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Guidelines for the Management of the Open Abdomen

Recommendations from a multidisciplinary expert advisory panel.

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Guidelines for the Management of the Open Abdomen

This supplement is based on a guidelines conference, which was held April 2 and 3, 2005, in Dallas, Texas. The purpose was to provide guidelines from a multidisciplinary expert advisory panel on the management of the open abdomen and to evaluate each treatment option in the context of evidence-based medicine. A review of the literature and the personal experience of the panel were used to provide recommendations.

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Guidelines for the Management of the Open Abdomen

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Abstract: The management of the open abdomen continues to pose a challenge for surgeons. After surgical exploration for abdominal trauma, operative misadventure, or relief of abdominal compartment syndrome, definitive closure of the abdominal fascia and abdominal wall immediately following laparotomy may be technically impossible. Alternatively, the abdomen may need to remain open to allow access for re-operation and time for decompression of the abdomen.

Multiple techniques for temporary abdominal closure have been described in the literature. To better understand the current treatment of the open abdomen, an expert panel of surgeons convened to review the literature and current practices in managing the open abdomen. The panel reviewed the reasons for the increasing number of open abdomen procedures as well as each treatment method in the context of evidence-based medicine. In addition, panel members shared their experiences using various techniques for treating the open abdomen.

The use of the open abdomen as a surgical option has increased in recent years. Benefits of maintaining an open abdomen include ease of re-exploration, control of abdominal contents, reduction of the risk of intra-abdominal hypertension and abdominal compartment syndrome, and fascial preservation for closure of the abdominal wall. The prolonged exposure of abdominal viscera can result in high rates of complications, including infection, sepsis, and fistula formation.

A number of techniques have been published, but no clear consensus on the best technique or device to manage an open abdomen exists. Recent intensive care unit advances, an awareness of intra-abdominal hypertension and abdominal compartment syndrome, and the increased usage of damage control laparotomy have resulted in a new class of challenging patients with open abdominal wounds.

Temporary abdominal closure techniques, such as the Bogotá bag or vacuum pack, have been described, along with other closure techniques, including allowing the wound to granulate through a biodegradable mesh and sequential closure using a Vacuum Assisted Closure® device (V.A.C.® Therapy™, KCI, San Antonio, Tex). Each of these methods is reported to reduce complications compared to traditional gauze dressings. The V.A.C.® System allows surgeons to close most open abdomens without the use of skin grafts. Future studies and continued innovation will hopefully lead to better understanding of optimal treatment strategies for these devastating injuries.

Historically, surgical management of open abdominal wounds has been a substantial challenge. The improvement of anesthesia, a better understanding of aseptic technique, blood banking, and the introduction of antibiotics have led to safer abdominal operations. An open abdomen following laparotomy has often been considered a sub-optimal treatment due to its high complication rate. Conventional treatment with moist gauze dressings

allows the bowel to desiccate, resulting in frequent fistulas, infections, and sepsis. Because of these predictable complications, the traditional surgical approach was to explore traumatic abdominal wounds, repair the injuries, and close the abdomen immediately. One-time procedures were performed without consideration of the underlying physiologic state of the patient. Many patients had their abdomens closed prematurely, which led to complications and otherwise preventable deaths.

Recently, improvements in surgical care have changed the approach to the open abdomen. Advances in critical care medicine have allowed surgeons to support patients in the peri-operative period with respiratory, cardiovascular, and renal support. There has also been an appreciation of the dangers associated with long operations after traumatic injury. The paradigm has shifted from a single definitive operation to first controlling immediate life-threatening events, such as hemorrhage, and then following with a later reparative surgery once the patient has stabilized. This approach has resulted in improved survival in the first few hours after traumatic injury. Also, recent evidence in the literature¹ explains the importance of intra-abdominal hypertension and the diagnosis of abdominal compartment syndrome. This has been extended to conditions other than trauma, such as sepsis and ruptured abdominal aortic aneurysm, which result in opening the abdomen as a life-saving maneuver for these critically ill patients. Surgeons now are commonly faced with patients with an open abdominal cavity, often with grossly swollen intestines that occupy several times their original volume (Figure 1). Fortunately, several methods have been developed to more effectively treat the open abdomen and reduce complication rates.

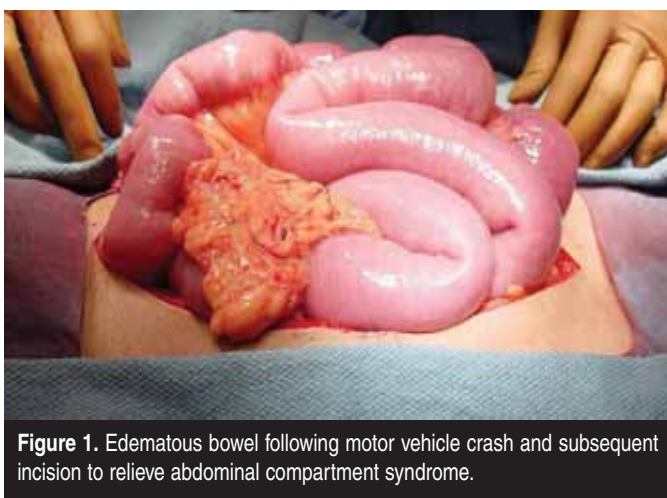


Figure 1. Edematous bowel following motor vehicle crash and subsequent incision to relieve abdominal compartment syndrome.

In this document, the evaluation of current published literature relevant to the treatment of traumatic open abdominal wounds is based on the classification of The Oxford Centre for Evidence-based Medicine.² The classification of evidence levels can be useful in critically evaluating decision-making in medicine. Evidence varies from the highest level (1) to the lowest (5) and is subcategorized by letters. Level 1a evidence is a systematic

review of randomized, controlled trials. Levels 2–4 are cohort studies of varying degrees of quality. Level 5 is considered the lowest level of evidence—expert opinion without explicit critical appraisal. Common surgical studies are retrospective or cohort studies and are often in the level 2–4 range. Compared to pharmaceutical studies, good surgical studies are more challenging to perform because of smaller patient populations, difficulties with randomization or unwillingness to randomize to the control arm, inability to blind subjects and/or evaluators, and the complexity in standardizing surgical procedures and general medical care.

Many reported techniques are based on surgeon preference and experience without uniform methods of management. Techniques have evolved from a static approach of containing the abdominal viscera or allowing the abdominal wall to granulate, placing a skin graft, and developing an abdominal wall hernia to more dynamic systems that control peritoneal fluid and facilitate earlier closure of the fascia and abdominal wall. The goal of temporary abdominal closure is to create a tension-free closure of the abdomen without elevating intra-abdominal pressure.

Retrospective studies have shown a marked improvement in survival of patients with open abdomens but have shown an increase in complications not previously appreciated.³ The most logical reason for this is that many patients previously did not survive the initial injury. Recognizing the benefits of an open abdomen, clinicians have developed methods to control abdominal contents. Methods have evolved from simple gauze packing, which had significant complications, to negative pressure systems that control abdominal contents, manage third space fluid, and facilitate wound closure.

To date, there are no reported prospective, randomized studies comparing various forms of closure. Surgeons currently choose methods of managing the open abdomen based on personal experience, available materials, comorbid diseases of the patient, and review of the relevant literature. An inherent problem with current clinical studies is the potential for publication bias, even in randomized, clinical trials,⁴ which can be challenging for studies involving surgical-related devices and procedures.⁵ More robust studies should be published to elevate the level of evidence in this relatively new field.

In light of significant controversy and the lack of a stan-

standardized approach to managing the open abdomen, a panel of physicians with recognized expertise in management of these patients convened to develop initial guidelines for the optimal management of the open abdomen with respect to technique, safety, available devices, and minimization of complications. The panel made every effort to incorporate known literature of the open abdomen in this report when making recommendations. When literature to support an opinion was absent, the panel attempted to gain consensus based on the panel members' wide range of clinical experience. The panel realizes that these opinions have not undergone the rigorous peer-review process common to many articles in the published literature and have attempted to clearly note when a consensus opinion was made. This is a rapidly evolving and innovative field where recommendations will likely change over time.

Pathophysiology of the Abdomen

The intestinal wall consists of a luminal surface comprised mostly of rapidly dividing enterocytes, with their nutrition dependent in part on intraluminal sources. Surrounding the mucosal surface are layers of submucosa, muscularis, and serosa. The intestine is a highly vascularized structure supplied through the mesentery. Within the intestinal wall, there is a rich network of arteries, veins, capillaries, and lymphatic vessels. In pathologic states, a decrease in clearance of fluid from the extracellular space can result in swelling of the intestinal wall several times the normal diameter, potentially interfering with perfusion of the bowel. Furthermore, the peritoneal surface is highly vascularized and colonized with inflammatory cells. The net result is a marked inflammatory response to trauma with excretion of pro-inflammatory substances that increase the local inflammatory response as well as systemic absorption. This can lead to a systemic inflammatory response syndrome (SIRS) and may progress to a multiple organ dysfunction syndrome (MODS). Premature closure of the abdomen can exacerbate the inflammatory response and potentially accelerate the syndrome.

Intra-abdominal Hypertension

Pressure within the abdomen is a function of the volume of intra-abdominal contents, the distensibility of the abdominal wall, and the state of contraction of the

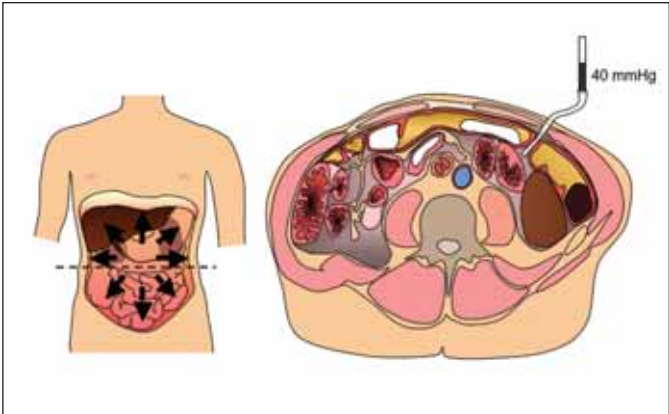


Figure 2. The effects of increased intra-abdominal pressure.

abdominal wall musculature and diaphragm. As the ribs and pelvis have little ability to expand, when intra-abdominal pressure (IAP) increases, the central abdomen distends, and increased displacement of the diaphragm and bladder occurs (Figure 2). Within the abdomen, organs lie within the peritoneal sac or in a retroperitoneal location. Bleeding, leakage of abdominal contents, bowel edema, or ascites in pathologic states can fill the peritoneal sac, causing an increase in IAP. Pathophysiology of increased IAP is directly related to the peritoneal inflammatory response to trauma and abdominal sepsis. Therefore, risk factors have been identified to predict the development of intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS). Factors that contribute to IAH are those that increase intra-peritoneal volume including free blood and clots, bowel edema, vascular congestion, excessive crystalloid resuscitation, intraperitoneal packing, and nonsurgical bleeding.^{6,7} Other contributory factors

Table 1. Grading system for levels of increased intra-abdominal pressure⁸

Grade	Intra-abdominal Pressure (IAP)
I	12–15 mmHg
II	16–20 mmHg
III	21–25 mmHg
IV	> 25 mmHg

include acidosis, hypothermia, transfusion of greater than 10 units of packed red blood cells in 24 hours, coagulopathy, and postoperative ileus.

The pathologic result is the development of IAH, which is a graded increase of IAP that can lead to organ dysfunction and eventually to an ACS. High IAP can lead to significant decreases in organ perfusion, most notably in the splanchnic blood flow. Abnormal IAP can induce moderate to severe organ dysfunction that may be undetected. If bladder pressures are not checked regularly in high-risk patients, the onset of pathologic IAH and ACS can be insidious and only detected when there is a high probability of organ failure or death.

Intra-abdominal pressure is usually between 0–5 mmHg but can be chronically elevated in patients who are morbidly obese or pregnant or have chronic liver failure with ascites. In a retrospective review of a mixed population of critically ill patients, Malbrain et al.⁹ found that on admission 32% of patients had elevated IAP that was undetected but was a positive predictor of mortality.



Figure 3. Edematous bowel with areas of ischemia from compression prior to surgical opening for relief of abdominal compartment syndrome.

Abdominal Compartment Syndrome

Abdominal compartment syndrome is a potentially lethal complication of uncontrolled IAH and is defined as IAP > 25 mmHg with dysfunction of 1 or more organs (ie, heart, kidneys, lungs, and central nervous system).¹⁰ Once the syndrome has been detected, immediate decompression of the abdomen is required (Figure 3). Normalization of organ function usually occurs, but a mortality rate greater than

50% has been reported secondary to ongoing organ failure.¹⁰ Therefore, early decompression for high-grade IAH may prevent the development of ACS and potential complications. To ultimately prevent ACS, more attention must be given to the relationship between IAH and ACS.

Abdominal compartment syndrome can be divided into 3 categories: primary ACS, secondary ACS, and tertiary ACS.

Primary ACS is associated with injury or a disease process within the abdomino-pelvic region. The syndrome appears early after a surgical intervention. Patients with primary ACS include those with injuries that had an initial period of non-operative management and those with pelvic injuries.¹¹

Secondary ACS refers to patients that developed an ACS from conditions that did not originate in the abdomen, such as sepsis, burns, and massive fluid resuscitation for non-abdominal injuries.¹¹

Tertiary ACS occurs in patients that develop ACS following a prophylactic attempt to prevent ACS.¹²

Bladder Pressure Monitoring

The diagnosis of IAH is frequently made through indirect bladder pressure monitoring (IDBP), which was first described in 1984 by Krone et al.¹³ Bladder pressure monitoring has become a vital tool in monitoring high-risk patients and should be measured in all high-risk surgical patients. Indirect bladder pressure monitoring is the only means to detect pathologic increases in IAP and the only way to detect the onset of the ACS. Bladder pressure is measured by instilling 10–40 cc of water into the bladder and measuring the pressure with a transducer placed at the level of the pubis with the patient in the supine position. Respiratory variations should be observed. Intra-abdominal pressure measurements are taken 1 to 6 hours apart in patients that are at high risk for the development of IAH/ACS. The trend toward higher pressure is important; as the pressure approaches 25 mmHg, the pressure can rise at a more rapid rate, leading to a full ACS. Intra-abdominal pressure monitoring is required for patients who have had major operative procedures, major traumas (operative and nonoperative), damage control surgery with packing, and those with temporary abdominal closure.

Fluid Resuscitation

The goal of fluid therapy is to ensure adequate tissue perfusion and maintain cellular aerobic metabolism.

Fluid resuscitation technique varies among surgeons, and no clear recommendation exists in the literature. Abdominal compartment syndrome is in large part an iatrogenic complication of current management of severe trauma (ie, damage control surgery and triage to the intensive care unit for goal-directed resuscitation). This clinical trajectory of ACS can be predicted soon after emergency department admission, and different strategies are needed. Hemorrhage control is paramount. According to Balogh et al., normalizing blood pressure with indiscriminant crystalloid volume loading should be avoided, and massive transfusion protocols that include fresh frozen plasma (FFP) at a ratio of 1 unit FFP per 1 unit of packed red blood cells should be implemented.^{14,15} Patients should be monitored closely for ACS and should undergo decompressive laparotomy early if IAP rises above 25 mmHg in patients requiring ongoing, vigorous resuscitation.

Heart rate, blood pressure, and urine output are not accurate measures of tissue perfusion, and other more specific endpoints should be considered. Due largely to the work of Shoemaker et al.,¹⁶ a resuscitation strategy based on a standardized process using O_2 delivery index (DO_2I) as an endpoint and a physiologic performance goal for interventions has been developed, studied, and refined for resuscitation of shock caused by major trauma. According to McKinley et al., $\text{DO}_2\text{I} \geq 600 \text{ mL O}_2/\text{min}/\text{m}^2$ is the only resuscitation endpoint variable that has been tested in prospective, randomized trials of trauma patient outcomes, but the studies are limited and the results inconclusive.¹⁷ It is thought that using DO_2I as an endpoint is helpful because it integrates 3 important variables—hemoglobin concentration, arterial hemoglobin O_2 saturation, and cardiac output. Other endpoints of resuscitation that include serum lactate, base deficit, mixed venous oxygen saturation, and intra-cellular gastric pH have been shown retrospectively to be important indicators of adequate tissue perfusion. Resuscitation endpoints are needed to minimize over-hydration and minimize the use of fluids that can precipitate IAH or lead to ACS. Further studies must be conducted to determine the most appropriate fluid resuscitation protocol, the most appropriate choice of fluid, and the most accurate endpoint to measure.

Rationale to Leave Abdominal Cavity Open

The concept of an open abdomen is not new, and its use is now increasing in surgical patients. The reasons for

not closing an abdomen are complex and multifactorial. Today, approximately 15–18% of trauma patients that undergo an exploratory laparotomy have their abdomens left open at the time of the initial exploration.³

The management of the open abdomen is a controversial topic in the literature. Surgeons have been reluctant to keep abdomens open and were willing to risk ACS due to the lack of adequate temporary abdominal closure and closure techniques. Methods of temporary abdominal closure have evolved from a skin-only closure using towel clips for rapid completion of a damage control procedure,¹⁸ to devices that control intra-abdominal contents, such as the Bogotá bag, to systems that allow for treatment of the underlying physiologic state as seen with the Vacuum Assisted Closure® System (V.A.C.® Therapy™, KCI, San Antonio, Tex) with a specialized abdominal dressing. Controlling physiologic causes could increase the rate of early closure and reduce the overall complications seen in patients with open abdomens.

Other indications for an open abdomen include bowel edema, severe intra-abdominal infection, hypothermia, acidosis, and significant risk of developing ACS. These patients require a temporary abdominal closure until the underlying physiologic insult has been controlled and they are stable enough to consider delayed primary closure or long-term temporization of the abdominal wall (ie, a skin graft).

The open abdomen presents numerous management challenges for the operating surgeon, particularly in patients with traumatic injuries to that region and those with intra-abdominal sepsis. Complications can be minimized with an understanding of the pathophysiology found in the open abdomen; proper use of materials that minimize trauma to the abdominal contents; utilization of closure techniques that minimize exposure of bowel; utilization of tension-free fascial closure; prevention of severe intra-abdominal sepsis; facilitation of multiple re-explorations; prevention of loss of the abdominal wall; and control of the inflammatory response found in the open abdomen.

After a traumatic or septic insult, the open abdomen should be considered a “hostile” environment.¹⁹ Extensive tissue destruction, contamination, hematoma, and inflamed friable tissue that requires aggressive debridement are often present. The end result is an intense inflammatory response mediated by shock, ischemia-

reperfusion injuries, and massive fluid resuscitation.²⁰ An accumulation of posttraumatic ascites, bowel edema, and third space fluid follows, resulting in the development of increased IAH and a potential for the development of ACS. Patients that require an open abdomen have experienced a higher incidence of overall complications, including SIRS, MODS, fistulas, post-operative ileus, and third space fluid losses.²¹ These complications may develop as a result of the underlying pathophysiology, severity of trauma, wound packing, bowel manipulation, abdominal pressure changes, or multiple surgical and nonsurgical procedures that are resource intensive. The abdominal wall cannot be closed in a tension-free manner in these cases due to loss of the abdominal wall and bowel edema. If these factors are not recognized and addressed, they can lead to an increased number of complications including death. However, control of the inflammatory factors may help minimize complications.

Complications of the Open Abdomen

Fistula

Fistula formation is perhaps the most dreaded complication of the open abdomen. Fistulas can develop if the bowel is exposed to air and allowed to desiccate, is abraded by dressings, or is deserosalized.²² Fistulas are also caused by “biomaterial adherence” to the bowel, causing transmural changes of the bowel wall. If the bowel is fixed to the abdominal wall, perforation with sudden changes in abdominal pressure may occur.²³ Fistula rates as high as 18.2% have been reported in patients with an open abdomen after damage control surgery.²¹ Ivatury et al. were able to significantly lower fistula rates with the use of early closure of the skin and fascial defects.²⁴ Chavarria-Aguilar et al. reported a 10.5% anastomotic breakdown in patients with an open abdomen and suggested placing the anastomosis deep in the peritoneal cavity to avoid exposure.²⁵

Abdominal fistulas often result in large amounts of contaminated bowel contents spilling into the wound, causing local infection, intra-abdominal abscess, or systemic infection with the potential for electrolyte imbalance. Some fistulas will close spontaneously; however, this is rare in the open abdomen where adequate soft tissue generally is not available to cover the fragile bowel wall. Reports of patients with open abdomens²⁶ have documented fistula rates between 2% and 25% and intra-

abdominal abscess rates as high as 83%. These patients require repeated invasive procedures including dressing changes, abscess drainage, and bowel resection.

Infection

The open abdomen has a high potential for infection, either from fistulas or from exposure to the environment. Traditional treatment with moist gauze dressings will almost universally result in wound contamination or infection. To minimize exposure and because of the potentially painful nature of the wounds, many of these dressing changes require treatment in the operating room or under conscious sedation. Abdominal wall closure may not be possible after major trauma or in septic patients for many reasons (Table 2).

Table 2. Abdominal wall closure may not be possible after major trauma or in septic patients for many reasons including:

- Massive intestinal edema
- Risk of ACS/treatment of ACS
- Rapid conclusion of procedure in damage control surgery
- Need for multiple re-explorations of the abdomen
- Fascia and abdominal wall preservation
- Triad of hypothermia, coagulopathy, and acidosis

Bleeding

Given the rich blood supply of the intestine and abdominal solid organs, bleeding is a significant risk, particularly when inflamed and traumatized bowel wall is exposed. Trauma patients with significant intra-abdominal injuries that require damage control procedures have an associated coagulopathy from hypothermia, acidosis, hypotension, dilution, and consumption of clotting factors. The anatomy and coagulopathy can lead to diffuse localized bleeding that can only be controlled with pressure dressings and resuscitation of the patient. A rapid increase in abdominal pressure is indicative of ongoing bleeding, and a rapid re-exploration of the abdomen is needed. There is no reported data that open abdominal techniques exacerbate intra-abdominal bleeding. V.A.C.[®] Therapy can allow for close monitoring of drainage for the development of or an increase in bleeding.

Loss of Bowel Function

Open abdominal wounds with exposed bowel often result in poor nutrition from the increased metabolic demands on the patient, the loss of bowel motility, and the patient's inability to tolerate oral feedings. Enteral feeding has been shown to decrease the incidence of infections in critically ill patients, presumably by enhancing the immune response.^{27,28}

Decreased Central Temperature

In the open abdomen, a large, moist surface area of the bowel is exposed to the environment and can suffer large evaporative water losses, significantly decreasing the core body temperature. Decreased core temperature contributes to a significant coagulopathy and is a significant cause of death in trauma patients. Post-operative management must include aggressive rewarming with the use of in-line fluid warmers, warming blankets, warm nasogastric lavage, and bladder lavage.

Fluid loss from the abdomen also contributes to heat loss by convection. Also, if third space fluid losses are uncontrolled and the patient is allowed to remain in a wet bed, heat loss from the patient will accelerate. The goal of a temporary abdominal closure is to maintain the patient in a dry environment with minimal heat loss.

Loss of Domain

Patients left with an open abdomen following a vertical midline incision have unopposed forces of the oblique muscle that tend to pull the abdominal wall in a lateral direction. As a result, after days of not having the abdominal wall re-approximated in the midline, the soft tissue shrinks, making re-approximation more difficult over time. These phenomena have been referred to as loss of domain (Figure 4). This can lead to planned hernia due to inability to close the abdominal wall. Attempts at early approximation could lead to a pathologic increase in IAP. A method of gradual abdominal closure is needed as the edema and fluid decrease.

Hernia

Damage to the abdominal fascia results in hernia formation. Closure of the abdominal wall with skin, muscle, and/or peritoneum will result in hernia formation over time. When intestines are allowed to granulate and are covered with a skin graft, a hernia universally develops.

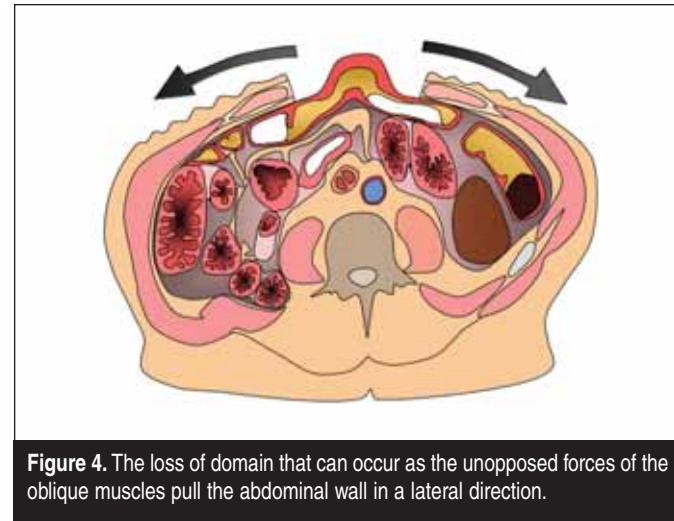


Figure 4. The loss of domain that can occur as the unopposed forces of the oblique muscles pull the abdominal wall in a lateral direction.

Hernias can be caused by abdominal distention, abdominal wall tension, fistula formation, and the underlying medical status of the patient.²⁹ Closure of planned hernias is usually complex and staged for complete fascial closure.³⁰ Hernias that form as a result of an open abdomen generally have little risk of strangulation of the bowel but cause considerable deformity and discomfort.

Temporary Abdominal Closure (TAC)

An open abdomen is maintained with a temporary abdominal closure (TAC) device. Patients with open abdomens require multiple trips to the operating room (ie, every 24–48 hours for as long as 2 or 3 weeks) using staged abdominal explorations. Thus, in addition to facilitating re-access to the abdominal cavity, an ideal TAC protects the abdominal contents; prevents evisceration; preserves fascia; minimizes desiccation and damage to the viscera; quantifies third space fluid losses; allows for selective tamponade; minimizes the loss of domain; lowers bacterial counts, infection, and inflammation; and keeps the patient dry and intact. High-risk patients can rapidly develop high abdominal pressures secondary to bleeding, pack placement, and rapid accumulation of third space fluid. A TAC can potentially minimize the development of IAH and ACS, and unlike a surgically closed abdomen, can be quickly removed with increased pressure, if necessary. Optimization of delayed closure can be achieved with a system that is non-reactive, easily removed from the bowel, pliable, permeable, and conformable to the shape and configuration of the abdominal contents and that minimizes bowel adherence to the

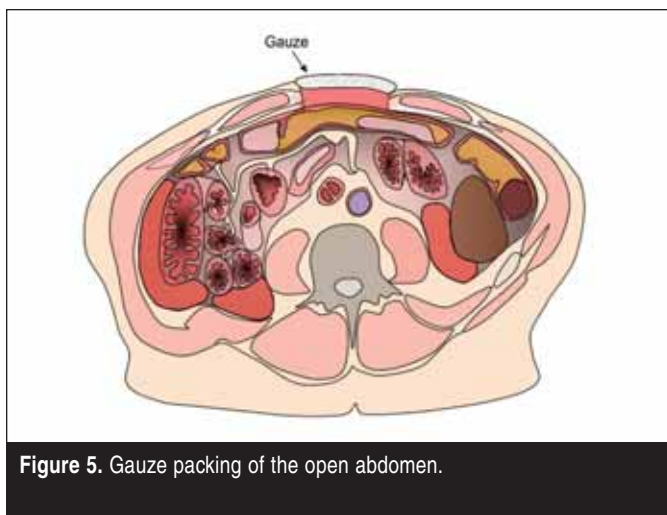


Figure 5. Gauze packing of the open abdomen.

abdominal wall.²⁹ Nonadherent dressings should be used in direct contact with the bowel, and the omentum can be used as a protective layer. The earliest TAC technique was gauze packing of the abdomen covered with an occlusive drape with eventual formation of granulation tissue and subsequent skin grafting (Figure 5).¹⁸ Numerous prosthetic materials have been used for temporary closure but can be associated with complications.²³ A significant risk (20–30%) for the development of ACS exists in abdomens covered with a TAC device; therefore, close monitoring of IAP is required.²³

A TAC is a technique developed to minimize the effects of increased IAP and to minimize the possibility of ACS development. Allowing the abdominal wall to expand in proportion to the pressure exerted by intra-abdominal forces allows pressure to be equilibrated, facilitating adequate tissue perfusion and visceral organ perfusion. Controversy exists regarding the benefit of TAC and the relationship between IAH and ACS. In a survey of surgeons that were members of the American Association for the Surgery of Trauma (AAST), Mayberry et al.³¹ reported that a majority of expert surgeons in the association would use TAC for instances of massive bowel edema, pulmonary decompression, hemodynamic instability, and packing in the abdomen. Only a minority of expert surgeons would leave the abdomen open for massive transfusions, gross contamination, hypothermia, acidosis, multiple abdominal injuries, and coagulopathy,³¹ all of which are known risk factors for the development of ACS. In the same study, 14% of surgeons surveyed would open the abdomen based solely on increased pressure without evidence of systemic signs of an ACS (ie, oliguria, increased airway pressures,

decreased cardiac perfusion, or elevated intracranial pressure). In a 1999 survey of the AAST, Mayberry et al.³¹ showed that surgeons utilize multiple TAC methods, including the Bogotá bag (25%); absorbable mesh (17%); polypropylene mesh (14%); polytetrafluoroethylene (PTFE) (14%); silastic mesh (7%); miscellaneous (28%); and towel clip closure (1%). Some surgeons (3%) responded that they “never used open abdomen technique.” Table 3 represents a summary of TAC methods.

In a retrospective study, Ivatury et al. demonstrated the effectiveness of TAC in preventing the development of IAH.²⁴ Patients defined as high risk for ACS included those with hemodynamic instability, multiple injuries, strong suspicion for the development of ACS, or a need for intra-abdominal packing. These patients were studied in 2 groups: group I had TAC placement using a loosely applied prosthetic mesh; group II had their abdomens closed at the time of surgery after bleeding was controlled and organs were repaired. Incidence of IAH (defined as pressure > 25 mmHg) was 22.2% in the mesh closure group versus 52% in the fascial closure group.²⁴ Survival was higher and organ dysfunction was less severe in patients that did not develop IAH. There was an overall survival of 90.1% in the mesh-closure group compared to 68% in the fascial closure group.²⁴ This study demonstrated the effectiveness of established guidelines to monitor and prevent the development of IAH.

In a retrospective study to evaluate the efficacy of placing a TAC to prevent ACS, Mayberry et al. compared the primary placement of absorbable mesh in patients at high risk for developing ACS at the time of the initial celiotomy to placement at second exploration.³² The group that had mesh placed secondarily had an increased incidence of ACS, necrotizing fasciitis, intra-abdominal sepsis, and enterocutaneous fistulas. The conclusion from this study suggested a benefit in early TAC placement.

Since patients closed with a TAC method are at risk for the development of ACS, serial bladder pressure monitoring is imperative. The incidence of ACS can be as high as 38% with a TAC.⁶ Progressive IAH and the development of an ACS can be predicted by a progressive increase in serial bladder pressures, and despite the method used for TAC, the IAP must be closely monitored. Kaplan reported that the trend of IAP is more important than an absolute number.³³ The most common cause of ACS is continued bleeding either from a surgical

bleeding site or coagulopathy. Moore stated that bladder pressures greater than 35 mmHg denote ongoing bleeding and warrant immediate decompression in the operating room.⁷ Ivatury et al. recommended immediate re-exploration at the bedside to check for increasing pres-

ures—even in the event of ongoing coagulopathy—to evacuate clots, control bleeding, and repack the abdomen.²⁴ Re-exploration can disrupt the cycle of acidosis, coagulopathy, and hypothermia by improving pulmonary and cardiac performance and reversing the

Table 3. Temporary closure techniques

Technique	Materials	Advantages	Disadvantages
Skin approximation	Towel clips; running suture	Inexpensive; rapid; maintains abdominal domain; minimizes heat and fluid loss	Risk of evisceration; damage to or loss of skin; high incidence of ACS; no control of fluid loss
Bogotá bag	3 L IV bag; Steri-Drape (3M, Minneapolis, Minn); 10-10 Drape; Bowel Bag; Silastic	Inexpensive; biologically inert; minimizes heat and fluid loss; nonadherent	Risk of evisceration; loss of abdominal domain; increased risk of ACS
Absorbable mesh	Vicryl (Ethicon, Somerville, NJ); Dexon (Davis & Geck, Danbury, Conn)	Absorbable; resistant to infection; protection from evisceration; possible definitive closure with split-thickness skin graft	50% hernia rate; fascial retraction; enterocutaneous fistula; may prevent fluid egress; increased risk of ACS
Marlex with zipper	Wittmann Patch™ (Starsurgical, Inc., Burlington, Wis)	Ease of re-exploration; maintains abdominal domain; extends time temporary closure is employed	Requires special equipment; requires multiple fascial manipulations
Vacuum pack closure	Fenestrated, nonadherent polyethylene sheet; moist surgical towels; silicone drains; iodoform-impregnated adhesive dressing; wall suction	Inexpensive; uses material found in the operating room; moderate fluid control; may allow abdominal wall closure	Lacks ability to approximate abdominal wall; moderate fluid control; lacks bleeding detection and safe guards to maintain constant suction
Vacuum Assisted Closure®	V.A.C.® Therapy™ (KCI, San Antonio, Tex)	Decreased incidence of ACS; prevents loss of abdominal domain; uniformly draws wound closed; extends time temporary closure is employed; minimizes heat loss; collects and quantifies fluid loss; minimizes suturing through fascia; assists in abdominal stabilization via splinting effect; nonadherent layer available; provides a barrier to infection	Requires special equipment

effects of cellular shock.⁷

Gracias et al.³⁴ reported that the development of an ACS was a rapidly progressive process in the open abdomen developing between 1.5 and 12 hours post-insult and was associated with significant mortality (60%). Patients with high crystalloid requirements and severe physiologic derangements were at risk for ACS, and these factors may be predictive of ACS development.^{35–37}

Earlier studies used TAC in cases with clinical evidence of ACS, while more recent studies suggest the use of TAC to minimize IAH and, therefore, decrease the probability of developing ACS and subsequent complications.²³ Controversy exists regarding the effectiveness of TAC in decompressing the abdomen and reversing the systemic effects on organ dysfunction with the onset of an ACS. A study completed by Meldrum and associates showed the detrimental effects of IAH and organ dysfunction.³⁷ This study demonstrated that rapid onset of ACS can be predicted by the physiologic state of the patient with use of an IAH grading system based on abdominal pressure and systemic manifestation. The study also demonstrated the effectiveness of early decompression in high-risk patients.

Sugrue et al. showed limited clinical efficacy in reversing the adverse systemic effects in patients that had increased IAP.²³ This prospective, nonrandomized study used a polypropylene mesh or PTFE patch for temporary closure of the abdomen. Reasons for TAC were decompression (22 patients), inability to close the abdomen (10), re-exploration (8), and multifactorial (9). Increased abdominal pressure was defined as greater than or equal to 18 mmHg. Mean abdominal pressure was 24.2 mmHg and was reduced to 14.1 mmHg upon decompression of the abdomen. Due to inadequate drainage or severe bowel edema, 25% of patients in the study could not have their IAP lowered below 18 mmHg. Patients that were

decompressed did not experience significant changes in their urinary output. Twenty-eight patients in this study had brisk diuresis. There was a reported improvement in dynamic lung compliance, but minimal improvement in gas exchange or acid base status. There was no significant improvement in renal function or oxygenation. While the benefits of decompression were minimal for IAH, the study suggested that IAH prevention might be the key to reducing complications in high-risk patients. In contrast, a retrospective study completed by Ertel et al. showed improvement in physiologic parameters of patients with documented ACS with defined clinical patterns and time of onset typical to ACS that underwent emergent decompression.³⁸ However, with improved hemodynamics, there was still a 35% mortality rate. Saggi et al. reported a 59% 30-day mortality rate after decompression for ACS because of MODS that resulted after the systemic inflammatory process.³⁹ Retrospective data suggest the prevention of ACS and IAH could lower the complications and mortality observed.

Management of Patients with TAC

Patients with open abdomens initially require placement in the intensive care unit. This class of patients is at risk for bleeding, hypothermia, significant fluid losses, and respiratory dysfunction. They are also at risk for SIRS and MODS. Aggressive fluid resuscitation can lead to increased abdominal pressures and ACS. According to the panel, all patients with open abdomens should have serial bladder pressures taken 1–6 hours apart to monitor changes in IAP. The development of IAH can be insidious if not monitored with the development of ACS as early as 12 hours postoperatively. Intra-abdominal pressure trends should also be monitored for the development of ACS. Patients with progressive increases in IAH or development of ACS should be decompressed immediately.

Patients with TAC should be periodically re-explored for bleeding and sepsis. This typically occurs every 48 hours but can be altered depending on the condition of the patient. Dressing changes and exploration can be performed at the bedside or operating room. A complete exploration should be performed with attention to drainage of interloop fluid and exploration of all gutters. Bowel should be dissected free from the abdominal wall to the lateral, superior, and inferior aspects of the abdomen. Every effort should be made to prevent the

Table 4. Requirements for TAC devices

- Allow multiple abdominal re-explorations
- Control peritoneal fluid and third space loss
- Minimize increases in intra-abdominal pressure
- Preserve fascial integrity/facilitate abdominal wall closure
- Minimize dressing changes and wound exposure
- Contain intra-abdominal contents
- Protect intra-abdominal contents
- Lower bacterial counts

bowel from adhering to the abdominal wall if fascial closure is desired. When bowel loops begin to congeal, they should not be separated, as this could cause a fistula.

Patients with TAC can be safely fed enterally. The exceptions are those patients that are hypotensive and on vasopressor therapy and patients with high output fistulas. The panel reported problems with enteral feeding tubes and recommends placement of a jejunal feeding tube in the most lateral position on the abdominal wall, use of a Moss tube, or placement of a nasogastric feeding tube at the time of laparotomy.

Continued exploration should be based on the patient's physiologic state. This will dictate final closure of the abdominal wall. In order to minimize fistulas and hernia formation, an attempt at early fascial closure should be made. If the patient is unstable or cannot tolerate multiple re-explorations, a skin-only closure is the next optimal method of closure, followed by skin grafting of the abdominal wall. When fascial closure is not possible, the patient will develop a hernia and require further surgical intervention.

Closure Techniques

The goal of TAC is to minimize the effects of sepsis, IAH, and secondary complications seen with an open abdomen. Early coverage of the abdominal contents will decrease complications, such as fistula formation with restoration of fascia integrity. Care must be taken to prevent desiccation and adherence of the bowel to dressings. Earlier studies using mesh closure alone had variable closure rates with a significant incidence of fistulas regardless of the material used.⁷ The introduction of dynamic closure devices, such as Velcro® closure or V.A.C.® Therapy, has improved closure and resulted in lower complication rates.³³

In cases where fascial closure is not feasible due to edema or ongoing sepsis, other closure options include allowing the abdominal wall to granulate and placing a skin graft, attempting to approximate the skin and allowing a ventral hernia to develop, or using a prosthetic material that can be skin grafted over granulation tissue. If a skin graft is placed over granulation tissue, a 6-month maturation period is usually needed before attempting to permanently close the abdomen.³⁰ This will allow the inflammatory process to subside and facilitate entry into the abdomen.

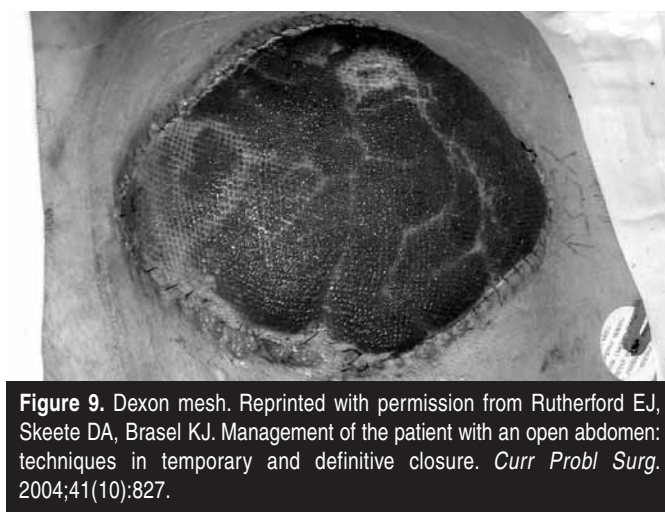
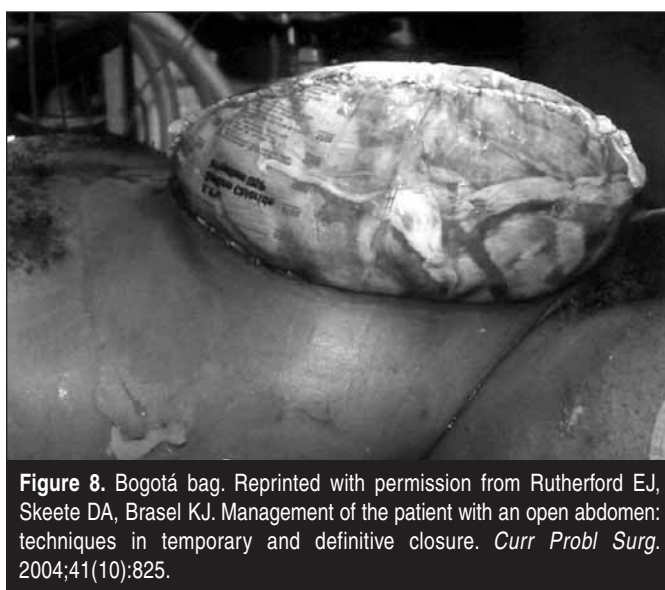
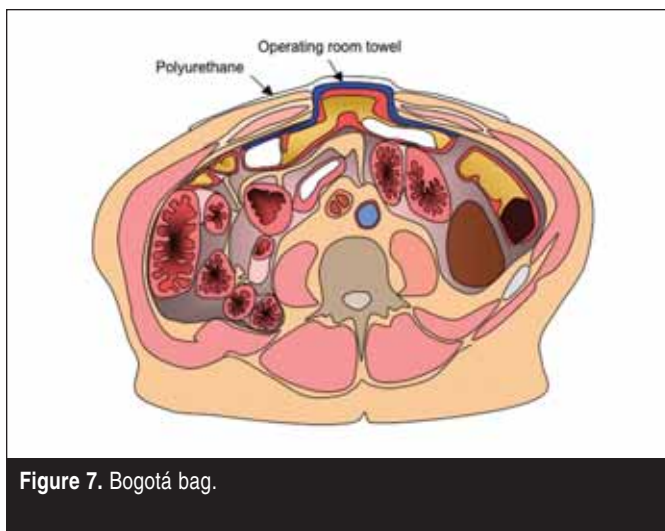


Figure 6. Towel-clip closure over Dexon mesh. Reprinted with permission from Rutherford EJ, Skeete DA, Brasel KJ. Management of the patient with an open abdomen: techniques in temporary and definitive closure. *Curr Probl Surg.* 2004;41(10):823.

Late abdominal wall reconstruction can be accomplished with a number of techniques. Fabian et al. used the separation of components technique effectively in a staged procedure to close the abdomen.³⁰ This procedure avoids the use of prosthetic material and therefore can be used when stomas are taken down with a lower risk of infection. There is a 33% incidence of hernia recurrence when mesh is used and 11% with the separation of components technique.³⁰

Skin-Only Closure

Skin-only closure was initially described as a rapid method to close the abdomen in an unstable, at-risk patient.⁴⁰ Towel clips or a running suture can be used for a skin-only closure (Figure 6). This technique can be used for rapid closure in patients that will need re-exploration within 24 hours. Retrospective studies have shown efficacy with complication rates similar to other methods; however, towel clips may interfere with other advanced diagnostic studies, such as abdominal computed tomography (CT) scans or magnetic resonance imaging (MRI), which many trauma patients with multiple injuries may require. Skin closure with 2-0 nylon may prevent interference with advanced studies for trauma patients who require rapid closure. Smith et al.⁴⁰ demonstrated a high rate of fascial closure in patients initially closed with towel clip closure. The authors reported a 14% risk of ACS development with towel-clip closure because the abdomen has a limited ability to expand with the increasing abdominal pressure. Skin-only closure has been replaced in most centers with placement of a prosthetic



material to cover the abdominal wall. Meldrum et al.⁴¹ reported that packing of major liver injuries with towel-clip skin closure resulted in significant compromise in cardiopulmonary function. They warned that while this may provide life saving tamponade of uncontrollable bleeding, timely alleviation of worsening IAH may be critical for ultimate salvage especially in patients with limited cardiopulmonary reserve.

Bogotá Bag

The Bogotá bag has been used in practice for more than 20 years. The use of an open intravenous (IV) bag was popularized in Bogotá, Columbia, and has been used since 1984 in the United States.^{42,43} Many variations have been reported (eg, sterile x-ray cassette sleeves, urology bags, silastic drapes, latex), but none appear to be advanced methods for keeping the abdomen open while maintaining control of the abdominal contents.

The Bogotá bag can be made from a pre-gas-sterilized 3-L urology bag that is cut into an oval shape and sutured to the skin (Figure 7 and 8).²⁴ The advantages of the Bogotá bag include low cost, nonadherence, prevention of evisceration, ease of application, and availability in the operating room.²⁰ Disadvantages include tearing of the skin, adherence of the bowel to the abdominal wall, difficult re-entry into the abdomen, and the need for gas sterilization of the bag before use.^{20,38} Control of third space loss is minimal, and any leakage from under the bag can leave the bed wet and increase the risk of worsening hypothermia.

The effectiveness of the Bogotá bag has mostly been illustrated in case reports and noncontrolled studies with a wide variety of patients. However, the Bogotá bag has gained wide acceptance, and this technique was a starting point for the development of new devices for the prevention and treatment of IAH and ACS.

Mesh Closure

The advantages of mesh closure include ease of placement, facilitation of re-exploration, the ability to open and re-close the abdomen at the bedside, and increased strength compared to Bogotá bag closure. Mesh closures have varied by type and material used. Experience with polypropylene mesh showed an advantage of closure of the abdomen by granulation and skin grafting, but the reported fistula rate with polypropylene mesh placed over

bowel has been between 50–75%.^{44,45} Mayberry et al. showed effectiveness in placement of an absorbable mesh for the prevention of ACS.³² The mesh can be removed easily and facilitates skin grafting and granulation tissue development.⁴⁶ However, Nagy et al. reported that the use of absorbable mesh resulted in significant formation of disabling hernias and a risk of late evisceration and, as a result, recommended the use of PTFE.⁴⁷ Polytetrafluoroethylene mesh is desirable because it is nonadherent to the underlying bowel and is related to a low fistula rate.⁴⁸ Disadvantages of PTFE use are the price, inability to skin graft, lack of resistance to infection, and chronic subcutaneous infections. GORE-TEX® (W.L. Gore & Associates, Inc., Newark, Del) has also been used for abdominal closure, but it does not allow for fluid removal, is prone to chronic infection, and is expensive.

Wittmann Patch

In 1990, Aprahamian et al. described an open abdominal technique with a Velcro®-like prosthetic placed over the abdomen.⁴⁹ This device allowed for easy entrance into the abdomen for re-exploration and facilitated closure of the abdomen with serial narrowing and trimming of the mesh until the abdomen was closed (Figure 10). The potential for IAH and ACS was high, and there was minimal control of third space fluid. Liner pressure placed on the abdominal wall can potentially lead to fascial necrosis. Complication rates were similar to other methods of closure, but reports in the literature on its use and effectiveness are limited.⁴⁸

Vacuum Pack

The vacuum pack technique is a modification of the Bogotá concept that allows for rapid closure of the abdominal wall with application of wall suction to control abdominal secretions (Figure 11 and 12). Barker et al. reported a 7-year retrospective experience with vacuum pack in 112 patients.⁵⁰ This technique utilizes a fenestrated, nonadherent polyethylene sheet that is placed over the viscera and covered with moist surgical towels. Two 10-French silicone drains are placed over the towels, and the wound is sealed with an iodoform-impregnated adhesive dressing. Continuous wall suction is applied at 100–150 mmHg. Patients are re-explored serially at dressing changes. This method is inexpensive and effective in managing an open abdomen. The authors achieved a fas-



Figure 10. Wittmann patch. Reprinted with permission from Rutherford EJ, Skeete DA, Brasel KJ. Management of the patient with an open abdomen: techniques in temporary and definitive closure. *Curr Probl Surg.* 2004;41(10):829.

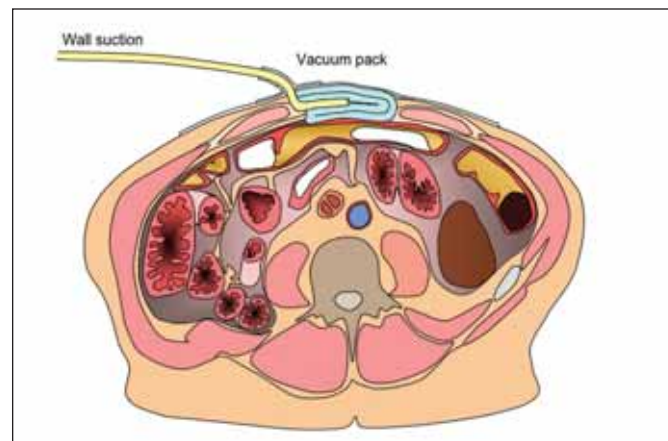


Figure 11. Vacuum pack technique.



Figure 12. Vacuum pack. Reprinted with permission from Barker DE, Kaufman HJ, Smith LA, Ciraulo DL, Richart CL, Burns RP. Vacuum pack technique of temporary abdominal closure: a 7-year experience with 112 patients. *J Trauma.* 2000;48(2):204.

cial closure rate of 55.4%. In this patient population, 23.3% had their abdomens closed with absorbable mesh and skin grafts. The fistula rate was 4.5%, which was lower than other reported techniques. Vacuum pack appeared to be an effective technique in managing the open abdomen. Barker et al. reported that if the abdominal wall could not be closed in 7–10 days, the bowel would adhere to the abdominal wall, and the abdomen could not be closed. At this point, the only option was to allow granulation tissue to form over the abdominal contents and then place a skin graft. The patient would then need definitive closure of the abdominal wall at a later date.

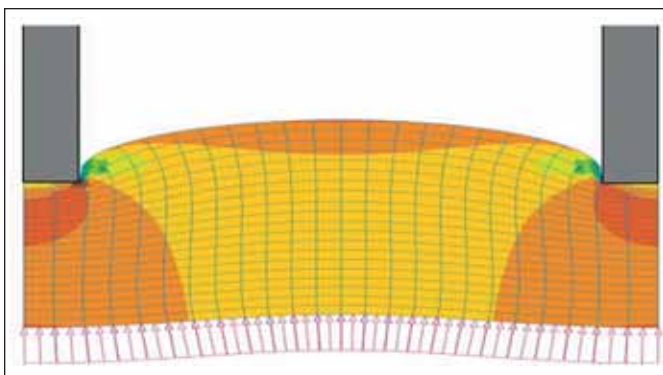


Figure 13. Finite element model of a V.A.C.® foam applied to a wound showing deformations. The wound surface is stretched in most areas of the device.⁵²

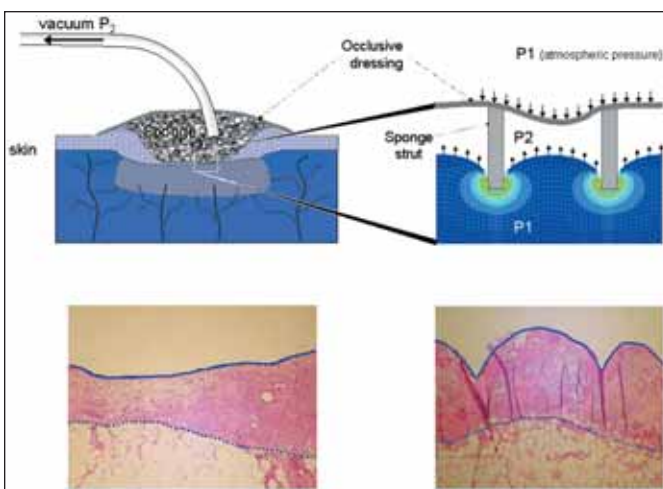


Figure 14. Application of V.A.C.® Therapy induces surface undulations stretching cells in the wound. Wound with V.A.C.® device at 7 days (lower right) has a higher surface area (blue line) and more blood vessels than a wound not exposed to the foam (lower left).⁵² Reprinted with permission from Saxena V, Hwang CW, Huang S, Eichbaum Q, Ingber DE, Orgill DP. Vacuum-assisted closure: Microdeformations of wounds and cell proliferation. *Plast Reconstr Surg*. 2004;114(5):1087.

V.A.C.® Therapy

Prior to the adoption of V.A.C.® Therapy, vacuum pack closure was the modality of choice for the majority of panel members. Historically, if the abdomen was not closed within 7–10 days, the combination of adhesions and fascial retraction frequently made primary fascial closure impossible, and creation of a planned ventral hernia was required.⁵⁰ Using the vacuum pack technique, Barker et al. were able to achieve fascial closure as late as 9 days post-operatively.⁵⁰ Since the adoption of V.A.C.® Therapy, Miller et al. have reported successful primary fascial closure as late as 49 days post-operatively.⁵¹ This technique applies subatmospheric pressure to the open abdomen through a reticulated polyurethane foam dressing. The device, dressings, tubing, and canisters are used as a complete system, and it is currently the only system verified by the Centers for Medicare & Medicaid Services (CMS) for negative pressure wound therapy.

V.A.C.® Therapy application uses a specialized dressing that includes a semi-occlusive drape and resilient, open-cell foam (V.A.C.® GranuFoam®) that can transmit pressure changes equally throughout the foam. The current V.A.C.® GranuFoam® Dressing can be modeled as multiple small suction cups applied to the wound. Using known mechanical properties of tissues, a finite element model can be constructed to predict deformation of the wound. Saxena et al.⁵² designed a finite element model of the wound in contact with the foam with pore sizes of approximately 1 mm (Figure 13). Using known mechanical properties of tissue, this model predicted that the wound would deform between contact points of the foam resulting in increased surface area of the wound. The deformations predicted are very similar to microscopic wound cross-sections observed a few days after V.A.C.® Therapy application when a rough surface of well-vascularized tissue may be seen (Figure 14). It is hypothesized that stretching the wound surface by inducing wound undulations stimulates cell division, proliferation, and angiogenesis through mechanisms described by Ingber.⁵³ This has been confirmed by a recent animal study by Chen et al.⁵⁴

As opposed to many wounds treated with V.A.C.® Therapy where the foam is directly in contact with wounds, surgeons have learned that placing the polyurethane foam directly on bowel may potentiate fistula formation. The panel agreed that extreme precaution must be taken to ensure the V.A.C.® GranuFoam® is

not in contact with the bowel. Thus, most surgeons using this technology use the V.A.C.® Abdominal Dressing System and place the specially designed nonadherent layer over the bowel (Figure 15) in order to protect the bowel while allowing fluid egress. The open-pore polyurethane foam is in contact with this non-adherent layer and also with the abdominal wall. In the experience of the panel, the open pore foam is efficient at both distributing the subatmospheric pressure throughout the abdomen and removing a large amount of fluid efficiently. Because of the specific characteristics of the open-pore polyurethane foam (V.A.C.® GranuFoam®), V.A.C.® Therapy may induce microdeformations of the wound edges while efficiently removing excess fluids from the open abdomen.

The subatmospheric or negative pressure for V.A.C.® Therapy is controlled with a computerized vacuum pump that applies a regulated negative pressure to the wound surface. A sensing device provides continuous feedback from the wound to ensure a prescribed amount of negative pressure is delivered to the wound and indicates when the canister is full of fluid.⁵⁵ While initially developed at Wake Forest by Argenta and Morykwas as an adjunct to wound healing,⁵⁵ the therapy has evolved into an effective device in the management of open abdomens (Table 5). When using V.A.C.® Therapy with an open abdomen, the patient is taken for re-exploration, separation of adhesions, and application of a new V.A.C.® Dressing every 48 hours.

The V.A.C.® Abdominal Dressing System should only be used with the V.A.C.® Therapy System. The pressure should be started at 125 mmHg and increased if an interface is utilized or lowered if not tolerated well. The initial research on V.A.C.® Therapy showed that 125 mmHg was the critical pressure to stimulate cell reproduction and to maximize the negative tissue expansion effect. V.A.C.® Therapy also has several safety features that other options do not: controlled delivery of negative pressure, alarms, pressure monitoring at the wound site, and regulated canister volume.

The initial layer of the V.A.C.® Abdominal Dressing System is composed of nonadherent fenestrated polyurethane that prevents bowel adherence to the anterior abdominal wall and facilitates fluid drainage into the foam. Preventing the fascia from adhering to the abdominal wall allows the fascia to be gradually pulled over the bowel and closed—preventing planned ventral hernia and/or complex closure procedures. Appropriate appli-

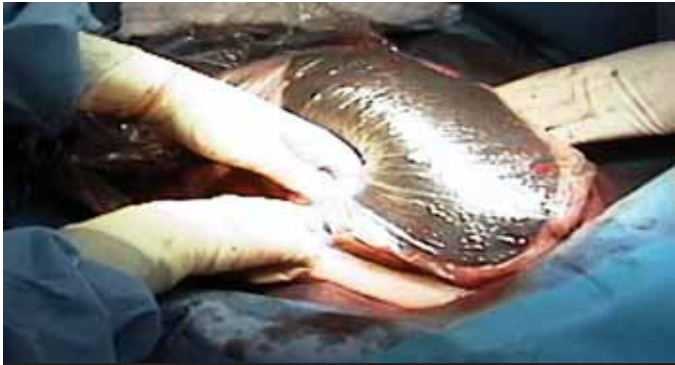


Figure 15. Application of the specially designed nonadherent layer with fenestrations from the V.A.C.® Abdominal Dressing System.

Table 5. Consensus panel summary of the benefits of V.A.C.® Therapy with the V.A.C.® Abdominal Dressing System

- Provides a bridge to closure of the fascia and abdominal wall
- Removes, collects, and quantifies abdominal fluids
- Removes infectious materials
- Minimizes frequency of dressing changes
- Helps protect the wound environment
- Helps promote wound healing and assists in granulation tissue formation
- Helps approximate wound margins

cation of the nonadherent layer requires placing the dressing down into the gutters. When properly applied, the V.A.C.® GranuFoam® will exert a macro-force on the abdominal wall, holding it together. From the panel experience with abdominal wounds left open, they tend to enlarge, probably due to the unopposed action of the oblique muscles that pull the abdominal wall laterally. Application of the V.A.C.® Therapy System visually shows a mechanical pull of the 2 edges of the abdominal wall together when negative pressure is applied. The net effect is a reverse tissue expansion of the abdominal wall, which pulls the abdomen together in a slow and progressive manner. The consensus of the panel is that the use of the V.A.C.® Therapy System will result in progressive approximation of the wound margins, a reduction in the size of the abdominal wall defect, removal and quantifying of abdominal fluid, and removal of infectious materials. The panel also hypothesizes that V.A.C.® Therapy assists in the removal of inflammatory substances that accumulate in the abdomen during inflammatory states.

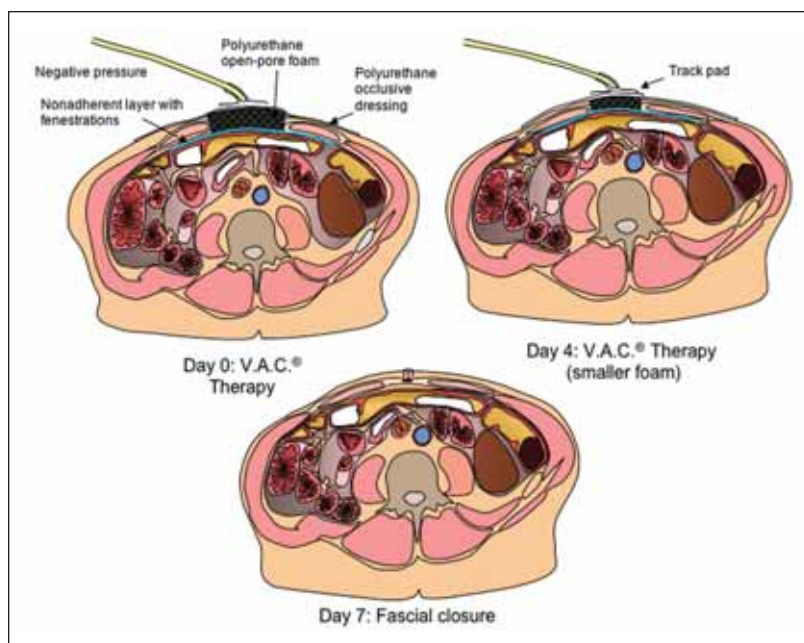


Figure 16. V.A.C.® Therapy with the V.A.C.® Abdominal Dressing System and the ability to progressively close the fascia and abdominal wall.

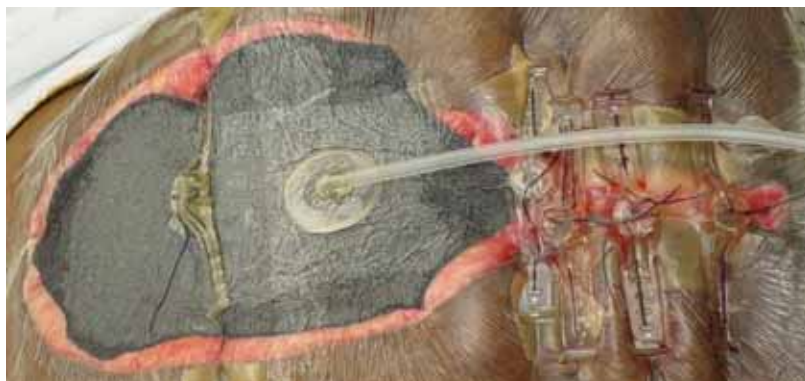


Figure 17. V.A.C.® Therapy System with retention sutures in place as negative pressure is being initiated.

Garner et al. reported the use of V.A.C.® Therapy in the early approximation of open wounds in patients that underwent decompressive laparotomy or damage control surgery.⁵⁶ The authors placed a Bogotá bag over the wound for 24–48 hours. If the abdomen could not be closed, they returned the patient to the operating room, applied V.A.C.® Therapy, and closed the abdomen. The authors reported a 92% fascial closure rate at an average time of 9.9 days in 14 patients. No fistulas or eviscerations were reported.

Suliburk et al. expanded on the experience of Garner et al. with the use of V.A.C.® Therapy in trauma patients.³ This group of 35 patients had a primary closure rate of 86% with a mean time to closure of 7 days. Four patients

failed to close using V.A.C.® Therapy, and 2 of those 4 developed fistulas.

Miller et al. reported their experience using V.A.C.® Therapy on the open abdomen. Of the 83 patients that survived their injuries, 59 patients (71%) had their fascia closed; 37 (62%) closed in less than 9 days; and 22 (37%) closed in greater than 9 days.⁵¹ These results compare favorably to other modalities of closure, and retrospective data show a greater percentage of closure in patients with V.A.C.® Therapy, decreasing the need for re-admission to the hospital for long and more complex closure procedures. In a more recent study by Miller et al.,⁵⁷ a protocol was developed based on the findings of the previous study and was strictly followed. Of the 45 (78%) patients that survived until abdominal closure, 88% were closed with the mean time to closure of 9.5 days, and 21 patients (48%) were closed at > 9 days. Miller concluded that by using a carefully defined protocol, they were able to achieve a significantly higher closure rate ($p = 0.03$), obviating the need for subsequent hernia repair in most patients.

Kaplan reported similar experiences with additional benefits of lower intensive care unit length of stay, primary closure of 78% of patients as compared to 12% using vacuum pack, and lower complications when compared to other techniques.³³ Based on these findings, a cost analysis demonstrated an average savings of \$31,842 when V.A.C.® Therapy was used including a cost of \$2,220 per patient for cost of V.A.C.® Therapy and supplies. The total cost of hospital charges

for latex was \$358,576 and the total cost of hospital charges for V.A.C.® Therapy was \$326,734. This cost analysis was based on 13 V.A.C.® Therapy patients and 9 vacuum pack patients from this study population; no other data was available for analysis on other patients.

The 7 retrospective studies reviewed by the panel for this document demonstrate the safety and efficacy of V.A.C.® Therapy and compare favorably to the vacuum pack technique. There may be an advantage in applying a dynamic closure device, such as the V.A.C.® Therapy System, to an open abdomen in that edema and third space losses can be controlled and the abdomen closed in a timelier manner. A critical component of V.A.C.® Therapy is the reticulated



Figure 18. Initial incision to relieve abdominal compartment syndrome (A); after 48 hours of V.A.C.® Therapy, abdominal compartment syndrome is resolved (B); and abdomen is closed (C).

Table 6. Summary of the various techniques of managing the open abdomen and their perceived benefits according to the consensus panel

Technique	Controls Abdominal Contents	Achieves Skin Closure	Achieves Fascial Closure	Actively Removes Exudate	Quantifies Third Space Losses	Promotes Granulation	Controls Infection
Bogotá bag	+	–	–	–	–	–	–
Wittmann Patch™	+	+	+	–	–	–	–
Prosthetic mesh	+	–	(+)	–	–	–	–
Vacuum pack method	+	–	+/-	+/-	+/-	+/-	+/-
Vacuum Assisted Closure®	+	+	+	+	+	+	+

+ demonstrated benefit; – no demonstrated benefit; +/- may or may not provide benefit; (+) technique facilitates the benefit. Adapted with permission from Swan and Banwell 2004.

foam, which helps approximate the abdominal wall while removing third space fluid from the peritoneal space, thus enhancing the ability to close the abdomen.

Comparison of the Various Techniques of Managing the Open Abdomen

A comparison was made of all of the TAC options previously discussed and their ability to meet the requirements of an optimal TAC (Table 6). Upon review of these outcomes, the consensus of the panel was that V.A.C.® Therapy meets the requirements and is therefore the preferred method of managing the open abdomen.

The panel reviewed current literature on the various techniques used to manage the open abdomen based on historical controls and nonrandomized, controlled stud-

ies as shown in Table 7.

In addition, a further analysis was performed of previous work that includes 6 vacuum pack articles and 7 V.A.C.® Therapy articles to assess fascial closure rates, mortality, and rates of fistula formation as presented in the published literature. A Fisher's Exact test was used to analyze the data found in the literature.

Clinical Phases in Management of the Open Abdomen

The panel developed a guide containing 3 phases for managing open abdomen patients based on the physiologic status of the patient. Figure 19 illustrates a clinical treatment pathway during these 3 phases.

The initial phase is the *acute resuscitative phase*. Patients

Table 7. Compilation of data comparing various techniques of managing the open abdomen as described in published literature

Technique	Articles	N	Trauma N (%)	Mortality N (%)	Fascial Closure* N (%)	Fistula Occurrence* N (%)
Polypropylene	5	175	126 (72)	46 (26)	44 (34)	28 (21)
Polyglactin polyglycolic	5	667	584 (88)	279 (42)	129 (33)	87 (22)
Bogotá bag/silo	4	553	446 (81)	293 (53)	48 (18)	35 (13)
Vacuum pack method	6	358	324 (91)	110 (31)	143 (58)	17 (7)
V.A.C. Therapy®	7	327	306 (94)	99 (30)	181 (79)	6 (2.6)
Total	27	2080	1786 (86)	827 (40)	545 (43)	173 (14)

*Calculations based on number of survivors

Table 8. Comparison of vacuum pack^{25,34,50,58-60} vs. V.A.C.® Therapy System^{3,33,51,56,57,61,62} (Fisher's Exact test)

Parameter	Vacuum pack (N = 358)	V.A.C.® (N = 327)	p value
Trauma	324 (91%)	306 (94%)	0.160
Fascial closure**	143 (58%)	181 (79%)	< 0.001*
Mortality	110 (31%)	99 (30%)	0.934
Fistula formation**	17 (7%)	6 (2.6%)	0.034*

*Significant at the 0.05 level; **percentages are based on the total number of survivors

in this phase are 24–48 hours removed from the initial incident requiring the abdomen to be left open. A TAC is used because of the inability to close the abdomen. This class of patients requires care in the intensive care unit including warming, hydration, correction of acidosis, correction of coagulopathy, ventilator support, intensive monitoring (including indirect bladder pressure monitoring), and prevention of IAH/ACS. This group has the highest risk of developing ACS, and these issues are usu-

ally seen in the first 12–24 hours postoperatively. Re-explorations for IAH/ACS and bleeding are considered part of the resuscitative phase. Types of TAC closure include the Bogotá bag, vacuum pack, and V.A.C.® Therapy. Due to the lack of data relevant to this treatment phase, the panel was undecided as to the best method of closure. However, the panel agreed that some form of negative pressure in the form of vacuum pack or V.A.C.® Therapy was more beneficial than static methods of TAC. Application of negative pressure to the abdomen will allow for control of third space losses,

keep the patient dry, and improve output monitoring. Additional retrospective data suggests a lower IAP in patients receiving V.A.C.® Therapy.³³

The second phase is defined as the *intermediate resuscitative phase* or *early reconstructive phase*. In this phase, patients have survived the initial physiologic insult, the abdominal packing has been removed, and the risk of IAH/ACS has been minimized. Patients are no longer hypothermic, and coagulopathy has been controlled. Sources of sepsis from bowel and solid organs have been controlled. This phase is usually seen 48 hours post-injury and can extend to 10 days. This period will have the highest incidence of primary abdominal wound closures. V.A.C.® Therapy has been retrospectively shown to have a significant benefit in this class of patients, and the panel recognizes the retrospective data to support the use of V.A.C.® Therapy in this phase.³⁰

The third phase is the *late reconstructive phase*. This phase is defined as the time between 10 days post-injury and either primary or secondary closure of the abdominal wall. The panel recognizes the importance of long-term protection of the abdominal contents with the patient's physiologic status as the main determinant. The panel reported personal experience using V.A.C.® Therapy for

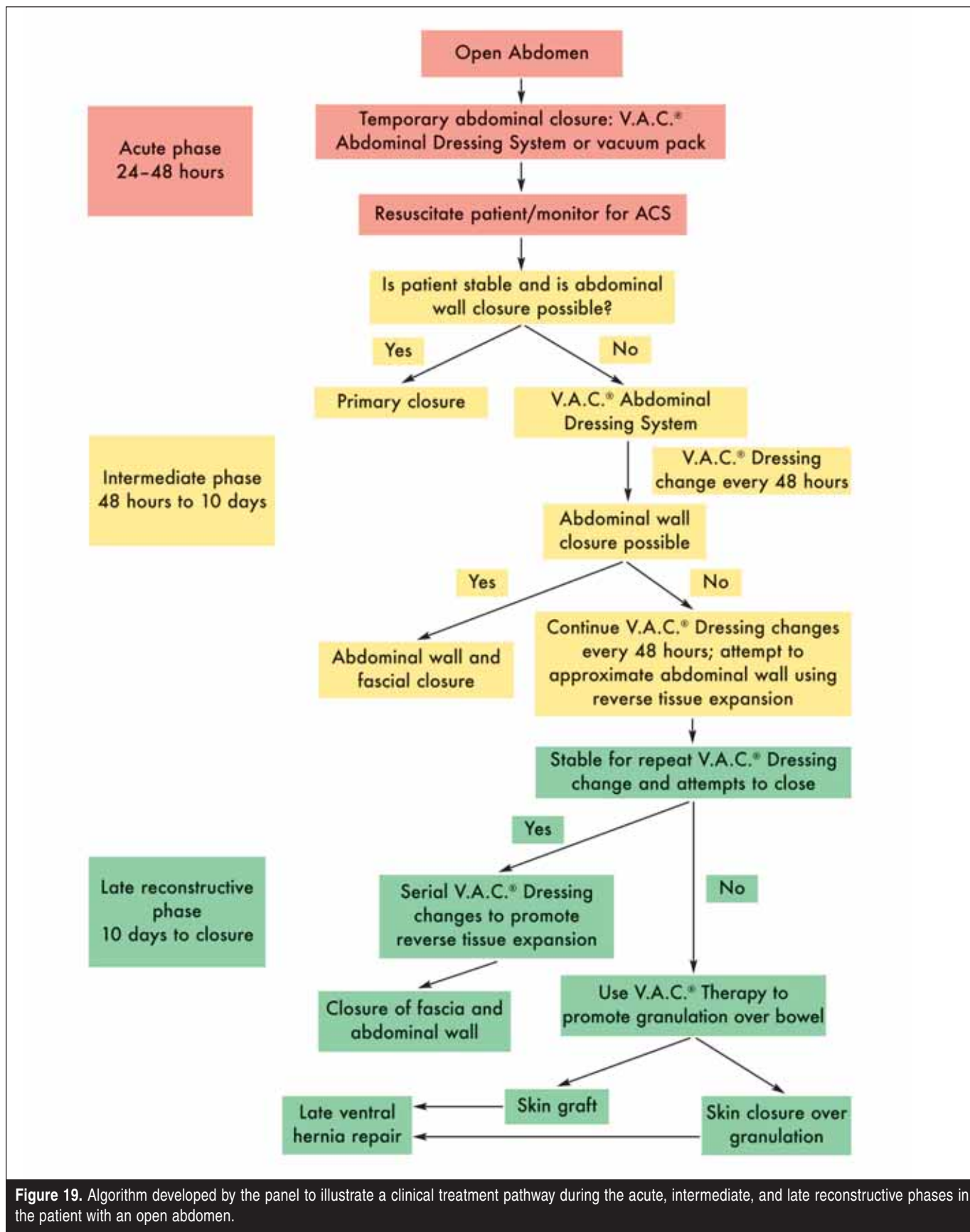


Figure 19. Algorithm developed by the panel to illustrate a clinical treatment pathway during the acute, intermediate, and late reconstructive phases in the patient with an open abdomen.

primary closure up to 49 days after the initial surgery. Patients that are stable and can tolerate multiple procedures can have a primary closure. In patients who are unstable or whose clinical status precludes multiple explorations, the abdominal wall is allowed to granulate until the skin is closed over the granulation tissue or a skin graft is placed. The panel agreed that use of V.A.C.[®] Therapy in this phase is beneficial because it promotes primary closure. If a primary closure was not feasible, V.A.C.[®] Therapy will promote the formation of dense and viable granulation tissue for protection of the abdominal contents. Also, in the cases of skin grafting, V.A.C.[®] Therapy will act as a malleable bolster to the irregular surface of the abdomen and promote adherence of the skin graft.

Panel Questions and Answers on Treatment of the Open Abdomen

1) How did the panel develop the guidelines and make recommendations?

- The panel convened over a 2-day period and was represented by surgeons that have recognized expertise in the management of patients with open abdomens. The guidelines were developed using a best practices model based on the current literature and experience of the panel. After each topic was discussed, a consensus of the panel was formulated to make recommendations. A unanimous majority was not always met, but recommendations were only made when a majority of the panel members agreed.

2) Why do trauma centers see more open abdomens?

- Advances in critical care medicine have allowed surgeons to support patients in the peri-operative period with respiratory, cardiovascular, and renal support. There has also been an appreciation of the dangers associated with long operations after traumatic injury. The paradigm has shifted from a single definitive operation to first controlling immediate life-threatening events, such as hemorrhage, and then following with a later reparative surgery once the patient has stabilized. This approach has resulted in improved survival in the first few hours after traumatic injury.

3) Under what circumstances should an abdomen remain open?

- Patients who are diagnosed with IAH or ACS should remain open. This has been extended to conditions other than trauma, such as sepsis and ruptured abdominal aortic aneurysm, resulting in opening of the abdomen as a life-saving maneuver for these critically ill patients.

4) What is the recommended resuscitation protocol to minimize elevation of IAP in trauma patients?

- There have not been any randomized, controlled trials that clearly indicate a specific fluid or specific protocol to be used in volume resuscitation. Until further research is done in this area, various protocols will continue to be used. The critical point is to closely monitor IAP and respond appropriately.

5) What is the best way to deal with massive bowel edema after a damage-controlled laparotomy?

- Vacuum pack and V.A.C.[®] Therapy are the 2 treatment choices that will actively remove fluid. There is no gold standard in the management of the open abdomen, but retrospective studies have shown some advantage of V.A.C.[®] Therapy in the management of the open abdomen. V.A.C.[®] Therapy delivers controlled, monitored, negative pressure and provides the safety of alarms and limited canister volume. V.A.C.[®] Therapy will also help promote granulation tissue formation at the wound edges due to the contact of the foam with the wound margins and will help approximate wound edges to allow closure of the fascia and abdominal wall.
- Refer to Table 8 for statistical significance of vacuum pack and V.A.C.[®] Therapy related to fistula rates and fascial closure rates.
- Gauze should not be used in the management of the open abdomen. Using gauze as a dressing has significant potential for complications related to its hydrophilic nature and the fact that it acts as a nidus for significant and uncontrolled bacterial growth.
- Negative pressure applied to open abdomens should be regulated to control pressure at the wound site, and controls should be utilized to warn the clinician and prevent exsanguination. Realistically, wall suction does not meet these criteria and should be avoided.

6) What are some tips on using V.A.C.® Therapy in an open abdomen?

- Use the V.A.C.® Abdominal Dressing System. If not using the dressing specifically indicated for this wound type, be sure to protect exposed bowel from exposure to air and potential desiccation, as well as damage due to abrasion by dressings. Failure to adequately protect exposed bowel by applying the V.A.C.® Abdominal Dressing System appropriately can potentially lead to fistula formation.

7) What are the optimal settings for V.A.C.® Therapy use in the open abdomen?

- Pressure should be initiated at 125 mmHg. For fluctuating fluid amounts, the pressure can be increased to 175 mmHg for copiously draining wounds and reduced to as low as 75 mmHg as drainage becomes controlled with V.A.C.® Therapy. Pressures may be titrated based on patient tolerance.
- Continuous therapy is recommended for the open abdomen in order to provide a splinting effect and gentle tension to the fascia to allow closure. Continuous therapy also helps prevent shifting of dressing materials, which could lead to bowel abrasion and subsequent fistula formation.

8) If the abdomen is skin grafted, what timing considerations are there for subsequent hernia repair?

- Consider waiting approximately 6 months for maturation before attempting to close the abdomen in order to allow the inflammatory process to subside and facilitate entry into the abdomen.

9) Does V.A.C.® Therapy cause fistulas?

- If the V.A.C.® Abdominal Dressing System is applied appropriately, the bowel is protected, and the risk of developing fistulas is minimal.
- Fistulas can develop if the bowel is exposed to air and allowed to desiccate, is abraded by dressings, or is deserosalized.⁶³ Fistulas are also caused by “biomaterial adherence” to the bowel, causing transmural changes to the bowel wall. If the bowel is fixed to the abdominal wall, perforation with sudden changes in abdominal pressure may occur.

10) In the case of fistula development, how can these open abdomens be managed?

- V.A.C.® Therapy has been shown to effectively treat wounds containing enteric fistulas. Specific techniques described in the literature can be applied to effectively close acute fistulas or to segregate effluent until surgical intervention is indicated.

11) What are the potential complications of using V.A.C.® Therapy in the open abdomen?

Bleeding:

- Precaution should be taken when using V.A.C.® Therapy for patients with active bleeding, and V.A.C.® Dressings should not be placed over exposed blood vessels or organs.
- Trauma patients with significant intra-abdominal injuries that require damage control procedures have an associated coagulopathy from hypothermia, acidosis, hypotension, dilution, and consumption of clotting factors, and these patients should be closely monitored.
- There is no reported data that V.A.C.® Therapy exacerbates intra-abdominal bleeding, and it can be an effective method to monitor ongoing bleeding or to detect new or increased bleeding. If sudden or increased bleeding is observed, immediately discontinue V.A.C.® Therapy. Take appropriate measures to stop bleeding and contact the physician. V.A.C.® Therapy dressings are not designed to prevent, minimize, or stop bleeding.

Foam retention:

- The maximum recommended dressing change interval for V.A.C.® Therapy is 48 hours. A reason this was established was to prevent large amounts of tissue ingrowth into the foam, which can prevent easy removal of the foam.
- Do not place V.A.C.® GranuFoam® Dressing into tunnels, sinus tracts, or undermined areas due to limited visibility and risk of not removing all components.
- Always count the total number of pieces of foam used in the dressing and document on the drape and in the patient’s chart.

12) What considerations, other than bladder pressures, should be considered when managing patients with open abdomens?

- Closely monitor fluid balance by keeping an accurate

intake and output log.

- Monitor hemodynamics closely to assess potential ACS and organ compromise.
- Utilize prophylactic antibiotics.
- Closely monitor serial labs including hemoglobin and hematocrit, electrolytes, liver enzymes, blood urea nitrogen and creatinine, arterial blood gases, and lactate levels. Also consider cultures if there are any concerns of sepsis.

Conclusions

The management of patients with open abdomens is an evolving concept. Review of retrospective data has shown that certain techniques for managing the open abdomen patient can be effective in treating IAH and ACS. An understanding of the pathophysiology is needed to understand the principles of management. The goal of therapy is to maximize tissue perfusion and minimize potential intra-abdominal complications, such as fistulas and hernias. Meticulous care of the bowel, minimizing trauma from techniques or systems used to cover abdominal contents, and protection of the bowel from exposure to the environment can reduce the complications associated with the open abdomen. A TAC device should not only protect the intra-abdominal contents, but facilitate primary closure of the fascia and minimize the need for secondary repairs of ventral hernias and subsequent repair. Serial bladder pressure monitoring should be a part of post-operative management protocols in high-risk patients, and decompression of the abdomen with a pressure of > 25–30 mmHg should be considered even without clear clinical evidence of ACS. While many closure techniques are reported in the literature, a dynamic closure device, such as V.A.C.[®] Therapy with the V.A.C.[®] Abdominal Dressing System, appears to have an advantage in meeting most requirements for managing an open abdomen.

Summary of Consensus Panel

1. The incidence of open abdomen use is increasing with the need for defined guidelines and approaches.
2. There is no gold standard in the management of the open abdomen, but retrospective studies have shown some advantage of V.A.C.[®] Therapy in the management of the open abdomen.
3. IAH and ACS remain the most significant considera-

tions for the management of the open abdomen.

4. IAH and ACS are in part iatrogenic and can be minimized with the appropriate resuscitation protocols.
5. Gauze should not be used in the management of the open abdomen. Using gauze as a dressing has significant potential for complications related to its hydrophilic nature and the fact that it acts as a nidus for significant and uncontrolled bacterial growth.
6. Abdominal dressings should be nonadherent to prevent the bowel from adhering to the abdominal wall, should allow for drainage of abdominal contents into a controlled system, and should facilitate primary closure of the abdominal wall once the patient is optimized. The panel agrees that if there is exposed bowel, a nonadherent interface or the V.A.C.[®] Abdominal Dressing must be placed over it prior to placing the V.A.C.[®] GranuFoam[®] Dressing in order to prevent fistula formation or other bowel damage.
7. Negative pressure applied to open abdomens should be regulated to control pressure at the wound site, and controls should be utilized to warn the clinician and prevent exsanguination. Realistically, wall suction does not meet these criteria and should be avoided.
8. Consideration for the type of closure is based on the patient's clinical status with the optimal result of primary fascial closure.
9. When the fascia cannot be closed, skin over granulation tissue is preferred to skin grafting over granulation tissue.
10. Complications found in patients with open abdomens may be minimized with V.A.C.[®] Therapy resulting in early closure of the abdomen.
11. V.A.C.[®] Therapy appears to provide the highest advantage in managing the open abdomen and is applicable to most phases of management of the open abdomen.
12. Further study is necessary to define patient populations, guidelines, and device application to optimize management of this class of patients.

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