Options for Closure of the Infected Abdomen

Kristin C. Turza,¹ Chris A. Campbell,² Laura H. Rosenberger,¹ Amani D. Politano,¹
Stephen W. Davies,¹ Lin M. Riccio,¹ and Robert G. Sawyer¹

Abstract

Background: The infected abdomen poses substantial challenges to surgeons, and often, both temporary and definitive closure techniques are required. We reviewed the options available to close the abdominal wall defect encountered frequently during and after the management of complicated intra-abdominal infections.

Methods: A comprehensive review was performed of the techniques and literature on abdominal closure in the setting of intra-abdominal infection.

Results: Temporary abdominal closure options include the Wittmann Patch, Bogota bag, vacuum-assisted closure (VAC), the AbThera™ device, and synthetic or biologic mesh. Definitive reconstruction has been described with mesh, components separation, and autologous tissue transfer.

Conclusion: Reconstructing the infected abdomen, both temporarily and definitively, can be accomplished with various techniques, each of which is associated with unique advantages and disadvantages. Appropriate judgment is required to optimize surgical outcomes in these complex cases.

THE INFECTED ABDOMEN poses substantial challenges to surgeons, and often, both temporary and definitive closure techniques are required. Temporary abdominal closure (TAC) allows surgeons ease of re-entry for multiple operations in an infected surgical field. Additionally, temporary closure helps reduce the risk of abdominal compartment syndrome (intra-abdominal hypertension) and its associated morbidity and mortality. Definitive reconstruction can be accomplished eventually in most cases through one of a variety of operative techniques. We review the multiple options available to close the abdominal wall defect satisfactorily during and after the management of complicated intra-abdominal infections.

Intra-abdominal infection carries a substantial risk of death, depending largely on the intensity of the patient's systemic response and the extent of the physiologic response, often measured by the Acute Physiology and Chronic Health Evaluation (APACHE) II score. The APACHE II score is a well-established and validated method by which to stratify risk in patients with intra-abdominal infections [1,2].

The goals of clinical management of intra-abdominal infections include control of bacterial or toxin sources, maintaining organ system function, and quelling the resultant inflammatory process [3]. Occasionally, multiple laparotomies are required to eradicate intra-abdominal bacterial sources. This approach should be undertaken only when definitive

closure of the abdomen is not possible initially. Performing re-laparotomy on demand, compared with planned re-laparotomy, yields a higher rate of anastomotic leakage, lower incisional hernias, and all surgery-related complications (intra-abdominal abscess, fistula, hemorrhage, perforation) [4]. In a sense, leaving the abdomen open in peritonitis is similar to the damage control approach for trauma.

Leaving the abdomen open not only enables multiple operations but also helps prevent abdominal compartment syndrome. Perioperative fluid resuscitation of the patient leads frequently to visceral and retroperitoneal edema, ischemic fascia, and abdominal compartment syndrome. An intra-abdominal pressure > 30 cm H₂O can result in decreased venous return and cardiac collapse, leading to multiple organ dysfunction syndrome, especially of the pulmonary, cardiovascular, renal, splanchnic, and central nervous systems (CNS). Temporary abdominal closure with a bridged biologic mesh or synthetic system (e.g., Wittmann Patch, Bogota bag, vacuum-assisted closure [VAC device], synthetic mesh) between the fascial edges can help prevent abdominal compartment syndrome while preserving the fascial for eventual closure. In the setting of known compartment syndrome and intra-abdominal infection, VAC device, the Wittmann Patch, or a synthetic mesh allow flexibility in bedside adjustment as needed. Each system is described with and without the use of negative pressure devices (Table 1).

Departments of ¹Surgery and ²Plastic and Reconstructive Surgery, University of Virginia Health System, Charlottesville, Virginia.

TABLE 1. OPTIONS FOR ABDOMINAL CLOSURE

<i>Name</i>	<i>Type</i>	<i>Advantages</i>	<i>Disadvantages</i>
Wittmann Patch	Temporary	Adjustment possible according to intra-abdominal pressure; facilitates re-operation; prevents lateral fascial retraction	Enterocutaneous fistula formation; no peritoneal fluid removed
Bogota bag	Temporary	Inexpensive; available worldwide; early diagnosis of intra-abdominal pathology (e.g., bowel leaks) because of visibility through bag	No peritoneal fluid removed
Vacuum-assisted closure (VAC)	Temporary	Prevents lateral fascial retraction; efficient removal of contaminated/infected peritoneal fluid; facilitates re-operation; low enterocutaneous fistula rate; adherence of viscera to device uncommon	Frequent sponge changes and complex nursing care required
Synthetic absorbable mesh	Temporary	Prevents lateral fascial retraction; facilitates re-operation	Hernia formation universal; no peritoneal fluid removed; adhesions of viscera to mesh; enterocutaneous fistula formation
Synthetic non-absorbable mesh	Temporary or definitive	Prevents lateral fascial retraction; facilitates reoperation	No peritoneal fluid removed; adhesions of viscera to mesh; enterocutaneous fistula formation
Biologic mesh	Temporary or definitive	Resists infection; may serve as definitive closure	Expensive; limited availability (institution-dependent selection); laxity/bulge failure with some materials over time
Components separation	Definitive	Autologous tissue used; resists infection	May weaken abdominal wall laterally
Tissue transfer	Definitive	Autologous tissue used; resists infection	Extensive surgical training required; donor site morbidity

Wittmann Patch

The Wittmann Patch (STARSURGICAL, Inc., Burlington, WI) was designed to allow adjustment in the laxity or redundancy of the closure material to accommodate changes in intra-abdominal pressure and prevent abdominal compartment syndrome. As described by Wittmann et al. in 1993, the patch consists of sheets of biocompatible polyamide and polypropylene, one containing multiple micro-mushrooms (hooks) and the other multiple slings (loops), enabling them to stick together similar to Velcro® [5]. They are anchored to the midline fascia with running non-absorbable suture, generally with the loop sheet sutured to the left fascia, and then fastened together in the midline. With the resolution of visceral edema, the excess material can be removed, and gradually, the fascial edges may be approximated. This system facilitates re-operation and helps prevent lateral retraction of the fascial edges, thereby aiding definitive delayed primary closure of the fascia.

Several studies have demonstrated that this technique ultimately increases the rate of delayed fascial closure after laparotomy. In one series of 103 open abdomens managed with the Wittmann Patch, 78% of patients were able to have delayed primary closure compared with 30% of those who did not receive the patch ($p < 0.001$) [6]. In another study of trauma and emergency general surgery patients, 82% had successful delayed fascial closure [7]. Of the four complications while the patch was in place, only one was related to primary patch infection. Another study demonstrated an 83% delayed primary closure rate using the Wittmann patch in intensive care unit (ICU) patients [8]. Six burn patients with open abdomens at high risk of abdominal compartment

syndrome (thermal and electrical burns, mean total body surface area affected 78%) were managed with the Wittmann Patch without a significant increase in intra-abdominal pressure [9]. The major complication associated with this technique is bowel fistulization. As such, great care must be taken to interpose a layer of non-adherent material between the device and the bowel.

Bogota Bag

The Bogota bag was first described by Oswaldo Borraez in Bogota, Colombia. To perform this technique, a sterile plastic 3-L genitourinary irrigation fluid bag is sutured to the fascial edges for TAC. Visualization is possible through the bag, allowing monitoring of intra-abdominal contents for ischemia. The advantage of this technique is it can be performed with minimal resources in almost any operating room.

One group evaluated use of the Bogota bag in 152 patients (79 with complications second to previous surgery, 57 with secondary peritonitis, 14 with complications second to trauma, two with mesenteric events) [10]. Twenty-four percent died secondary to infection complications. Of the survivors, nine patients were found early to have small-bowel leaks because of the ability to see through the bag. Thirty-five percent ultimately had successful delayed abdominal wall repair [10].

Vacuum-Assisted Management

Vacuum-assisted closure of the open abdomen entails the use of a non-adherent sheet covering the exposed viscera, as well as a sponge, placed under negative pressure. The system is based on the principles of traction and countertraction in

that the suction provides the traction on the abdominal wall while the sponge creates countertraction. Overall, the system prevents abdominal wall retraction, potentially enabling closure. Another advantage is the relatively clean and efficient removal of infected peritoneal fluid and quantification of that loss.

In 1986, Schein et al. first described three cases using polypropylene mesh (Marlex; CR Bard Inc., Cranston, NJ) placed directly atop bowel, sutured to fascia and then covered by an adhesive, transparent polyurethane (OPSITE™, Smith Nephew) film with the interposition of suction tubes to create negative pressure throughout [11]. All three patients Nephew had abdominal infections (gangrenous transverse colon, sepsis after gastrectomy and wound dehiscence, and a pancreatic abscess involving the transverse mesocolon). The reported success of this closure system depended on the mesh being permeable to purulent contents while resisting evisceration, OPSITE™ London, United Kingdom serving as a transparent elastic film protecting the skin from damaging fluids while decreasing evaporation, and catheters suctioning fluid from between the mesh and the OPSITE™ [11].

The vacuum pack technique is similar to this concept and design. The vac-pack is a three-layer, sutureless dressing with a vacuum seal. The first layer, abutting the abdominal viscera, is a polyethylene sheet placed under the peritoneum of the abdominal wall. A moist, sterile surgical towel is placed over the polyethylene sheet. Two drains are placed on top of the towel and tunneled underneath the skin approximately 4–5 cm away from the wound. A polyester sheet backed with acrylic adhesive is placed on the skin after it has been painted with tincture of benzoin or a similar adhesive. A Y-shaped adapter is connected to the drains, and suction is maintained at -100 to -150 mm Hg. The abdominal contents are free to expand from visceral and retroperitoneal edema during the acute phase of resuscitation, with minimal chance of abdominal compartment syndrome. Multiple operations are facilitated by this design as well, and there is a reported low rate of bowel fistula formation, retraction of the abdominal wall fascia, and intestinal adherence to the prosthesis.

Reasonable rates of definitive abdominal wall closure have been seen with the vac-pack for the infected abdomen. A study of general surgery patients (diagnoses including necrotizing pancreatitis and perforated viscus) closed via vac-pack had a 71% rate of successful delayed abdominal wall closure [12]. Of the 55 trauma patients also in this series, 76% underwent delayed abdominal wound closure successfully [12]. The vac-pack has proved useful according to validated scales in improving the somatic and emotional health of patients within the first three months after abdominal wall closure. Patients receiving the vac-pack had shorter ICU stays and earlier ambulation from appropriate fluid management [13].

Since it was introduced in 1996, the VAC technique has been performed commonly utilizing a polyurethane sponge (VAC; Kinetik Concepts Inc. [KCI], San Antonio, TX). It has been observed that fascial closure can be accomplished more frequently with the sponge than by the standard surgical towel method, as the sponge is placed in direct contact with the fascia and thereby applies constant medial traction directly [14]. The VAC technique performed in this way includes placing a polyethylene sheet over the bowel and underneath the fascial edges and a sponge atop this [14]. Suction tubing is placed, along with an occlusive dressing, to

complete the set-up. This is changed every three to five days. Using this method in 45 trauma patients, the closure rate was 88% with a mean closure time of 9.5 days [14]. Two patients (4.6%) developed wound dehiscence, whereas one (2.3%) had a ventral hernia [14].

The utility of the VAC dressing appears to be greater when early control of the infectious source is obtained. In a study of patients with abdominal compartment syndrome and a definitive source of infection, primary fascial closure rates were 100% when early infection control was obtained compared with 40% when source control was delayed [15]. Similarly, the mean duration of open abdomen was significantly longer with delayed source control (34.2 vs. 8.5 d; $p < 0.005$) [15]. Compared with other techniques, including zipper closure, the silastic sheet “silo,” and loose packing (among others), VAC yielded the highest rates of fascial closure and the lowest mortality rate [16].

The AbThera™ Open Abdomen Negative Pressure Therapy System (KCI) is also an option for temporary abdominal closure. The benefits are similar to those of the VAC, including easy access for reoperation, placement without suturing, protection of abdominal viscera, and barrier protection from external contaminants. It also purports to provide active abdominal therapy by removing contaminated intra-abdominal fluid, helping estimate fluid loss, and minimizing fascial retraction and domain loss [17].

Application of the ABThera includes a visceral protective layer that is placed in the abdomen; this layer is fenestrated to allow fluid to be drained. Perforated foam is then applied over the top, and the adhesive drape is placed over the perforated foam followed by application of the interface pad and suction tubing. Dressing changes are performed every one to three days, depending on patients' needs; patients who have intra-abdominal contamination or infection may require device changes more frequently. Continuous suction is placed at 125 mm Hg, but this too may differ according to the patients' needs. One study evaluated the pressure propagation through the dressing on the bowel surface in a porcine model and found that for pressure ranges of -50 to -150 mm Hg, negative pressure reaching the bowel surface is minimal and remains constant even when the system pressure is decreased [18]. In their model, the system also drained the abdominal cavity entirely of fluid [18].

Synthetic Mesh Closure of the Infected Abdomen

Both absorbable and nonabsorbable synthetic meshes often are considered in the management of the open infected abdomen. The benefits of synthetic mesh include fascial margin preservation, easy reaccess to the abdomen for multiple operations, and a lower cost than biosynthetic meshes [19]. Interposing greater omentum between the mesh and the bowel has been suggested to decrease fistula rates, so when possible, this should be performed [19]. The mesh is sewn to the fascial edges with a running suture and incised down the center to allow easy reentry. The medial mesh edges are trimmed as the intra-abdominal pressure decreases, and the edges of the mesh are brought together gradually.

Although synthetic materials are used for temporary closure of infected abdomens, there is the risk of persistent and symptomatic infection of the mesh [20–23]. When synthetic materials are placed in infected or contaminated fields, glycoproteinaceous binding material forms to which bacteria

adhere, leading to production of a biofilm and permanent fixation [24]. Antibiotic penetration into the slime, an amorphous extracellular polysaccharide layer, is hindered [24]. For this reason alone, most synthetic meshes are not used for permanent closure in this setting.

Non-absorbable synthetic mesh

Non-absorbable mesh has demonstrated utility in keeping the rate of abdominal compartment syndrome (ACS) low. In one study of abdominal closure in patients who had undergone repair of abdominal aortic aneurysm (AAA) and abdominopelvic trauma, the rate of subsequent ACS with use of non-absorbable mesh was low at 5.5% [25]. Use of a synthetic material for abdominal closure may help prevent fascial edge retraction and other such complications of an open abdomen. However, there are reports of high overall complication rates (as high as 55%) with use of polypropylene (PP) in emergency situations [26]. This rate was reduced significantly in one study with early postoperative use of full-thickness skin or muscle flaps or mesh removal as early as possible (within two weeks) for definitive fascial closure [26]. With these two approaches, the overall complication rate decreased to 15% [26].

Non-absorbable mesh options include polytetrafluoroethylene (PTFE) and PP. PTFE is hydrophobic, whereas PP is hydrophilic. It has been suggested that hydrophobic material may initially repel bacteria-laden fluids, but ultimately, any such property is likely to be overcome by integration via the fibroblastic response [24]. Expanded PTFE (ePTFE) also is used for abdominal wall closure, and because it does not adhere to bowel serosa, fistula formation reportedly is less common than with PTFE [19]. Persistent infection has been a problem with PTFE [27,28].

Polypropylene mesh is available as heavyweight constructions (Surgipro [110 g/m²], United States Surgical, Norwalk, CT; Prolene [105 g/m²], Ethicon Inc., Somerville, NJ; Marlex [95 g/m²]), midweight (Prolene Soft Mesh [45 g/m²], Ethicon), and lightweight (Ultrapro [35 g/m²], Atrium Medical Company, Hudson, NH). Lightweight PP (defined as PP content <35 g/m²) has lower density than standard PP and thereby elicits less foreign-body reaction in native tissue. The result is less abdominal wall stiffness from scar tissue and some native tissue regeneration into the mesh scaffold, which certainly is preferable in the setting of infection [29,30]. Polypropylene is classified as macroporous (4-mm pores) or microporous (0.8-mm pores). Macroporous PP becomes infiltrated with a loose array of perifilamentous fibrosis with fat tissue, whereas microporous PP elicits dense perifilamentary granulomas and poorly vascularized scar tissue [29].

In vivo, the greater native tissue regeneration that occurs with lightweight, macroporous PP appears, in fact, to result in a lower bacterial count on the mesh. Within a group of contaminated meshes implanted subcutaneously (bioluminescent *Staphylococcus aureus* on multifilament PP, monofilament PP, lightweight PP, and PTFE), monofilament PP and lightweight PP have consistently lower bacterial persistence and spread in the infected area [31]. In fact, in clean-contaminated cases, such as biliopancreatic diversion, use of PP mesh has been associated with no infections [32].

Reported fistula rates differ widely with use of non-absorbable mesh in infected abdomens, from 4% to 75% [33]. In one series of closures with nonabsorbable mesh in the

presence of abdominal fecal contamination, relatively low surgical site infection rates (7%) and fistulae (3.4%) were noted [34]. Similarly, in patients with intra-abdominal sepsis or abdominal compartment syndrome, after definitive closure with mesh, 3% of patients developed enterocutaneous fistulae [13]. However, other authors have reported fistula rates as high as 75% [33]. Some authors report success in lowering fistula and mesh (PP) infection rates by placement of omentum between the bowel and the mesh in contaminated abdominal wall defects caused by necrotizing fasciitis after radical debridement [35]. Because of these complications, the placement of nonabsorbable synthetic mesh in the setting of an active infection usually is a temporary measure, and the mesh is removed prior to definitive fascia-to-fascia closure.

Absorbable synthetic mesh

Absorbable mesh options include polyglactin 910 (Vicryl; Ethicon, Norderstedt, Germany) and polyglycolic acid (Dexon; Braun-Dexon, Spangenberg, Germany). These absorbable meshes differ from non-absorbable meshes in an infected abdomen in that they lose a significant amount of their strength via degradation in approximately three weeks and generally are absorbed by about six weeks [19,36]. Many surgeons apply a split-thickness skin graft to cover the bowels more safely. Polyglycolic acid mesh has wider interstices and reportedly allows more efficient drainage of infected abdominal fluid [37]. As a result, some authors recommend its use in the infected abdomen [20]. Another benefit of absorbable mesh in the setting of infection is its ability to stimulate fibrous granulation tissue and ultimate epidermal cell proliferation as it is hydrolyzed [19]. Even when infection would prevent definitive closure of the abdominal wall, regeneration of native abdominal wall fibrous tissue continues. With the use of either absorbable mesh, the reported rates of enterocutaneous fistulae range from 8.3% in patients with a definitive peritonitis [38] to 23% in multi-injured trauma patients [39].

On the other hand, one retrospective study, albeit with a small sample, demonstrated no benefit of absorbable mesh in the infected abdomen [40]. In fact, progressive intra-abdominal sepsis was more common in the absorbable mesh group, and 77% of the patients had subsequent mesh infection with no significant difference between the absorbable and nonabsorbable mesh groups [40]. Absorbable mesh use in critically ill patients also carries a higher risk of infectious complications than autologous fascial closure during the first eight days [41]. One major drawback in the use of absorbable meshes is the universal development of a large ventral hernia, resulting in additional morbidity and cost. The use of absorbable mesh should be restricted to cases where definitive fascial closure is unsafe during the index hospitalization.

Bioprosthetics

Bioprosthetic materials have a potentially important role in managing patients with infected abdomens. Bioprosthetics consist of commercially processed decellularized mammalian tissue (human, porcine, or bovine) and can be harvested from multiple sites, including the dermis, small intestinal submucosa, or pericardium. One key advantage of bioprosthetics compared with synthetics is that they provide a scaffold in which native tissue fibrovascular remodeling can occur, thereby regenerating host tissue.

Supra-physiologic chemical cross-linking is a process by which the tensile strength of a prosthetic is increased. Some materials (CollaMend, Bard; Permacol; Covidien, Inc., Mansfield, MA) are processed by proprietary methods in this manner, whereas others (Strattice, LifeCell Corp., Bridgewater, NJ; AlloDerm LifeCell; SurgiMend, TEI Biosciences, Boston, MA) are not. Even though the bioprosthetic becomes stronger through this processing, results from a well-established animal model show that rather than being integrated into host tissue through cellular and vascular infiltration, cross-linked materials become encapsulated with dense fibrotic tissue [42]. The ultimate tensile strength at the connection site between the bioprosthetic and native tissue also is weaker in cross-linked materials than in non-cross-linked ones, but it is unclear whether this translates into a higher incidence of hernia recurrence [42]. Both cross-linked and non-cross-linked bioprosthetics are used for closure of the infected abdomen.

Although a more costly option than synthetic materials, bioprosthetics, whether cross-linked or not, have advantages in the infected abdomen. A study evaluating bacterial clearance of biologic grafts in hernia repair using porcine small intestinal submucosa, cross-linked porcine dermis, and non-cross-linked porcine dermis contaminated with *S. aureus* demonstrated that organism clearance at postoperative day (POD) 30 ranged from 58% in porcine small intestinal submucosa to 92% in non-cross-linked porcine dermis, as measured by fluorescence imaging and quantitative bacterial studies [43]. The control, synthetic polyester mesh, demonstrated no bacterial clearance at POD 30 [43].

The microbiology of human acellular dermal matrix implanted for abdominal wall closure in the setting of intra-abdominal sepsis reveals that post-implantation, 24% of patients had culture-diagnosed bioprosthetic infection with *Escherichia coli*, *Pseudomonas aeruginosa*, or methicillin-resistant *S. aureus* [44]. These were organisms similar to those present at the time of mesh implantation. However, none resulted in mesh loss, and all were cleared by silver sulfadiazine applied to the mesh and moist dressings [44]. Human acellular dermal matrix also has been compared with PTFE in the setting of *S. aureus* contamination in a rabbit model, demonstrating that the biologic mesh resists surgical site infection [45]. Animals treated with human acellular dermal matrix had lower inoculation counts at PODs 7 and 21 than those implanted with PTFE ($p=0.006$ and 0.002 , respectively), as well as fewer abscesses ($p=0.008$). The suggestion was made that the biologic material performs better in the setting of infection because of its ability to clear bacteria and revascularize [45].

Additional studies have evaluated the longer-term results with bioprosthetics. In one group of patients with high-risk hernia defects and infection, 96% of those repaired with human acellular dermal matrix ultimately had healing of their defects, even though 45% suffered wound-healing complications requiring either the skin to remain open or percutaneous drainage [46]. Cross-linked porcine acellular dermal matrix has been successful for abdominal wall repair in infected settings with no explantations during the acute infection phase, and an 11% rate of skin-dehiscence long-term hernia recurrence [47].

Components Separation

Components separation was described initially by Ramirez et al. and entails separation of the external and internal

oblique muscles and medialization of the rectus complexes to aid abdominal wall closure [48]. Bilateral subcutaneous skin flaps are elevated from the midline fascial edge to the linea semilunaris. The external oblique aponeurosis is released 1.5 cm lateral to the lateral edge of the rectus sheath from the costal margin to the pubis. Dissection is performed between the external and internal oblique muscles laterally to the midaxillary line. The rectus complexes are medialized, and, ideally, complete midline musculofascial closure is obtained.

Laparoscopic and endoscopic methods have been developed for components separation, which aim at reducing subcutaneous dead space and large devascularized skin flaps. Laparoscopic components separation utilizes a 1-cm incision below the costal margin to expose and incise the external oblique aponeurosis. A laparoscopic balloon dissector aids in blunt dissection, and two 5-mm ports are placed, one umbilical at the posterior axillary line, the other just above the inguinal ligament lateral to the rectus, to allow intramuscular dissection from the costal margin to the inguinal ligament [49]. The external oblique muscle is released from the costal margin to the inguinal ligament. Some results are promising with use in the setting of abdominal infection. One study demonstrated that in patients with contamination from exposed mesh or contaminated fluid around the mesh, the laparoscopic approach allowed tension-free primary fascial closure [49]. Some studies document shorter hospital stays, lower overall cost [50], and fewer postoperative complications [51], but still others found no substantial benefits to laparoscopy [52,53].

Synthetic materials, absorbable or non-absorbable, also are potential options for definitive closure in conjunction with components separation. Soft PP mesh used as an underlay for midline abdominal wall reinforcement demonstrated lower complication and hernia recurrence rates than acellular cadaveric dermis in a comparative study [54]. Synthetic materials have been used for definitive abdominal reconstruction with components separation in morbidly obese patients, yielding a 10% surgical site infection rate with an average follow-up of 50 months [55]. Long-term abdominal wall reconstruction with PP mesh reinforcement and free latissimus dorsi muscle flap coverage has been successful in trauma patients with large full-thickness abdominal wall defects and colostomies [56]. The success of such reconstruction likely was aided by the addition of a well-vascularized piece of autologous tissue.

Autologous Tissue Transfer

Local autologous tissue transfer techniques that can be considered for definitive abdominal closure include rectus abdominis muscle flap advancement with mesh inlay for the superior, middle, and inferior abdomen and rotation flaps based on the quadriceps muscle supplied by branches of the lateral femoral circumflex femoral artery (LCFA) for the inferior abdomen. Although more complicated than mesh repair or components separation, these methods can rebuild the abdominal wall in particularly challenging circumstances.

Unilateral or bilateral rectus abdominis muscle flap advancement is the most common tissue transfer technique for midline hernia repair in the superior, middle, or inferior abdomen. Mesh inlay often is used to buttress the repair when rebuilding the structural integrity of the abdominal wall. The

flare of the ribs poses the biggest complicating factor for the superior third of the abdomen. Closure is performed in this area by suturing to the xiphoid and the costal margin. The rectus muscle has the greatest mobility in the middle third of the abdomen, as described in the components separation literature. Repair of the inferior third of the abdomen requires mobilization of the bladder and suturing to the pubis centrally.

The thigh muscles based on the LCFA are useful for reconstructing the inferior abdominal wall. The tensor fasciae lata flap is based on the ascending branch of the LCFA and can be rotated to provide fascial coverage of the inferior abdomen. The anterolateral thigh flap supplied by the descending branch of the LCFA can be elevated as a fasciocutaneous or myocutaneous flap, depending on the coverage needs of the abdomen. When a large area of coverage is required, a subtotal thigh flap can be harvested off the entire LCFA system. When taken bilaterally, the subtotal thigh flap can cover the inferior and middle thirds of the abdomen. There is greater morbidity with this procedure for ambulatory patients, as the rectus femoris muscle also is harvested to include the perforators to the medial thigh skin.

Successful use of free tissue transfer also has been demonstrated for abdominal wall defects [56]. Free muscle flaps, using the latissimus dorsi most commonly, can be anastomosed to the deep inferior epigastric artery and placed over mesh to reconstruct large defects when the rectus abdominis muscles are not available for advancement. Enervation of free muscle flaps can be performed by anastomosis to the intercostal nerves, but this does not improve abdominal wall integrity over the use of free flaps alone with mesh reinforcement.

Selecting the appropriate flap design for an individual patient requires a focus on defect characteristics, especially the location on the abdominal wall. One study that reported a 92% success rate of definitive complex abdominal wall reconstruction found that 80% of the defects in which a substantial amount of skin was absent over the hernia received flap reconstruction [57]. In this same series, placement of PP mesh was preferred for defects where the skin was intact without reported visceral complications or repair failures. Use of a tensor fasciae lata flap was opted for in lower abdominal wall defects with absent skin, whereas rectus advancement was utilized for midline defects whether or not there was skin atop the defect [57].

Finally, perforator flap design has created new options for abdominal wall reconstruction. Free-style perforator flaps known as "propeller" flaps are designed from computed tomography angiography images of the abdominal wall. A skin paddle can be centered over a perforator from the deep inferior epigastric artery (DIEA), which can then be rotated over an abdominal skin defect at the same time as the rectus muscle housing the DIEA is advanced to reconstitute the midline abdominal wall [58]. It is unclear how commonly these technically demanding flaps will be used or what their long-term outcome will be.

When Can the Abdomen Be Closed Definitively?

If the abdomen cannot be closed at the time of the source control procedure, general physiologic and microbiologic principles are important to consider when determining the

timing of definitive closure. These factors hold true regardless of the original diagnosis (necrotizing fasciitis, pancreatic abscess, other intra-abdominal infection). To prevent abdominal compartment syndrome, the intra-abdominal pressure must consistently be <25–30 mm Hg, and bowel edema must be resolved to a great extent. The fascia has to be closable without undue tension or increasing the intra-abdominal pressure. All of the patient's abdominal operations should be complete, and any type of infection controlled. Determining the extent of infection control is based on the clinical signs. Specifically, source control must be complete, the patient should be afebrile, and there should be no obvious signs of invasive infection. If there is concern or question about soft tissue or cutaneous infection, quantitative cultures may be performed. Generally, intra-abdominal fluid cultures are not performed to determine whether an infection or contamination is still present before definitive closure, as such cultures will almost certainly be positive. This protocol will optimize the wound environment for definitive closure and increase the chances of success.

Considerations in Definitive Closure

Once basic physiologic and microbiologic goals are met, many options are available for definitive closure. The first question is determining whether the fascia can be closed primarily or whether components separation or an interposition graft, either synthetic or biologic mesh, is required. If the patient's fascia is strong and can be approximated without undue tension, primary fascial closure may be considered. However, if the intra-abdominal pressure increases to >25 mm Hg when the fascia is pulled together, as assessed by bladder pressures, or the tissue quality is poor, an alternative technique should be used. Peak airway pressures may be monitored also to ensure that fascial tension is not excessive.

Because it avoids the use of prosthetic materials, a components separation is often the next choice when primary closure is not feasible. These methods can yield additional centimeters of medial closure and frequently are adequate absent substantial abdominal wall loss, poor muscular or fascial quality, or fascial margins that have retracted far laterally.

Reconstruction of patients with an enterocutaneous fistula and an open abdomen presents unique challenges. Optimizing these patients with respect to infection treatment and nutritional status is crucial in preventing postoperative complications. Even when optimized fully, patients undergoing surgical fistula resection and reconstruction by suture repair with or without components separation, or by suture repair with absorbable or non-absorbable mesh, experience a high rate of major complications (82.5%) [59]. This same study demonstrated an 11.1% re-fistulization rate, and this was greater when prosthetic mesh was used (24%) than after suture repair with components separation (zero) [59].

Special Circumstances

Necrotizing fasciitis

Necrotizing fasciitis of the abdomen presents a challenge for the surgeon attempting abdominal closure. *Escherichia coli* is the most common pathogen [60], but involvement of anaerobic bacteria is associated with an increase in the number

of surgical revisions required ($p=0.005$) [61]. Definitive closure of the abdomen can be considered after thorough surgical debridement, antibiotic therapy, and hyperalimentation [60]. In one study, the average time to initial reconstruction was 19.5 mo [62]. A specific challenge in these patients comes when there is substantial loss of abdominal wall musculature secondary to aggressive but appropriate debridement. In these settings, components separation or even complex forms of advanced tissue transfer may be required. These patients also are the ones most likely to require implantation of bioprosthetic or absorbable mesh for closure.

Infected necrotizing pancreatitis

As with necrotizing fasciitis, infected necrotizing pancreatitis can be challenging when planning abdominal closure. Surgical management of this condition often is completed with either direct pancreatic debridement or transgastric debridement via a cystgastrostomy. Although some patients require only a single procedure, others require multiple laparotomies. In one study, 14% of patients required two and 14% required three operations for complete debridement [63]. The principles of definitive abdominal closure remain the same. Surgical management must be complete, infection resolved in its entirety, and the aforementioned basic physiologic goals met. One particularly challenging aspect of managing this condition is the inevitability of closing the abdomen in the presence of a relatively high pathogen burden no matter how complete the debridement or the efficacy of the antimicrobial agents given. As such, extra attention must be paid to the provision of adequate drainage of the retroperitoneum, usually through closed suction drains. In addition, antimicrobial therapy generally will be prolonged, although the ideal treatment course remains unknown.

Stoma Management

Any patient with an open abdomen may have or will require a stoma that must be taken into consideration when performing either TAC or definitive closure. The stoma site depends on body habitus and natural abdominal fold locations. Preoperative stoma marking is valuable, although not always possible in urgent settings. Such planning helps prevent nursing difficulty with leakage, ill-fitting ostomy appliances, skin irritation, and pain [64]. Other stoma positioning issues include patient contractures, mobility and use of a wheelchair, previous radiation therapy, and the type of ostomy diversion anticipated (i.e., ileostomy, colostomy, urostomy).

One special consideration when placing a stoma is the potential for future components separation. Frequently, a stoma will be placed through one of the rectus muscles to minimize the risk of a parastomal hernia. If a components separation is planned or contemplated, the surgeon may choose to place a stoma lateral to the rectus muscles in order to preserve their fascia for separation and ultimate abdominal closure.

In patients without complicating comorbidities, stoma take-down frequently is considered three months after placement. Resolution of the intra-abdominal process is a requisite for take-down to ensure the highest chance of success, especially with respect to infection. Complications from ostomy take-down are common. For instance, in one study of trauma patients who underwent colostomy take-down after a

mean of 4.8 months, a 25% all-cause morbidity rate was reported, including bowel obstruction and abscesses [65]. Hence, the patient must be in as optimal a medical condition as possible. Planning must address the timing of ostomy take-down if definitive closure is being considered with components separation or musculofascial flaps or both. A particular challenge occurs with the presence of a stoma in the setting of an abdomen that was closed using an absorbable mesh and subsequent skin graft. Reconstruction of the abdominal wall itself frequently is difficult and may require placement of a synthetic or bioprosthetic mesh to achieve closure. If a stoma that needs reversal is in place, the surgeon may elect to perform the reversal first followed by definitive abdominal wall closure, often using components separation or a prosthetic mesh weeks or months later.

Conclusion

The infected abdomen undoubtedly poses challenges for surgeons. Many temporary and definitive options exist for closure, each with associated benefits and drawbacks. Obtaining source control is paramount in the setting of infection, and temporary closure affords ease of re-entry for multiple operations to achieve this end. Definitive abdominal reconstruction is the ultimate goal, aiming to minimize long-term morbidity associated with lack of abdominal domain.

Author Disclosure Statement

No competing financial interests exist. There are no disclosures for Drs. Turza, Campbell, Rosenberger, Politano, Davies, Riccio, or Sawyer.

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Address correspondence to:

Dr. Kristin C. Turza
University of Virginia Health System
P.O. Box 800679
Charlottesville, VA 22908

E-mail: kt4p@virginia.edu