

Practical Approaches to Definitive Reconstruction of Complex Abdominal Wall Defects

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Published online: 19 November 2015
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Abstract With advances in abdominal surgery and the management of major trauma, complex abdominal wall defects have become the new surgical disease, and the need for abdominal wall reconstruction has increased dramatically. Subsequently, how to reconstruct these large defects has become a new surgical question. While most surgeons use native abdominal wall whenever possible, evidence suggests that synthetic or biologic mesh needs to be added to large ventral hernia repairs. One particular group of patients who exemplify “complex” are those with contaminated wounds, enterocutaneous fistulas, enteroatmospheric fistulas, and/or stoma(s), where synthetic mesh is to be avoided if at all possible. Most recently, biologic mesh has become the new standard in high-risk patients with contaminated and dirty-infected wounds. While biologic mesh is the most common tissue engineered used in this field of surgery, level I evidence is needed on its indication and long-term outcomes. Various techniques for reconstructing the abdominal wall have been described, however the long-term outcomes for most of these studies, are rarely reported. In this article, I outline current practical approaches to perioperative management and definitive abdominal reconstruction in patients with complex abdominal wall defects, with or without fistulas, as well as those who have lost abdominal domain.

Introduction

More than 350,000 ventral hernias are repaired in the United States annually, of which 75 % are primary ventral hernias (e.g., umbilical or epigastric hernias) [1], and according to the Agency for Healthcare Research and Quality (AHRQ), between the years 2008 and 2012, there were 512,409 hernia repairs performed nationally in the US, which were non-inguinal and non-femoral (i.e., other hernias) [2]. The proportion of these hernia repairs that would be classified as complex is not described, and while the true prevalence is not clear, the need for complex abdominal wall reconstruction (CAWR) has expanded. Once used mostly for trauma patients who had undergone

damage control laparotomy (DCL), CAWR is now being utilized more and more in emergency surgery for patients who are managed by open abdomen and/or survive acute catastrophic abdominal conditions such as perforated viscus, grossly contaminated abdomen, or in patients for whom the abdomen cannot, will not, or should not be closed at all. DCL has been shown to save lives and has been accepted around the world both for trauma and emergency surgery, but its liberal use has its consequences and DCL has been described as an “overused procedure” [3]. The most serious consequences of the open abdomen procedure are significant morbidity and mortality associated with enterocutaneous fistulas (ECFs) or enteroatmospheric fistulas (EAFs), and the inability to be fully functional due to massive ventral hernias. Seventy-five to eighty-five percent of ECFs/EAFs are postoperative. Especially, challenging is the combination of ECFs large abdominal defects or stomas [4], but the frequency of the combination of ECFs/EAFs and abdominal wall hernias is

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unknown [4]. The incidence of ECFs in combination with an open abdomen, on the other hand, has been reported to be as high as 75 % [5]. Although it is unclear as to what percentage of patients are treated for ECFs in concurrence with reconstruction surgery for large abdominal wall defects, in our practice this percentage is about 20 [4].

Closing the open abdomen and establishing a functional abdominal wall in patients with fistulas and stomas represent a major challenge, often requiring surgical creativity, and a strategy that encompasses various aspects of care from diagnosis to long-term follow-up. Multidisciplinary approaches and advanced surgical techniques are required as well [6]. In order to optimize the outcomes, there has been a suggestion that these patients are managed on a specialized unit [7].

When one approaches patients with a complex abdominal wall defect, with or without fistulas, there are significant challenges that need to be understood primarily by the surgeon, as well as by the patient. These challenges range from defining the pathology, to understanding the impact of the clinical condition and physiology, nutritional status, and wound care. Redefining the anatomy and physiology, timing the definitive surgery, executing the operative plan, making intraoperative decisions that are often considered “outside surgical dogma,” long-term follow-up, and ensuring full recovery of the patient to normal functional status are all basic requirements. One very important factor for the successful outcome of these operations is the expertise and dedication of the surgeon to these patients and to their surgical problems. These operations are not to be performed by an “itinerant surgeon.” While all general surgeons should be able to repair a large hernia, complex reconstructions of the abdominal wall of patients with fistulas and/or stomas should be done only by those who have both the clinical interest and the experience in this truly complex subject. The management of these patients should be approached in a step-wise fashion, ensuring that each phase is truly understood by the surgeon, as well as by the patient and their family.

Establishing disciplined protocols and implementing a well-planned strategy, particularly in patients with ECFs/ EAFs, will make the intraoperative management process easier and may improve postoperative outcomes. Such a strategy has been described in a six-step strategy for management of ECFs, known as “SOWATS” (S = Sepsis Control, O = Nutrition Optimization, W = Wound Care, T = Timing, A = Anatomy and S = Surgery) [8]. These authors reported on 79 patients managed by a focused treatment for ECF. Spontaneous closure occurred in 23 (29 %) patients after a median period of 39 (range 7–163) days. Forty-nine patients underwent operative repair after median period of 101 (range 7–374) days; closure was achieved in 47 (96 %) patients. The authors reported a mortality of 10 % during the study period, although in a separate publication, they reported

that 44/135 or 32.5 % of patients died [9]. This strategy is applicable in the acute setting but does not address three important aspects of management: initial diagnosis, in particular in the immediate postoperative period; postoperative care following definitive surgery; and finally long-term follow-up. To address these aspects, our group has modified their six-step strategy to nine steps, and we call it “ISOWATS PL” [10] (I = Identification and diagnosis of postoperative fistula; S = Sepsis and Source Control; O = Optimization of Nutrition, W = Providing and Ensuring Wound Care; A = Redefining the anatomy and understanding the pathology at hand; T = Timing of definitive surgery and/or take-down of fistulas; S = Definitive surgery and surgical creativity; P = Postoperative care; and L = Long-term follow-up). We adhere to the “ISOWATS PL” strategy as much as possible, although we sometimes cannot strictly follow all nine steps in certain patients, as these patients often require emergency surgery. In this paper, I will discuss our nine-step approach.

Identification and diagnosis of abdominal defects and fistulas

The majority (75–85 %) of ECFs is postoperative, and most patients with ECFs also have abdominal wall defects, through which the ECFs become evident. The diagnosis, that is, the early identification of the fistulas, needs to be established in a timely fashion and without much delay, while the presentation depends on the clinical situation [11]. The cause of postoperative wound infections and abdominal dehiscence is often difficult to distinguish between a technical catastrophe or necrotizing soft tissue infection and those resulting from fistulas or an intra-abdominal process, such as an anastomotic leak. Depending on the cause of the fistula, one can predict the outcomes; those that are the result of malignancy or open abdomen have the worst prognosis [12]. In all patients with abdominal wound dehiscence, especially after the creation of a single or multiple anastomoses, with or without lysis of severely dense adhesions, the surgeon must think about the potential occurrence of fistulas or some other sort of catastrophe, particularly, if the patient is not doing well postoperatively.

Preoperatively, complex defects must be identified by whatever method is available to the surgeon: a computed tomography (CT) scan or Magnetic Resonance Imaging (MRI). The definition of the anatomy of the fistulas can be done with CT scan, upper gastrointestinal (UGI) series with small bowel follow-through, a fistulogram, gastrografin or barium enemas, or an “eye-scan” that is intraoperatively by the surgeon. Most recently, the CT scan has become the standard radiographic study, although MRI is gaining more

and more popularity [13]. For fresh postoperative patients, wound exploration, often in the operating room, is required to completely assess the wound (as well as the sub-fascial collections and intestines lying under the sutures, which could easily erode into the lumen and cause new fistulas). However, most of these patients in practice receive a CT scan as well before the surgeon has the chance to evaluate them. The CT scan or MRI will identify any deep peritoneal or pelvic collection that could be drained, guided by CT or ultrasound. In the first few postoperative days (and in my practice the first 10–14 days), one should not hesitate to take the patient back to the operating room for an exploration and direct assessment, if clinically warranted.

Sepsis and source control

Management of a patient with a wound infection, infected seromas, acute wound dehiscence, or fistulae is complex and not straightforward. One of the biggest hesitations of a surgeon is taking the patient back to the operating room, though this hesitation is more prevalent in elective surgery than in a trauma setting. The basic treatment strategy for patients with acute postoperative wound dehiscence, severe soft tissue infections, or simple wound infections, as well as of those with enterocutaneous fistulas (ECFs) or enteroatmospheric fistulas (EAFs) includes: disruption or source control, proper antibiotic therapy, aggressive electrolyte and fluid normalization, correction of coagulation factors and hemoglobin levels, achievement of hemodynamic stability, and provision of nutritional support while patient undergoes diagnostic or therapeutic interventions, or simply while is being observed for any reason. In the last few decades, the achievement of complete sepsis and source control has undergone significant changes. In addition to the early use of powerful antibiotics and goal-directed resuscitation of critically ill patients, less-invasive methods for treating intra-abdominal sepsis have become routine [14, 15]. The mainstay of therapy for intra-abdominal abscesses remains drainage, be it surgical or percutaneous [16], but broad-spectrum antibiotics may be initiated and subsequently tailored based on culture results. Necrotic tissue needs to be debrided entirely.

Recent trends, however, are worrisome, as more and more surgeons rely on interventional radiologists to drain pus and care for surgical patients for every possible nidus of infection, including paracentesis and thoracocentesis [17]. One has to remember though, while the intra-abdominal or intra-thoracic sepsis may be the main culprit of their clinical deterioration, these patients may still have other sources of sepsis, such as urinary tract infection, line sepsis, pneumonia, and other hospital acquired infections that require careful examination.

Provision and optimization of nutrition

Initiating, maintaining, and optimizing the nutrition in patients with fistulas (both ECFs and EAFs) is difficult and require a planned approach [18]. Unfortunately, providing adequate nutritional support is not done adequately in the majority of patients [19]. Often while we provide sophisticated cancer therapy to our surgical patients, we simultaneously allow severe malnutrition to develop in front of our eyes. Awaiting gastrointestinal function to return postoperatively before initiating oral or enteral nutrition is an old dogma that is still practiced in many hospitals across the world. In this scenario, the patient may start on some sort of salty and tasteless (clear) liquids 4–5 days after major operation, if not longer. If, on the other hand, the patient develops any of the aforementioned complications, this process can be prolonged ever further. One has to remember that we should initiate and maintain nutrition enterally or parenterally throughout the hospitalization. In a very busy practice, it is easily forgotten that a patient who underwent a major surgical operation needs aggressive nutrition support. In patients with a recent weight loss of 10–15 %, or with a serum albumin level less than 3 grams/deciliter (g/dL), elective procedures should be postponed, if at all possible. Albumin levels of less than 2.5 g/dL have been associated with a significant increase in mortality and morbidity. A strong relation was reported between preoperative albumin levels and surgical closure ($p < 0.001$) and mortality ($p < 0.001$) [20]. Before major surgery, the nutritional status of all patients (unless urgent or emergent surgery is required) should be optimized to the extent possible [21–28]. In a few patients, however, despite all attempts, reversing hypoalbuminemia and malnutrition may be impossible; such failure likely indicates continuous infection, sepsis, or incessant loss of nutrients through fistula effluent. The combination of a continuous inflammatory state and malnutrition is detrimental to the patients and their prognosis, and therefore, it should be disrupted as soon as possible; surgery can be thought of as source control for continuous malnutrition. A somewhat less common approach to improve the nutritional status of patients with fistulas is fistuloclysis [29–31], which has been shown to reduce the need for parenteral nutrition and improve all hepatic and nutritional indices in a select group of patients. While technically demanding, this technique is valuable in the armamentarium of surgeons caring for these patients and should be used if at all possible, and for the most part, it is tolerated by patients. A recent report on fistuloclysis used in patients who were assigned into either the fistuloclysis group ($n = 35$, receiving fistuloclysis plus total enteral nutrition (TEN)) or the control group ($n = 60$, receiving TEN) demonstrated that this adjunct technique

improved hepatic and nutritional parameters in patients with high-output upper enteric fistulas, particularly those with biliary fistulas [29].

Providing adequate wound care

One of the most important elements in the management of complex open wounds with or without fistula, and/or stomas, is continuous wound care and reduction of the overall infectious bioburden. Therefore, avoiding skin excoriations from the bile salts, intestinal fluids, or stool is essential. The vacuum-assisted closure (VAC) and proper stoma equipment have revolutionized wound care [32–34]; however, collecting all the fluids in patients with large open abdominal wall defects (which we have termed “fistula city”) may prove extremely difficult (Fig. 1). The wound VAC is meant to control the output of fistulas, and help with granulation process, but the surgeon must be cognizant of the amount of fluid that the patient loses and must ensure appropriate fluid replacement. The wound VAC therapy has become mainstream therapy for wounds, in particular for treating surgical wound healing by secondary intention [34–37]. Yet, one has to be mindful that fistula



Fig. 1 Patient with multiple fistulas following open abdomen management, which we have called it “Fistula city”

formation with wound VAC has been reported with an incidence varying between 10 and 21 % [38].

Redefining the anatomy and understanding the pathology

The 5th step in “ISOWATS PL” strategy is redefining the anatomy. Again, if there are questions, here the surgeon should use any of the available techniques to confirm the anatomy and understand the pathology at hand [39, 40]. Whenever available, previous operative reports and radiologic comparisons at different stages of the disease process should be obtained and studied carefully, and if possible, a direct conversation with the previous surgeon should be conducted. This is particularly important if the patient was operated on at a different hospital or by another surgeon.

Timing to definitive surgery and or takedown of fistulas

The decision if and when to re-operate on patients should be individualized, represents perhaps the most important step in the management of this group of patients, and is dependent on the clinical presentation. The decision is based on many factors, but particularly on the concomitant co-morbid diseases and on the anatomy of the surgical problem. Let us first consider the CAW defects without fistulas. A large defect can be functionally devastating and leads to further weight gain and more problems (Fig. 2). In some cases, the skin gets very thin, excoriates, and is almost transformed into a fistula and abdominal catastrophe. Many of these patients cannot be operated upon, despite the fact that they have a major defect. If they have serious co-morbid diseases, such as extreme obesity, severe heart, high-grade liver cirrhosis, or lung disease (home O₂ dependent), and do not have symptoms of obstructions, one should not operate without having multiple conversation with the patient and their family. On the other hand, when these patients present with intestinal obstruction not responding to conservative treatment, one has no choice but perform a definitive surgery. While not all surgeons agree, in many patients the strategy of surgical management should be “more is less,” and often the complex definitive surgery is the only choice and should be performed. As abdominal wall defects will not get smaller over time, I prefer to operate earlier rather than later assuming that the patient is not prohibitively high-risk.

While timing when to repair large abdominal wall hernias is less debatable [41–43], operating on fistulas and knowing how long should we wait until takedown is more contentious. Some suggest that delaying surgery anywhere from 12 to



Fig. 2 A 57-year-old male s/p right nephrectomy for adenocarcinoma with subsequent development of a giant hernia and visible stigmata of portal hypertension from alcohol and hepatitis induced cirrhosis

36 months will improve the outcomes in patients with ECF [44]. Others [45] state that prolonging surgery for longer than 1 year following ECF diagnosis doubles the risk of postoperative refistulization. This risk for fistula recurrence has been found to be five times greater if one waits longer than 36 weeks [46]. While operating on these patients may pose a risk for serious complications, often the only way to disrupt the vicious cycle of sepsis and reducing the exacerbation of malnutrition [18, 45] is through definitive surgery itself. I use the individual patient's condition as a guide, rather than any strict predetermined timeline, although I try to avoid operating in the first two to three months after diagnosis, unless the fistula becomes apparent in the first two postoperative weeks, and I do not think that it will close spontaneously on TPN.

Definitive surgery and surgical creativity

The approach of definitive surgery one selects in patients with complex abdominal wall defects (CAWD) and/or fistulas depends on many factors. The key aspect of repairing complex defects is to understand the anatomy of the abdominal wall and have the requisite surgical experience [47]. Most patients who have previously undergone large abdominal surgery have had a midline abdominal incision,

so their lateral abdominal wall is usually free of scars and defects, thereby providing a well-vascularized soft tissue donor site. There are a number of exceptions, however, especially when the patient has had any lateral incision, or had stomas. Unless the patient had many surgeries, such as those with open management, or had a giant hernia with loss of abdominal domain, the abdominal wall can be anatomically restored with minimal tension and without compromising the integrity of the abdominal muscles, vessels, and nerves. Understanding the pathophysiology and the distorted anatomy of a difficult abdomen is paramount [47].

While the principles of surgery on this patient population are the same as in any patient, surgical creativity is essential. The section below details the main elements that the surgeon must consider, including the kind of incision, repair techniques, and mesh placement and fixation. The surgical goals are to establish GI tract continuity (in case of intestinal fistulas) and obtain full closure of the abdominal wall, minimize the formation or recurrence of fistulas, hernias, wound infections, and return the patient to full functionality.

Surgical approach

The abdomen of most patients with ECFs and/or EAFs is hostile and not easily approachable; often entering the abdomen itself presents a significant challenge. When possible, the surgeon should avoid going through the same incision used in prior operations, instead attempting to enter from non-violated areas of the abdominal wall (such as the superior epigastric region or subxiphoid or just over the pubic region). However, doing so may not be possible, especially in patients with prior major operations (such as major laparotomy for trauma). An alternative method of entering the abdomen through a transverse incision has been advocated [26, 27], although I have not used this approach in my re-operative surgery practice. In cases when a split-thickness skin graft (STSG) is present, the skin graft can be easily elevated from the underlying tissue when pinched between the surgeon's thumb and forefinger, and the operation can then be performed. When excision is attempted while the skin graft is adherent, dissection is likely to result in enterotomies and risk of recurrent fistula formation [48]. My strategy is to start removing the skin graft laterally on each side and to start taking it down from the superior to inferior part of the abdomen.

Issues with adhesiolysis

Once the abdominal cavity is entered, the surgeon often faces a large ball of intestines wrapped by adhesions. Should these adhesions be separated or not? That

question is as old as the surgery itself [49]. In my opinion, the surgeon should mobilize the entire segment of intestines, from the ligament of Treitz to the rectosigmoid. Doing so is tedious and time-consuming, given previous abdominal surgeries and intra-abdominal inflammatory processes, and is often complicated by new iatrogenic enterotomies; other surgeons do not agree entirely with our approach.

Fistula resection

In patients with multiple ECFs and/or EAFs, resecting all of the fistulas may be challenging, but all of them must be resected [40, 45, 50, 51]. The best scenario is when multiple fistulas are in close proximity to each other, so that the surgeon can excise the segment of fistulous tract “en masse.” Yet, if the fistulas are 30 cm apart, more than one resection—and subsequently more than one anastomosis—may be required, all of which is technically challenging. Because such patients are at high risk for developing short gut syndrome, I have used adjunct procedures such as strictureplasty to help avoid removing large segments of intestines. Intraoperatively, it is very important for the surgeon to identify all fistulas. Care should be taken to avoid enterotomies, but if they do occur, any inadvertent injury to the bowel must be either repaired immediately or tagged with a long suture (so that it can be easily identified later on during the course of the operation). In difficult situations, bypass of the “intestinal ball” has been suggested, but in my practice, I have never had to do it.

Anastomoses

Establishing intestinal continuity should be done using the hand sewn double-layer technique [40], and I prefer using continuous Vicryl sutures (Connel technique) and 2.0 silk sutures. If the integrity of the anastomosis is questionable, it is reasonable to revise it or to create a proximal diverting ostomy. Excessive trimming of the mesentery, tension on the anastomosis, and inclusion of diseased bowel in the anastomosis must all be avoided [26, 27]. Operative treatment with takedown of ECFs is successful in 80–90 % of patients, although the presence of an open abdomen lowers the success rate to 77.3 % [20, 45].

Definitive abdominal wall reconstruction

Creating a new abdominal wall may represent a serious surgical challenge, and both the surgeon and the patient physiology should be up to the task, after considering the

hours spent lysing adhesions and establishing the continuity of the GI track (in the case of fistulas or other intestinal resections). Some authors have suggested that another team should take over, specifically a plastic surgeon [52]. During complex, long operations, I have used the principle of damage control, returning the next day or so to complete the operation. During the first stage of the operation, I complete the lysis of adhesions, anastomosis(es) and release of lateral compartments (Fig. 3a, b). On the final stage of the operation, usually 12–24 h later, I perform the final inspection of all segments of intestines and perform mesh placement and the final closure. It is easy to miss a small enterotomy or “cut the corner” when you have been for hours in the operating room, thus I prefer to have a “second look” if you will at the operation when

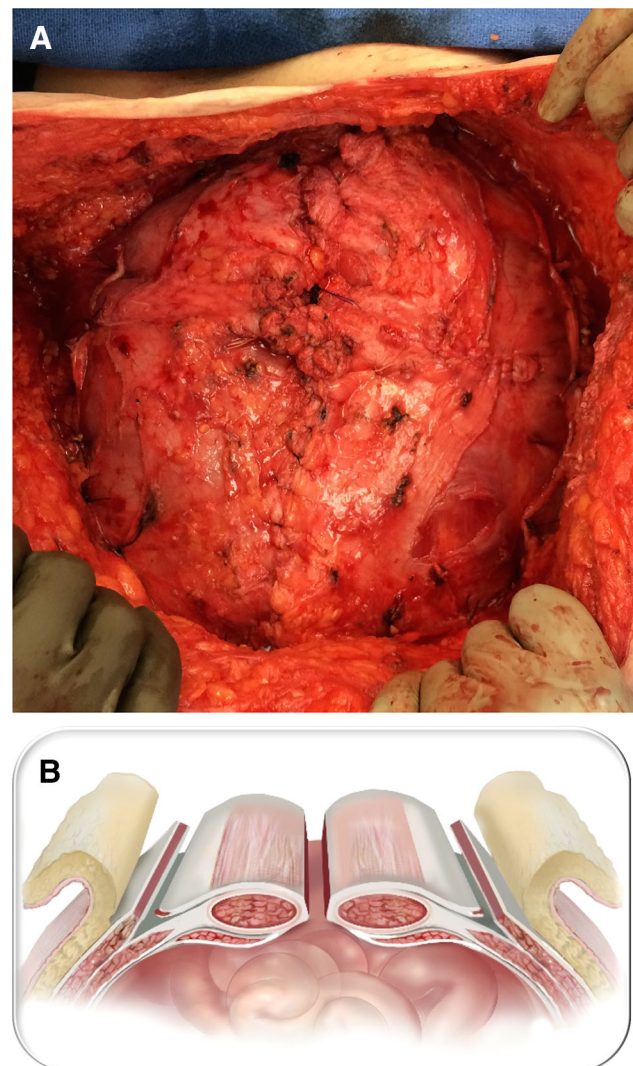


Fig. 3 **a** Example of bilateral compartment release with approximation of midline. **b** Illustration of lateral compartment release

both the patient and the surgeon have their physiology restored. Whatever strategy is used, however, the goal is to create coverage of the abdominal cavity and to improve the patient's quality of life. If native tissue can be used without undue tension, then it should be used. If that is not possible, biologic or prosthetic mesh can be used instead. In most patients, some sort of combination of reconstruction techniques will be needed. If the midline tissue cannot be easily approximated, or if mesh reinforcement is needed (as it is in almost all abdominal wall defects larger than 6 cm), then other techniques must be considered. For example, if midline tissue cannot be easily approximated, then lateral components need to be released and a neo-abdominal wall created. Tissue transposition of myocutaneous flaps through lateral component separation, as described previously [53, 54], is the procedure of choice. Component separation results in medial advancement of intact rectus myofascial units bilaterally, enabling us to close defects of up to 10 cm in the upper abdomen, 20 cm in the mid abdomen, and 6–8 cm in the lower abdomen. The component separation technique is based on an enlargement of the abdominal wall surface by separating and advancing the muscular layers (Fig. 3a, b). Some form of component separation, alone or in combination with other adjunct procedures, has become common practice [55–59].

Choice of mesh

By definition, patients with ECFs, EAFs, and/or stomas have contaminated wounds. Synthetic mesh has been used in the past, but it was associated with high rates of wound infection (often necessitating removal of infected mesh for source control of infection) and with other complications (such as newly created fistulas). Reconstruction of major abdominal walls with modified tissues that are harvested from human or porcine sources has become a common practice although as stated earlier, the long-term outcomes are not clear.

Graft placement

Either open or laparoscopic surgical techniques can be used to repair abdominal wall defects; however, in patients with ECFs and/or EAFs, the open approach is preferred. The three most common techniques used to place mesh during abdominal wall reconstruction are *onlay* placement, *underlay* placement, and *interposition or bridge* placement. Each of these techniques has their pros and cons, and should be used based on surgeon expertise and patient selection.

Onlay placement

Technically, onlay mesh placement is the easiest way to place the mesh. I used this technique at the beginning of my practice and still use it on occasions when we are able to approximate the abdominal wall edges without any major dissection. Furthermore, in clean cases, when there is a contraindication to use synthetic mesh, I prefer the onlay technique (Fig. 4a, b). There is always a small risk of wound infection, and one may need to remove the mesh if it gets infected, but currently this is a standard of care; I see no reason to use biologic mesh in such cases. The key element of this approach is fixing the mesh both laterally and over the edge of midline to ensure close approximation to the fascia. I prefer fixing mesh to fascia using absorbable sutures, either interrupted or continuous. The main objective is to reduce the risk of seromas. I use 3 or 4 large, closed-suction drains (19 French) under the subcutaneous tissue and keep them in until the individual drain output is less than 25 mL over 24 h.

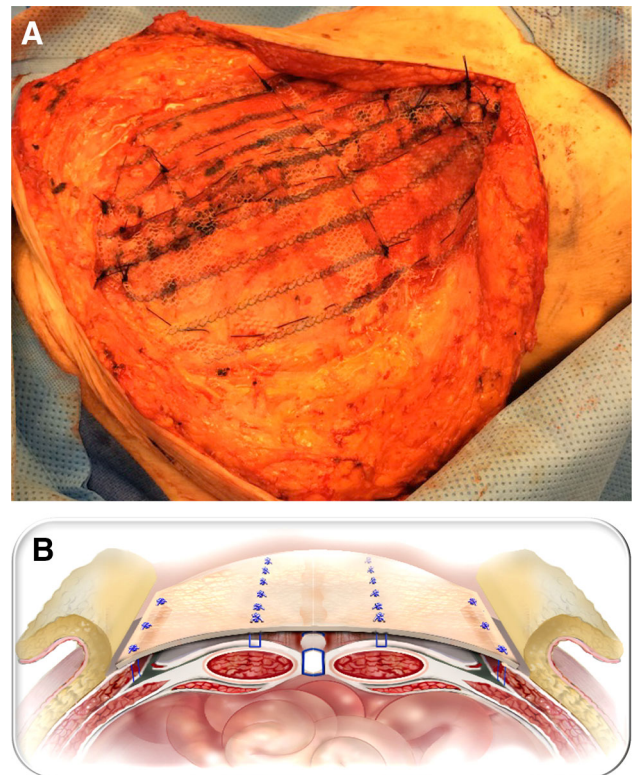


Fig. 4 **a** Onlay synthetic mesh placement in a patient following large hernia following left colectomy for diverticulitis. **b** Illustration of onlay mesh placement

Underlay placement

Underlay graft placement (Fig. 5a, b) has now become the main technique of graft placement in all high-risk and complex ventral hernia defects reconstruction. It is more involved, but once it is learned and perfected, it does not add significant operative time. It is believed that underlay graft placement is associated with lower incidence of seromas [60]. The key element of this technique is freeing the abdominal wall from any adhesions, as far laterally as possible both on the posterior and anterior aspects.

Placement of the interrupted sutures should ensure complete stretching of mesh once sutures are tight. Suture are placed using “parachuting” technique under direct vision at

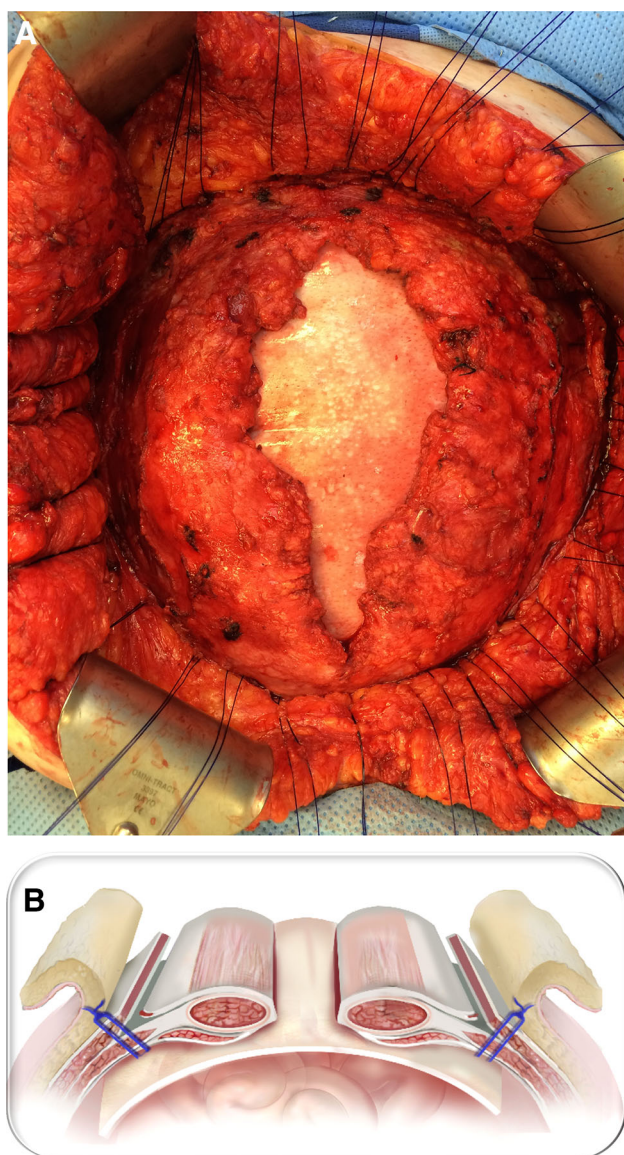


Fig. 5 **a** Underlay biologic mesh placement; **b** illustration of underlay mesh placement

all times. The placement of sutures under direct-vision using parachuting technique minimizes the potential for bowel injury during fixing of graft on the abdominal wall. If lateral component release is used, which my practice is done almost in all patients requiring major abdominal wall reconstruction, one has to place sutures in the anterior abdominal wall as far laterally as possible to include the medial edge of the external oblique fascia. Doing so the surgeon will prevent bulging laterally at the release component site (the patient might think bulging is a new hernia). A number of techniques of “underlay” placement have been described, including retro-rectus and sublay, as well as release of posterior aspect of the rectus. If one has an intact peritoneum, it is a good idea to place the mesh retro-rectus and preperitoneum [61]. While retromuscular mesh repair has gained popularity, a number of complications have been reported, including surgical site infections (SSI) in 19.6 % of cases, and the overall recurrence rate was 16.9 %. In a recent study, the highest rate of recurrence (25 %) occurred when hernia was repaired with biologic mesh, followed by synthetic mesh (16.2 %) and bio-absorbable mesh (17.1 %). The lightweight mesh use was associated with 22.9 % versus mid-weight mesh (10.6 %) ($p = 0.045$). The only predictor of recurrence was the presence of an SSI (OR 3.1, 95 % CI 1.5–6.3; $p < 0.01$). Similarly, after multivariate analysis, diabetes, hernia width >20 cm, and the use of biologic mesh were statistically associated with the development of a surgical site occurrence (SSO) ($p < 0.05$). Notably, the mere presence of contamination was not independently associated with wound morbidity ($p = 0.11$). SSO and SSI rates anticipated by a recent risk prediction model were 50–80 and 17–83 %, respectively, compared with our actual rates of 20–46 and 7–32 % [62].

Bridge mesh placement

When there is a major loss of abdominal wall domain and the surgeon cannot bring together the medial edges of the abdominal wall without major tension (Fig. 6a, b), despite performing bilateral anterior or posterior compartment release, then the only remaining option is to use mesh as a bridge (Fig. 6b). In these situations, biologic mesh is the preferred type of mesh [63], but patients should be advised that there is high chance of hernia recurrence and/or wall laxity that will mimic hernia. During bridge mesh placement, the surgeon must ensure that the suture bites are placed at least 2 or 3 cm into the muscles and fascia. If possible, the surgeon must avoid suturing the mesh on the edge of the fascia, in order to reduce the risk of herniation or suture failure. If at all possible, the “bridge” should be covered with native skin and subcutaneous tissue. However, when mesh is used as a bridge and there is no skin or subcutaneous tissue to cover the mesh, then the use of a wound Vacuum-Assisted Closure (VAC) with continuous irrigation is very useful to keep the mesh moist and

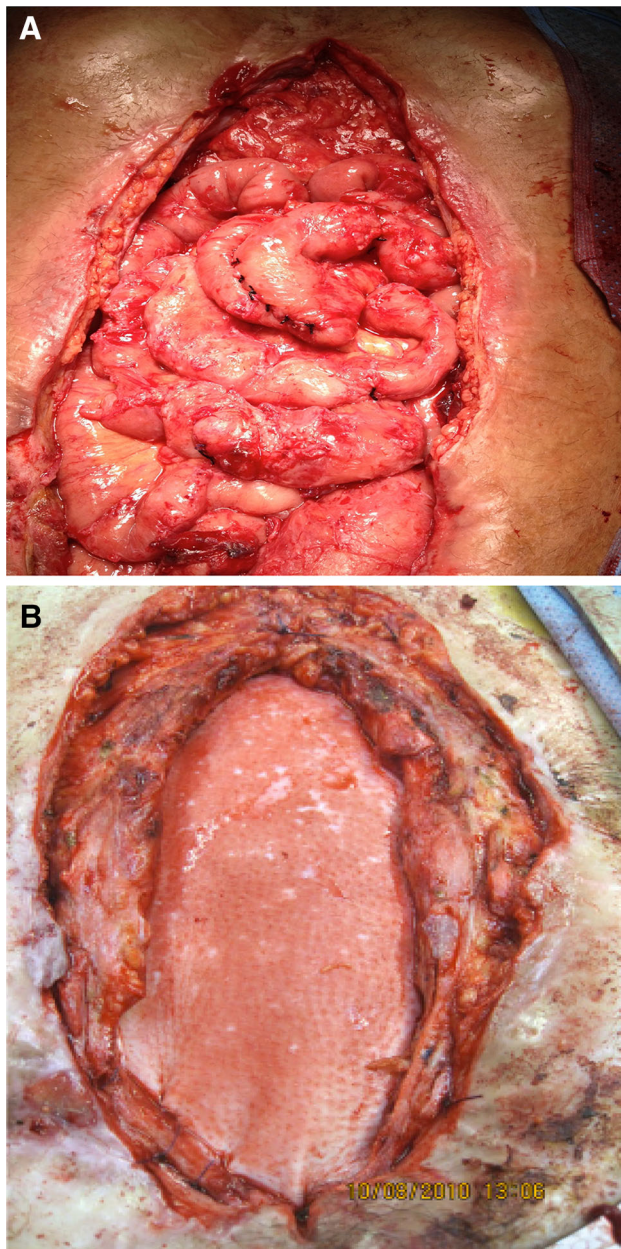


Fig. 6 **a** Patient with massive abdominal wall domain loss. **b** Bridge placement of biologic mesh

to speed the process of granulation for later skin grafting (Fig. 6c).

Postoperative management

Postoperative care of patients after major exploratory laparotomy with takedown of fistulas and abdominal wall reconstruction is as complex as the operation itself. Such patients require continuation of parenteral nutrition until full return of GI tract function, at which time they may be

able to resume full oral intake. Postoperatively, I prefer to give the patients massive doses of vitamin C intravenously (2 g intravenously every 4 h for at least 1 week). In addition, I administer vitamin E, zinc, selenium, and when appropriate, vitamin A, above and beyond the standard doses in total parenteral nutrition. The most common complications include wound infections and other surgical site complications, hernia recurrence, fistula recurrence (depending on the type of mesh used), small bowel obstructions, and pain. The real complication rate, however, can be extremely high, and both patients and their families need to be made aware.

Current data on biologic grafts and long-term follow-up

Data on long-term applications of biologic mesh are lacking, although its use has risen dramatically in patients with active infections or are at high risk for infection. In an experimental study examining biologic grafts in comparison to synthetic material, biologic grafts are able to clear a *Staphylococcus aureus* contamination; however, they do so at different rates [64]. The authors created a chronic hernia model in rats and then used various meshes (one synthetic polyester as control material ($n = 12$) and four different biologic grafts ($n = 24$ per material)). Biologic grafts evaluated included Surgisis (porcine small intestinal submucosa), Permacol (crosslinked porcine dermis), Xenmatrix (non-crosslinked porcine dermis), and Strattice (non-crosslinked porcine dermis). Half of the repairs in each group were inoculated with *S. aureus* at 104 CFU/mL and survived for 30 days without systemic antibiotic. There was a significant difference of bacterial clearance between biologic meshes. To this end, the use of biologic mesh in Northern America has become standard in high-risk patients with contaminated and dirty-infected wounds, despite the very high cost associated with the use of biologic mesh and a lack of empirical evidence.

Previously, we reported our own study of sixty patients who underwent acellular dermal matrix (ADM) implantation for abdominal wall reconstruction [65]. In 56 patients studied retrospectively, we used two brands of ADM: Alloderm (LifeCell Corporation, Branchburg, NJ) in 38 patients (68 %) and Strattice (LifeCell Corporation) in 18 patients (32 %). A total of 9 patients had concomitant ECFs and/or EAFs; for those 9 patients with ECFs and/or EAFs, we used underlay placement in 4 (44 %) and interposition or bridge placement in the remaining 5 (56 %). We found that the abdominal wall reconstruction results between patients with versus without concomitant ECFs and/or EAFs did not statistically differ in terms of the rates of overall complications, recurrence, or infectious

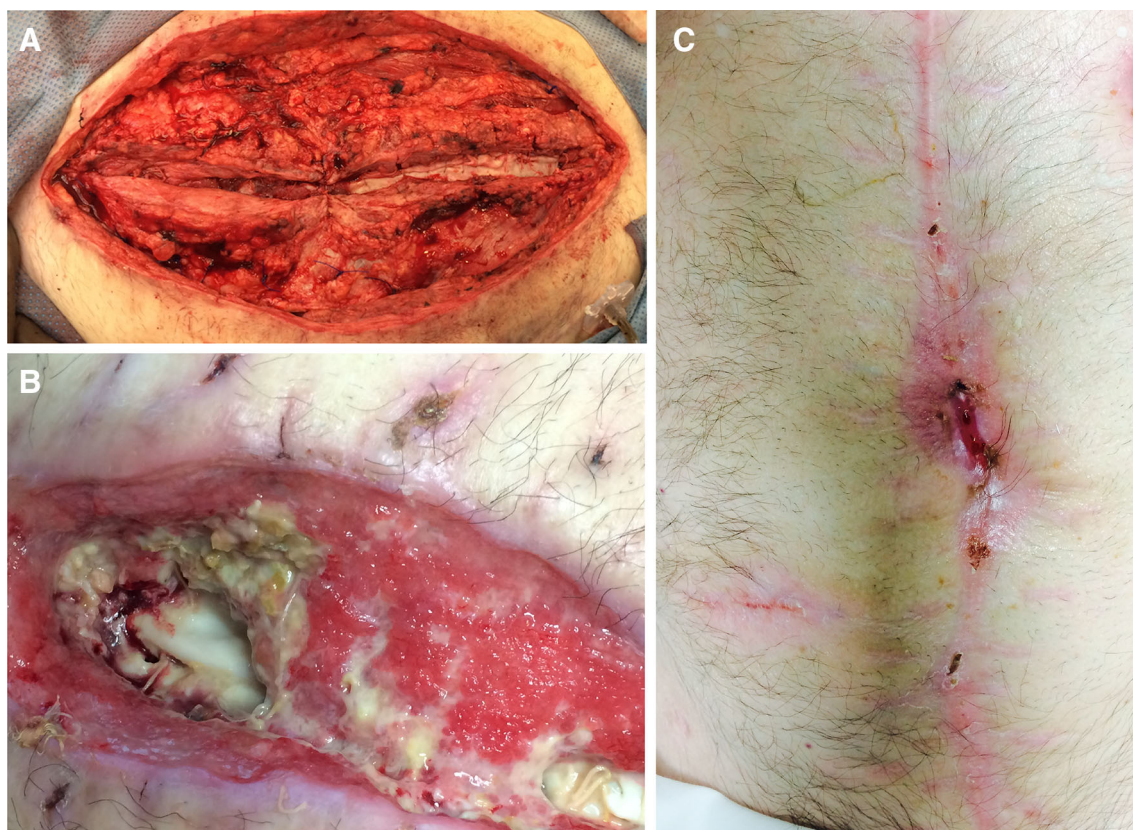


Fig. 7 **a** A case of reoperation in a patient post reconstruction with underlay biologic mesh. **b** Patient developed a wound infection but biologic mesh was not removed. **c** Two months later, wound closed.

complications. However, we lack long-term data on these patients.

Others have also reported that ADM implantation can be safely used to repair large and complex ventral hernia defects in patients with clean-contaminated or dirty-infected wounds. In our study mentioned above, of the 56 of patients who underwent ADM implantation with either Alloderm or Strattice, 35 (62.5 %) had contaminated fields as defined by the presence of intra-abdominal or soft tissue infections, stomas, or fistulas. Of those 35 patients, the majority—26 (74 %)—had Grade 4 infections, per a hernia grading system [66]. A recent study of 108 patients with grade II and III classification of hernias based on the Ventral Hernia Working Group (VHWG) has questioned the need to use biologic mesh on these two groups [67].

Our results suggest that biologic mesh implantation is a valid option for CAWR in the high-risk trauma and acute care surgery population; however, long-term results are not evident yet. However, other surgeons have reported abdominal wall closure in the infected field as well. In a recent study of 82 patients with ventral hernia repaired predominantly with Alloderm and Strattice, 32 (39 %) had had concomitant intestinal surgery [68]. There was no difference in hernia recurrence (contaminated group—

28 % vs. non-contaminated group—34 %, $p = 0.58$), surgical site infections (contaminated—28 % vs. non-contaminated—20 %, $p = 0.40$) or other complications when patients with and without concomitant bowel surgery were compared.

Complications of biologic grafts

One of the major complications of the biologic mesh has been hernia recurrence rate, which has been reported as greater as 30 % [69], a level of laxity that troubles both the patients and surgeons alike. In this study [70], seven of the nine patients reconstructed with component separation followed by interpositional Alloderm presented with abdominal wall laxity. Laxity was defined as a condition in which patients had clinical evidence of abdominal bulge at follow-up and required secondary reconstruction. While laxity has been common in our own patients as well, long-term data are missing [71]. In a systematic review of twenty-five retrospective studies, Slater et al. [72] found that recurrence rate depended on wound class, with an overall rate of 13.8 %, while the recurrence rate in contaminated/dirty repairs was 23.1 %. Abdominal wall laxity

occurred in 10.5 % of patients, and the surgical morbidity rate was 46.3 %. As it has been known for a while now, there are no randomized clinical trials; however, biologic grafts are associated with a high salvage rate when faced with infection.

The use of biologic mesh has made possible “one operation only” as it is attempted by most surgeons who perform abdominal wall reconstruction at the time of hernia repair, or at the time of takedown of ECFs and/or EAFs, even in contaminated fields. A staged operation for closing the open abdomen [73] has fallen out of favor, and in our practice, we aim to complete the definitive procedure in a single operation. In a study of 128 patients (76 F, 52 M) with large hernia defect (range 40–2450 cm²), infected mesh was present in ($n = 45$), stoma ($n = 24$), concomitant gastrointestinal (GI) surgery ($n = 17$), ECF ($n = 25$), open non-healing wound(s) ($n = 6$), enterotomy/colotomy ($n = 5$), and chronic draining sinus ($n = 6$) [69]. Despite the high rate of wound morbidity (47.7 %) associated with single-staged reconstruction of contaminated fields, the authors concluded that biologic mesh can be placed without consequences. However, these authors also concluded that the long-term durability seems to be less favorable. In a similar study, this group of authors reported the simultaneous reconstruction of ECF and complex abdominal wall defects resulted in successful single-stage management of these challenging cases in nearly 70 % of patients [74]. To this end, many authors now believe that CAWRs using ADM have low rates of surgical site occurrence (SSO) and surgical site infection, despite increasing degrees of wound contamination. If the wound is infected, or if the patient requires reoperation, the biologic mesh can be saved and does not need to be removed (Fig. 7a–c).

Yet, AWR itself has serious complications with or without biologic mesh [70]. In a report of 106 patients [75] (seventy-nine patients of whom had preoperative co-morbid conditions), sixty-seven (63 %) patients developed a post-operative complication, with skin necrosis being the most common complication ($n = 21$, 19.8 %); this is similar to our experience [4]. Other complications of AWRs include seroma ($n = 19$, 17.9 %), cellulitis ($n = 19$, 17.9 %), abscess ($n = 14$, 13.2 %), pulmonary embolus/deep vein thrombosis ($n = 3$, 2.8 %), small bowel obstruction ($n = 2$, 1.9 %), and fistula ($n = 8$, 7.5 %). Using the Methodological Index for Non-Randomized Studies, 554 patients from 16 studies from six different mesh products, had an overall infection rate of 24 % and a recurrence rate of 20 % [46]. The authors called for caution when using biologic mesh products in infected fields, because there is a paucity of controlled data and none have U.S. Food and Drug Administration approval for use in infected fields. When biologic mesh was compared to non-biologic mesh in a recent meta-analysis, it was found that biologic grafts had significantly fewer

infectious wound complications ($p < 0.00001$), but recurrence rates were not different. In addition, there were no differences in wound infections or recurrence between the human and porcine-derived biologic grafts [76].

Finally, all patients undergoing complex reconstruction require long-term follow-up; we suggest following up these patient at least yearly. Data for long-term effects of these CAWR are lacking [71]. Furthermore, the functionality, regenerative capacity, and long-term fate of these products have not been defined [77]. Based on the surgical technique used in the repair of hernia defect, the hernia recurrence rate could be as high as 63 % at 10 years, when mesh is not used [78].

Conclusion

Surgical management of complex abdominal wall defects, including patients with ECFs and/or EAFs, is challenging. Careful planning and mastery of advanced surgical techniques are required, often involving the use of biologic mesh and/or composite tissue transfer.

Compliance with ethical standards

Conflicts of interest No potential or real conflicts of interest to report.

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