subcutaneous tunnels are created using lighted retractors to identify the external oblique fascia. The superior and inferior tunnels are connected using cautery and retractors while maintaining the subcutaneous attachments of the periumbilical region. The linea semilunaris is identified by palpation, and the external oblique is incised 2 cm lateral to this junction. The aponeurotomy is extended several centimeters above the costal margin and to the pubic tubercle. The external oblique muscle is separated from the internal oblique muscle in the avascular plane toward the posterior axillary line. One series reported a significant reduction in wound morbidity with the periumbilical perforator-sparing technique compared with the standard open CS technique (2% vs 20%; $P < 0.05$).³⁹

The periumbilical perforator-sparing approach has several limitations. One of the benefits of minimally invasive CS is to reduce subcutaneous dead space. The periumbilical perforator-sparing technique creates considerable dead space and sacrifices more perforator vessels to the skin than other minimally invasive techniques. When skin mobilization is necessary, adequate advancement occasionally can be difficult to achieve because the midline skin is still invested in the periumbilical region. Additionally, the placement of a wide piece of mesh as an underlay can be difficult given the large subcutaneous paddle that is still attached. However, several authors have described approaches to overcome these challenges.

Minimally invasive CS (MICS)

Butler and colleagues modified the standard open Ramirez-style procedure that does not involve additional abdominal skin incisions and further reduces the subcutaneous dead space and maximize the blood supply to the abdominal skin with rectus perforator preservation.⁴⁰ The MICS technique is designed to avoid division of the musculocutaneous perforators overlying the rectus sheath and thus maintain perfusion to the paramedian skin. MICS minimizes subcutaneous dead space, which decreases the potential for seroma formation, wound infection, and wound dehiscence. MICS is often combined with an inlay of bioprosthetic mesh.⁴¹ Synthetic mesh is also used with MICS when synthetic mesh is indicated.

After lysis of adhesions and identification of the fascial edges, bilateral, 3-cm wide, subcutaneous access tunnels are created over the anterior rectus sheath from the midline to the linea semilunaris at the level of the costal margin (Fig 8). Through these access tunnels, the external oblique aponeurosis is vertically incised 1.5 cm lateral to the linea semilunaris. The tip of a metal Yankauer suction handle (Cardinal Health, Dublin, OH), without suction, is inserted through the opening in the avascular plane between the internal and external oblique aponeuroses, separating them at their junction with the rectus sheath. The suction tip is advanced inferiorly to the pubis and superiorly to above the costal margin. A narrow (2.5-cm

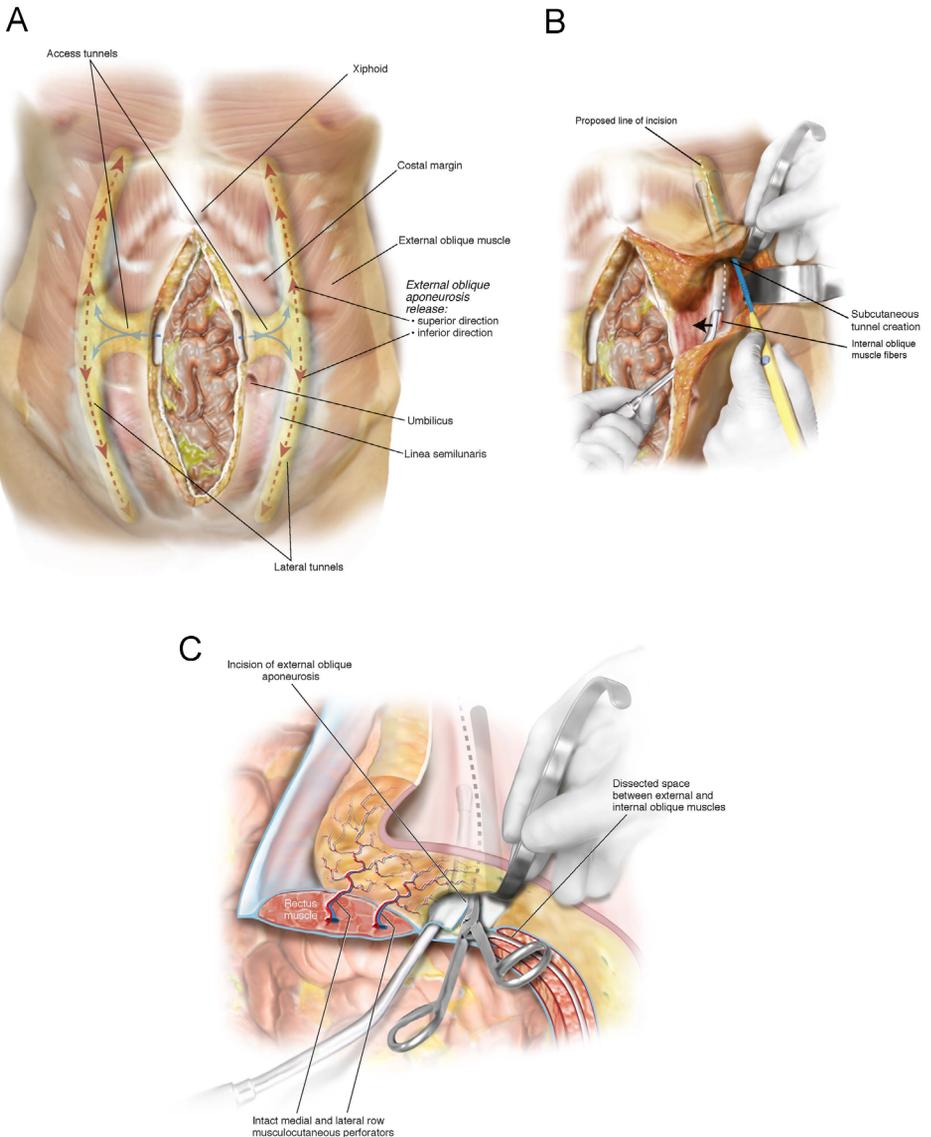


Fig. 8. The Butler minimally invasive component separation (MICS) technique. (A) Access to the external oblique aponeurosis is achieved through a small tunnel from the midline to the supraumbilical external oblique aponeurosis. Vertical tunnels are created dorsal and ventral to the planned release site of the external oblique aponeurosis. Periumbilical perforators and the subcutaneous tissue overlying the anterior rectus sheath are left undisturbed. (B) The external oblique aponeurosis is then divided from the pubis to above the costal margin. The external oblique aponeurosis in the upper abdomen is released with electrocautery as muscle is transected at, and superior to, the costal margin. (C) Scissors are generally used to release the external oblique aponeurosis inferiorly. This MICS approach preserves the attachments of the subcutaneous tissue (including myocutaneous perforators) to the anterior rectus sheath throughout its course. (Adapted with permission from Rosen M. *Atlas of Abdominal Wall Reconstruction*, pp. 15–195, Copyright Elsevier, 2012.) (Color version of figure is available online.)

wide), vertical subcutaneous tunnel is created with electrocautery superficial to the external oblique aponeurosis over the planned release location using a narrow retractor and light source. The external oblique aponeurosis is then released approximately 1.5 cm lateral to the lateral edge of the rectus sheath from 12 cm above the costal margin superiorly to near the pubis

inferiorly. Next, lateral dissection between the internal and external oblique muscles is performed to the midaxillary line.

Minimal subcutaneous skin flaps are then elevated over the anterior rectus sheath circumferentially to the medial row of rectus abdominis perforator vessels, and a retrorectus or preperitoneal mesh inlay is generally used. If a preperitoneal inset is used the preperitoneal fat is dissected from the posterior sheath circumferentially to allow the mesh to be inlaid directly against the posterior sheath or rectus abdominis muscle (below the arcuate line). Mesh is inserted to the semilunar line with #1 polypropylene sutures via the horizontal access tunnels and the cranial and caudal aspect of the defect. Next, the myofascial edges are advanced and reapproximated over the mesh with sutures placed through the myofascia and mesh. Interrupted resorbable 3-0 sutures are placed to affix the posterior sheath to the mesh, thereby obliterating dead space and reducing the potential for fluid collection.

The redundant medial aspects of the skin flaps are carefully excised in a vertical panniculectomy. Closed-suction drainage catheters are placed in each CS donor site area, in the space between the rectus complex closure and bioprosthetic mesh, and in the subcutaneous space. The remaining undermined skin flaps are sutured to the myofascia with vertical rows of interrupted resorbable 3-0 quilting sutures to reduce dead space and potential shear between the subcutaneous tissue and myofascia.

A controlled study demonstrated that patients had significantly fewer wound-healing complications (32% vs 14%, $P = 0.026$) and skin dehiscences (28% vs 11%, $P = 0.01$) with MICS than with traditional open CS.⁴² These improved wound-healing outcomes are likely due to preservation of the vascularity of the overlying skin flaps and reduction of paramedian dead space—the surgical principles underlying the MICS procedure. The learning curve for the MICS technique is similar to the learning curve in the early open CS experience. The MICS technique represents the evolution from maximally invasive open procedures to minimally invasive procedures that not only reduce donor site morbidity but also improve the primary outcomes of the procedure.

Posterior CS

The concept of a posterior CS is based on the retromuscular Rives-Stoppa approach to ventral hernia repair. Unlike the Ramirez CS focusing on external oblique aponeurosis release, the posterior CS focuses on transversus abdominis aponeurosis release. As previously mentioned, the transversus abdominis aponeurosis actually forms the posterior rectus sheath in the upper two-thirds of the abdomen. By incising this myofascial aponeurosis, the surgeon accesses the preperitoneal space. This provides substantial advancement of both the posterior fascial flap and the anterior myofascial compartment.

The initial release is completed by incising the posterior rectus sheath approximately 1 cm lateral to the linea alba and the posterior rectus sheath is separated from the overlying rectus muscle (Fig 9A). The deep inferior epigastric vessels are carefully preserved. As in a standard Rives-Stoppa repair, the dissection is carried to the lateral border of the rectus abdominis muscle, and the perforating intercostal nerves are identified. Next, the transversus abdominis muscle is incised just medial to the intercostal nerves, and the underlying transversalis fascia and peritoneum are identified. This myofascial release is extended the entire length of the posterior rectus sheath (Fig 9B). The potential space between the transversus abdominis muscle and the peritoneum is developed as far laterally as necessary, even to the psoas muscle if needed. This plane can be extended superiorly to the costal margin, retrosternally above the xiphoid, and inferiorly into the space of Retzius. The posterior sheath is then closed, to completely exclude any mesh from the viscera. An adequately sized piece of mesh is then secured, similar to a standard retromuscular repair, but with greater overlap. The midline is then reapproximated.

This posterior CS technique maximizes our ability to preserve the abdominal wall blood supply by avoiding large skin flaps, while allowing for significant medial advancement of all components of the abdominal wall. In a recent comparative review of open anterior CS with

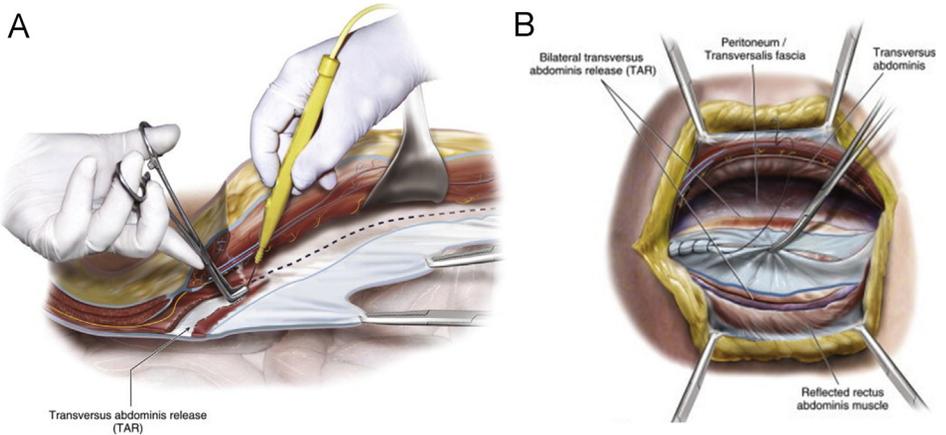


Fig. 9. Posterior component separation. (A) The initial release is completed by incising the posterior rectus sheath approximately 1 cm lateral to the linea alba, and the posterior rectus sheath is separated from the overlying rectus abdominis muscle. Dissection is carried to the lateral border of the rectus muscle, and the perforating intercostal nerves are identified, marking the linea semilunaris. (B) Next, the transversus abdominis muscle is incised just medial to the intercostal nerves, and the underlying transversalis fascia and peritoneum are identified. This myofascial release is extended the entire length of the posterior rectus sheath. The potential space between the transversus abdominis muscle and the peritoneum is developed as far laterally as necessary. (Adapted with permission from Rosen M. *Atlas of Abdominal Wall Reconstruction*, pp. 15–195, Copyright Elsevier, 2012.) (Color version of figure is available online.)

posterior CS for complex abdominal wall reconstruction, Krpata and colleagues reported similar fascial advancement but a 50% reduction in wound morbidity with the posterior approach.⁴³

CS in the face of rectus violation

In the past, surgeons avoided CS when the rectus abdominis complex had been violated by previous or concurrent ostomies, transected, or resected. There were concerns that extensive scarring would complicate the CS dissection and compromise surgical outcomes.^{14,25} In addition, it has been suggested that medial advancement of the skin flaps in relation to the underlying myofascia can result in shearing of the ostomy and restricted skin advancement. In cases such as these in which CS would otherwise be helpful, CS is often avoided and less favorable reconstructive options are used, such as primary fascial coaptation under excessive tension or bridging the fascial defect with mesh. A controlled study from MD Anderson Cancer Center demonstrated that CS is a valuable technique that improves outcomes for large midline fascial defects, thereby avoiding CS in cases with rectus violation may be unwarranted and preclude the opportunity to provide the optimal reconstruction.⁴³ CS can in fact be performed in the absence of a rectus abdominis muscle within the rectus sheath. Anterior rectus sheath defects that exist after harvest of a vertical rectus abdominis myocutaneous flap (VRAM) are often difficult to advance to the contralateral rectus fascia without excessive tension on the closure. Releasing the external oblique aponeurosis can offload tension from the remaining ipsilateral rectus fascia and linea semilunaris so that the rectus complex can be advanced medially for midline coaptation under less tension. A comparative study, which also first described this technique, showed improved abdominal wall donor site outcomes in patients who underwent VRAM reconstruction with ipsilateral CS for pelvic defects.⁴⁴ The patients who had CS ipsilateral to the VRAM donor site developed fewer hernias and bulges than patients who had primary closure or mesh placement without CS.

With these advances, there are few absolute contraindications to CS. Full-thickness resection of the lateral abdominal wall through the oblique muscular substance negates the potential benefit of CS on abdominal wall closure. Resection of the transversus abdominis or internal oblique muscles prevents CS from being performed effectively.

Outcomes data on ventral hernia repair

Given the wide spectrum of patient characteristics and defect complexities, no single approach to ventral hernia repair will be the best choice for all patients, and comparing different approaches is difficult. Furthermore, there is no standard nomenclature system to accurately stratify ventral or incisional hernias. This has led to the use of poorly defined, confusing terms such as “complex ventral hernia repair,” “large defects,” and “loss of abdominal domain.” Recently, a group of ventral hernia surgeons (the Ventral Hernia Working Group—VHWG) attempted to develop a classification system for ventral or incisional hernias.⁴⁵ The resulting grading system takes into account underlying patient comorbidities and the presence of wound contamination during the repair (Fig 10).

In the VHWG system, grade 1 includes hernias in patients with a low risk of complications and no history of wound infection. Grade 2 includes hernias in patients who smoke or have chronic obstructive pulmonary disease; are obese, diabetic, or immunosuppressed. Grade 3 includes hernias in patients with a previous wound infection, a stoma, or violation of the gastrointestinal tract (ie, hernias in potentially contaminated surgical fields). Finally, grade 4 includes hernias in patients with infected mesh or septic dehiscence of their wound. Based on this classification system, the VHWG recommended the use of synthetic mesh for grade 1 and bioprosthetic mesh for grades 3 and 4 hernias. No consensus recommendations were made for grade 2 hernias.

This grading system represents an important first step in developing a classification system to improve reporting and allow appropriate comparative studies to be performed. However, this grading system has not yet been validated in a large patient cohort. Furthermore, Blatnik and colleagues recently challenged the concept that a prior wound infection predisposes patients to subsequent surgical site infections. In a series of patients who underwent abdominal wall reconstruction after a prior wound infection but had a clean wound at the time of repair, the authors did not note a higher rate of wound morbidity than in a group with no prior infection.⁴⁶ Further studies are necessary to validate these results.

Two recent systematic reviews of the use of ADMs in abdominal wall reconstruction have echoed the difficulty of direct comparisons of study results because of differences in patient variables, techniques, nomenclature, and definitions of outcomes.^{47,48} The conclusions of these reviews were that there is no consensus on risk factors predicting recurrence or wound morbidity, there is limited consensus on terminology for defect characteristics, and there is no consensus on terminology for outcomes. Clearly, grading systems, such as those described earlier, and the need to accurately assess and report outcomes will be drivers for future studies from multiple institutions and authors that will help define the role of ADMs in abdominal wall reconstruction.

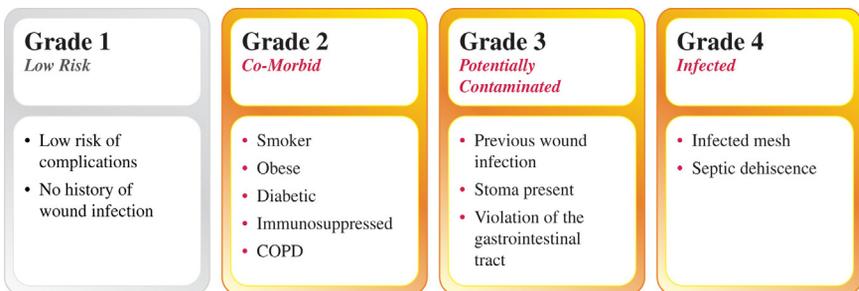


Fig. 10. Ventral Hernia Working Group ventral hernia grading scale. (Reprinted from *Surgery*, 148(3), Ventral Hernia Working Group, Breuing K, Butler CE, Ferzoco S, Franz M, Hultman CS, Kilbridge JF, Rosen M, Silverman RP, Vargo D, Incisional ventral hernias: review of the literature and recommendations regarding the grading and technique of repair, 544–558, Copyright 2010, with permission from Elsevier.) (Color version of figure is available online.)

Several studies have compared the results of laparoscopic ventral hernia repair to open ventral hernia repair. It is important to point out that most of these studies were fairly small series with short follow-up, and that the technique of open ventral hernia repair was not standardized. In general, however, these studies tend to favor laparoscopic ventral hernia repair with regard to wound morbidity and mesh infections.^{38,40,41,49–51}

A recent randomized trial by the Veterans Administration compared laparoscopic and open ventral hernia repairs in 146 patients.⁴² This series had several important methodologic issues that deserve mention when interpreting the results. First, the authors focused on relatively small defects, with the mean defect size in both groups averaging 46 cm². Second, the open technique involved an onlay approach in which subcutaneous flaps are created, and the polypropylene mesh is placed above the fascia. Finally, the mesh placement included only 3 cm of fascial overlap. The authors reported a significantly higher wound morbidity rate with the open approach (23%) than with the laparoscopic technique (6%). Overall recurrence rates were similar in the 2 groups (8.2% open vs 12.5% laparoscopic; $P = 0.44$). Although the overall complication rate was lower in the laparoscopic group, the incidence of severe or major complications was higher in the laparoscopic group. Most notably, the rate of enterotomy was higher in the laparoscopic group (4.1%) than in the open group (0%).

In general, the laparoscopic approach to ventral hernia repair is a good technique for obese patients or elderly patients with small to medium defects (< 10 cm wide) in which the morbidity of extensive skin flaps and soft tissue dissection can be avoided. However, in patients who have severe adhesions or have undergone multiple abdominal surgeries or both, the surgeon should exercise caution when performing adhesiolysis laparoscopically and have a low threshold for conversion to an open approach to avoid bowel injury.

Complications of hernia repair

Surgical site infection

Surgical site infections are common after open ventral hernia repair, although the exact incidence is difficult to determine as most series poorly define this outcome variable. The U.S. Centers for Disease Control and Prevention (CDC) recommends that surgical site infections be specified as superficial, deep, or organ space infections.⁵² Additionally, categorization of the intraoperative level of wound contamination based on CDC criteria into clean, clean-contaminated, contaminated, and dirty wounds is important to appropriately stratify patients by risk of surgical site infection. In patients with clean-contaminated and contaminated wounds, a prospective multi-institutional study evaluating the role of a porcine ADM to repair abdominal wall defects reported a 34% rate of superficial surgical site infections. In contrast, studies of clean wounds have reported infection rates of 0%–12%.¹⁸

Synthetic mesh infection

Mesh infections are one of the most serious complications that can occur after ventral hernia repair. The exact incidence of this problem is difficult to discern from the literature owing to the use of poorly defined terms and inconsistent reporting practices. The Centers for Disease Control (CDC) defines mesh infections as occurring up to 1 year after implantation of prosthetic mesh.⁴³ Mesh infections are reported to occur in 0%–3.6% of laparoscopic ventral hernia repairs and 6%–10% of open repairs employing mesh.^{44,53–55} The most common organism infecting mesh is *S. aureus*, seen in up to 81% of cases; this suggests skin flora contamination during mesh implantation.⁵⁴ However, gram-negative organisms, such as *Klebsiella* and *Proteus* spp., have been implicated in up to 17% of mesh infections.

Management of mesh infections is complex and requires patient individualization. In general, control of local sepsis is important, as is preserving native tissue for eventual reconstructive

procedures. In some cases, macroporous polypropylene meshes that become infected can be salvaged with local wound measures and antibiotics and do not require removal. Several reports suggest that lighter-weight polypropylene mesh might be safe in clean-contaminated environments.⁵⁶ However, microporous ePTFE mesh does not tolerate infection and almost always requires excision.

Seromas

Seroma formation can occur after laparoscopic or open ventral hernia repair. During routine laparoscopic ventral hernia repair, the hernia sac is often not excised; in such cases, a seroma is universally present postoperatively. It is important to counsel patients so that they are not surprised. In most cases, the seroma will be reabsorbed over time. If symptomatic, the seroma can be aspirated.

In open ventral hernia repair, drains are often placed in an attempt to obliterate the dead space caused by the hernia and tissue dissection. These drains can cause retrograde bacterial contamination, and seromas can form after drain removal. To reduce the risk of retrograde bacterial infection Butler has advocated the use of long subcutaneous tunnels, meticulous securing of drain exit sites with drain sutures that prevent intussusception of the drain and meticulous drain exit site wound management using antibiotic impregnated dressings.

Seroma formation is common after open CS owing to the extensive tissue dissection, and drains are often necessary for up to 4–6 weeks. Intraoperative techniques, such as quilting sutures or the progressive tension suture technique (described previously), may help to prevent or reduce seroma formation.

In general, seroma treatment starts with serial percutaneous aspirations and external garment compression therapy. If this is unsuccessful, drains can be replaced by direct open implantation or radiographically guided percutaneous placement. The use of sclerosing agents, such as doxycycline or fibrin sealant injection, has also been described.⁵⁷ The final option involves operative exploration, pseudocapsule excision, quilting suture placement, and drain placement.

Enterotomy

Unintentional intestinal injury during adhesiolysis can be catastrophic. Appropriate management of an enterotomy during a hernia repair is controversial and depends on the segment of intestine injured (small vs large bowel) and amount of spillage. Options include aborting the hernia repair, continuing the hernia repair and repairing the enterotomy with local tissue or bioprosthetic mesh using a primary tissue or bioprosthetic mesh repair, or performing a delayed repair using mesh in 3–4 days. When there is gross contamination, the use of synthetic mesh is generally contraindicated. Regardless of the approach taken, it is important that patients understand preoperatively the risk of this complication and how it might alter intraoperative decisions.

Enterocutaneous fistula management

Magnitude of the problem

The unexpected appearance of intestinal contents draining through an abdominal surgical incision is a devastating event for the patient and the surgical team. The treatment of patients with enterocutaneous fistulas (ECFs) is complex and time-consuming, requires a multi-disciplinary approach, and challenges every gastrointestinal and reconstructive surgeon. ECFs can range from relatively straightforward low-output colcutaneous fistulas to proximal high-output small bowel fistulas in the middle of an open abdomen in a critically ill patient.

The exact incidence of ECF formation is unknown owing to lack of reporting; however, it is likely that it is fairly low. Given the infrequent nature of this problem, no randomized controlled

studies have been or likely will be performed to guide management. Most recommendations are based on expert opinions or single-center retrospective case series. Despite their rarity, when they occur, ECFs can result in extremely high utilization of resources, placing a financial burden on the system and the patient. The underlying cause of an ECF has significant implications as to the prognosis for spontaneous closure or need for operative intervention.

By definition, an ECF is an abnormal communication between the bowel lumen and the skin. ECFs can be classified based on their anatomy, output, or etiology. The anatomical classification is based on the segment of the intestines that is involved in the fistula: gastrocutaneous, biliocutaneous, enterocutaneous, or colocutaneous. The output classification system is based on the volume of effluent from the fistula: low output, < 200 mL/day; moderate output, 200–500 mL/day; or high output, > 500 mL/day. The etiologic classification system is based on the underlying disease process. Most ECFs are related to a prior surgical procedure. Approximately 20% of ECFs are related to a bowel resection in a patient with Crohn's disease.⁵⁸ Other causes of ECFs include trauma, foreign body, infectious disease, and malignancy.

Approximately one-third of ECFs will close spontaneously with appropriate wound care, nutritional support, and medical therapy.⁵⁹ Several prognostic factors have been linked to nonhealing fistulas. A common mnemonic to describe these factors is FRIENDS of a fistula: foreign body, radiation enteritis, inflammatory bowel disease, epithelialization of the fistula tract, neoplasm, distal obstruction, and ongoing sepsis.

Enteroatmospheric fistulas are particularly problematic because there is no overlying skin or soft tissue; an enteroatmospheric fistula essentially forms a stoma. Enteroatmospheric fistulas will not heal without surgical intervention.

The first major report evaluating outcomes of ECFs, from 1960, had a dismal mortality rate of nearly 50% owing to malnutrition and electrolyte disturbances.⁶⁰ With improvements in parenteral nutrition, surgical techniques, and medical care, mortality rates now range from 5%–25%.^{21,60,61} One of the most significant challenges in abdominal wall reconstruction is managing a patient with a large abdominal wall defect in conjunction with an ECF.

Medical management

There are 3 phases of ECF management: (1) recognition and stabilization, (2) anatomical definition and decision, and (3) definitive operation.²⁹ Published guidelines refer to the SOWATS management algorithm: control of sepsis, optimization of nutritional status, wound care, assessment of fistula anatomy, timing of surgery, and surgical strategy.⁶² Once a fistula is identified, 4 factors must be addressed simultaneously: (1) fluid and electrolyte repletion, (2) control of fistula effluent and protection of the surrounding skin, (3) control of infection and drainage of abscesses, and (4) nutritional support.^{27,30}

Depending on the location of the fistula along the gastrointestinal tract and the volume of output, significant electrolyte disturbances can occur. In particular, proximal high-output fistulas can result in substantial losses of bicarbonate, which must be adequately replaced.

Diligent protection of the surrounding skin is one of the most important and difficult aspects of ECF management. A dedicated enterostomal nurse is essential to the success of wound management. Every ECF presents unique challenges and requires an individualized approach to the application of stoma devices. These applications can take hours to perform successfully but can result in a significant improvement in the emotional and physical well-being of the patient. Leaking bags can cause significant patient frustration, place extreme economic burdens on families, and result in the inability to appropriately delay surgical interventions. Furthermore, destruction of local skin can seriously affect eventual reconstructive options. At times, patients can require inpatient hospital admission to achieve adequate control of drainage from difficult fistulas.

The utilization of negative-pressure wound therapy (NPWT) has had mixed results in ECF management. Some series have suggested that NPWT stimulates wound healing and promotes ECF closure.^{63,64} Other series have argued that NPWT can create a fistula when placed over

granulating bowel.^{48,65} Instead, we often perform early skin grafting to stabilize the wound. Alternatively, in cases in which a fistula is already present, an NPWT device can be helpful to isolate the fistula from the surrounding wound and to allow a skin graft to heal.

An undrained intra-abdominal abscess is one of the most common causes of sepsis and failure of ECF closure. In medically frail patients with ECFs, signs of sepsis can be subtle and require a heightened level of suspicion. Patients with low-grade jaundice, failure to respond to nutritional support, persistently low albumin levels, and development of organ failure should all be suspected of having a septic focus.²⁸ Early radiographic evaluation with computed tomography (CT) is important, and CT should be repeated early if clinical improvement does not occur. Most intra-abdominal collections can be drained percutaneously under radiographic guidance, although operative intervention is occasionally necessary, particularly if mesh is being removed. In cases of uncontrolled intestinal leakage, a proximal diverting stoma can be lifesaving. When a proximal diversion cannot be achieved owing to a foreshortened mesentery or extremely dilated or hostile bowel, appropriate tube drainage can be helpful.

Nutritional supplementation is one of the most important aspects of reducing deaths related to ECFs. Nutritional requirements should be adjusted accordingly for patients with proximal high-output fistulas. During initial management of an ECF, parenteral nutritional support is preferred. However, once the sepsis is controlled and the patient is stabilized, enteral feedings are initiated. Enteral feedings preserve the intestinal mucosal barrier, improve immunologic function, and avoid central-line sepsis. In addition, maintaining patients on a nothing-by-mouth status for prolonged periods can be psychologically challenging. We often utilize a combination approach in which enteral nutrition is favored and parenteral nutrition is provided as an adjunct for nutritional support only when necessary. In patients with high-output fistulas that are difficult to manage with ostomy appliances, enteral feeding may not be possible. In patients with proximal ECFs, the fistulas themselves can be used to provide enteral access for feeding. This approach, termed “fistuloclysis,” has been used successfully by several investigators to eliminate the need for parenteral nutrition.

After the patient has been stabilized, the anatomy of the fistula is determined. This is important because the location of the fistula may provide valuable prognostic information about the likelihood of spontaneous closure and because any obstruction identified must be addressed during the formal reconstruction or closure will not be possible. Furthermore, the amount and location of small bowel remaining have important implications for the likelihood of short bowel syndrome after formal reconstruction; and tissue loss, including the absence of muscle components, has implications for reconstructive options.

Initially, an abdominopelvic CT study with oral and intravenous contrast is performed. This provides valuable information about undrained collections, bowel length, and the integrity of the anterior abdominal wall. An appropriately performed small bowel x-ray series is also helpful. In conjunction with our radiology team, we perform an initial upper gastrointestinal tract x-ray series with small bowel follow-through using water-soluble contrast material. Next, the fistula is cannulated, and the exact anatomy of the fistula and the remaining small bowel are documented. If necessary, a barium enema is performed to delineate the distal anatomy. In difficult cases, these procedures are performed under endoscopic guidance. Once the entire gastrointestinal tract anatomy is established, a general repair plan for the number of anastomoses, the amount of bowel requiring resection, and the amount of remaining bowel is made.

The decision to proceed to surgical reconstruction is individualized, but some general parameters are constant. If the fistula output is steadily decreasing and the wound is healing, surgery should be avoided as the fistula might heal spontaneously.⁶⁴ Most importantly, the patient must be free of infection, be nutritionally stable, and have pliable tissues.²⁹ There is no absolute limit as to how long to wait prior to performing the formal reconstruction; in general, it is advisable to wait as long as possible. In cases of peritonitis, reoperation within the first 6 weeks can be treacherous and result in death. If the tissues are supple and the patient is stable by 6 months after ECF identification, it is reasonable to operate. In patients requiring parenteral nutrition, repeated line indwelling catheter infections can necessitate earlier interventions.

In patients with enteroatmospheric fistulas, when the fistula begins to prolapse out of the wound, the peritoneal cavity has reestablished itself, and it is safe to proceed to surgery.

Surgical management

Surgical repair of an ECF is a time-consuming, challenging operation. The goals of the procedure are to resect the segment of bowel involved in the fistula, reestablish gastrointestinal tract continuity, cover the anastomosis with well-vascularized soft tissue, and provide a stable abdominal wall closure. As the operation is long and difficult, we advocate a 2-team approach. The first team is responsible for reestablishing gastrointestinal tract continuity, and the second team performs the abdominal wall reconstruction. Good communication between these 2 groups is critical to ensure the goals are met during the reconstruction.

The abdomen is typically opened through a full midline incision that excises all old scars, ischemic skin, and ulcerations. All adhesions are lysed from the ligament of Treitz to the rectum. Adhesiolysis is important to avoid any distal stenosis or obstruction points past an anastomosis; also, by freeing the abdominal wall of the visceral block, more mobilization is possible during closure. In most cases, the involved segment of bowel is resected, as partial wedge resection of fistulas has been associated with high refistulization rates.²¹ It is preferable to preserve as much ileum as possible for gastrointestinal function, and enterotomies in this area of the bowel are repaired if possible. Proximal diversions are considered on a case-by-case basis and are performed in a loop fashion, when possible, to facilitate closure.

The patient and the surgeon should clearly understand the goals of abdominal wall reconstruction in the setting of complex ECF repairs. The primary goal is to provide well-vascularized soft tissue coverage of the gastrointestinal tract, to prevent early exposure and refistulization. Soft tissue coverage over the GI track should be accomplished with the least amount of dissection possible. In particular, in cases in which extensive gastrointestinal tract dissection is necessary, the addition of a long, complex abdominal wall reconstruction is ill advised. Unfortunately, in certain cases, the defect is too large to close primarily and the surgeon is forced to address the abdominal wall in the same operation to provide stable coverage. Ideally, these patients would have been identified preoperatively, and the gastrointestinal surgeon will have involved the reconstructive surgeon in the planning of the operation.

An autologous tissue graft or bioprosthetic mesh is preferable to synthetic mesh in this population given the heavy contamination often present as a result of the fistula. Bioprosthetic mesh has been used to bridge the fascial defect in ECF cases with limited success. Although bioprosthetic meshes are very expensive and likely may not prevent a ventral hernia for a long term in these patients, as mentioned, that is not the primary goal of ECF repair.⁴⁷ However, one should avoid spanning a wide defect with bioprosthetic mesh if there will not be stable skin and soft tissue coverage over the mesh. If the mesh is exposed, it can degrade and potentially expose the intestines. The use of local advancement flaps (CS) is a reasonable option if available. Other options include pedicled or free muscle, myocutaneous, or fasciocutaneous flaps. However, these flap procedures can be associated with major postoperative morbidity and should be used judiciously in this patient population.

When planning reconstruction of an abdominal wall in the setting of a large hernia defect and a concomitant fistula, it is important to have all of the reconstructive options available and utilize the option that provides the best soft tissue coverage with the least morbidity for the individual case. The most options are likely available in centers where a multidisciplinary team is available.

Outcomes

Given the relative infrequency of ECFs, no prospective randomized trials are available to guide treatment. In addition, the heterogeneous nature of the patient population that has ECFs

makes comparisons of studies difficult. Some fistulas as a result of bowel injury during adhesiolysis have a high rate of spontaneous closures, whereas fistulas associated with inflammatory bowel disease likely represent an entirely different population.

In a series of 135 patients with ECFs, Visschers and colleagues⁶² reported successful restoration of gastrointestinal tract continuity in 91% of patients, with a 9.6% mortality rate, despite fairly early surgical repair (mean of 53 days from ECF development). Highlighting the difficulty of managing ECFs in the presence of large abdominal wall defects, these authors noted that the predominant negative prognostic factor for spontaneous closure of a fistula was a concomitant abdominal wall defect. Among 53 patients with concomitant abdominal wall defects, 77% required surgical intervention for closure, and the mortality rate was 15%. Among the 82 patients without an abdominal wall defect, the mortality rate was only 6%. Malnutrition was correlated with failure of surgical closure and increased mortality rates.

Wind and colleagues⁶⁶ reported 15 cases of ECF repairs in patients with large abdominal wall defects who had simultaneous open CS; most patients also received an onlay of Vicryl mesh. Four recurrent fistulas occurred within 4 months of surgery. With a median follow-up time of 20 months, 22 of the patients developed a ventral hernia, although most hernias were small and asymptomatic.

The potential benefit of adding bioprosthetic mesh to the closure of the abdominal wall was evaluated by Connolly and colleagues in a series of 61 patients undergoing ECF repair in the presence of a large open abdominal wound.⁶⁷ These authors utilized cross-linked porcine dermis (Permacol, Covidien, Mansfield, MA), placed as an intraperitoneal underlay, to augment the CS closure. They noted an alarmingly high rate of refistulization in patients who had reconstruction with porcine mesh (42%) vs those patients who had primary closure of their CS without mesh (0%). Whether an ADM from a different source or one that is not cross-linked might alter these outcomes is currently unknown and requires further study.

Repair of composite defects

Full-thickness loss of the abdominal wall musculofascia and overlying soft tissue—a composite defect—can result from tumor resection, necrotizing soft tissue infection, or traumatic injury. These clinical scenarios represent the most complicated abdominal wall reconstructions, sometimes requiring multiple staged procedures.

Composite defects due to en bloc tumor resection can be repaired at the time of tumor extirpation, provided clear margin status is confirmed. However, composite defects due to necrotizing soft tissue loss or trauma may require serial debridements to control the infectious process, establish the zone of injury, or stabilize the patient before definitive reconstruction of the abdominal wall. When serial debridements are required, temporizing measures must be taken to stabilize the abdominal wall, contain and protect the viscera, provide a wound environment that mitigates fluid and protein losses, and be durable enough to withstand prolonged mechanical ventilation.

Early reestablishment of myofascial continuity is paramount to setting the stage for a durable abdominal wall reconstruction. Reconstituting the deficient myofascia with an inlay of bioprosthetic mesh converts the open abdomen to a more manageable abdominal wall wound. When early fascial closure is not an option owing to ongoing debridement of the myofascia or the need to perform a second-look laparotomy, a temporizing abdominal wall closure can be utilized, such as the NPWT system. A static bridging wound dressing protects and insulates the viscera while controlling fluid loss in the wound bed and provides abdominal stability for patients undergoing mechanical ventilation and ambulation in some cases.

Composite abdominal wall defects often involve significant loss of innervated myofascia and overlying skin in a dimension that is greater than the surrounding tissue's ability to be recruited and mobilized for closure. In such cases, regional or distant tissue flaps must be used for closure,

and the resultant repair will no longer be dynamic and coordinated with the remaining abdominal wall musculature.

Defects from composite resection

The goals of abdominal wall reconstruction after full-thickness composite resection are to reestablish the integrity of the myofascial layer and provide external cutaneous coverage. The prevailing strategy in full-thickness composite reconstruction of the abdominal wall is to avoid patching the defect and instead reinforce the entire section of abdominal wall. This is accomplished through inlay (intra-abdominal) mesh placement with the mesh sutured to stable points of fixation: innervated myofascia, lamellar aponeurotic tissue, or bone.

Surgical planning in abdominal wall reconstruction must include accommodating for the loss of both skin and myofascial tissue. Local wound conditions, including bacterial contamination, previous operations, presence of ostomies, and prior radiation therapy, can increase the risks of compromised wound healing and surgical site infections. For midline defects, myofascial reconstruction is generally performed with CS, with or without the use of mesh, to ensure the structural integrity of the repair. Both synthetic and bioprosthetic mesh materials have been used. Surgeon preference and the variables of any given clinical scenario will determine whether bioprosthetic mesh or synthetic mesh is implanted. Regardless of mesh type, the expectations are that the mesh will maintain the abdominal wall contour, without development of a hernia or bulge. In addition, the mesh should be able to interface with the intra-abdominal viscera without forming extensive adhesions or erosion that can lead to fistulization. Bioprosthetic and synthetic meshes can meet these expectations, and the decision to use either is based on patient comorbidities, wound contamination, prior radiation, availability of greater omentum, and the quality of the overlying soft tissue. Skin coverage is generally accomplished with local skin advancement and occasionally requires a regional pedicled or free flap when formal pedicled or free flaps are used the most common donor site is the thigh or back.

Anchoring the mesh to stable fixation points in the abdominal wall is a key element of a successful repair. The abdominal wall pillars are stable fixation points; these include the costal margin and rib superiorly, the linea semilunaris and linea alba anteriorly, the inguinal ligament and iliac crest inferiorly, and the investing lumbar and paraspinal fascia posteriorly.⁶⁸ To achieve a stable repair, it is important to create an inlay mesh inset that links these anatomical structures. Options for anchoring mesh to the iliac crest and pubic bone depend on the degree and quality of oblique muscle, tendon, and periosteum that are preserved. Fixation techniques include direct suture to periosteum, transosseous suture placement through preplaced drill holes, or unicortical bone anchor sutures. In addressing the chest wall, the mesh will need to be anchored to the rib cage and costal margin. Options for fixation to ribs include circumcostal sutures (placed over the superior border of the rib) or transcostal sutures (placed through previously drilled holes).

Posterolateral composite abdominal wall defects merit separate discussion. The anatomical boundaries of the posterior abdominal wall that abut the posterior retroperitoneum include the paraspinous, quadratus lumborum, and iliopsoas muscles. When these muscular layers have been resected, divided, or denervated, their integrity must be restored to prevent a lumbar hernia or bulge. The goal is to support the retroperitoneal viscera and redefine the retroperitoneal reflection to prevent solid organ migration and adrenal or kidney and colon herniation. A true mesh inlay repair may not be feasible owing to the proximity of important neurovascular structures (posteromedial insertion of diaphragm, spine, aorta, and vena cava) to the retroperitoneal defect. In this situation, mesh can be placed in an onlay fashion. When significant dead space exists after reinforcement of the retroperitoneal boundary, a soft tissue flap can be included to obliterate the dead space and buttress the mesh repair externally. The overlapping angiosomes of the abdominal wall's cutaneous blood supply allow for wide undermining and skin advancement. In addition, tissue expansion can be performed in the trunk to increase the surface area and availability of local fasciocutaneous flaps to avoid

a pedicled or free flap donor site. In cases of prior radiation, prior surgery, or excessive skin resection, a pedicled regional or free flap may be required to provide adequate soft tissue coverage.

Options for pedicled flaps in the upper abdomen include VRAM, latissimus dorsi, and omental flaps. Thigh-based flaps, such as anterolateral thigh, vastus lateralis, and tensor fascia lata flaps, are able to reach the lower abdomen and flank as pedicled flaps. If a pedicled flap is not available or feasible, a thoracoepigastric bipedicled fasciocutaneous flap may provide a local tissue alternative and avoid a free tissue transfer.

However, when the volume of tissue loss or the arc of rotation needed precludes a pedicled flap transfer, a free flap is required for soft tissue coverage. The thigh can serve as a source of fasciocutaneous flaps and myocutaneous flaps that provide large skin paddles and significant muscle volume.⁶⁹ Recipient vessels in the lateral abdominal wall include the deep inferior epigastric vessels, superior epigastric vessels, internal mammary vessels, intercostal artery perforators, and thoracolumbar perforators. When no local recipient vessels are available, vein grafts to the internal mammary or femoral vessels may be required.

Parastomal hernia repair

A parastomal hernia is an incisional hernia defect at the site where the intestine traverses the abdominal wall to create a stoma.⁷⁰ Parastomal hernias are a common early complication of stoma formation, with the majority forming 1–2 years after ostomy.⁷¹ The incidence of parastomal hernia varies from 0%–39%; the smallest incidence is after loop ileostomy and the greatest after end colostomy. The majority of parastomal hernias are asymptomatic, causing only a cosmetic contour deformity, and therefore can be treated conservatively. Given the challenges in repairing parastomal hernias and the high recurrence rates, surgical intervention should be reserved for hernias that disrupt the ostomy appliance and cause chronic pain, skin breakdown, or intestinal obstruction, incarceration, or strangulation.

Owing to the incidence of parastomal hernias and morbidity associated with their repair, attention has focused on preventive measures at the time of ostomy. Meticulous technique centering the stoma through the rectus abdominis muscle substance and avoiding the transverse mid-rectus tendinous inscriptions is paramount to creating a functional stoma with a low risk of herniation.⁷¹ It is critical to avoid lateralizing the stomal aperture and subsequently inducing a rectus muscle denervation injury and to avoid creating a focal weakening that could give rise to myofascial attenuation and parastomal hernia formation. Reinforcement (either prophylactically or in the treatment of parastomal hernias) with inlay mesh placement in a preperitoneal or intraperitoneal plane has been adopted to further reduce the risk of parastomal hernia. Randomized controlled trials comparing the benefits and risks of mesh reinforcement of stomas with conventional methods of stoma formation have shown that mesh reinforcement reduces parastomal herniation (relative risk [RR] 0.23, 95% confidence interval [CI] 0.06–0.81; $P = 0.02$) and the percentage of parastomal hernias requiring surgical intervention (relative risk 0.13, 95% CI 0.02–1.02; $P = 0.05$) compared with conventional stoma formation.⁷¹

Surgical treatment options for parastomal hernias may include relocation of the stoma or in situ repair of the hernia with or without mesh reinforcement. Repair of parastomal hernias by any of these techniques can be performed through either an open or laparoscopic approach. Relocating the stoma to an unviolated quadrant of the abdominal wall provides the best option to reduce the risk of subsequent parastomal hernia formation. However, this approach violates a new area of the abdominal wall that may develop another parastomal hernia and require another repair. Furthermore, the availability of the relocation option is dependent on the type of ostomy, length of remaining mesentery, and presence or absence of additional laparotomy incisions, stomas, and hernias. Repair of the original parastomal defect site with fascial closure and inlay mesh reinforcement, as well as prophylactic reinforcement of a newly created stomal site with mesh, are key to minimizing the risk of parastomal reherniation.

Direct suture repair of a parastomal hernia is the most straightforward surgical approach. Direct suture repair requires a balance between narrowing the stomal aperture to prevent bowel from migrating through the abdominal wall and having an adequate aperture to allow for uninterrupted stoma function. Direct repair can be performed from an intra-abdominal or preperitoneal approach, but both have generally been replaced by mesh-based repairs.

Two techniques of intraperitoneal mesh placement are most often used to repair parastomal hernia defects: the keyhole technique and the Sugarbaker technique. The keyhole technique, described in 1977 by Rosin and Bonardi,⁷² is performed by placing the bowel through a circular opening in the mesh. The benefit of the technique is that the nonyielding mesh reinforces the attenuated myofascia. The downside of this technique is that the bowel passes perpendicular to the mesh plane, and there is a small area between the bowel serosa and the mesh ring through which the intra-abdominal contents can migrate.

In 1985, Sugarbaker⁷³ described placing a single uncut piece of mesh as an intraperitoneal patch over the parastomal defect and then lateralizing the bowel so as to allow the stoma site to be covered by the mesh (Fig 11). Thus, the stoma did not traverse the plane of the mesh repair in a perpendicular fashion but traveled parallel to the mesh before traversing the abdominal wall. Avoiding direct passage of the bowel through the mesh led to a reduction in rates of both asymptomatic recurrences and those requiring reoperation. The Sugarbaker repair can be performed by open or laparoscopic approaches. The technique was modified to address the issue of attenuation of the fascial annulus by directly coapting the fascial edges with sutures before placing the mesh.

An extensive meta-analysis of more than 30 studies, both retrospective and prospective, showed that direct suture repair results in a significantly increased recurrence rate when compared with the keyhole or Sugarbaker mesh repair techniques (odds ratio 8.9, 95% CI 5.2–15.1; $P < 0.0001$).⁷⁴ Recurrence rates for keyhole and Sugarbaker mesh repairs have ranged from 6.9%–17% and do not differ significantly. In patients undergoing laparoscopic repair, the Sugarbaker technique has resulted in fewer recurrences than the keyhole technique (odds ratio 2.3, 95% CI 1.2–4.6; $P = 0.016$).⁷⁴ These findings support the use of a mesh-reinforced parastomal hernia repair technique individualized to the patient's defect and comorbidities and the surgeon's preference.

Future directions in hernia repair

The renewed interest in ventral hernia repair and abdominal wall reconstruction is likely multifactorial. Given the ever-growing problem of obesity, the increasing complexity of hernia defects, and the disappointing results with conventional reconstructive methods, plastic and general surgeons have been forced to identify innovative solutions. Without a doubt, the current reconstructive approaches described in this section have offered hope of a successful reconstruction for many patients once deemed inoperable. Likely further refinements of these procedures will be developed to reduce wound morbidity, minimize mesh infections, and provide a long-term durable repair. Further significant improvements in mesh materials will be seen. Novel synthetic materials are under development that will reduce mesh infections and improve tissue integration, minimizing foreign body reaction. Likewise, bioprosthetic mesh will be further improved to result in a more durable repair, reducing recurrence rates and improving tissue regeneration capabilities.

With hernia registries and multispecialty collaborative groups, it seems likely that a unified classification system will soon be developed to standardize outcome reporting for ventral hernias and adjust for patient risk. Ultimately, we hope that through improved patient selection, better defined relative and absolute indications and contraindications, refinements in technique, and new technologies, we can improve patient outcomes while avoiding or minimizing potential complications.

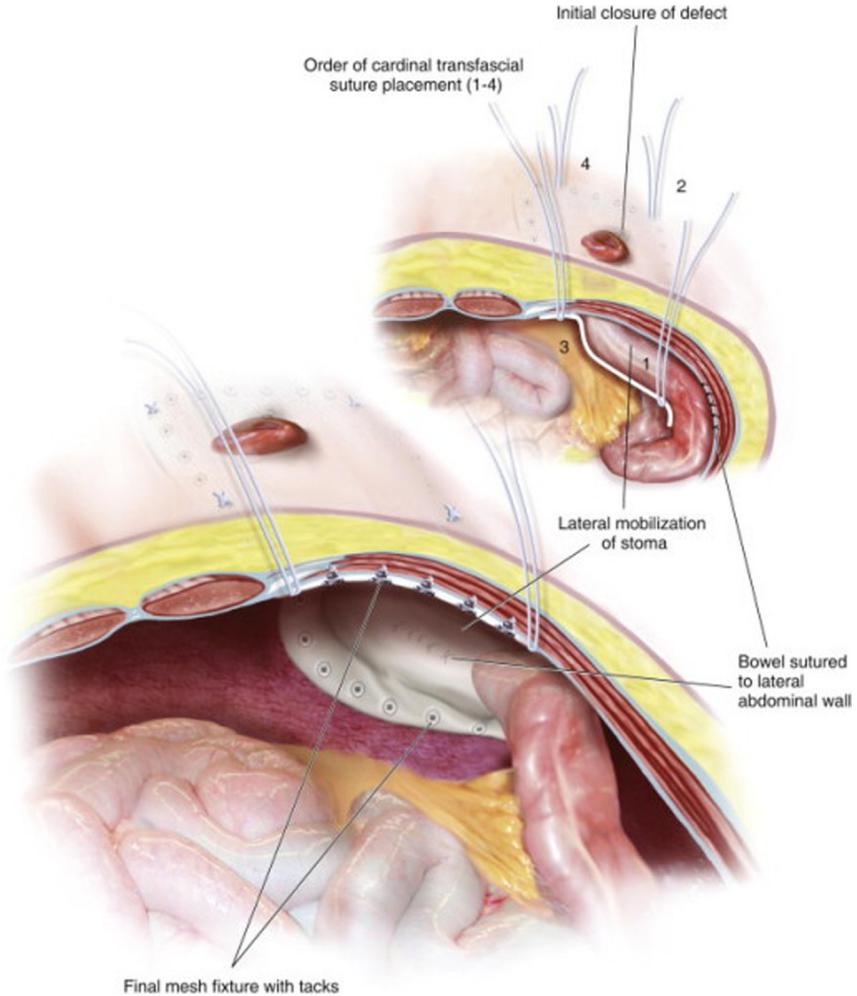


Fig. 11. Sugarbaker parastomal hernia repair. The parastomal hernia annulus is closed and supported by a mesh inlay, directing the bowel laterally and parallel with the abdominal wall. This redirection of the end ostomy reduces the risk of other bowel loops disrupting the plane between the end ostomy and the posterior rectus sheath. (Adapted with permission from Rosen M. *Atlas of Abdominal Wall Reconstruction*, pp. 15–195, Copyright Elsevier, 2012.) (Color version of figure is available online.)

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