Eastern Association for the Surgery of Trauma: A Review of the Management of the Open Abdomen—Part 2 "Management of the Open Abdomen"

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During the course of the last 30 years, several authors have contributed their clinical experience to the literature in an effort to describe the various management strategies for the appropriate use of the open abdomen technique. There remains a great degree of heterogeneity in the patient population, and the surgical techniques described. The open abdomen technique has been used in both military and civilian trauma and vascular and general surgery emergencies. Given the lack of consistent practice, the Eastern Association for the Surgery of Trauma (EAST) Practice Management Guidelines Committee convened a study group to establish recommendations for the use of open abdomen techniques in both trauma and nontrauma surgery. This has been a major undertaking and has been divided into two parts. The EAST practice management guidelines for the open abdomen part 1 "Damage Control" have been published.[1]

During the development of the open abdomen part II "Management of the Open Abdomen," the current literature remains contentious at best, current methods of treatment continue to change rapidly, and patient populations are so heterogeneous that clear recommendations could not be provided. What follows is a thorough review of the current literature for the management of the open abdomen: part 2 "Management of the Open Abdomen" and provides clinical direction regarding the following specific topics.

1 Early and Delayed Abdominal Fascial Closure (DAFC).
2. Management of intestinal fistula in the setting of the open abdomen.
3. Management of the planned ventral hernia.

Process

A computerized search of the National Library of Medicine Medline database was undertaken using the PubMed Entrez interface. English language citations were identified during the period of 1984 through 2009 using the primary search strategies outlined. Given the complexity of this literature, several strategies were necessary to appropriately capture the breadth of evidence on the topic. The search excluded case reports, reviews, letters/commentary, editorials, and articles focusing only on pediatric participants.

The PubMed Related Articles algorithm was also used to identify additional articles similar to the items retrieved by the primary strategy, in addition to hand searching of the reference lists of key articles retrieved by the searches. Of ~1,300 articles identified by these two techniques, only prospective or retrospective studies examining open abdominal management were selected, consisting of 79 institutional studies evaluating open abdomen management strategies in the adult surgical/critical care population. The articles were reviewed by a group of 16 surgeons who collaborated to produce this clinical review. The chair, vice chair, and three committee members (JJD, WD, MO) reviewed all the articles to categorize them into the three study topics. They were distributed to all members of the study group for critical review. Each committee member was to answer the following three questions of each article reviewed:

1. What is the class of evidence in the article?
2. Are the results of the article valid based on the data presented?
3. What is your conclusion based on the evidence the article provides.

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Review

During the development of this review, a common language for the closure of the open abdomen was developed, which is provided in Table 1. Figure 1 is a proposed flow diagram for the closure of the open abdomen in trauma, emergency general, and vascular surgery.

Early Abdominal Fascial Closure

Timing

Trauma surgeons have gained an immense amount of experience with multiple techniques used to achieve abdominal closure of the open abdomen, but questions still remain. How long can the abdomen remain open? When does the risk of complications begin to increase? Is there a specific technique that is better than the rest for closing the open abdomen? At what point should all attempts at delayed fascial closure be abandoned and a planned ventral hernia performed? Miller et al.,[2] in a study of 344 damage control laparotomies demonstrated that early abdominal fascial closure can be achieved in the majority (63%) of damage control cases during the initial re-laparotomy. They showed that DAFC before 8 days was associated with fewer complications: 12% in those closed before 8 days and 52% closed after 8 days. Yet, in a study of trauma patients with an open abdomen, massive visceral edema, and loss of domain, fascial closure could be achieved using the V.A.C. therapy (vacuum-assisted closure, KCI, San Antonio, TX) overtime out to a 4-week period with acceptable complication rates.[3] With this degree of variation in timing to closure and the dreaded risk of life threatening complications more data were needed.

Delayed Abdominal Fascial Closure

Techniques (Nontraumatic/Traumatic Fascial Closure)

Multiple studies have shown that DAFC is safe and effective at achieving successful fascial closure in 65% to 100% of patients with an open abdomen.[2,4–25] There is evidence that vacuum-assisted closure devices (VACD) facilitate delayed primary fascial closure with high success rates and low morbidity.[3–5,7,13,14,16–18,26] The literature describes both commercially available devices (V.A.C. therapy) as well as "home make" noncommercial "vacuum packed–negative pressure dressing" devices as being helpful in achieving DAFC (Table 2).

In the setting of intra-abdominal sepsis, the effectiveness of VACD to achieve DAFC has not been as successful as the experience seen in trauma patients.[27] Wondberg et al.[28] studied 30 patients with intra-abdominal sepsis and an open abdomen. They showed that only 33% of the study group was able to achieve DAFC with the use of the V.A.C. therapy KCI. Failure to achieve DAFC is associated with significant financial cost, increased morbidity including wound infections and the formation of intestinal fistula.[29–31] Although, studies have shown that using VACD in conjunction with dynamic serial fascial advancement, can achieve fascial closure with success rates of 86% to 100% in trauma patients.[4,7,18,32]

The Wittmann Patch (Starsurgical, Burlington, WI), an "artificial burr" Velcro-like device that is sutured to the abdominal fascia, when used to manage an open abdomen has been shown to facilitates DAFC with a success rate >80% in a group of mixed trauma and abdominal sepsis patients.[10,23] The Wittmann Patch can be used as a successful tool to provide dynamic tension in a process toward fascial closure.[28,29] Similar to the Wittmann Patch, the use of temporary prosthetic mesh (most commonly polytetrafluoroethylene) with serial tightening/pleating has resulted in fascial closure rates from 89% to 100%.[14–21] Serial/dynamic suture tightening, a technique involving repeated partial closure of the fascia, has also been used to achieve DAFC at rates between 61% and 90%.[6,12,15] Table 3 describes the most commonly used abdominal closure surgical techniques and the differences between them.

There is one randomized prospective study comparing various techniques for DAFC. Bee et al.[33] compared the use of a VACD versus using a temporary polyglactin mesh and showed no difference in the rate of DAFC (31% vs. 26%). However, the success rates of DAFC in this study are significantly lower than other published studies, making the results difficult to interpret.

Fascial Bridge Closure

It has been previously described, a patient with an open abdomen can undergo multiple re-operations with progressive closure of the fascial defect, with or without the use of a VADC, and have their fascial defect closed.[3] In the setting of ongoing intra-abdominal infection or the formation of an enterocutaneous fistula abdominal fascial closure is often not possible.[19] Fascial closure may not be possible because of ongoing visceral edema with loss of abdominal domain or from loss of fascia from infection. At this point, a fascial bridge closure of the resulting abdominal fascial defect may be considered. The abdominal viscera will become cocoon in the 14-day period to 21-day period. Attempting re-enter into the abdomen cavity to free the visceral off the abdominal wall

TABLE 1. Definition of Abdominal Closures and Planned Ventral Hernia: Trauma, Emergency General, and Vascular Surgery

Definitions of Abdominal Closures and Planned Ventral Hernia Damage Control	Initial Abbreviated Laparotomy
EAFC	Performed <8 d of the initial damage control laparotomy
DAFC	Performed >8 d of the initial damage control laparotomy
Fascial bridge closure	Mesh repair of fascial defect as either onlay or underlay placement of mesh without midline approximation of the fascia
Acute components separation	Performed during the initial hospitalization for the acute illness/trauma
Planned hernia ventral	Patient is discharged with a fascial defect with either skin closure only, chronic granulating wound, or a skin graft to protect the viscera

EAFC, early abdominal fascial closure.

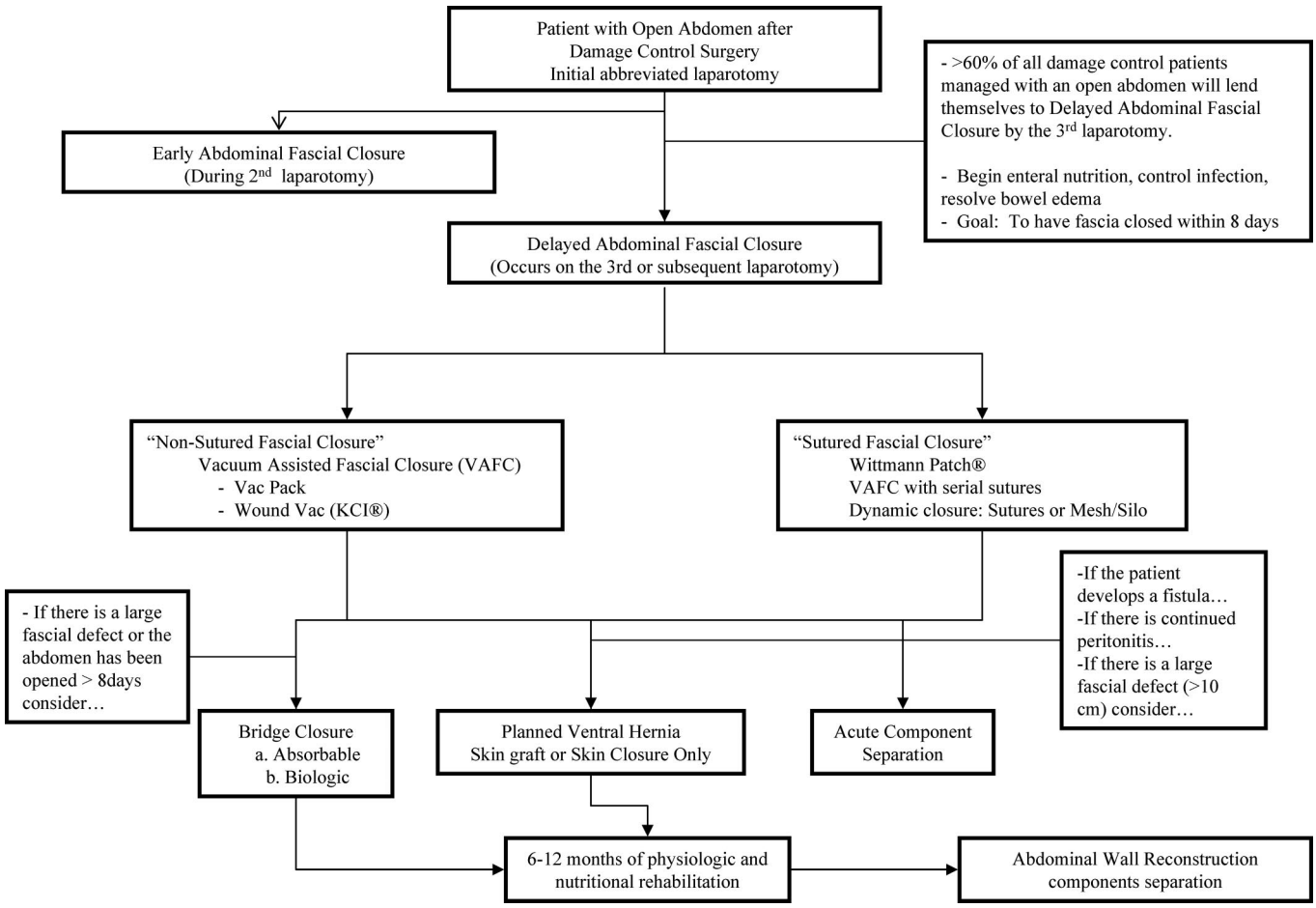

Figure 1. The closure of the open abdomen in trauma, emergency general, and vascular surgery flow diagram.

to allow for an easier abdominal fascial closure is both difficult and dangerous.

The surgeon is limited in the available surgical options: (1) bridge repair of the fascial defect using a mesh to create a bridge closure, (2) performing an acute abdominal wall reconstruction using most commonly a version of component separation, or (3) a planned ventral hernia.

Fansler et al.[34] reported their experience with the fascial bridge closure of the open abdomen with permanent prosthetic mesh. In a series of combined trauma and abdominal sepsis patients, polypropylene was used as a fascial bridge for early definitive closure. They had significant complications including a 50% enterocutaneous fistula rate, which were noted with the use of polypropylene mesh. Voyles et al.[35] reported a similar experience with a high rate of complications and fistula formation. The association of synthetic prosthetic mesh with bacterial colonization is well known. Once colonized or infected, the prosthetic mesh acts as a chronic source of contamination.[27,33,36] The use of permanent prosthetic mesh such as polypropylene, polytetrafluoroethylene, and polyester products has been abandoned in these circumstances because of the high rates of complications seen with their use.

Biological mesh material has been commercially available for almost 10 years. Biological mesh originates from human donors, bovine, and porcine animals. Biological mesh has been successfully used to bridge the defect as a result of an open abdomen. Human acellular dermal matrix (HADM) (AlloDerm, LifeCell Corp.) has been shown to be successfully used as a fascial bridge after open abdomen in multiple studies.[19,37–39] HADM does not seem to form significant adhesions, seems to tolerate bacterial contamination, and does not require removal in the setting of infection.[19,37,38,40–42]

Also, HADM has been successfully used for tissue coverage and closure of large traumatic wounds in the setting of significant skin and soft tissue loss.[32] Once the HADM has developed a good granulated tissue base, a skin graft can be placed. The authors noted that when no soft-tissue coverage is available, keeping the graft moist is critical to the graft's survival. Moist saline dressings or KCI V.A.C. therapy are most often used for this purpose. Bacterial colonization with overgrowth can occur on the grafts. This has been reported in the early postoperative phase and before the graft has had time to revascularize. The use of silver sulfadiazine or sulfamylon-soaked dressings on the graft should decrease bacterial counts until vascular in-growth has occurred and may prevent early graft loss from infection.

The long-term success of using HADM as a fascial bridge for hernia repair after an open abdomen technique is unclear.

TABLE 2. Delayed Abdominal Fascial Closure

References	Year	Class	N	Evidentiary Bullet
Smith et al.	1992	III	13	Temporary skin coverage is more effective than synthetic mesh in promoting delayed primary fascial coverage
Wittmann	2000	III	128	Use of an "artificial burr" material used in peritonitis had 93% closure are during initial hospitalization
Garner et al.	2001	III	14	VAC combined with serial fascial closure is successful in this small case series (90%)
Koniaris et al.	2001	III	13	"Dynamic retention" sutures (AKA—full thickness/transabdominal wall horizontal mattress sutures in a retention suture fashion) assist in abdominal closure, no fistulas recorded
Miller et al.	2002	III–>II	22	Primary facial closure may be done up to a month after initial operation with VAC sponge, with no difference in complication rate
Navsaria et al.	2003	III	55	TAC with modified sandwich is easy, rapid, cost-effective, and effective in containing abdominal wall contents
Suliburk et al.	2003	III	55	VAC use along with serial fascial closure achieves high rate of delayed primary fascial closure (86%)
Guy et al.	2003	III	9	Early single stage closure of open abdomen resulting from ACS may be achieved with acellular dermis and bipedicle flaps
Miller et al.	2004	II	53	VAC extends the potential delayed primary fascial closure deadline to as much as 3–4 wk with acceptable fistula rate
Howdieshell et al.	2004	III	88	TAC with silicone sheeting is safe and effective
Stone et al.	2004	III	48	Vacuum-assisted closure is effective with rates of delayed primary closure comparable to other techniques in the trauma population, fluid balance less than 20 L positive is associated with improved closure success
Tsuei et al.	2004	III	71	Trauma patients more likely to achieve fascial closure, GI sepsis more likely to require mesh closure and pancreatitis more likely to have no closure. Mortality: trauma 20%, GI 36%, and pancreatitis 43%. Incidence of fistula 16.9% (trauma 12%, GI 16%, and pancreatitis 24%)
Howdieshell et al.	2004	III	88	TAC with silicone sheeting is safe and effective
Cipolla et al.	2005	III	17	Four step algorithm: (1) delayed primary fascial closure within 48 h, (2) KCI VAC up to 7-d postop, (3) Wittmann Patch after 7 d of KCI VAC, and (4) absorbable mesh with skin graft after 3 wk
Cothren et al.	2006	III	14	KCI VAC-assisted fascial approximation using serial fascial tightening is an effective method for early abdominal closure and may avoid planned ventral hernia
Scott et al.	2006	III	37	Early aggressive closure of the open abdomen is possible with a combination of vacuum pack, vacuum assisted wound management, and HADM
Vertrees et al.	2006	III	29	Sequential tightening of a Gore-Tex mesh bridge, may be a useful tool for fascial closure
Vogel et al.	2006	III	276	Failure of primary fascial closure is associated with more extra abdominal infectious complications
Perez et al.	2007	II	37	VAC system is a useful tool in the severely ill general surgery patient with large abdominal wounds. Facial closure rates = 70%. Patients closed with VAC system had similar quality of physical and mental health scores at 3 months compared to "controls"
Hadeed et al.	2007	III	24	The rate of closure using the Wittmann patch is equivalent to other commonly used methods
Kushimoto et al.	2007	III	11	Bilateral anterior rectus sheath turnover flaps may be useful for definitive closure of the open abdomen that is not amenable to delayed primary fascial closure, particularly if the defect is less than 15 cm at greatest width
Petersson et al.	2007	III	7	Vacuum-assisted delayed primary fascial closure can be effective with dynamic serial tensioning of mesh-mediated fascial traction
Gaddnas et al.	2007	III	11	Continuous retention suture may be helpful in achieving delayed primary fascial closure through dynamic serial tension
Defranzo et al.	2008	III	37	VAC-assisted closure may facilitate delayed primary fascial closure and simplify abdominal wall reconstruction with low morbidity
Vertrees et al.	2008	III	85	Complex open abdominal wounds have lower delayed primary fascial closure rates and are more likely to require biologic or non-biologic prosthesis
Singh et al.	2008	III	10	HADM provides for successful bridge in open abdomens both clean and infected fields with low complication rates
Teixeira et al.	2008	II	900	The majority of damage control laparotomy abdomens can be closed primarily, which may substantially reduce development of enterocutaneous fistula. Deep space infection and intra-abdominal abscess are independently associated with failure to close the abdomen
Tieu et al.	2008	III	29	Wittmann patch results in >80% rate of delayed fascial closure in trauma and EGS patients
Wondberg et al.	2008	III	30	KCI vacuum-assisted closure of complex abdomen has worse outcomes compared to published closure rates trauma patients
de Moya et al.	2008	II	10	HADM effectively closes/bridges complicated abdomen with low rate of fistula formation. Laxity is long-term complication
Weinberg et al.	2008	III	159	Wittmann patch increases rate of delayed fascial closure with no difference in abdominal complications
Bee et al.	2008	I	51	Patients requiring TAC, no difference between negative pressure devices and primary Vicryl mesh closure with regard to mortality, fistula rate, or primary closure rate. Of all methods, KCI VAC is associated with the highest hospital charges

TABLE 2. Delayed Abdominal Fascial Closure (continued)

References	Year	Class	N	Evidentiary Bullet
Reimer et al.	2008	III	23	Dynamic fascial closure system may assist in delayed primary fascial closure in the complex abdomen
Vertrees et al.	2009	III–>II	65	Delayed colonic repair is acceptable in the face of damage control; primary repair is more likely to fail in the setting of concomitant organ injury
Awad et al.	2009	III	17	Alloderm is susceptible to infection from source control bacterium. Silver-based antimicrobials placed in conjunction with dressing changes may prevent critical colonization; during the time, it takes to revascularize AlloDerm graft
Subramonia et al.	2009	III	51	KCI VAC provides negative pressure wound therapy for open abdomen with acceptable complication rate
Gonullu et al.	2009	III	37	Bogotá bag is inexpensive when used for TAC and allows for abdominal viewing
				37 Studies, 29 Level III, 7 Level II, 1 Level 1

TAC, temporary abdominal closure.

TABLE 3. Definitive Abdominal Fascial Closure of the Open Abdomen

	Techniques		
DAFC	Vacuum-assisted closure devices*	Wittmann Patch (WP)	Serial/dynamic suture closure
Description	Creation of a negative pressure dressing to pull the fascial edges together; performed over a period of several days during serial laparotomies until the fascia can be closed	"Artificial burr" Velcro-like device to sequentially pull the fascia together over a period of several days during serial laparotomies until the fascia can be closed	Placement of fascial sutures placed over a series of laparotomies until the fascia is closed; may be used with a vaccum system
Fascial trauma	None	Serial tension	
Fascial closure rates	33–100%	77–93%	61–90%
Trauma	86–100%	75–100%	61–90%
Peritonitis	33–75%	†93%	No data
Time line to DAFC	Mean time 9.5 d, safe up to 3 wk	Mean time 13–15.5 d, safe up to 3 wk	Mean time 9.5 d, safe up to 3 wk
Complications	Intestinal fistula	Intestinal fistula, surgical wound infection	Intestinal fistula, surgical wound infection
Fascial bridge closure	Onlay with biologic or synthetic mesh	Underlay with biologic or synthetic mesh	Interposition placement of mesh
Description	Mesh is placed on top of the fascia and sown into place with several (3–5) cm of overlap	Mesh is placed underneath the fascia and sewn into place with several (3–5) cm of overlap	Mesh is sewn directly to the edge of the fascia
Benefits	Potential long-term success	Potential long-term success	None
Complications	Biologic mesh high rate of hernia recurrence	Biologic mesh high rate of hernia recurrence	Highest rate of recurrence
Acute components separation	Step-up approach		
	Release of the external oblique muscle	Plus—separation of parts or release of the rectus fascia	Plus—"Open Book" rectus flip

* Included VAC and vacuum pack (perforated plastic sheet, surgical towels, drains, and Ioban drape).
† Only one study.[9]

There are a number of studies suggesting that the long-term strength of the HADM decreases overtime. This multifactorial may be attributable to collagen re-modeling, mesh attenuation, or tissue growth resulting in a high rate of hernia formation.[43,44] However, HADM bridge ventral hernia repairs have been performed after trauma and many patients have had definitive repairs.[16] Singh et al.,[38] report on 10 liver transplant patients treated with an open abdomen and closed with an HADM fascial bridge. In short-term follow-up (10 months), there were no cases of herniation noted. Conversely, de Moya et al.,[45] demonstrated that patients treated with an HADM bridge repairs and that at 1-year follow-up had evidence of recurrent hernia or significant abdominal wall laxity.

The use of HADM as a fascial bridge under the circumstances of the unclosable abdomen after damage control is supported by the available literature. It protects the viscera from fistulization and may provide definitive abdominal wall strength. Yet, the long-term results in providing definitive fascial strength are not known.

Acute Component Separation

One option for closure of the open abdomen is an acute abdominal wall reconstruction using the component separation techniques. Ramirez et al.,[46] were the first to describe the component separation technique for reconstruction of large abdominal wall fascial defect without the use of prosthetic

mesh. In its basic form, the technique is as follows: (1) the anterior abdominal wall skin flaps are developed and dissected out to the anterior superior iliac spine and the chest wall, (2) the aponeurosis of the external oblique muscle is divided lateral to the semilunar line on to the chest wall to the level of the xiphoid, (3) free up the external oblique, which will allow the rectus myofascial component to be mobilized medially, and (4) the midline is sutured together. The component separation has become the most commonly used surgical technique for closure of large "planned" ventral hernias with a skin graft during the elective reconstructive phase.[11,47,48] Its use for acute definitive closure in the setting of an open abdomen has not been well studied. Formal component separation is generally considered an "elective" reconstructive technique. Its use in the acute setting in the face of resolving intra-abdominal sepsis, visceral, and abdominal wall edema as a result of systemic inflammatory response syndrome and ongoing systemic sepsis is not advisable. Once a formal component separation has been performed, it is eliminated as an option for later abdominal wall reconstruction.

There are at least three versions of the component separation technique. The original description by Ramirez et al. is described above. Another surgical technique is the "separation of parts" by the Memphis group. There is also a "open book" technique, which in addition to the lateral release of the external oblique, the rectus fascia (either anterior or posterior) is flipped into the midline using the linea alba as the fulcrum to extend the midline. The rectus roll-over technique by itself has been studied in the setting of definitive closure after the open abdomen in both trauma and general surgery patients. The anterior rectus fascia is incised near its lateral border on both sides, medialized, and sewn in the midline. In a series of 29 patients, the technique was used successfully to close defects up to 15 cm.[30] In follow-up of 65 months, no recurrent abdominal wall hernias were noted, although mid-abdominal bulging was noted in 50% of patients.

Enteroatmospheric Fistula as a Complication of the Open Abdomen

During the initial damage control laparotomy, the open abdomen technique is used for rapid re-entry into the abdomen. DAFC can be commonly achieved once all the intra-abdominal injuries have been addressed. In the setting of intra-abdominal sepsis and/or pancreatitis, DAFC is not as successful.[49] It is well recognized that the longer the time period to fascial closure, the higher the complication rates especially intestinal fistulas.[50,51] In addition, the obese patient is at increased risk of having more complications after damage control laparotomy and longer time period to primary fascial closure.[50,52] Trauma patients who required a prolong period of an open abdomen as part of their damage control management have five times the fistula rate verses those patients who were closed during the initial trauma laparotomy. The enteroatmospheric intestinal fistula results in the setting of the open abdomen. The fistula can develop as a result of an anastomotic leak with exposed suture lines, traumatized bowel, and nontraumatized bowel, which has been exposed for a period of time. This is one of the most devastating complications of the open abdomen. The foremost risk factors are the inability to perform primary abdominal facial closure in a timely manner, and deep space infections, and intra-abdominal abscess.[19]

The use of polypropylene mesh for bridge repair of the open abdomen has been shown to have unacceptably high rates of fistula complications and is no longer recommended for definitive closure in the acute setting of open abdominal management.[34] Fistulae arising during early clinical management of open abdomens result in leakage of intraluminal contents over the unprotected surface of bowel. The patient with an enteroatmospheric fistula has extremely complicated critical care, open abdomen, and nutritional management issues. Inadequate fistula management will result in acute protein calorie malnutrition, electrolyte disturbances, and prolonged hospitalization.[53]

The key components of management of the patient with an enterocutaneous fistula are as follows: (1) sepsis control, (2) nutritional support, and (3) local wound care (Fig. 2). A key to treating entero-atmospheric fistulas is management of the initial inciting events and treatment of resulting complications. Source control and eradication of sepsis are essential. If possible, promote spontaneous closure and diminish the catabolic strain on the tissues.[54] In patients with intestinal fistulas with a tract or skin coverage, management of fistula output has been assisted by hormonal agents; however, randomized control trials do not favor octreotide as the standard of care.[55] Medical management has decreased the need for operative management of intestinal fistulas. More than 50% of patient with intestinal fistulas will require surgery for the control of sepsis and subsequent surgical repair for failure to

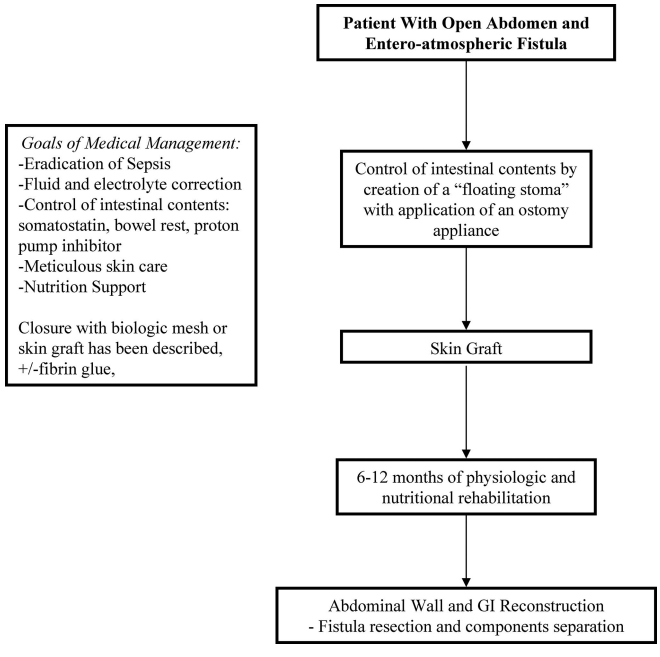

Figure 2. Intestinal fistula complicating the open abdomen flow diagram.

close spontaneously.[56,57] Nutrition support either enteral or parenteral is considered a critical supportive measure to prevent malnutrition in an already debilitated patient.[58] Although, a full discussion of the management of intestinal fistula is beyond the scope of this article, Table 4 provides additional literature.

Local wound care can be extremely problematic in the patient with an open abdomen and an entero-cutaneus fistula. In an attempt to mitigate the inflammatory state preventing resolution of the entero-atmospheric fistula, Jamshidi and Schecter[59] treated seven patients with direct application of a biological dressing (HADM and/or cadaveric split thickness skin graft). Five of this series of seven closed with only two requiring further operative management. Physiologically similar, the application of skin graft to the granulated wound bed can have good results with as much as 93% graft take at 1 week.[60] The use of an innovative negative pressure dressings or the KCI V.A.C. therapy to collect the draining succus entericus to keep the open abdomen clean can be a daily wound management issue. An innovative option for improving wound care is the creation of the "floating stoma." Recent case studies have described techniques for "floating stoma" with or without KCI V.A.C. therapy of the wound bed in attempts to simplify treatment before and after definitive repair.[61]

The restoration of gastrointestinal continuity at the time of the abdominal wall reconstruction is safe and the preferred treatment for entero-atmospheric fistula.[62] Success depends on the achievement of the goals set out in the management phase; the eradication of sepsis, optimizing nutrition status (albumin >3.25 g/dL), and delaying operative repair a minimum of 3 months to 12 months to allow for the development of a "neo-peritoneal cavity."[63] An essential management priority is to stage the "elective" gastrointestinal reconstruction when the patient's sepsis has resolved. After the inflammatory process within the abdominal cavity has resolved, the intra-abdominal adhesions will progress through the various stages of inflammation to vascularize and loosen fibrous adhesions resulting in a safer operative procedure.[64] Even in the most optimized patient, entero-atmospheric fistulas remain among the most challenging problems, a surgeon will face.

Planned Ventral Hernia

Fabian et al.[65] and other authors are credited with the initial description of the stages of damage control. The goals of damage control are (1) patient survival, (2) reconstruction of the patient's traumatic injuries with the final goal and (3) being abdominal fascial closure.[47,62,66,67] As noted above, there are multiple techniques to achieve early or DAFC. When this is not possible, the planned ventral hernia technique is used.

Once it has been determined that the abdominal fascia will not come together because of massive visceral edema, loss of domain, and/or loss of abdominal wall tissue, the only option left is a planned ventral hernia or fascial bridge with biological mesh or absorbable mesh.[68,69] The initial goal of a planned ventral hernia is to keep the viscera within the abdominal cavity. This is accomplished by using absorbable mesh (Vicryl [Ethicon] or Dexon [Covidien]) to prevent evisceration. This allows time for the viscera to adhere together. This occurs during the course of 2 weeks to 3 weeks. Once the base of the open wound has granulated, a skin graft can be performed to cover the viscera. If the fascial

TABLE 4. Enterocutaneous and Entero-atmospheric Fistula

References	Year	Class	N	Evidentiary Bullet
Sleeman et al.	1995	III	12	Previous open abdomen is not contraindication to operation for restoration of bowel continuity and abdominal wall reconstruction
Fansler et al.	1995	III	26	Polypropylene should not be used as a temporary or definitive closure in the acute setting of an open abdomen because of >50% fistula rate
Dumanian et al.	1996	III	64	Skin grafted may help simplify wound care including those with fistulas
Heller et al.[75]	2006	III	21	Use of KCI VAC achieves delayed primary fascial closure successfully with low morbidity in facial dehiscence
Sriussadaporn et al.	2006	III	8	Planning for closure of the open abdomen with fistula should take into account resolution of acute catabolic phase, metabolic indicators such as Albumin >3.0 (average greater than 4 months)
Jamshidi and Schecter	2007	III	7	Intestinal fistulas after open abdomens may benefit from closure with application of biologic dressings (alloderm and/or cadaveric skin graft)
Connolly et al.	2008	III	71	Delayed primary fascial closure can be more commonly achieved in trauma vs. abdominal sepsis/pancreatitis, which can be more difficult
Teixeira et al.	2008	II	900	The majority of postdamage control laparotomies can be closed primarily with a reduced incidence fistula. Deep space infection and intra-abdominal abscess are independent risk factors for failure to close the abdomen
Teixeira et al.	2009	III	2373	Fistula rate is low in trauma population (1.5%) but is significantly higher in open abdomens (7%) and is significantly associated with inability to perform delayed primary fascial closure (54%). Management is associated with longer ICU LOS and expense
Duchesne et al.	2009	III	104	Severely obese are vulnerable patients for complications after damage control laparotomy
Haricharan et al.	2009	III	148	Overweight and obesity is associated with longer time to delayed primary fascial closure and higher complication rates
				11 Studies, 10 Level III, 1 Level II, No Level I

TABLE 5. Planned Ventral Hernia

References	Year	Class	N	Evidentiary Bullet
Fabian et al.	1994	III	88	Planned 4-stage; 1 prosthetic insertion, 2 prosthetic removal, 3 planned ventral hernia ± skin graft, 4 definitive reconstruction, open abdomen closure is safe, inexpensive, and provided good results with had moderate size fascial defects
Brenneman et al.	1995	III	9	Acute, traumatic abdominal wall disruptions, present major reconstruction challenges. Reconstruction of the traumatic damage can be delayed and optimal after intestinal continuity has been achieved
Sleeman et al.	1995	III	12	Previous open abdomen is not contraindication to operation for restoration of bowel continuity and abdominal wall reconstruction
Yeh et al.	1996	III	13	Fascial closure possible with or without mesh onlay and low morbidity after silastic sheet temporary closure and skin grafting resulting in good functional and aesthetic results
Mathes et al.	2000	III	106	Mesh closure for midline hernias and flap closure for lateral hernias can be accomplished with acceptable complication rates
Cohen et al.	2001	III	24	Staged reconstruction should allow for early visceral coverage (Gortex) followed by skin graft. Definitive repair should be delayed greater than 7 months, skin graft does not need to be removed entirely, dermabrasion with resulting neo-peritoneum is acceptable
Sukkar et al.	2001	III	64	Definitive repair of the hernia with components separation/flap is highly successful with low morbidity
Jernigan et al.	2003	III	274	A 3-stage approach to giant abdominal wall defects using absorbable mesh, skin graft, and eventual component separation has low complication rates with 8% fistula, 8% mortality, and 5% recurrent hernia rate
Sriussadaporn et al.	2003	III	9	Bilateral bipedicle flaps is an effective management of the open abdomen to achieve early definitive closure. Stoppa repair effective in late repair of giant ventral hernias
Howdieshell et al.	2004	III	88	TAC with silicone sheeting is safe and effective
Cipolla et al.	2005	III	17	Four step algorithm: (1) delayed primary fascial closure within 48 h, (2) KCI VAC up to 7-d postop, (3) Wittmann Patch after 7 d of KCI VAC, and (4) absorbable mesh with skin graft after 3 wk
Rodriguez et al.	2007	III	23	Biologic and synthetic onlay mesh may support primary fascial closure with or without component separation as well as interpositional mesh during abdominal wall reconstruction
Vertrees et al.	2008	III	85	Complex open abdominal wounds have lower primary fascial closure rates and are more likely to require biologic or nonbiologic prosthesis
Teixeira et al.	2008	II	900	The majority of damage control laparotomy abdomens can be closed primarily, which may substantially reduce development of enterocutaneous fistula. Deep space infection and intra-abdominal abscess are independently associated with failure to close the abdomen
Bee et al.	2008	I	51	Patients requiring TAC, no difference between negative pressure devices and primary vicryl mesh closure with regard to mortality, fistula rate, or primary closure rate. Of all methods, KCI VAC is associated with the highest hospital charges
Taner et al.	2009	II	13	Acellular dermal matrix is satisfactory for some fascial replacement applications such as parastomal hernias
Liu et al.	2009	III	41	Autogenous, pedicle, demucosalized small intestinal sheets can be used for abdominal wall reconstruction of infected complex abdominal wall defects. Mean size of defect closed was 108 cm^2. Long-term follow-up show few complications other than regeneration of intestinal mucosa through meshed skin graft
				17 Studies, 14 Level III, 2 Level II, 1 Level I

defect is not large, another option is to elevate skin flaps and perform a skin only closure.[70] Caution must be exercised when elevating skin flaps in the setting of continued intra-abdominal sepsis, lack of source control, and massive visceral edema; because this setting has a high risk of skin flap infarction and flap loss. In this setting, allowing the wound base to progress to a good granulated base and proceeding to skin graft tissue coverage may be the safest option. Regardless of the technique used, visceral coverage is essential to decrease metabolic burden and prevent the formation of entero-atmospheric fistulae as a result of trauma from exposure or dressing changes.

Temporary abdominal closure with silicone sheets or Gortex has also been used to keep the abdominal contents from eviscerating.[11,71] This is done until the viscera have adhered together. The prosthetic mesh is removed and the granulation bed is skin grafted. Others have used bilateral bipedal flaps to cover the granulation bed with skin. The goal is to decrease the incidence of intestinal fistula formation.[37,72]

The introduction of biological mesh has been used in an attempt to do single stage repairs of ventral hernias.[16,38] The data to date suggests that the majority of patients repaired with biological mesh may develop laxity of the repair resulting in a hernia 6 months to 12 months later.[45] The role of biological mesh in the healing process has not been completely elucidated.

The final stage of damage control is an "elective" abdominal wall reconstruction.[71,73] Because of the complexity of this topic, the EAST Open Abdomen Committee is in

TABLE 6. Classification of the OA

Grade	Description
1A	Clean OA without adherence between bowel and abdominal wall or fixity (lateralization of the abdominal wall)
1B	Contaminated OA without adherence/fixity
2A	Clean OA developing adherence/fixity
2B	Contaminated OA developing adherence/fixity
3	OA complicated by fistula formation
4	Frozen OA with adherent/fixed bowel; unable to close surgically; with or without fistula

OA, open abdomen.
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the process of developing a set of guidelines for abdominal wall reconstruction after the open abdomen. Questions regarding the preoperative evaluation, operative approach, and postoperative management and follow-up will be addressed (Table 5).

CONCLUSION

Damage control laparotomy in severe trauma, emergency general, and vascular surgery, in the setting of an abbreviated laparotomy as a result of physiologic exhaustion, has become the standard of care. The open abdomen technique has become an essential component of the procedure.

The management and closure of the open abdomen has developed into a separate surgical entity and remains a challenging problem to the surgeon. Several techniques have been developed to close the open abdomen. The majority of open abdomens can undergo early abdominal fascial closure during the initial re-laparotomy. If three or more laparotomies are required, DAFC can be achieved in the majority of cases using three surgical techniques (Wound Vac, Wittmann device, dynamic/suture closure with or without the use of a wound vacuum device). When the midline fascia cannot be approximated, two other techniques to consider are bridge closure with absorbable mesh or acute component separation.

The development of the entero-atmospheric fistula is a major clinical complication of the open abdomen. The development of the "floating stoma" and skin graft of the open abdomen becomes paramount in achieving control of enteric contents and wound sepsis. Finally, when DAFC cannot be achieved, one may proceed to plan ventral hernia, with the hope of accomplishing abdominal wall reconstruction in the future.

Future Direction

The management of the open abdomen remains a very heterogeneous area of study. This is due to various issues such as the etiologies of the open abdomen (trauma, emergency general, and vascular surgery) and the presence of intra-abdominal sepsis. In addition, there are no accepted classification systems for the open abdomen. Recently, a consensus meeting of experts was held in January 2009 to propose a classification system for the open abdomen.[74] The classification is simple and can be applied to future studies. Currently, there is no sponsoring organization of the classification proposed and it has not been studied or validated. However, a standard classification system of the open abdomen is necessary, if a scientific approach is to be taken in regards to this vexing clinical problem (Table 6).

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