Damage control surgery in emergency general surgery: What you need to know

William B. Risinger, MD *and* **Jason W. Smith, MD, PhD***, Louisville, Kentucky*

ABSTRACT: Damage-control surgery (DCS) is a strategy adopted to limit initial operative interventions in the unstable surgical patient, delaying definitive repairs and abdominal wall closure until physiologic parameters have improved. Although this concept of "physiology over anatomy" was initially described in the management of severely injured trauma patients, the approaches of DCS have become common in the management of nontraumatic intra-abdominal emergencies. While the utilization of damage-control methods in emergency general surgery (EGS) is controversial, numerous studies have demonstrated improved outcomes, making DCS an essential technique for all acute care surgeons. Following a brief history of DCS and its indications in the EGS patient, the phases of DCS will be discussed including an in-depth review of preoperative resuscitation, techniques for intra-abdominal source control, temporary abdominal closure, intensive care unit (ICU) management of the open abdomen, and strategies to improve abdominal wall closure. (*J Trauma Acute Care Surg.* 2023;95: 770–779. Copyright © 2023 Wolters Kluwer Health, Inc. All rights reserved.)

Although damage-control methods have been utilized by surgeons for over a century, it was not until the 1980s when damage-control surgery (DCS) began to take shape. In the setting of intraoperative coagulopathy, Stone et al. demonstrated the benefit of a shortened laparotomy that only addressed life-threatening hemorrhage, delaying complete surgical repair and abdominal closure.[1] This methodology emphasized a "physiology over anatomy" approach centered on preventing exsanguination while maximizing resuscitation and reversal of physiologic derangement.[2]

Damage-control strategies soon proliferated in trauma centers nationwide in response to increased injury severity and further comprehension of the lethal triad. At this time, hypothermia, acidosis, and coagulopathy became the key indications for DCS.[3] In the early 1990s, Rotondo et al. officially coined the phrase "damage-control surgery" and established the contemporary stages.[3] Following the success of damage-control techniques in the management of trauma, DCS soon transitioned to emergency general surgery where it remains an essential technique today.[4]

While the tenets of DCS are readily transferable to nontraumatic pathology, the overall outcomes in the two populations are distinct. The use of DCS in the management of intra-abdominal sepsis (IAS) has been shown to result in reduced rates of primary fascial closure (PFC), increased intra-abdominal complications, and a higher 90-day mortality rate when compared to its utilization following traumatic injury.[5] As such, knowing when and how to implement damage control methods in the EGS patient is of the utmost importance and is the topic of this review.

Various nomenclature is used in the description of DCS. For the purposes of this review, the terms open abdomen (OA), temporary abdominal closure (TAC), second-look laparotomy, and delayed fascial closure are all considered methods of damage control.

INDICATIONS FOR DAMAGE CONTROL TECHNIQUES IN EMERGENCY GENERAL SURGERY

The decision to perform a damage control procedure in nontraumatic abdominal crises is complex and continuously evolving. In general, DCS should be considered in patients with profound physiologic derangement, select cases of intra-abdominal sepsis, in those with intestinal ischemia who require a "second look" to evaluate intestinal viability, and in circumstances in which profound bowel distention prevents fascial closure (Table 1).

PHYSIOLOGIC DERANGEMENT

As DCS was created to address profound physiologic derangement seen in the traumatically injured, the use of the lethal triad as an indication for damage control in nontraumatic intra-abdominal pathology is intuitive. Although intra-abdominal septic and hemorrhagic shock have distinct pathophysiology, the presence of acidosis, hypothermia, and coagulopathy remain markers of decompensated shock, regardless of inciting etiology. Significant shock indicators (temperature, <34°C; pH, < 7.2; lactic acid, >5; base deficit, >15; and coagulopathy) define patients who are unlikely to tolerate a definitive operation who should be managed with damage-control techniques. In addition, severe hemodynamic derangement including systolic blood pressure <90 mm Hg, operational blood loss >4 L, increasing vasopressor/inotropic requirements, and the use of >10 units of blood product or 12 liters

Submitted: June 20, 2023, Revised: July 3, 2023, Accepted: July 5, 2023, Published online: July 14, 2023.

From the Department of Surgery, University of Louisville School of Medicine, Louisville, KY.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site (www.jtrauma.com).

Address for correspondence: Jason W. Smith, MD, PhD, MBA, University of Louisville School of Medicine, Department of Surgery, 550 South Jackson St, Louisville, KY 40202; email: jasonw.smith@louisville.edu.

DOI: 10.1097/TA.0000000000004112

TABLE 1. Indications for DCS in Nontraumatic Abdominal Pathology

(1) Physiologic Derangement	Evidence of Persistent Acidosis, Hypothermia, or Coagulopathy Despite Adequate Resuscitation and Source Control (Lethal Triad): ▪ pH < 7.2, Base Deficit >15, Lactic Acid >5 ▪ TEG, PT/INR > 2, Intraoperative Visualization of Nonsurgical Bleeding ▪ Temperature < 34° C Evidence of Persistent Hemodynamic Instability Despite Adequate Resuscitation and Source Control: ▪ Systolic Pressure <90 mm hg ▪ Operational Blood Loss >4 L ▪ Utilization of >10 Units of Blood Product OR > 12 L of Crystalloid ▪ Increasing Vasopressor or Inotropic Requirements
(2) Intra-Abdominal Sepsis	The routine use of an OA for IAS should be avoided. Specific indications in which DCS should be considered: ▪ Inability to obtain complete source control or high suspicion for recurrent/persistent intra-abdominal infection despite presumed source control ▪ Inability to safely perform GI tract reconstruction ▪ Significant uncertainty regarding intestinal viability
(3) Intestinal Ischemia	The routine use of a "second look" laparotomy in the management of intestinal ischemia is generally recommended, particularly in the following situations: ▪ Physiologic derangement ▪ Findings of IAS from perforated viscous or necrotic intestine ▪ Significant uncertainty regarding intestinal viability
(4) Profound Bowel Distention & Abdominal Compartment Syndrome (ACS)	Regardless of etiology, diffuse bowel distention may require an OA approach due to: ▪ Physical inability to reapproximate the midline fascia ▪ Development of ACS symptoms (ex. new or worsening hypotension, increased peak airway pressures) ▪ Significant concern for eventual ACS development in the postoperative setting if primary fascial closure performed

of crystalloid can also be used as indications for a damage-control procedure.[6]

Although preoperative findings of decompensated shock can be used to identify DCS candidates, the intraoperative trend in shock indicators (ex. base deficit, pH, urine output, etc.) should guide decision making. Persistent acidosis, hypotension, hypothermia, and/or coagulopathy despite adequate resuscitation and source control all indicate the need for damage-control techniques. By contrast, those with improving physiology may benefit from definitive surgical repair and abdominal closure during the index operation.

INTRA-ABDOMINAL SEPSIS

Outside of overt physiologic derangement, the indications for DCS become less defined. While the application of DCS has been demonstrated in a wide variety of nontraumatic pathologies (ex. abdominal compartment syndrome, ruptured abdominal aortic aneurysm, necrotizing pancreatitis, and abdominal wall necrotizing soft tissue infections), the use of damage-control methods in intra-abdominal sepsis has generated significant debate.[7] Driven by inflammation or perforation of the gastrointestinal (GI) tract, severe IAS can result in diffuse peritonitis, septic shock, and multisystem organ failure.[8]

Surgical strategies for severe IAS have historically consisted of three approaches: on-demand relaparotomy, planned relaparotomy, and an OA with reexploration. On-demand relaparotomy is a single-stage approach in which definitive surgical repair and closure occurs during the index operation. A second, "on-demand" laparotomy is only performed if clinically mandated. By contrast, in the planned relaparotomy approach, the abdominal wall is still closed during the index operation, but patients return to the operating room in 24 hours to 72 hours regardless of clinical status. Subsequent takebacks are performed until the abdomen is clinically negative for ongoing signs of infection.

Proponents for this approach cite the high risk of failed source control in which the incomplete removal of the intra-abdominal infection (IAI) predisposes patients to ongoing clinical deterioration. It is well known that even with adequate source control during initial exploration, patients with diffuse contamination often suffer from recurrent or persistent disease.[9] A planned relaparotomy theoretically allows for quicker identification of residual infection and for expeditious intervention.[10] However, studies have noted that up to 66% of planned relaparotomies are negative for additional intra-abdominal septic findings.[11] As such, an on-demand relaparotomy strategy may prevent unnecessary surgical interventions. The shortcomings of the on-demand approach arise when providers fail to identify patients with persistent IAI or subtle clinical deterioration who require relaparotomy. Unfortunately, it has been demonstrated that the specific etiology of IAS as well as the operative findings during the index case do not predict patients who ultimately will require an additional intervention.[12]

Given the reasonable benefits from both strategies, studies have attempted to identify whether a planned or on-demand relaparotomy approach provides a survival benefit. In a landmark randomized control trial of patients with severe peritonitis, no significant difference in mortality at 12 months was found between the groups. However, both hospital length of stay (LOS) and cost were statistically lower in the on-demand relaparotomy arm.[11] These results align with multiple other studies that have all demonstrated improved or equivalent outcomes with decreased cost using an on-demand approach to reoperation.[13,14] As a result, the planned relaparotomy approach to IAS has largely been abandoned.

The final surgical approach to IAS is the OA with reexploration. Although similar to a planned relaparotomy approach in that a second operation always occurs, the abdominal wall is not closed during the index case and a temporary abdominal closure is applied. For patients with profound physiologic derangement, the concept of an OA with reexploration is identical to traditional DCS in which an abbreviated laparotomy is performed due to the patient's inability to tolerate a definitive operation. However, for IAS, this methodology has also been implemented in the absence of decompensated shock. In addition to allowing for reassessment of the peritoneal cavity and additional source control if needed, randomized control trials evaluating an OA approach to Hinchey type III/IV perforated diverticulitis have demonstrated a reduced risk of anastomotic leak and a decreased requirement for intestinal diversion when a two-stage approach is utilized.[15,16]

Although studies have demonstrated increased mortality and all-cause complication rates in patients managed with an OA approach, questions remain about the true role of damage-control techniques for IAS.[17,18] The Closed or Open after Source Control Laparotomy for Severe Complicated Intra-Abdominal Sepsis (COOL trial) is a large, randomized control trial seeking to elucidate whether an on-demand relaparotomy (closed) or an OA with reexploration (open) ultimately provides better outcomes for patients with IAS.[8,19]

Given the current state of the evidence, an on-demand relaparotomy approach should be used in the management of most cases of severe IAS (Table 2). The routine use of an OA with reexploration should be used with caution. However, specific indications remain for the use of damage control methods. Outside of physiologic derangement, the inability to perform definitive reconstruction (often due to concern for anastomosis integrity), the need to reevaluate questionably viable viscera, the inability to achieve complete source control (ex. inability to identify perforated hollow viscous despite large enteric contamination, necrotizing infections), or a high clinical suspicion for persistent intra-abdominal infection despite presumed source control can all direct surgeons towards a damage control procedure.

ACUTE MESENTERIC ISCHEMIA

The concept of a "second look" laparotomy has historically been used in the management of acute mesenteric ischemia. This approach optimizes intestinal length by sparing resection of questionably viable bowel at the index operation that demonstrates improved perfusion during relaparotomy. Likewise, bowel that remains borderline ischemic or has become necrotic can be excised, removing additional sources of contamination. Historically, up to 50% of patients require additional intestinal resection at relaparotomy.[20] However, studies examining this two-step therapy have revealed mixed survival benefits.[21–23]

Given the discrepancies in previous studies and the various etiologies of intestinal ischemia (arterial occlusion, mesenteric venous thrombosis, nonocclusive mesenteric ischemia) the use of DCS is appropriate in most cases. In addition to physiologic derangement, the concomitant presence of intra-abdominal sepsis and the significant uncertainly regarding the viability of the remaining intestine both indicate the need for an OA and planned reexploration.[20]

PROFOUND BOWEL DISTENTION AND ABDOMINAL COMPARTMENT SYNDROME (ACS)

Regardless of etiology, the presence of profound bowel distention may limit the ability to perform a primary fascial closure during the index operation. This can be due to either a physical inability to reapproximate the midline or to the development of abdominal compartment syndrome (ACS) during abdominal wall closure.[24]

Even in circumstances in which the fascia can be closed, surgeons can elect to leave the abdomen open if there remains significant concern that ACS may develop in the postoperative setting. An awareness of patients who have received or are likely to receive significant volume resuscitation is crucial as excessive fluid therapy is a risk factor for secondary ACS.[25]

THE PHASES OF DCS

The treatment algorithm for DCS in nontraumatic pathology follows a stepwise approach (Fig. 1). Although often initiated prior to the decision to perform a damage-control intervention, preoperative resuscitation is considered a crucial part of the DCS pathway and is often referred to as phase 0. The index operation, phase 1, includes an abbreviated laparotomy centered on expeditious contamination/hemorrhage control, followed by temporary abdominal closure. Phase 2 consists of ongoing resuscitation and management of the OA in the ICU. Once physiologic parameters have been restored, patients return to the operating room for definitive surgical repair/reconstruction (Phase 3) followed by abdominal wall closure (Phase 4).

PHASE 0: PREOPERATIVE RESUSCITATION

Preoperative resuscitation is determined by etiology. Patients with hemorrhagic shock are resuscitated using strategies developed for the bleeding trauma patient. This includes balanced blood product resuscitation and minimization of crystalloids until bleeding is controlled.[26] When available, massive transfusion protocols should be initiated and blood products transfused in a 1:1:1 ratio of packed red blood cells, plasma, and platelets.[27] While trauma centers have shifted to the use of low titer type-O whole blood, studies have only just begun to evaluate the benefits of using this product in non-traumatic hemorrhage.[28] Thromboelastography (TEG) should be used to guide resuscitation. Ultimately, hemorrhage control is of the utmost importance, and preoperative resuscitation should last only as long as it takes to transport the patient to the operating room.

The resuscitation strategy for intra-abdominal sepsis differs. Although early control of the infectious source is imperative, preoperative resuscitation enhances outcomes.[4] Hypovolemia and vasoplegic shock characterize the hemodynamic profile of IAS. In general, crystalloid resuscitation is the first line therapy. The use of balanced salt solutions (ex. Lactated ringers, Plasmalyte) over normal saline is recommended as numerous studies have demonstrated a survival benefit.[29] Despite initial enthusiasm, the use of colloids, such as albumin, has not been found to improve survival in septic shock.[30] Likewise, uncertainty persists surrounding the role of plasma in sepsis resuscitation.[31]

TABLE 2. Comparison of an OA Versus on-Demand Relaparotomy Approach for Severe Intra-Abdominal Sepsis

OA vs. on-Demand Relaparotomy for Severe Intra-Abdominal Sepsis		
	OA	**On-Demand Relaparotomy**
Description	▪ OA approach with negative pressure temporary abdominal closure during index operation ▪ Planned reexploration in 24–48 hours regardless of clinical condition	▪ Definitive surgical repair/reconstruction with abdominal closure during index operation ▪ Additional relaparotomy only if clinically indicated
Benefits	▪ Allows for early detection of persistent or recurrent intra-abdominal infection ▪ Removal of peritoneal fluid containing inflammatory mediators; may reduce local and systemic inflammatory burden and reduce risk of multi-organ failure ▪ Potential decreased need for intestinal diversion and decreased risk of anastomotic leak	▪ Improved or equivalent survival benefit ▪ Avoids unnecessary surgical interventions ▪ Avoids morbidity of the OA, the key source of complications in DCS ▪ Reduced hospital length of stay ▪ Reduced cost
Negatives	▪ Increased mortality ▪ Risk of unnecessary interventions ▪ Complications arising from an OA (ex. enterocutaneous fistula, fluid/heat loss, catabolic state, fascial retraction, and loss of domain)	▪ No reevaluation of the abdominal cavity to assess for additional infectious foci ▪ Requires consistent observation for clinical deterioration and a high clinical suspicion to identify patients who require additional surgical infection control ▪ Increased need for intestinal diversion and increased risk of anastomotic leak
Indications	▪ Severe physiologic derangement ▪ Inability to safely perform GI tract reconstruction (deferred anastomosis) ▪ Need to reassess questionably viable intestine ▪ Inability to obtain complete source control or high suspicion for persistent infection	▪ Should be utilized in all situations of severe IAS unless specific clinical indications for an OA are present

After preload optimization, patients with severe IAS often require vasopressor and/or inotropic support to maintain mean arterial pressure (MAP). The 2021 Surviving Sepsis and Septic Shock Guidelines recommend norepinephrine as the first line agent, with vasopressin and epinephrine serving as adjuncts to achieve MAP levels greater than 65 mm Hg.[32] Early administration of broad-spectrum antibiotics covering intestinal pathogens is paramount. While empiric anti-fungal coverage can be considered in cases of foregut perforation, multiple studies have failed to demonstrate a survival benefit or a decrease in intra-abdominal

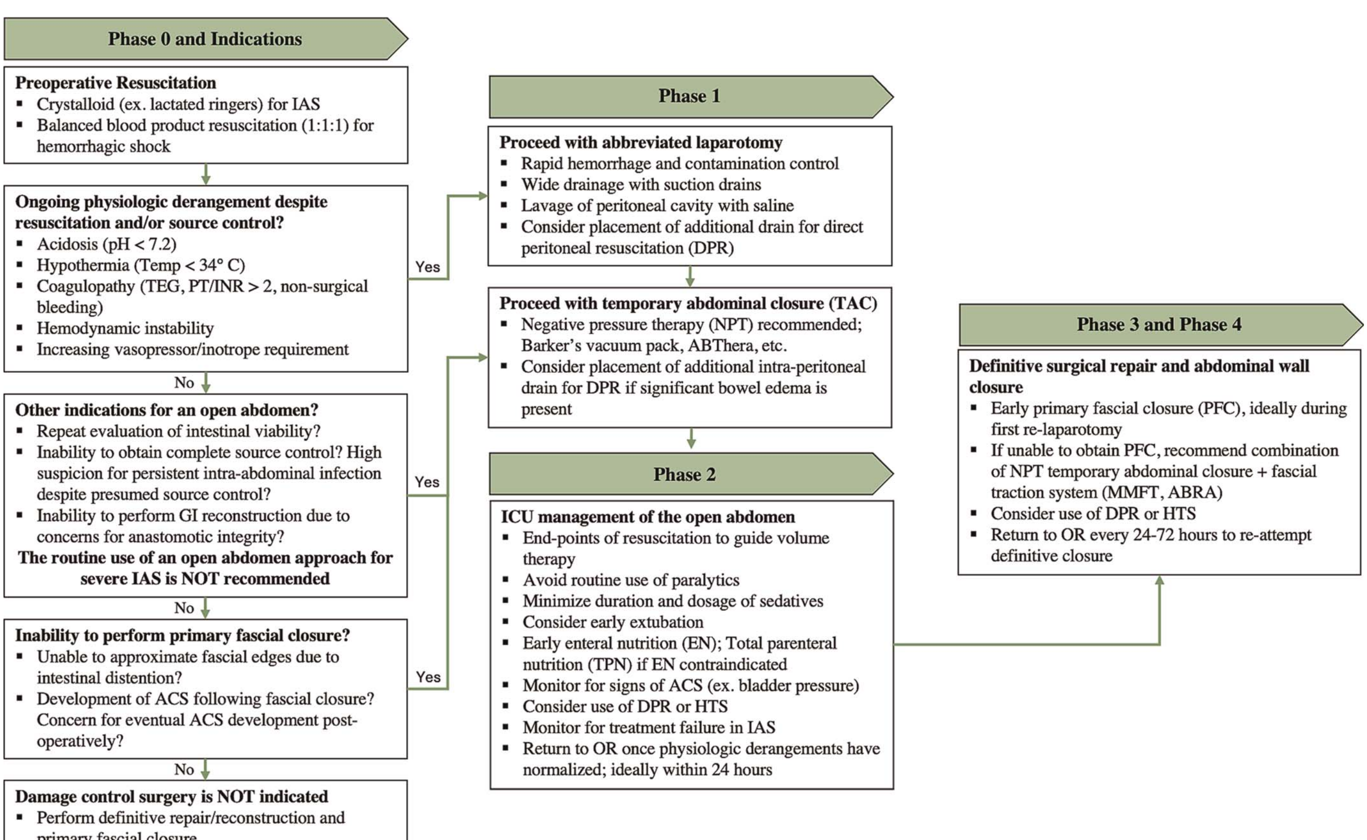

Figure 1. Treatment algorithm for DCS in nontraumatic intra-abdominal emergencies.

complications.[33,34] Local hospital antibiograms should be referenced when selecting antibiotic regimens.

PHASE 1: SOURCE CONTROL DURING THE ABBREVIATED LAPAROTOMY

Regardless of the indication, the goal of the abbreviated laparotomy is to control enteric contamination and hemorrhage as quickly as possible. The means by which this is achieved will vary significantly based on the inciting etiology. Although the emergency general surgeon encounters a wide range of pathologic conditions, the remainder of this section will focus on the topic of source control for IAS.

Source control refers to interventions aimed at removing the nidus of infection (often a disruption or perforation along the GI tract) along with any additional infectious foci present within the abdominal cavity.[35] While antibiotics and percutaneous image-guided drainage are important adjuncts in the management of IAS, operative intervention remains the mainstay of treatment for severe disease.[36] Resection of diseased segments along the GI tract is the ideal measure for source control. Although less effective, primary repair can be used to temporarily control enteric contamination in patients with severe inflammation or adhesions in which a time-consuming dissection may not be tolerated. Additional pockets of infection and gross contamination throughout the peritoneal cavity must be addressed. This can involve drainage of infected fluid collections, debridement of necrotic or ischemic tissue, and irrigation of the peritoneal cavity with saline.[37] The removal of all foci of infection reduces bacterial load thereby reducing the chance for recurrent or persistent infection to develop postoperatively.[35] Extensive wide drainage with suction drains should be used to control ongoing enteric contamination. To avoid interference with the temporary abdominal closure, drains should be extracted as lateral as possible. In the damage control setting, no attempts at restoration of the GI tract, placement of enteral access, or maturation of ostomies should be performed.

Early source control leads to improved outcomes. In an observational study of patients with secondary peritonitis, an urgent procedure, between 2 hours and 6 hours of diagnosis, was associated with improved survival.[38] In addition, a retrospective review of patients with severe IAS secondary to peptic ulcer perforation demonstrated a 6% increase in mortality for each hour of delay to source control.[39] Taken together, patients with IAS should be taken to the operating room as soon as possible.

Cemented in the debate of planned versus on-demand relaparotomy described above is the concept of failed source control. Although definitions vary, failed source control or treatment failure is often defined by the need for additional procedures to manage new or persistent IAI. Despite the broad definition, multiple studies have determined that failed source control is a key risk factor for mortality in patients with IAS.[38] This is particularly concerning as a recent retrospective study demonstrated that up to 50% of patients with IAI ultimately required an additional procedure (operative or percutaneous drainage), even though most providers believed adequate source control was obtained during the initial intervention.[40] Although thorough exploration, lavage of the peritoneal cavity, and wide drainage can reduce the risk of failed source control, providers must appreciate the complexity of IAS and the high risk for persistent disease regardless of whether damage-control methods are utilized.

PHASE 1: TEMPORARY ABDOMINAL CLOSURE

Inherent to all damage-control procedures is the concept of the OA in which surgeons forgo abdominal wall closure during the index operation.[41] In addition to exposing the underlying viscera, an OA results in excessive fluid and heat loss, both of which are detrimental to the critically ill surgical patient. The temporary abdominal closure is performed to address these concerns. Although multiple techniques for TAC exist, negative pressure therapy (NPT) or vacuum-assisted closure (VAC) is recommended for damage-control procedures.[42]

Negative pressure therapy offers a variety of advantages. The efflux of peritoneal fluid through the fenestrated layers and out via the drains allows for continuous monitoring of the net volume and type of fluid being evacuated. In addition, the ongoing removal of inflammatory ascites has been shown to reduce end-organ injury in animal models.[43,44] Placement is relatively quick and simple, making them ideal for abbreviated laparotomies. Perhaps most important, NPT closures have been shown to promote increased rates of primary fascial closure.[45] Despite initial concern over NPT and enterocutaneous fistula (ECF) development, numerous studies have demonstrated a decreased incidence of ECF when NPT abdominal closure is performed.[46]

NPT temporary abdominal closure can be performed using standard operating room supplies or with commercial products including the ABThera system. Originally described by Barker et al. as the "vacuum pack," a "home-made" NPT closure consists of a nonadhesive fenestrated sheet placed between the abdominal viscera and the parietal peritoneum, providing protection of the underlying viscera, and reducing early adhesion formation to the anterior abdominal wall. Moist surgical

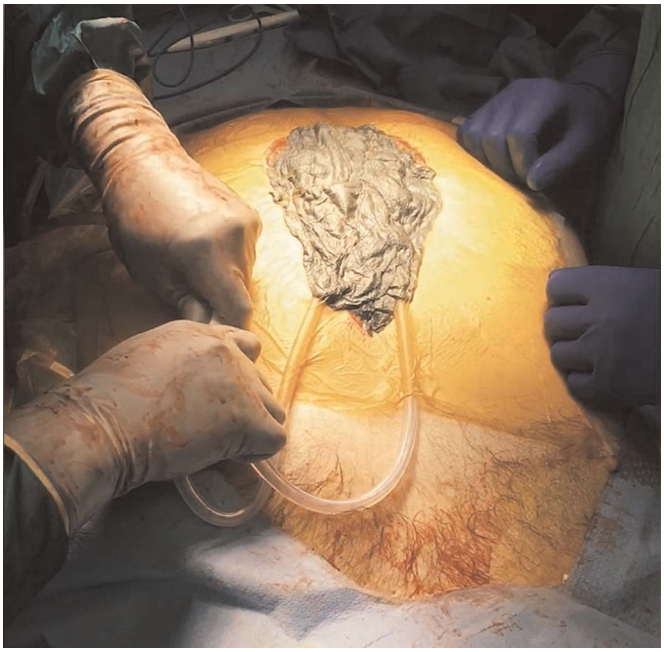

Figure 2. Negative pressure temporary abdominal closure using common operating room supplies.

towels and a conduit for fluid removal (ex. drain tubing or thoracostomy tubes) make up the middle layer. Finally, a large adhesive dressing covers the entire OA with significant overlap circumferentially creating a tight seal. The drains are then attached to wall suction to generate the negative pressure or vacuum[10,47](Fig. 2).

In commercially available systems, a polyurethane foam-based middle layer is used that consists of multiple finger-like extensions that can be placed deeper into the abdomen including the paracolic gutters. This may allow for improved fluid removal and applied negative pressure. Whether such products provide additional benefit has been the topic of multiple studies. In a prospective observational study, patients managed with the ABThera system had improved 30-day primary fascial closure rates and decreased mortality.[48] Likewise, a single-center randomized control trial comparing the two methods demonstrated reduced 90-day mortality in the ABThera treatment arm but no difference in PFC rates. The peritoneal fluid/plasma cytokine levels were similar between the two groups suggesting no difference in decreased overall inflammatory mediator burden.[43]

Despite these findings, significant variation exists in how individual surgeons create "home-made" negative pressure closures. As such, either method is appropriate in the management of the OA.[24] Simplified TAC such as a skin only closure or the Bogota bag (plastic visceral covering only) should be avoided.[49]

PHASE 2: ICU MANAGEMENT OF THE OA

The ICU management of patients undergoing DCS is challenging and involves ongoing resuscitation, close observation to identify treatment failure in patients with IAS, and management of the OA. In the setting of severe physiologic derangement, the first step in management should be aimed at vigorous reversal of the lethal triad. While intravascular volume repletion optimizes preload and cardiac output, intravenous fluids must be given judiciously due to the negative outcomes associated with hypervolemia in patients suffering septic shock.[50] Endpoints of resuscitation including lactic acid, base deficit, and urine output can guide resuscitation. In addition, dynamic measurements of fluid responsiveness including pulse pressure or stroke volume variation can be analyzed using arterial waveforms in mechanically ventilated patients.[51]

Given the high incidence of treatment failure in IAS and the challenges in identifying which patients are at risk of failed source control based on initial intraoperative findings, clinicians must have a high index of suspicion for ongoing infectious processes in the postoperative setting. Early postoperative findings of physiologic decompensation including elevated heart rate and worsening PaO_2/FIO_2 ratios may help identify those with persistent infection.[12] Although studies evaluating specific organ-failure scoring systems (e.g., SOFA, APACHE) as predictors for ongoing infection have yielded mixed results, ongoing organ dysfunction can be used as a marker of treatment failure.[37,52,53] Treatment failure is managed with relaparotomy in unstable patients and those with an OA. For IAS treated without DCS methods, percutaneous image-guided drainage can be considered in the stable patient with suspected failed source control.

Patients managed with NPT closures remain susceptible to ACS even though the abdomen is theoretically decompressed. Continuous surveillance of bladder pressure (surrogate for intra-abdominal pressure [IAP]) can be utilized to help in the early detection of intra-abdominal hypertension.[24] Intra-abdominal pressure greater than 16 mm Hg to 20 mm Hg or clinical deterioration should prompt an evaluation of the TAC to ensure tubing is not kinked, collection chambers are not full, and the source of suction is functioning properly. The TAC can be taken down at bedside to decompress the abdominal cavity quickly when needed.

Historically, patients with an OA remained intubated, heavily sedated, and frequently paralyzed until definitive fascial closure was obtained, even if multiple reoperations were needed.[54] However, it is now firmly established that stable patients can safely be extubated. In a retrospective study, patients extubated before fascial closure had similar reintubation rates but decreased LOS and decreased risk of pneumonia when compared to those extubated after abdominal wall closure.[55] Likewise, limiting sedation and avoiding paralytics is recommended. Results from the SLEEP-TRAUMA study evaluating sedation management in DCS demonstrated that a shorter duration of sedation exposure not only reduced incidence of ICU delirium but also hastened fascial closure.[56] Formerly believed to prevent evisceration and promote fascial closure, neuromuscular blockade should only be pursued in patients who require paralysis for other indications. In a retrospective review of trauma patients undergoing DCS, paralytic utilization was not associated with decreased time to abdominal closure.[57]

In addition to the hypermetabolic state commonly seen in critically ill patients, the presence of the OA results in the loss of electrolyte- and protein-rich fluid, placing patients with an OA at risk for malnutrition.[58] Apart from patients with hemodynamic instability or GI tract discontinuity, OA patients are candidates for early enteral nutrition (EN) for which numerous studies have demonstrated beneficial effects.[24] In a multicenter study of injured patients, early EN resulted in decreased mortality, decreased infectious complications, and increased rates of abdominal wall closure.[59] A similar retrospective review noted that EN started before hospital day four was associated with earlier abdominal wall closure and lower rates of ECF development.[60] In the acute setting, enteral nutrition can be delivered via a postpyloric nasogastric feeding tube. Extubated patients can be fed per oral. In patients with ongoing GI tract discontinuity, high-output ECF, or an inability to tolerate EN, total parenteral nutrition (TPN) may be required to meet nutritional demands.[61]

PHASE 3: DEFINITIVE SURGICAL REPAIR

Although the definitive surgical repair and reconstruction are key steps in the DCS pathway, the surgical techniques required vary significantly based on inciting pathology and the operation performed during the index intervention. However, all surgeons must determine when to return to the operating room for definitive repair. In the early days of DCS, it was not uncommon for relaparotomy to be delayed for up to 48 hours to 72 hours. However, current guidelines recommend returning to the operating room as soon as possible, often once central hemodynamics and physiologic indices normalize. Ideally, this should occur within the first 24 hours of hospitalization. However, in cases of a second look in mesenteric ischemia or IAS, it is reasonable to delay the second exploration to 48 hours.[20] Efforts

TABLE 3. Complications of DCS and the OA

	Description	Prevention
(1) Fluid and heat loss	▪ Evaporative heat and fluid loss from exposed viscera ▪ Can result in hypothermia, hypovolemia, and electrolyte imbalances	▪ TAC ▪ Account for fluid loss when determining daily fluid requirements ▪ Electrolyte replacement
(2) Damage to underlying abdominal viscera	▪ Lack of fascial covering places abdominal viscera at risk of injury, particularly during subsequent relaparotomies and dressing changes to the OA	▪ Temporary abdominal closure ▪ Early fascial closure ▪ Caution during reexploration, TAC takedown, and wound care
(3) Malnutrition	▪ Catabolic state from underlying critical illness ▪ Loss of protein-rich fluid from the peritoneal cavity	▪ Early EN ▪ TPN in setting of GI tract discontinuity or EN intolerance
(4) Increased infectious complications	▪ Increased incidence of intra-abdominal and abdominal wound infections ▪ Increased incidence of sepsis and pulmonary complications	▪ Early fascial closure
(5) Fascial retraction, loss of abdominal domain	▪ Lateral retraction of the midline fascia resulting in loss of abdominal domain ▪ Risk of chronic OA or large ventral hernia defects resulting in poor quality of life and need for complex operative reconstruction	▪ Early fascial closure ▪ Negative pressure TAC ▪ Fascial traction systems
(6) Enterocutaneous fistula	▪ Fistulous connection between the exposed viscera and the skin ▪ Results in increased mortality, infectious complications, malnutrition, and poor quality of life	▪ Early fascial closure ▪ Negative pressure TAC ▪ Early enteral nutrition ▪ Caution during reexploration, TAC takedown, and wound care to avoid intestinal injury

should be made to perform all definitive repairs during the first relaparotomy, as additional takebacks are associated with increased all-cause infectious complications and a decreased likelihood of abdominal wall closure, the last phase of DCS.[62–64]

PHASE 4: ABDOMINAL WALL CLOSURE AND COMPLICATIONS OF THE OA

A review of abdominal wall closure would be incomplete without a discussion about the complications of DCS, the majority of which are related to the presence of an OA and the inability to close it (Table 3). Aside from the complications of fluid/heat loss, malnutrition, and risk of injury to exposed viscera, patients with an OA have an increased risk of multiple infectious complications (ex. intra-abdominal infections, abdominal wound infections, pneumonia, and ongoing sepsis). The lateral retraction of the midline fascia and resulting loss of domain places patients at risk of failed fascial closure and the subsequent challenges associated with a chronic OA. Enterocutaneous fistula is perhaps the most feared complication stemming from DCS and is defined by an abnormal connection between the intestinal lumen and skin. In patients with a chronic OA, a fistulous connection may emerge onto the mesh or inflammatory tissue (functional closures) overlying the exposed viscera. In this instance, the term enteroatmospheric fistula is used.[65] Although severity depends on location and daily output, ECF results in long-term infectious complications, malnutrition, poor quality of life, chronic pain, and overall increased mortality.[66]

Given the significant morbidity associated with the OA, efforts should be made to close the abdominal wall as early as possible, ideally via primary fascial closure. Achieving PFC at the first relaparotomy is associated with the decreased incidence of severe complications including intra-abdominal abscess formation, anastomotic leak, pneumonia, bacteremia, acute respiratory distress syndrome, ECF development, and multiorgan failure.[67] In addition to the short-term benefits, early abdominal wall closure (within 7 days) is associated with improved long-term quality of life including higher rates of returning to work and improved physical/emotional health.[68]

Consequently, strategies to improve early PFC have been pursued. In a prospective, multicenter study, reducing the interval between the index laparotomy and initial takeback improved PFC rates, with each hour delay reducing the likelihood of success.[69] Likewise, in a retrospective review, returning to the operating room within 24 hours and minimizing the total number of reoperations predicted successful PFC in both trauma and EGS patient populations.[62]

In addition to negative pressure TAC, fascial traction systems offer another surgical option to increase rates of PFC.[49] Although not utilized in the unstable patient during the abbreviated laparotomy, these methods are often required when the OA cannot be closed at the initial relaparotomy. These techniques counteract the lateral retraction of the fascia and are adjusted or "tightened" over time to slowly reapproximate the midline. Mesh-mediated fascial traction (MMFT) involves the circumferential anchoring of a polypropylene mesh that is often cut down the middle to create two leaflets which are then sewn together to create traction. During subsequent reoperations (often at 24–72 hours intervals), the medial aspects of the two leaflets are shortened (either by cutting or rolling back the edges) and subsequently sewn back together to progressively medialize the midline fascia.[70] The Abdominal Reapproximation Anchor (ABRA) system provides similar medial traction using multiple horizontal elastomers. Each elastomer passes through all layers of the abdominal wall and exits the skin approximately 5 cm lateral to the fascial margin on each side of the OA. Progressive fascial closure is obtained via daily adjustments.[71] While initial trials sought to compare PFC rates between fascial traction systems and traditional negative pressure TACs, a recent meta-analysis and practice guidelines from the Eastern Association for the

Surgery of Trauma recommends that both be used in combination in patients with an OA that cannot be closed during relaparotomy.[72]

Additional nonsurgical adjuncts have been utilized to enhance PFC. Direct peritoneal resuscitation (DPR) is a revolutionary resuscitation technique that continuously irrigates the peritoneal cavity using a glucose-based dialysis solution. In addition to optimizing intestinal blood flow and reducing systemic inflammatory mediator burden, the hypertonicity of the dialysate solution decreases intestinal wall edema.[73] In retrospective studies, adjunctive DPR resulted in earlier primary fascial closure in patients suffering both traumatic pathology and IAS.[74,75] Likewise, in a small, randomized control trial, traumatically injured patients receiving adjunctive DPR had reduced mortality in addition to earlier abdominal wall closure.[76] Hypertonic saline may also reduce bowel edema and improve rates of PFC. In retrospective studies of injured patients, the use of 3% hypertonic saline as a maintenance fluid was associated with higher rates of PFC.[77,78]

When multiple failed attempts at PFC have occurred, a functional closure can be considered. This either involves a bridging mesh or simply allowing granulation tissue to form over the exposed viscera. Split-thickness skin grafting can be performed once the abdominal wound bed has matured, and complex surgical repair can be delayed until the patient recovers from the acute hospitalization.[79]

SUMMARY AND KEY RECOMMENDATIONS

Despite the general lack of firm evidence, DCS remains an essential technique for all surgeons managing nontraumatic intra-abdominal emergencies. When applied to the right patient population, damage control techniques can be lifesaving. However, the severe complications associated with an OA can be detrimental and DCS should be used with caution in emergency general surgery.

Key Recommendations

- Persistent physiologic derangement, intestinal ischemia, and profound bowel distention limiting fascial approximation are the key indications for DCS in nontraumatic pathology. An OA with reexploration in the management of severe intra-abdominal sepsis should be avoided unless specific indications are present. This includes physiologic derangement, concern for failed source control, high suspicion for persistent intra-abdominal infection despite presumed adequate source control, inability to perform GI tract reconstruction, and the need to reevaluate questionably viable viscera.
- Negative pressure therapy should be used in all cases of temporary abdominal closure and can be performed with common operating room supplies or commercially available products.
- Key ICU management of the OA includes early enteral nutrition (within 48 hours), early extubation, avoidance of paralytics, minimization of sedation, and close monitoring for abdominal compartment syndrome and treatment failure in intra-abdominal sepsis.
- Early relaparotomy (ideally within 24 hours), negative pressure temporary abdominal closure, and fascial traction systems can improve rates of primary fascial closure. Adjunctive direct peritoneal resuscitation and hypertonic saline may also promote abdominal wall closure by reducing intestinal wall edema.

AUTHORSHIP

W.B.R., J.W.S. participated in the article drafting. W.B.R., J.W.S. participated in the edits/revision of article. W.B.R., J.W.S. participated in the final approval of article.

DISCLOSURE

The authors declare no funding or conflicts of interest.
Author Disclosure forms have been supplied and are provided as Supplemental Digital Content, http://links.lww.com/TA/D178.

REFERENCES

1. Stone HH, Strom PR, Mullins RJ. Management of the major coagulopathy with onset during laparotomy. *Ann Surg*. 1983;197(5):532–535.
2. Burch JM, Ortiz VB, Richardson RJ, Martin RR, Mattox KL, Jordan GL Jr. Abbreviated laparotomy and planned reoperation for critically injured patients. *Ann Surg*. 1992;215(5):476–483; discussion 83–4.
3. Roberts DJ, Ball CG, Feliciano DV, Moore EE, Ivatury RR, Lucas CE, et al. History of the innovation of damage control for management of trauma patients: 1902–2016. *Ann Surg*. 2017;265(5):1034–1044.
4. Weber DG, Bendinelli C, Balogh ZJ. Damage control surgery for abdominal emergencies. *Br J Surg*. 2014;101(1):e109–e118.
5. Smith JW, Nash N, Procter L, Benns M, Franklin GA, Miller K, et al. Not All Abdomens Are the Same: A Comparison of Damage Control Surgery for Intra-abdominal Sepsis versus Trauma. *Am Surg*. 2016;82(5):427–432.
6. Roberts DJ, Bobrovitz N, Zygun DA, Ball CG, Kirkpatrick AW, Faris PD, et al. Indications for use of damage control surgery in civilian trauma patients: a content analysis and expert appropriateness rating study. *Ann Surg*. 2016;263(5):1018–1027.
7. Ordonez CA, Caicedo Y, Parra MW, Rodriguez-Holguin F, Serna JJ, Salcedo A, et al. Evolution of damage control surgery in non-traumatic abdominal pathology: a light in the darkness. *Colomb Med (Cali)*. 2021;52(2):e4194809.
8. Kirkpatrick AW, Coccolini F, Ansaloni L, Roberts DJ, Tolonen M, McKee JL, et al. Closed or open after source control laparotomy for severe complicated intra-abdominal sepsis (the COOL trial): study protocol for a randomized controlled trial. *World J Emerg Surg*. 2018;13:26.
9. Koperna T, Schulz F. Relaparotomy in peritonitis: prognosis and treatment of patients with persisting intraabdominal infection. *World J Surg*. 2000;24(1):32–37.
10. Sartelli M, Abu-Zidan FM, Ansaloni L, Bala M, Beltran MA, Biffl WL, et al. The role of the open abdomen procedure in managing severe abdominal sepsis: WSES position paper. *World J Emerg Surg*. 2015;10:35.
11. van Ruler O, Mahler CW, Boer KR, Reuland EA, Gooszen HG, Opmeer BC, et al. Comparison of on-demand vs planned relaparotomy strategy in patients with severe peritonitis: a randomized trial. *JAMA*. 2007;298(8):865–872.
12. van Ruler O, Lamme B, Gouma DJ, Reitsma JB, Boermeester MA. Variables associated with positive findings at relaparotomy in patients with secondary peritonitis. *Crit Care Med*. 2007;35(2):468–476.
13. Opmeer BC, Boer KR, van Ruler O, Reitsma JB, Gooszen HG, de Graaf PW, et al. Costs of relaparotomy on-demand versus planned relaparotomy in patients with severe peritonitis: an economic evaluation within a randomized controlled trial. *Crit Care*. 2010;14(3):R97.
14. Robledo FA, Luque-de-Leon E, Suarez R, Sanchez P, de-la-Fuente M, Vargas A, et al. Open versus closed management of the abdomen in the surgical treatment of severe secondary peritonitis: a randomized clinical trial. *Surg Infect (Larchmt)*. 2007;8(1):63–72.
15. Kafka-Ritsch R, Zitt M, Perathoner A, Gasser E, Kaufman C, Czipin S, et al. Prospectively randomized controlled trial on damage control surgery for perforated diverticulitis with generalized peritonitis. *World J Surg*. 2020;44(12):4098–4105.
16. Cirocchi R, Popivanov G, Konaktchieva M, Chipeva S, Tellan G, Mingoli A, et al. The role of damage control surgery in the treatment of perforated colonic diverticulitis: a systematic review and meta-analysis. *Int J Colorectal Dis*. 2021;36(5):867–879.
17. Kao AM, Cetrulo LN, Baimas-George MR, Prasad T, Heniford BT, Davis BR, et al. Outcomes of open abdomen versus primary closure following emergent laparotomy for suspected secondary peritonitis: a propensity-matched analysis. *J Trauma Acute Care Surg*. 2019;87(3):623–629.
18. Proano-Zamudio JA, Gebran A, Argandykov D, Dorken-Gallastegi A, Saillant NN, Fawley JA, et al. Delayed fascial closure in nontrauma abdominal emergencies: a nationwide analysis. *Surgery.* 2022;172(5):1569–1575.

19. Kirkpatrick AW, Coccolini F, Tolonen M, Minor S, Catena F, Gois E Jr., et al. The unrestricted global effort to complete the COOL trial. *World J Emerg Surg*. 2023;18(1):33.
20. Bala M, Catena F, Kashuk J, De Simone B, Gomes CA, Weber D, et al. Acute mesenteric ischemia: updated guidelines of the World Society of Emergency Surgery. *World J Emerg Surg*. 2022;17(1):54.
21. Ding W, Wang K, Liu B, Fan X, Wang S, Cao J, et al. Open abdomen improves survival in patients with peritonitis secondary to acute superior mesenteric artery occlusion. *J Clin Gastroenterol*. 2017;51(9):e77–e82.
22. Endo A, Saida F, Mochida Y, Kim S, Otomo Y, Nemoto D, et al. Planned versus on-demand relaparotomy strategy in initial surgery for non-occlusive mesenteric ischemia. *J Gastrointest Surg*. 2021;25(7):1837–1846.
23. Proano-Zamudio JA, Argandykov D, Renne A, Gebran A, Dorken-Gallastegi A, Paranjape CN, et al. Revisiting abdominal closure in mesenteric ischemia: is there an association with outcome? *Eur J Trauma Emerg Surg*. 2022.
24. Coccolini F, Roberts D, Ansaloni L, Ivatury R, Gamberini E, Kluger Y, et al. The open abdomen in trauma and non-trauma patients: WSES guidelines. *World J Emerg Surg*. 2018;13:7.
25. Cotton BA, Guy JS, Morris JA Jr., Abumrad NN. The cellular, metabolic, and systemic consequences of aggressive fluid resuscitation strategies. *Shock*. 2006;26(2):115–121.
26. Duchesne JC, McSwain NE Jr., Cotton BA, Hunt JP, Dellavolpe J, Lafaro K, et al. Damage control resuscitation: the new face of damage control. *J Trauma*. 2010;69(4):976–990.
27. Holcomb JB, Tilley BC, Baraniuk S, Fox EE, Wade CE, Podbielski JM, et al. Transfusion of plasma, platelets, and red blood cells in a 1:1:1 vs a 1:1:2 ratio and mortality in patients with severe trauma: the PROPPR randomized clinical trial. *JAMA*. 2015;313(5):471–482.
28. Smith AA, Alkhateb R, Braverman M, Shahan CP, Axtman B, Nicholson S, et al. Efficacy and safety of whole blood transfusion in non-trauma patients. *Am Surg*. 2021;31348211048831.
29. Beran A, Altorok N, Srour O, Malhas SE, Khokher W, Mhanna M, et al. Balanced crystalloids versus normal saline in adults with sepsis: a comprehensive systematic review and meta-analysis. *J Clin Med*. 2022;11(7):1971.
30. Jiang L, Jiang S, Zhang M, Zheng Z, Ma Y. Albumin versus other fluids for fluid resuscitation in patients with sepsis: a meta-analysis. *PLoS One*. 2014; 9(12):e114666.
31. Dietrich M, Holle T, Lalev LD, Loos M, Schmitt FCF, Fiedler MO, et al. Plasma transfusion in septic shock—a secondary analysis of a retrospective single-center cohort. *J Clin Med*. 2022;11(15):4367.
32. Evans L, Rhodes A, Alhazzani W, Antonelli M, Coopersmith CM, French C, et al. Surviving sepsis campaign: international guidelines for management of sepsis and septic shock 2021. *Crit Care Med*. 2021;49(11):e1063–e1143.
33. Barmparas G, Alhaj Saleh A, Huang R, Eaton BC, Bruns BR, Raines A, et al. Empiric antifungals do not decrease the risk for organ space infection in patients with perforated peptic ulcer. *Trauma Surg Acute Care Open*. 2021;6(1):e000662.
34. Huston JM, Kreiner L, Ho VP, Sanders JM, Duane TM. Role of empiric anti-fungal therapy in the treatment of perforated peptic ulcer disease: review of the evidence and future directions. *Surg Infect (Larchmt)*. 2019;20(8): 593–600.
35. Wu XW, Zheng T, Hong ZW, Ren HJ, Wu L, Wang GF, et al. Current progress of source control in the management of intra-abdominal infections. *Chin J Traumatol*. 2020;23(6):311–313.
36. Sartelli M, Coccolini F, Kluger Y, Agastra E, Abu-Zidan FM, Abbas AES, et al. WSES/GAIS/SIS-E/WSIS/AAST global clinical pathways for patients with intra-abdominal infections. *World J Emerg Surg*. 2021;16(1):49.
37. Mazuski JE, Tessier JM, May AK, Sawyer RG, Nadler EP, Rosengart MR, et al. The surgical infection society revised guidelines on the management of intra-abdominal infection. *Surg Infect (Larchmt)*. 2017;18(1):1–76.
38. De Pascale G, Antonelli M, Deschepper M, Arvaniti K, Blot K, Brown BC, et al. Poor timing and failure of source control are risk factors for mortality in critically ill patients with secondary peritonitis. *Intensive Care Med*. 2022; 48(11):1593–1606.
39. Boyd-Carson H, Doleman B, Cromwell D, Lockwood S, Williams JP, Tierney GM, et al. Delay in source control in perforated peptic ulcer leads to 6% increased risk of death per hour: a nationwide cohort study. *World J Surg*. 2020;44(3):869–875.
40. van de Groep K, Verhoeff TL, Verboom DM, Bos LD, Schultz MJ, Bonten MJM, et al. Epidemiology and outcomes of source control procedures in critically ill patients with intra-abdominal infection. *J Crit Care*. 2019;52: 258–264.
41. Regner JL, Kobayashi L, Coimbra R. Surgical strategies for management of the open abdomen. *World J Surg*. 2012;36(3):497–510.
42. Smith LA, Barker DE, Chase CW, Somberg LB, Brock WB, Burns RP. Vacuum pack technique of temporary abdominal closure: a four-year experience. *Am Surg*. 1997;63(12):1102–1107; discussion 7–8.
43. Kirkpatrick AW, Roberts DJ, Faris PD, Ball CG, Kubes P, Tiruta C, et al. Active negative pressure peritoneal therapy after abbreviated laparotomy: the intraperitoneal vacuum randomized controlled trial. *Ann Surg*. 2015;262(1): 38–46.
44. Kubiak BD, Albert SP, Gatto LA, Snyder KP, Maier KG, Vieau CJ, et al. Peritoneal negative pressure therapy prevents multiple organ injury in a chronic porcine sepsis and ischemia/reperfusion model. *Shock*. 2010;34(5):525–534.
45. Perez D, Wildi S, Demartines N, Bramkamp M, Koehler C, Clavien PA. Prospective evaluation of vacuum-assisted closure in abdominal compartment syndrome and severe abdominal sepsis. *J Am Coll Surg*. 2007;205(4):586–592.
46. Pliakos I, Papavramidis TS, Michalopoulos N, Deligiannidis N, Kesisoglou I, Sapalidis K, et al. The value of vacuum-assisted closure in septic patients treated with laparostomy. *Am Surg*. 2012;78(9):957–961.
47. 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):201–206; discussion 6–7.
48. Cheatham ML, Demetriades D, Fabian TC, Kaplan MJ, Miles WS, Schreiber MA, et al. Prospective study examining clinical outcomes associated with a negative pressure wound therapy system and Barker's vacuum packing technique. *World J Surg*. 2013;37(9):2018–2030.
49. Chiara O, Cimbanassi S, Biffl W, Leppaniemi A, Henry S, Scalea TM, et al. International consensus conference on open abdomen in trauma. *J Trauma Acute Care Surg*. 2016;80(1):173–183.
50. Malbrain MLNG, Van Regenmortel N, Saugel B, De Tavernier B, Van Gaal PJ, Joannes-Boyau O, et al. Principles of fluid management and stewardship in septic shock: it is time to consider the four D's and the four phases of fluid therapy. *Ann Intensive Care*. 2018;8(1):66.
51. Russell A, Rivers EP, Giri PC, Jaehne AK, Nguyen HB. A physiologic approach to hemodynamic monitoring and optimizing oxygen delivery in shock resuscitation. *J Clin Med*. 2020;9(7):2052.
52. Paugam-Burtz C, Dupont H, Marmuse JP, Chosidow D, Malek L, Desmonts JM, et al. Daily organ-system failure for diagnosis of persistent intra-abdominal sepsis after postoperative peritonitis. *Intensive Care Med*. 2002;28(5):594–598.
53. van Ruler O, Kiewiet JJ, Boer KR, Lamme B, Gouma DJ, Boermeester MA, et al. Failure of available scoring systems to predict ongoing infection in patients with abdominal sepsis after their initial emergency laparotomy. *BMC Surg*. 2011;11:38.
54. Choi JH, Luo-Owen X, Brooks SE, Turay D, O'Bosky KR, Mukherjee K. Sedation and paralytic use in open abdomen patients-results from the EAST SLEEP Survey. *Surgery*. 2019;166(6):1111–1116.
55. Sujka JA, Safcsak K, Cheatham ML, Ibrahim JA. Trauma patients with an open abdomen following damage control laparotomy can be extubated prior to abdominal closure. *World J Surg*. 2018;42(10):3210–3214.
56. Kim T, Celis C, Pop A, McArthur K, Bushell TR, Luo-Owen X, et al. More medications, more problems: results from the sedation level after emergent exlap with packing for TRAUMA (SLEEP-TRAUMA) study. *Eur J Trauma Emerg Surg*. 2022;48(2):943–952.
57. Smith SE, Hamblin SE, Guillamondegui OD, Gunter OL, Dennis BM. Effectiveness and safety of continuous neuromuscular blockade in trauma patients with an open abdomen: a follow-up study. *Am J Surg*. 2018;216(3):414–419.
58. Cheatham ML, Safcsak K, Brzezinski SJ, Lube MW. Nitrogen balance, protein loss, and the open abdomen. *Crit Care Med*. 2007;35(1):127–131.
59. Burlew CC, Moore EE, Cuschieri J, Jurkovich GJ, Codner P, Nirula R, et al. Who should we feed? Western Trauma Association multi-institutional study of enteral nutrition in the open abdomen after injury. *J Trauma Acute Care Surg*. 2012;73(6):1380–1387; discussion 7–8.
60. Collier B, Guillamondegui O, Cotton B, Donahue R, Conrad A, Groh K, et al. Feeding the open abdomen. *JPEN J Parenter Enteral Nutr*. 2007; 31(5):410–415.
61. Bansal V, Coimbra R. Nutritional support in patients following damage control laparotomy with an open abdomen. *Eur J Trauma Emerg Surg*. 2013; 39(3):243–248.
62. Kwon E, Krause C, Luo-Owen X, McArthur K, Cochran-Yu M, Swentek L, et al. Time is domain: factors affecting primary fascial closure after trauma and non-trauma damage control laparotomy (data from the EAST SLEEP-TIME multicenter registry). *Eur J Trauma Emerg Surg*. 2022; 48(3):2107–2116.

63. Foster K, Yon J, Pelzl CE, Salottolo K, Mentzer C, Quan G, et al. Six-year national study of damage control laparotomy and the effect of repeat re-exploration on rate of infectious complications. *Trauma Surg Acute Care Open*. 2021;6(1):e000706.
64. Loftus TJ, Jordan JR, Croft CA, Smith RS, Efron PA, Mohr AM, et al. Temporary abdominal closure for trauma and intra-abdominal sepsis: different patients, different outcomes. *J Trauma Acute Care Surg*. 2017;82(2):345–350.
65. Teixeira PG, Inaba K, Dubose J, Salim A, Brown C, Rhee P, et al. Enterocutaneous fistula complicating trauma laparotomy: a major resource burden. *Am Surg*. 2009;75(1):30–32.
66. Williams LJ, Zolfaghari S, Boushey RP. Complications of enterocutaneous fistulas and their management. *Clin Colon Rectal Surg*. 2010;23(3):209–220.
67. Hatch QM, Osterhout LM, Podbielski J, Kozar RA, Wade CE, Holcomb JB, et al. Impact of closure at the first take back: complication burden and potential overutilization of damage control laparotomy. *J Trauma*. 2011;71(6):1503–1511.
68. Fox N, Crutchfield M, LaChant M, Ross SE, Seamon MJ. Early abdominal closure improves long-term outcomes after damage-control laparotomy. *J Trauma Acute Care Surg*. 2013;75(5):854–858.
69. Pommerening MJ, DuBose JJ, Zielinski MD, Phelan HA, Scalea TM, Inaba K, et al. Time to first take-back operation predicts successful primary fascial closure in patients undergoing damage control laparotomy. *Surgery*. 2014;156(2):431–438.
70. Jacobs R. We asked the experts: modified mesh-mediated fascial traction in the management of the open abdomen. *World J Surg*. 2023;47(1):103–105.
71. Wang Y, Alnumay A, Paradis T, Beckett A, Fata P, Khwaja K, et al. Management of open abdomen after trauma laparotomy: a comparative analysis of dynamic fascial traction and negative pressure wound therapy systems. *World J Surg*. 2019;43(12):3044–3050.
72. Mahoney EJ, Bugaev N, Appelbaum R, Goldenberg-Sandau A, Baltazar GA, Posluszny J, et al. Management of the open abdomen: a systematic review with meta-analysis and practice management guideline from the Eastern Association for the Surgery of Trauma. *J Trauma Acute Care Surg*. 2022;93(3):e110–e118.
73. Schucht JE, Matheson PJ, Harbrecht BG, Bond L, Ashkettle GR, Smith JW. Plasma resuscitation with adjunctive peritoneal resuscitation reduces ischemia-induced intestinal barrier breakdown following hemorrhagic shock. *J Trauma Acute Care Surg*. 2021;90(1):27–34.
74. Smith JW, Neal Garrison R, Matheson PJ, Harbrecht BG, Benns MV, Franklin GA, et al. Adjunctive treatment of abdominal catastrophes and sepsis with direct peritoneal resuscitation: indications for use in acute care surgery. *J Trauma Acute Care Surg*. 2014;77(3):393–398; discussion 8–9.
75. Smith JW, Garrison RN, Matheson PJ, Franklin GA, Harbrecht BG, Richardson JD. Direct peritoneal resuscitation accelerates primary abdominal wall closure after damage control surgery. *J Am Coll Surg*. 2010;210(5):658–664, 64–7.
76. Smith JW, Matheson PJ, Franklin GA, Harbrecht BG, Richardson JD, Garrison RN. Randomized controlled trial evaluating the efficacy of peritoneal resuscitation in the management of trauma patients undergoing damage control surgery. *J Am Coll Surg*. 2017;224(4):396–404.
77. Loftus TJ, Efron PA, Bala TM, Rosenthal MD, Croft CA, Walters MS, et al. The impact of standardized protocol implementation for surgical damage control and temporary abdominal closure after emergent laparotomy. *J Trauma Acute Care Surg*. 2019;86(4):670–678.
78. Harvin JA, Mims MM, Duchesne JC, Cox CS Jr., Wade CE, Holcomb JB, et al. Chasing 100%: the use of hypertonic saline to improve early, primary fascial closure after damage control laparotomy. *J Trauma Acute Care Surg*. 2013;74(2):426–430; discussion 31–2.
79. Cheesborough JE, Park E, Souza JM, Dumanian GA. Staged management of the open abdomen and enteroatmospheric fistulae using split-thickness skin grafts. *Am J Surg*. 2014;207(4):504–511.

