Damage control in trauma and abdominal sepsis

Brett H. Waibel, MD, FACS; Michael F. Rotondo, MD, FACS

Damage control surgery, initially formalized <20 yrs ago, was developed to overcome the poor outcomes in exsanguinating abdominal trauma with traditional surgical approaches. The core concepts for damage control of hemorrhage and contamination control with abbreviated laparotomy followed by resuscitation before definitive repair, although simple in nature, have led to an alteration in which emergent surgery is handled among a multitude of problems, including abdominal sepsis and battlefield surgery. With the aggressive resuscitation associated with damage control surgery, understanding of abdominal compartment syndrome has expanded. It is probably through avoiding this clinical entity that the greatest improvement in surgical outcomes for various emergent surgical problems has occurred in the past two decades. However, with its success, new problems have emerged, including increases in enterocutaneous fistulas and open abdomens. But as with any crisis, innovative strategies are being developed. New approaches to control of the open abdomen and reconstruction of the abdominal wall are being developed from negative pressure dressing therapies to acellular allograft meshes. With further understanding of new resuscitative strategies, the need for damage control surgery may decline, along with its concomitant complications, at the same time retaining the success that damage control surgery has brought to the critically ill trauma and general surgery patient in the past few years. (Crit Care Med 2010; 38[Suppl.]:S421–S430)

Key Words: damage control; resuscitation; abdominal wounds; sepsis; trauma

Historically, application of the skill set used for elective surgery failed to obtain satisfactory results in the treatment of the severely injured patient, mainly because of the differences in physiology and anatomical issues between those patients. The multisystem trauma patient has the potential for severely destructive injuries across multiple organs and/or body spaces; this, and the ongoing bleeding and visceral contamination that occur until definitive care, can alter the patient’s physiology on presentation. In addition, the initial evaluation between these patients is fundamentally different, as the multisystem trauma patient may not have the physiologic reserve to undergo extensive evaluation and imaging commonly utilized with elective surgical patients. Furthermore, the shock state common in emergent surgical patients often precludes the patient from being able to provide a basic medical history. It is these fundamental differences of altered physiology, delay of presentation, complications from ongoing bleeding and contamination, and limited or absent preoperative medical history and evaluation that make the traditional attempt of definitive repair at presentation often futile. Ongoing bleeding from coagulopathy, initial physiologic failure from unresuscitable shock, and subsequent multiple organ system failure later in the patient’s hospital course present specific challenges that defy conventional therapy (1–3).

Although some discussion of the failure of traditional methods was made in the early 20th century, it was not until the early 1980s that the foundations of damage control were established. The work by H. Harlan Stone et al (4) in the early 1980s that the foundations of damage control were established. The work by H. Harlan Stone et al (4) in the early 1980s that the foundations of damage control were established. The work by H. Harlan Stone et al (4) in the early 1980s that the foundations of damage control were established. The work by H. Harlan Stone et al (4) in the early 1980s that the foundations of damage control were established. The work by H. Harlan Stone et al (4) in the early 1980s that the foundations of damage control were established. The work by H. Harlan Stone et al (4) in the early 1980s that the foundations of damage control were established. The work by H. Harlan Stone et al (4) in the early 1980s that the foundations of damage control were established. The work by H. Harlan Stone et al (4) in the early 1980s that the foundations of damage control were established.

Indications of Damage Control

The core concepts of damage control surgery evolved out of the failure of traditional approaches to exsanguinating hemorrhage from traumatic injury. In the traditional approach, definitive repair and closure of the abdomen were performed at the first surgery. Damage control involves termination of the initial laparotomy before the development of physiologic exhaustion, as noted by the development of acidosis, coagulopathy, and hypothermia (“the bloody vicious cycle”) (25). Instead, rees-
null
techniques for washing and transfusion to the patient. Note that these techniques remove the clotting factors, which can lead to a coagulopathy in a similar fashion as massive red cell transfusion.

Although specifics of operative intervention are described and argued elsewhere, some underlying themes can be elucidated (41). Identification and control of injured vasculature and bleeding solid organs are required. Suture ligation of vessels is commonly used along with control of the vascular pedicle of solid organs. Some solid organs can be killed if repair times would be prohibitively prolonged. Those vessels that provide supply or outflow to critical organs, such as the suprarenal vena cava and portal vein, require repair. Shunting techniques are possible to allow temporary restoration of flow during the resuscitation phase before definitive repair at a later time while decreasing ischemic injury (42–44). Abdominal packing is another technique to obtain hemorrhage control, especially with hepatic, retroperitoneal, and pelvic injuries. A host of hemostatic agents have become available over the last few years (45). Whereas human use is limited to case series, animal data do exist showing improved outcomes in hemorrhage control. Early generation agents, due to the large release of thermal energy, have led to burns of uninjured tissues (46).

Hollow viscus injuries, causing contamination, are the second critical component of this phase. Closure of the visceral wound with suture or stapling techniques can easily and quickly control ongoing contamination. Definitive repair is avoided in the unstable patient in order to proceed to resuscitation in the ICU.

Temporary abdominal closures can further decrease the time in the operating room. Use of the abdominal pack or vacuum-assisted abdominal dressing allows for rapid reentry into the abdomen at the same time preserving fascial integrity for latter definitive closure (47–51). In addition, effluent from the abdominal cavity can be managed and quantified to facilitate the ongoing resuscitation.

Part 2: Resuscitation

After control of ongoing hemorrhage and visceral contamination, the patient is transferred to the ICU for restoration of physiology by aggressive resuscitation with correction of hypothermia, acidosis, and coagulopathy. Adjuncts, such as angiographic embolization, may be needed to obtain hemorrhage control in inaccessible areas.

Fluid choice for resuscitation can have significant effects. Normal saline can lead to a hyperchloremic (nongap) metabolic acidosis (52–54), whereas animal models suggest the potential for proinflammatory mediator stimulation with lactated Ringer’s resuscitation. Colloids as an alternative resuscitative fluid lacks evidence of superior results compared with crystalloid, is more costly, and maybe even increases mortality in trauma patients (55–57). Hypertonic saline has shown in animal models to reduce inflammatory mediator activation but has failed to show improvements in mortality or morbidity in clinical trials (58–60). Isotonic crystalloids are used for the majority of resuscitations.

Currently, a debate over the best transfusion policies in patients requiring massive transfusion protocols (>10 units of packed red blood cells in the first 24 hrs) rages (20–23, 61–67). Many are now recommending a 1:1:1 platelet/plasma/packed red blood cell transfusion ratio compared with the traditional 1:4 to 1:5 plasma/packed red blood cell ratio. Although most civilian literature seems to support this aggressive transfusion protocol in a small group of trauma patients (1% to 3%), not

Figure 1. Damage control timeline. ED, emergency department; ICU, intensive care unit.
all studies have shown survival benefits. In addition, the optimal ratio of plasma to red blood cells has yet to be fully elucidated. Massive transfusion is not without complications (45). These include the potential for acute transfusion reactions and injuries, electrolyte disorders like hypocalcemia and hyperkalemia, acidosis, hypothermia, dilutional coagulopathy, and alteration of red blood cell morphology and oxygen-binding affinity.

Recombinant factor VIIa, as an adjunct in hemorrhage control from acquired coagulopathy of trauma, has been evaluated. Although multiple case reports exist with variable results, to date only one single, randomized, controlled trial has been done (68–73). The recent multicentered CONTROL trial was discontinued for futility due to low mortality rates (74). Overall, the medication seems to reduce transfusion requirements, especially if given early, and correct the coagulopathy profile, but mortality does not seem to be improved with its use. Also, the potential for thromboembolic events has been argued (75).

Although hypothermia has shown benefits with some elective surgical interventions, hypothermia on arrival in trauma patients has been reported almost uniformly to have negative consequences (76–82). Evidence of differences in energy metabolism/depletion in the hypothermic trauma patient exists compared with elective surgical patients (83, 84). Although hypothermia has some potential positive effects relative to cellular preservation, especially on the tissues of the central nervous system, a multitude of negative effects are noted. These include alterations in metabolism and drug clearance, altered renal function and diuresis, electrolyte disturbances due to ion shift and renal loss, and inhibition of the coagulation pathways and platelet dysfunction (85). Given the increased risk of death associated with hypothermia in trauma, rewarming is recommended. A multitude of noninvasive and invasive measures, including intravascular heat exchange catheters and body cavity lavage, exist (86).

In addition to hemodynamic issues, metabolic concerns abound in the unstable trauma patient. Electrolyte disturbances are common and should be corrected in an expedient manner. Hyperglycemia is more the rule than exception in these critically ill patients. Although aggressive insulin therapy for rigid glycemic control has become common since Van den Berghe’s landmark study (87) in 2001, more recent studies have given variable results (88–90). A recent meta-analysis found an increased risk of hypoglycemia and no survivability benefit with rigid glycemic control (91). When stratified into the type of patient, survival benefit was noted in the surgical population.

Although multiple end points of resuscitation have been described, no single test is perfect (92–94). Even after normalization of vital signs, the patients exhibit other evidence of inadequate tissue perfusion/oxygenation (95). Resuscitation should continue until resolution of the shock state by multiple methods of evaluation has occurred. The use of a right ventricular end-diastolic volume index pulmonary artery catheter can help guide the volume for resuscitation and direct pressor use in the difficult resuscitation (96, 97). In general, the patient can be resuscitated for return to the operating room in 24–48 hrs. Although normalization of vital signs occurs rapidly, the patient usually needs additional time to regain true physiologic reserve. In hypothermic trauma patients, the energy stores lag behind normalization of vital sign, even >24 hrs from the time of injury (83). Failure to regain a stable physiology in short order is an indication that ongoing bleeding is present or the patient is developing an ACS and will accelerate the return to the operating room for re-exploration before recovery of reserve.

Inappropriate ventilatory strategies are one area that can produce or extend injury. Based on the ARDSNet studies, the ventilator is a major inducer of pulmonary injury and acute respiratory distress syndrome, and a lung protective strategy of 4–6 mL/kg lean body weight should be used (98–101). Sedation and analgesia are commonly needed to promote patient-ventilator synchrony with these strategies (102). Few patients should require neuromuscular blockade to achieve synchrony. Neuromuscular blockade has not shown improvement in either mortality or oxygen consumption in acute respiratory distress syndrome but has been associated with higher incidence of myopathy and neuromyopathy, especially in asthmatics and patients with renal or hepatic dysfunction (103–106).

A common complication seen during the resuscitative phase is the development of ACS. Although it may be noted during the initial operation with increased visceral edema preventing the return of the visceral block to the peritoneal cavity, subsequent ongoing aggressive resuscitation can lead to delayed presentations of ACS (16). Routine monitoring for this clinical entity hallmark by increased pulmonary ventilatory pressure, oliguria, and hypotension in the presence of elevated intra-abdominal pressure is necessary and easily performed by bladder pressure measurements (107, 108). Delays in identification carry increases in morbidity and mortality, while decompression of the abdominal cavity improves perfusion and organ function (109, 110). With aggressive monitoring and treatment of ACS based on the World Society of Abdominal Compartment Syndrome guidelines, the mortality of patients with an open abdomen after severity adjustment approached that of patients without an open abdomen (32, 111).

Part 3: Definitive repair of injuries

After resuscitation, definitive repair can be undertaken (Table 2). Abdominal packing is removed, and a complete examination of the abdomen is performed. All injuries are identified, and any bleeding points are addressed. Uncontrolled hemorrhage, hemodynamic instability, or inability to undergo a prolonged operation would prompt an abbreviated laparotomy. Definitive repair of identified injuries, including reestablishment of intestinal continuity, is undertaken next. Some repairs can be considered that would not have been undertaken in a traditional, single operative setting. For example, isolated colon injuries have traditionally been treated with an ostomy. In a resuscitated patient, one might consider a primary anastomosis, especially if the patient would poorly tolerate the ostomy (112). Afterward, the abdomen is irrigated thoroughly.

Although percutaneously placed feeding access may be safe, stomas and tube enterostomies should be avoided if possible due to the potential for complications, as considerable changes in the geometry of the abdominal wall can occur (113, 114). Postpyloric nasoenteric feeding tubes can offer potential for continued feeding options even in patients undergoing multiple returns to the operating room. Although the initiation of enteral feeds should be delayed in unstable patients due to the potential for intestinal ischemia, enteral feeding should be started shortly after normal physiology is restored and proven to be stable. Early enteral feeding in the open abdomen (115) represents a potential strategy to reduce the risk of an ACS.
abdomen is feasible and associated with reduced septic complications (115–117). It is also associated with earlier primary fascial closure, lower fistula rates, and decreased cost compared with later enteral (>4 days) feeding in one study of open abdomens (118).

Consideration of a tracheostomy should be made at the time of definitive repair (119–122). Acute lung injury and acute respiratory distress syndrome usually manifest themselves during the initial hospital period, and disruption of the ventilator circuit after onset of pulmonary dysfunction can have devastating consequences. Early placement of a tracheostomy in select patients can create a more secure airway during this time. In addition, early tracheostomy may decrease time of ventilator use and ICU stay, but care should be taken in evaluating this literature due to a high degree of misclassification (123).

Part 4: Open abdominal wounds and definitive closure of the abdomen

As a result of the aggressive resuscitation used with damage control at present, definitive closure of the abdomen can be complicated. Approximately 40% to 70% of patients cannot have primary fascial closure immediately after definitive repair (49, 50, 124). Temporary closures are needed for patients undergoing repeated operations and those with a distended visceral block. Increases of airway pressure of >10 mm Hg from baseline while closing the abdomen indicate a significant amount of edema remains and the abdomen should not have fascial closure at that time.

A host of temporary closure methods are available to choose from (Table 3) (47–49, 51, 124–126). Optimally, the temporary closure should contain the viscer a at the same time preventing further contamination of the peritoneal cavity or visceral injury. It should seal the abdomen and control effluent from the wound to preserve skin integrity. Undue tension across the closure should be avoided to prevent increases in intra-abdominal pressure and subsequent ACS. Finally, the fascial integrity should be maintained for use later with definitive closure.

Initially, temporary closures involving skin closure techniques, silo placement, or vacuum pack techniques are most commonly employed. Although skin closure techniques using suture or towel clips are the easiest closures that avoid fascial injury, the closure is rarely watertight and creates radiographic artifacts that can complicate such adjuncts. Silo placement (Bogota bag) has declined in recent years due to the dynamic properties of the vacuum-assisted abdominal closures (125, 127–129). The vacuum pack dressing (Barker technique abdominal dressing) can be easily created from commonplace surgical supplies (Fig. 2) (47–49). Commercial vacuum-assisted dressings exist that facilitate fluid collection at the same time providing continuous medial traction on the fascial edges to help prevent loss of domain (Fig. 3).

If definitive closure is delayed further, other techniques are commonly employed, such as sequential closure with use of temporary abdominal dressings in the remaining defect. Vacuum-assisted dressings are often used in conjunction with interpositional meshes (130). Decreases in organ system failure, ACS, necrotizing fasciitis, and fistula formation have been noted in different patient populations with the interpositional meshes (131–133). No single mesh is perfectly ideal. Some are prone to tearing due to low tensile strength, whereas others have higher tensile strength but induce an inflammatory reaction associated with higher fistula rates.

Closure rates vary greatly in the literature (134). Interpositional mesh closures have rates from 22% to 88%, with most of the literature in the lower portion of that range (126, 131, 135–137).

---

Table 2. Sequence of definitive repair

1. Careful removal of packs
2. Inspection/identification of all injuries
3. Control of remaining errant bleeding points
4. Definitive gastrointestinal repair
5. Thorough abdominal washout
6. Avoid stomas and tube enterostomies, if possible
7. Nasoenteric feeding tube placement
8. Closed suction drainage, if needed
9. Temporary versus definitive abdominal wound closure
10. Tracheostomy, if needed
11. Radiographic evaluation of abdomen for retained packing

Table 3. Closure of open abdominal wounds

1. Immediate Term
a. Skin closure only
b. Vacuum pack abdominal dressing
2. Intermediate Term
a. Sequential fascial closure
b. Sequential skin closure
c. Interpositional mesh placement
d. Vacuum-assisted abdominal dressing
3. Long Term (Planned Ventral Hernia)
a. Interpositional Vicryl mesh placement followed by split-thickness skin grafting and abdominal wall reconstruction

---

Figure 2. Vacuum pack abdominal dressing (Barker technique abdominal dressing).

Figure 3. KCI Vacuum-Assisted Closure System on open abdominal wound demonstrating polyurethane sponge.
Vacuum-assisted techniques range from 29% to 100%, with most studies in the higher end of the range (49, 50, 125, 134, 138–141). Only one prospective study (142) has compared interpositional mesh with vacuum-assisted abdominal dressings and found no difference in fascial closure rates between mesh and vacuum-assisted techniques (26% vs. 31% respectively). More complex closures with fascial releases or permanent synthetic meshes are avoided at this stage. They carry increased infection and wound complication rates while complicating or preventing further abdominal wall reconstruction techniques, such as component separation, at later dates (51).

For those patients in whom definitive closure is not possible, a planned ventral hernia is an acceptable fallback position. A split-thickness skin graft is applied to the open wound to obtain coverage. After 6–12 months, the underlying viscera will fall away from the skin graft, allowing for abdominal wall reconstruction at that time, using a variety of techniques (143–145). Allograft meshes have begun to be used to help bridge remaining defects, but long-term outcomes are unknown (146–148). However, the potential for tissue regeneration and resistance to infection compared with permanent synthetic makes these meshes potentially superior in the future.

Before definitive abdominal closure is obtained, a radiographic evaluation of the abdomen is made, because closing counts cannot be trusted from the initial operations due to use of packing. An abdominal film allows us to confirm retained foreign bodies are not present and provides for a permanent record of complete pack removal.

### Complications

Given the presentation of the patient in extremis, missed injuries have a higher potential to exist. Repeated examinations can help ameliorate some of these issues, but a thorough evaluation of the abdomen during surgery is needed (149, 150). Damage control is not a substitute for complete injury identification and control. Intra-abdominal infection rates, which probably relate to the length of time abdominal packs are retained, vary from 10% to 70% (151–153). Although more frequent washouts seem to reduce abscess formation, the risk of fistula formation increases with bowel manipulation. Weekly abdominal computed tomography scans may be necessary in patients with persistent leukocytosis or fever.

Enterocutaneous fistula formation depends on several factors, including the extent of bowel manipulation and closure technique of the abdomen. Fistula rates generally vary between 1% and 15%, but higher rates have been noted (124, 142, 154, 155). Fistula with open abdomen tends to be more aggressive enterostomal fistula that occurs within the granulating wound bed with lower nonsurgical closure rates than typical fistula (approximately 25%) (126). In addition to standard therapies of bowel rest and total parenteral nutrition, control of the caustic effluent is paramount. Many techniques exist in the literature beyond use of frequent dressing changes and suction drains, but all fall short of ideal (156–161). If control of the effluent can be achieved, a skin graft may be beneficial for placement of an enterostomal appliance, and the fistula can be managed as an ostomy. Closure of these fistulas is routinely delayed until abdominal wall reconstruction and is associated with increased morbidity and complications (162).

### Damage Control and Abdominal Sepsis

Damage control and open abdomen techniques from trauma have quickly been adopted for emergency surgery. When unable to obtain source control due to patient instability or need for further intra-abdominal debridement, the open abdomen technique allows for the ability to have rapid, easy ingress to the peritoneal cavity, peritoneal toilet, and effective drainage of the peritoneal cavity with control of effluent (17). However, study results (18, 163–167) vary concerning mortality between the open and closed abdomen. The studies to date have generally been small and often contained mixed populations of abdominal sepsis, trauma, and ACS. It is probably the prevention of ACS, which is common in this setting, that has most influenced the use of the open abdomen after an operation for peritonitis.

Some alterations to the sequence need to be noted for abdominal sepsis. The patient with an intra-abdominal catastrophe without hemorrhage needs initial stabilization of vital signs with resuscitation before operative intervention. Once physiology has been reestablished, which can generally be done in a few hours with aggressive resuscitation, the operation is performed with the goal of source control and wide drainage of the process. If repeat operations are needed for debridement or source control, significant visceral edema is present preventing closure without development of ACS, or patient instability and need for further resuscitation would have high risk of creating an ACS, then a temporary abdominal closure is used. Again, resuscitation is performed at that time with close monitoring for the development of a distributive shock, which is common and generally self-limiting to a few days after surgery for abdominal sepsis. The open abdomen can be managed with any of the techniques described, but vacuum-assisted techniques are becoming commonplace. Fascial closure rates, however, may be lower than that found in traumatic injury (168). Overall however, many of the concerns in management of the trauma patient undergoing damage control surgery and the abdominal sepsis patient during the resuscitative phase and management of the open abdomen are similar. The skill sets needed for the treatment of one can often be extended to the other patient type.

### REFERENCES

controlled trial. Arch Surg 2008; 143: 139–148
88. Schreiber TC, Boyle WA III: Lung injury caused by mechanical ventilation: Patients with acute respiratory distress syndrome are not the only ones at risk. Contemp Crit Care 2005; 3:1–11
91. Hall JB, Schweickert W, Kress JP: Role of analgesics, sedatives, neuromuscular block-