17 Damage Control Phase III: Repair of All Injuries, General Surgery

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17.1 Goals and Timing of Damage Control Phase III

The primary goals of the third phase of damage control surgery (DC III) are to achieve definitive repair of organ injuries and to close the fascia over surgical wounds where possible. Although the optimal timing is variable and dependent on numerous patient factors, DC III is typically undertaken 24–36 h after the initial surgery. This time is needed for appropriate resuscitation, allowing the patient to reestablish proper homeostasis. The patient will thereby tolerate the longer operative time and more extensive intervention(s) that may be necessary to definitively repair the injuries sustained. Specifically, the decision to proceed with DC III should not be undertaken until the patient's coagulopathy has been corrected and he/she is normothermic and has a normal acid-base balance. Additional considerations such as vasopressor requirements also impact on the timing and probability of success of DC III. Ideally, patients should be weaned off of vasopressors entirely or, at a minimum, their pressor requirements should be decreasing. Ongoing physiologic instability or hypothermia despite appropriate medical therapy should raise concern for a missed injury. Definitive repair should be delayed but early operative re-exploration to evaluate for missed injury may be warranted. On-demand repeat laparotomy in these cases can decrease patient mortality [1].

Some notable scenarios exist wherein earlier timing of definitive repair is potentially favorable. For example, in peripheral vascular injury, thrombosis of a temporary shunt and subsequent potential for tissue loss may motivate earlier initiation of DC III. There are no studies assessing the maximal time that bowel segments can be left in discontinuity, but most trauma surgeons recommend creation of anastomoses or stoma to decompress isolated segments of the intestine no later than 96 h following DC I. It is logical to assume that earlier anastomosis or creation of a stoma is preferred, as long as the patient has been appropriately resuscitated and normal physiologic milieu reestablished.

17.2 Repair of Injuries: General Considerations

Once in the operating room, the patient should be positioned, prepped, and draped to ensure adequate exposure of all injuries to be addressed. This may include extremity exposure sufficient to allow proximal and distal control of vascular injuries and to allow for autologous vein harvest. In cases where a single position to undertake all

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necessary repairs is not possible, phases of the operation should be planned preoperatively. The surgeon can also elect to stage the procedures based on the patient's physiologic reserve and status. Communication and coordination with the anesthesia team both before and during the operation are vital in making these decisions, and the surgeon must be prepared to adjust the operative plan if the patient shows signs of instability.

17.3 Repair of Vascular Injury

Vascular repair in DC III involves removal of shunts placed in DC I and placement of interposition grafts. Although vascular surgery can be consulted to assist with definitive repair, excellent outcomes have been reported following vascular repair by experienced trauma surgeons [2]. As with elective vascular operations, proximal and distal control is obtained using atraumatic clamps. Next, the vessel wall should be inspected for damage to the intima or muscular layers and should be debrided as necessary. The portion of the vessel that was used to tie and fix the shunt in place should be resected. If the ends of the vessel are not long enough to support a tension-free end-to-end anastomosis, an interposition graft should be fashioned. Prior to completion of the anastomosis, care should be taken to remove any intraluminal thrombus. The proximal vessel is allowed to bleed for several pulses, while the distal vessel may be allowed to backbleed in order to remove thrombus. A Fogarty balloon catheter should be used to remove clot. The full technique for performing a vascular anastomosis is standardized, and full details are beyond the scope of this chapter. Use of extraanatomic bypass may be necessary when autologous sources are unavailable and contamination is severe.

The choice of conduit is an important consideration in planning repair of vascular injuries. The choice between autologous conduit (commonly a reversed saphenous vein graft) and synthetic alternatives such as polytetrafluoroethylene (PTFE) remains controversial. Data regarding where synthetic grafts can be safely used following damage control surgery are conflicting, and there are no definitive, well-designed trials upon which to base strategy. In a review of surgical experiences surrounding the Korean and Vietnam conflicts, synthetic grafts were found to have a 77% complication rate and a higher incidence of amputation than vein grafts (31% vs 18%) [3]. The small numbers of prosthetic grafts placed and high energy wounding patterns limited this review. A study of 206 patients with vascular trauma demonstrated that PTFE had lower rates of long-term patency than autologous grafts, but that infectious complications only occurred in the setting of exposed graft and concomitant osteomyelitis [4]. Similarly, a small study using a canine model and a small number of trauma patients found that the use of vein conduits in contaminated wounds was associated with a greater incidence of vascular disruption than PTFE; however, the small numbers involved in the study limit its generalizability [5]. In a subsequent retrospective review, Mitchell and Thal concluded that fears of anastomotic dehiscence following infection of vein autograft were overstated and found vein to be a safe conduit in vascular trauma [6].

In the absence of definitive data comparing synthetic with autologous grafts in trauma patients, the choice of conduit should be informed by careful consideration of patient factors, which include the caliber of the damaged vessel, location (extremities versus trunk), and amount of contamination present within the wound. Large vessels can be treated with either prosthetic graft or cadaveric homografts [7, 8]. While use of synthetic grafts allows for speedier operation and obviates the need to create more wounds, use of autologous material or homograft may be associated with lower infection and therefore anastomotic dehiscence rates. Regardless of the choice of conduit, every attempt should be made to cover the anastomosis in order to prevent complications such as pseudoaneurysm formation or actual free disruption and life-threatening hemorrhage.

17.4 Repair of Injuries: Solid Organ Abdominal Injuries

Following removal of the temporary abdominal closure device, the abdominal contents should be carefully inspected with particular attention paid to

any repairs made during the index operation and for identification of possible missed injuries. Special consideration is required in patients following ballistic injuries as the zone of injury can extend beyond the direct path of the projectile, resulting in a delayed manifestation of the true extent of injured tissue. This may necessitate further bowel resection to allow for safe anastomosis.

Similarly, the severity of pancreatic injury may be better assessed during this phase because small volume leak from the pancreatic substance will manifest as saponification. This finding will frequently lead the trauma surgeon to drain the pancreatic bed or consider pancreatic resection, depending on the nature of the injury and timing since injury [9].

Severe hepatic injury is often initially managed with packing and embolization or ligation of bleeding vessels. At the time of DC III, depending on the location and severity of the injury, resection of devitalized segments of the liver may be necessary. Whereas most surgeons avoid hepatic resection as much as possible, one study found that an aggressive debridement strategy resulted in a significant decrease in the overall number of procedures as well as complications. However, this approach was also associated with a significant risk of intraoperative hemorrhage [10]. At the least, the presence of devitalized hepatic tissue or deep laceration should raise concern for a postoperative bile leak or abscess, and the region should be drained preemptively.

The right hemidiaphragm should be inspected in any injury pattern that includes significant hepatic injury. Diaphragmatic defects should be repaired as best as possible in order to decrease the risk of biliopleural fistula [11]. Although rare, formation of a biliopleural fistula is associated with the need for prolonged tube thoracostomy and possible respiratory failure due to inflammation of the lung [12].

17.5 Repair of Gastrointestinal Injury

The repair of gastrointestinal injuries during DC III is a complex issue. Although creation of a small bowel anastomosis is generally considered to be safe and appropriate in DC III, creation of an anastomosis involving the large intestine requires careful consideration. Overall, the literature favors primary repair and the creation of delayed anastomosis after damage control laparotomy but with due consideration of known risk factors for anastomotic leak. In one meta-analysis of randomized controlled trials, primary repair had lower morbidity and procedure-related cost than diversion with no difference in mortality [13]. A similar multicenter prospective randomized study of 297 patients found no difference in abdominal complications between the ostomy and primary anastomosis groups, irrespective of associated risk factors [14]. A single-institution review of patients with colonic injury following penetrating trauma found that 81% were successfully treated with delayed anastomosis of their injuries following damage control laparotomy but found that persistent metabolic acidosis or intraabdominal contamination were risk factors for leak [15]. Other smaller studies also support this finding, demonstrating that delayed anastomosis and immediate anastomosis have similar complication rates [16]. Recent military data also have shown no difference in complications between delayed anastomosis and diversion [17]; however, one study found lower complication rates in patients treated with an immediate ostomy than those who underwent damage control [18]. Conversely, other studies have found that delayed colonic anastomosis has higher complication rates than seen with anastomoses created in a single laparotomy, suggesting that the open abdomen is particularly deleterious to the viability of colonic anastomoses [19–21]. Although there is no clear consensus, overall these studies suggest that delayed anastomosis is a viable and safe management strategy for colonic injury within the damage control sequence.

Following creation of an anastomosis, studies suggest a significant risk of enteral leak if the abdominal wall is not closed. While a perceived inability to definitively close the abdomen should not rule out anastomosis during DC III operations, the risk of leak and fistula formation with a persistent open abdomen must be taken into consideration. If the abdomen is left open following

definitive repair of bowel injury, conventional teaching involves attempting to minimize these risks by covering anastomoses with omentum or bowel. Studies supporting this intervention involve esophageal anastomoses [22]; there are no studies upon which to base this strategy following damage control operation.

Potential for abdominal closure is not the only important determinant of optimal surgical management of bowel injuries. The decision between creation of an anastomosis during DC III and formation of an ostomy should be undertaken after consideration of the patient-specific risk factors. Factors such as the presence of significant medical comorbidities, tobacco use, and malnutrition present well-known risks for anastomotic leaks [23–25]. Other risk factors that are especially relevant to trauma patients and to patients undergoing damage control laparotomy include ongoing malperfusion due to sepsis, cardiopulmonary failure, or any other cause as well as perioperative blood transfusions [26]. Unfortunately, there are few studies evaluating risk factors specifically due to delayed anastomosis following injury. Demetriades et al. found that anastomotic leak was increased in penetrating trauma patients with severe fecal contamination, transfusion of four or more units of blood within the first 24 h, and in those who received single-agent antibiotic prophylaxis perioperatively [27]. Another study of patients undergoing colon resection for cancer found that the probability of leak was independently associated with the American Society of Anesthesiologists grade and need for emergency operation [28]. Similarly, perioperative vasopressor requirements are associated with a more than fourfold increase in anastomotic leak rates [29]. These findings underscore the importance of appropriate timing of DC III operations. If patient risks cannot be adequately managed in a timely fashion, bowel anastomosis should not be undertaken at the time of DC III operations, and instead an ostomy should be formed with closure of the abdomen. Alternatively, the timing of DC III should be delayed.

Patients with traumatic brain injury rely on maintenance of normal cerebral perfusion pressure, and in these patients any septic insult and subsequent depression of blood pressure can be especially deleterious. Because of their inability to tolerate the possible septic complications of an anastomotic leak, patients with TBI and risk factors for leak should be managed with an ostomy rather than attempt at anastomosis during DC III operations. Similarly, elderly or chronically ill patients with little physiologic reserve are less likely to survive the septic complications of an anastomotic leak, and preference should be given to formation of an ostomy in these cohorts.

The anatomic location of the injured bowel is important in determining whether to attempt anastomosis. Proximal small bowel injuries should be managed during DC III with anastomosis whenever possible in order to maximize the amount of bowel available for absorption and to reduce complications related to malnutrition and electrolyte shifts during recovery. Although not specific to trauma, the colorectal surgical literature demonstrates higher leak rates for low colonic and rectal anastomoses, suggesting that these injuries should be treated with creation of an ostomy or at least protected initially by a proximal diverting stoma [26]. Similarly, left-sided anastomoses present a risk factor for anastomotic leak [19].

Creation of a stapled versus hand-sewn anastomosis during DC III remains controversial. One multicenter retrospective study showed a slight increase in leak rates for stapled anastomoses in trauma patients [30], and another study showed a more than twofold increase in risk for anastomotic leak in stapled anastomoses in emergency general surgery patients [31]. The possible reason to account for this involves bowel edema which may preclude adequate sealing of the two loops of the intestine using a stapler. However, a prospective multicenter study of trauma patients showed no difference in outcomes between the two techniques [27]. Furthermore, while not specific to trauma patients, one randomized prospective study of 652 patients found no significant difference in leak rates between stapled and hand-sewn anastomoses [32], and a larger prospective study of 1,417 patients with anastomoses above the peritoneal reflection also found no difference in leak rates [28]. Ultimately, the

surgeon's technical proficiency with each technique should determine the operative approach to anastomosis with the understanding that the operative strategy must be tailored to the patient and the condition of the tissues.

If creation of an anastomosis during DC III is ruled out based on any of the above factors, stoma formation should be undertaken. When creating an ostomy, the site should be chosen in order to minimize potential for fecal contamination of the midline laparotomy wound and subsequent necrosis of the abdominal fascia. Choice of an ostomy site 3–4 cm lateral to the lateral edge of the rectus abdominis muscle in order to reduce proximity to the midline laparotomy wound may help to minimize risks associated with spillage of intestinal contents into the surgical wound and will facilitate application of stoma appliances without interfering with midline wound dressings. Furthermore, such lateral placement of stomas will facilitate component separation closure of the abdominal wall should the patient develop a hernia.

Lastly, consideration for placement of feeding tubes or tubes to decompress the alimentary tract is appropriate during this phase of damage control operation. The overall care plan must now also include how to allow the patient to convalesce. Durable enteral feeding access should be considered prior to abdominal closure as gastrostomy or jejunostomy tube placement may be risk prohibitive after DC III. When placed, the tubes should exit the abdominal wall well away from the lateral border of the rectus abdominis muscles so as to minimize risk that a leak will contaminate the midline wound. In addition, as discussed above, leaving the medial border of the external oblique muscle unviolated facilitates a later component separation operation.

17.6 Abdominal Wall Closure

Once all necessary operative goals are met, definitive abdominal closure should be attempted as quickly as possible to minimize the deleterious effects of an open abdomen. The length of time the abdomen is left open correlates directly with the incidence of complications and is inversely related to the probability of primary fascial closure [33]. If repeated attempts at fascial closure are unsuccessful, the abdominal wall should be closed using an inlay mesh or via intentional creation of a ventral hernia with skin-only closure. Planned future ventral herniorrhaphy may be necessary with either technique.

Primary fascial closure is the optimal method for closing the abdomen. This technique involves the direct approximation of the fascial edges and has the lowest incidence of hernia and enterocutaneous fistula formation following damage control laparotomy. Although complications are less likely with primary fascial closure, care must be taken to avoid excessive tension on the abdominal wall, as this can precipitate failure of the closure or may predispose patients to development of abdominal compartment syndrome [34]. Although it is the preferred method for abdominal wall closure, a ventral hernia will develop in up to 30% of these patients [35]. Although not studied well, primary fascial closure can be augmented with mesh reinforcement in an attempt to lower this risk [36, 37]. Permanent, synthetic meshes are relatively contraindicated in patients with risk factors for mesh infection such as wound soilage, and many authors recommend use of biologic mesh in these instances. More advanced techniques of fascial closure such as a separation of abdominal wall components laterally to allow for direct apposition of the fascia at the midline may be used, but a detailed discussion of these methods is beyond the scope of this chapter [38, 39].

If primary fascial closure is not possible, an alternative is functional closure by placing a mesh inlay as a bridge between the edges of the fascia. Most commonly, a biologic mesh is used due to concern about infection. The mesh acts as a scaffolding for ingrowth of native fascial tissue [40]. Once the mesh is placed, the skin is closed and drains can be placed to prevent seroma accumulation as needed. Unfortunately, the natural evolution of an inlay placement of biologic mesh is development of a "neo-hernia" due to stretching of the mesh over time. This can lead to patient dissatisfaction and need for repeat operative

repair. While the late incidence of ventral hernia formation after functional closure is not well established, one study using acellular dermal matrix found an 80% incidence over a mean follow-up of 21.4 months despite skin closure over the mesh [41].

If skin closure is not possible, inlay placement of biologic mesh should be avoided as exposed mesh will undergo degradation and dissolution until it is replaced by granulation tissue over the viscera. Rather, a less expensive dissolving mesh, such as Vicryl™, can be used. This process usually occurs over 3–6 weeks. The resultant granulation tissue will require skin grafting and will ultimately lead to a ventral hernia which can be repaired in 8–12 months when the inflammatory process in the abdomen has resolved and the viscera are again mobile [42]. This delayed ventral herniorrhaphy is frequently referred to as DC IV. The granulation phase, prior to skin grafting, is associated with up to 20% risk of developing an entero-atmospheric fistula formation. As noted above, this risk is highest in patients with an exposed anastomosis [43].

Conclusion

In conclusion, DC III refers to the phase of damage control related to definitive repair of injuries and closure of surgical incisions and wounds. The timing and method of repair need to be customized to each patient by taking into account patient- and injury-specific factors that impact on the probability of success.

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