2 Applications of Damage Control Surgery in Modern Civilian Trauma Care

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Abstract

Modern trauma damage control (DC) integrates the stages of DC surgery into the process of DC resuscitation. Although widely believed to improve survival when appropriately indicated, there is limited evidence supporting a benefit of DC surgery (and its component DC interventions) in injured patients. Further, the procedure is associated with a number of potentially severe and often resource-intensive complications. Several studies have recently reported data suggesting that a variation exists in the use of DC laparotomy across trauma centers or that the procedure may be overused. These and other studies have also suggested that overutilization of the procedure may be associated with increased morbidity and mortality. Variation in the use of DC surgery between trauma centers may occur because surgeons are frequently uncertain which "operative profile" (i.e., DC or definitive surgery) is best in varying clinical situations. In this chapter, I review the structure, effectiveness, and safety of modern trauma DC; recent studies suggesting variation in and potential harm related to the overuse of DC surgery between trauma centers; and published consensus indications for the use of DC surgery and DC interventions that aim to reduce this variation and guide future research.

2.1 Background

In injured patients receiving traditional, crystalloid-based resuscitation, significant hemorrhage is frequently complicated by development of a "bloody vicious cycle" (a.k.a., "lethal triad") of hypothermia, acidosis, and coagulopathy [1–3]. Resuscitation of hemorrhagic shock also produces ischemia-reperfusion injury of the bowel, which increases intestinal wall permeability, leading to sequestration of fluid in the bowel wall and its supporting mesenteries (i.e., abdominal visceral edema) [1, 4, 5]. This process, when combined with large-volume crystalloid fluid administration, increases intra-abdominal pressure (IAP) and may culminate in post-injury abdominal compartment syndrome (ACS; defined by the Abdominal Compartment Society as a sustained IAP >20 associated with new organ dysfunction/failure) [1, 6–8]. The vicious cycle and ACS have historically been associated with a high risk of death after major injury despite attempts at definitively controlling hemorrhage and preventing and/or treating intra-abdominal hypertension (IAH), respectively [1, 2].

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In an attempt to prevent the onset of and/or limit the effects of the vicious cycle and post-injury ACS, surgeons adopted damage control (DC) laparotomy to manage severely injured civilians in the 1980s/early 1990s [1]. In 1983, Stone et al. reported that "staged" laparotomy [i.e., abbreviated initial laparotomy with planned reoperation after a period of ongoing resuscitation in the intensive care unit (ICU)] was associated with improved survival in injured patients who developed "major coagulopathy" during operation [9]. Rotondo, Schwab, and colleagues subsequently proposed in 1993 that abbreviated trauma laparotomy be termed "damage control" and reported data suggesting that it improved survival in a "maximum injury subset" of patients with abdominal vascular and multiple concomitant abdominal visceral injuries [10]. In 1998 (during the early dispersion and exploration stage of the innovation of trauma DC), during a time when high-volume crystalloid fluid resuscitation (and therefore severe abdominal visceral edema) was common, Ivatury and colleagues advocated for routine temporary abdominal closure (TAC) of the open abdomen (i.e., open abdominal management) after DC to prevent the adverse physiologic consequences of IAH [1, 11]. Finally, beginning largely in the mid-1990s, the DC concept was adapted to rapidly manage visceral and vascular injuries in the neck, chest, and extremities [1].

In contrast to definitive (i.e., single-stage) surgery, DC allows the initial operation for control of exsanguinating hemorrhage and/or gross contamination to be abbreviated using what Feliciano et al. termed "rapid conservative operative techniques" (now also referred to, using the DC lexicon, as "DC interventions") [1, 12, 13]. This approach has long been thought to benefit critically injured patients who are "more likely to die from an uncorrected shock state than from failure to complete organ repairs" [14]. In the abdomen, DC interventions include therapeutic perihepatic packing, closed suction drainage of pancreaticobiliary injuries, rapid intestinal resection without re-anastomosis (leaving the intestinal tract in discontinuity until a later operation), and lateral arteriorrhaphy (e.g., superior mesenteric artery injuries), temporary intravascular shunting (e.g., common iliac artery injuries), and ligation (e.g., infrarenal inferior vena cava injuries) of major abdominal vascular injuries [15]. Abbreviating the index operation during DC theoretically limits further declines in core body temperature and pH and therefore allows for rewarming and correction of metabolic and coagulation disturbances in the ICU [16]. Once physiology is deemed adequately restored, injured patients are returned to the operating room (OR) for additional surgery (e.g., removal of temporary intravascular shunts and performance of vascular repairs or intestinal anastomoses for reestablishment of bowel continuity) and/or primary fascial closure (i.e., fascia-to-fascia closure of the open abdomen within the index hospitalization), often within 6–48 h of initial operation [1, 16].

In this chapter, I review the structure, effectiveness, and safety of modern trauma DC; recent studies suggesting variation in and potential harm related to the overuse of DC surgery between trauma centers; and published consensus indications for the use of DC surgery and DC interventions that aim to reduce this variation and guide future research.

2.2 The Structure of Modern Trauma DC (Integrating the Stages of DC Surgery with the Process of DC Resuscitation)

The stages of DC surgery were initially suggested by Rotondo, Schwab, and colleagues to include DC 1 [immediate operation for control of hemorrhage and contamination using one or more DC interventions followed by temporary closure of the abdomen (or thorax) and transfer to the ICU], DC 2 (resuscitation in the ICU with the goal of correcting hypothermia, acidosis, and coagulopathy), and DC 3 [reoperation for definitive repair of injuries and closure of the abdomen (or thorax)] [1, 16]. This group and others later expanded these stages to include DC 0 [or "damage control ground zero," which includes those interventions performed in the prehospital and immediate in-hospital setting before operation (e.g., prehospital

transport/care, rewarming, and initiation of a predesigned massive transfusion protocol)] and DC 4 (abdominal wall reconstruction, frequently using component separation methods and synthetic or biological mesh reinforcement) [17, 18].

DC interventions are rapid, often technically simple procedures that may be used in either the pre- [e.g., balloon catheter tamponade of significant, ongoing hemorrhage from a zone III neck wound in the emergency department (ED)] or intraoperative setting [15]. These interventions are designed to temporarily or sometimes definitively manage exsanguinating hemorrhage, gross contamination, and/or a massive pulmonary air leak in situations where several uncommonly encountered thoracic (e.g., a penetrating, through-and-through pulmonary parenchymal injury that does not involve the hilar structures), abdominal (e.g., devascularization or massive destruction of the pancreas, duodenum, or pancreaticoduodenal complex), pelvic (e.g., severe blunt pelvic trauma with ongoing, massive extraperitoneal hemorrhage), and/or vascular (e.g., significant, ongoing bleeding from a zone I or III penetrating neck injury) injuries are encountered [15, 19–46]. These injuries are characteristic of those that few surgeons have experience treating and therefore are associated with massive hemorrhage, physiological exhaustion (hypothermia, acidosis, and coagulopathy), and a high mortality when attempts are made to manage them definitively (see Table 2.1 for consensus definitions of a number of DC interventions reported in 2015) [15, 19–46].

Table 2.1 Reported descriptions of thoracic, abdominal/pelvic, and vascular damage control interventions reported in 2015

Intervention	Description
Thoracic damage control interventions	
Pneumonorrhaphy [19–21]	After small injured vessels and bronchi within the parenchyma of a superficial pulmonary laceration are selectively ligated, the edges are approximated
Pulmonary tractotomy [19–23]	The lung bridging a pulmonary parenchymal wound is divided using a GIA 55/75 vascular stapler or between two long vascular clamps, and then small injured parenchymal vessels and bronchi lying underneath are selectively ligated
Pulmonary wedge resection [19–21]	A GIA 55/75 or TA 30/60/90 vascular stapler is used to resect a peripheral portion of a pulmonary lobe or segment of the lung
Rapid, simultaneously stapled pneumonectomy [21, 24]	A TA 90/55 vascular stapler is placed across the pulmonary hilar structures and fired, resulting in an en masse simultaneous division of the main stem bronchus and pulmonary vessels
Intraluminal drainage of the proximal esophagus and wide drainage of the pleural space [25, 26]	The esophagus above or at the site of an esophageal injury is drained with a nasogastric tube connected to low suction, while the pleural space is widely drained with thoracostomy tubes
Therapeutic mediastinal and/or pleural space packing [27–29]	Compressive gauze packing is applied to the mediastinal and/or pleural surface to tamponade venous and/or coagulopathic hemorrhage at least until the first reoperation (which frequently occurs within <24–48 h)
Temporary thoracic closure [25–27, 30]	The thoracotomy incision is temporarily closed en masse using a heavy, nonabsorbable, running suture or with towel clips, a patch or silo/Bogotá bag, or a modified Barker's vacuum pack or commercial negative pressure wound therapy device
Abdominal/pelvic damage control interventions	
Therapeutic perihepatic packing	Compressive gauze packing is placed around the liver to tamponade venous and/or coagulopathic hemorrhage from the hepatic parenchyma or surrounding juxtahepatic veins at least until the first reoperation (which frequently occurs within <24–48 h)

(continued)

Table 2.1 (continued)

Intervention	Description
Staged pancreaticoduodenectomy [31–34]	During the index laparotomy, major vascular hemorrhage is controlled; where necessary (sometimes this has already been done by the inciting trauma), the duodenum distal to the pylorus, common bile duct, pancreas distal to the injury, and distal duodenum or jejunum are transected; and the right upper quadrant and peripancreatic space are widely drained (some authors also report use of T- or biliary drainage tubes at this time). Reconstruction (pancreaticojejunostomy, hepaticojejunostomy, and duodenojejunostomy) is delayed until reoperation
Therapeutic renal fossa packing [35]	Compressive gauze packing is applied to the renal fossa to tamponade venous and/or coagulopathic hemorrhage from the kidney at least until the first reoperation (which frequently occurs within <24–48 h)
Bilateral externalized ureteral stenting and diversion [35]	When neither transurethral or suprapubic drainage effectively evacuates urine from the injured bladder, J-stents are passed up each ureteral orifice and then externalized to divert the urinary output of both kidneys until definitive repair of the bladder is possible
Temporary abdominal closure/ open abdominal management	The abdomen is temporarily closed using a Barker's vacuum pack, commercial negative pressure peritoneal therapy device, silo/Bogotá bag, mesh or sheet, or another technique
Extraperitoneal pelvic packing [36–38]	After a 6- to 8-cm midline incision is made extending from the pubic symphysis cephalad (dividing the midline abdominal fascia) and the preperitoneal space is opened using digital dissection (where necessary), laparotomy pads are placed on either side of the bladder, the fascia is closed with a heavy suture, and the skin is closed with staples
Bilateral internal iliac artery ligation [39]	Both internal iliac arteries are ligated using heavy, permanent sutures during laparotomy
Vascular damage control interventions	
Balloon catheter tamponade [40–44]	A Foley, Fogarty, Sengstaken-Blakemore, or improvised balloon catheter (created using a red rubber catheter and Penrose drain) is inserted into a bleeding wound tract. The balloon of the catheter is then inflated with sterile water and repositioned until adequate hemostasis is achieved
Temporary intravascular shunting [45, 46]	After an embolectomy and administration of local intravascular heparinized saline, the defect in the injured artery and/or vein is bridged with a Pruitt-Inahara, Argyle, Javid, or Sundt vascular shunt or with a piece of an intravenous line or nasogastric/chest tube (cut to length such that it overlaps within the vessel by approximately 2 cm and secured into place with a heavy silk tie on either end). The shunt is left in place until at least the first reoperation (which frequently occurs within <24–48 h)

Where *GIA* indicates gastrointestinal anastomosis and *TA*, thoracoabdominal
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In modern civilian trauma care, many surgeons have suggested that DC surgery (or, more specifically, DC 1) should most appropriately be considered one of the first, essential components of the process of DC resuscitation [47]. DC resuscitation is characterized by rapid hemorrhage control (open or endovascular, including the use of DC interventions in the preoperative setting or in the OR during DC 1), permissive hypotension, administration of blood products in a ratio approximating whole blood [i.e., 1:1:1 plasma/platelets/packed red blood cells (PRBCs)], and minimal use of crystalloid fluids [48–50]. This now internationally adopted resuscitation strategy is initiated in the prehospital setting (a.k.a., during DC 0) and continued through DC stages 1–4. DC resuscitation was developed in order to preemptively treat the lethal triad (including the acute coagulopathy of trauma, which occurs early after injury, is likely caused by the degree of tissue injury after trauma, and is independent of the amount of crystalloid fluids administered to the patient), preserve oxygen-carrying capacity, repair the endothelium, and prevent the adverse

physiological consequences of large-volume crystalloid fluid resuscitation [47–50]. In the recently reported PROPPR randomized controlled trial (RCT) comparing a 1:1:1 versus 1:1:2 ratio of plasma/platelets/PRBCs, although 24-h and 30-day mortality was similar between the study groups, more patients in the 1:1:1 group achieved hemostasis, and fewer experienced death due to exsanguination at 24 h [50]. Thus, DC resuscitation with a 1:1:1 ratio of blood products likely has a hemostatic benefit among exsanguinating civilian trauma patients.

2.3 Effectiveness and Safety of DC Surgery in Civilian Trauma Patients

Although widely believed to improve survival when appropriately indicated, there is limited evidence supporting a benefit of DC surgery in injured patients [1, 16]. A Cochrane systematic review on DC laparotomy conducted in 2013 identified few relevant observational studies and no RCTs [16, 51]. Importantly, as the "operative profile" (DC versus definitive surgery) chosen in these seven observational studies was not randomly assigned, their conclusions are inherently limited by confounding by indication. This relatively common limitation of observational treatment studies occurs when other, unmeasured reasons associated with the choice to perform DC surgery and with patient outcome confound the association between DC surgery and outcomes (i.e., those selected for DC are inherently different from those selected for definitive surgery because they were selected to undergo DC surgery for a reason) [52].

Considering the above limitation, Stone et al., Rotondo et al., and Chinnery et al. each reported a large improvement in unadjusted survival when DC or staged laparotomy was used instead of definitive surgery to manage: (1) patients who developed a "major coagulopathy" during laparotomy, (2) hemodynamically unstable patients with combined abdominal vascular and pancreas gunshot injuries, and (3) those who received >10 U PRBCs and had ≥1 major abdominal vascular and ≥2 abdominal visceral injuries, respectively [9, 10, 53, 54]. Further, Rice and colleagues reported that, when compared to only minor deviations, moderate or major deviations from a protocol that suggested the use of DC surgery in patients with a temperature <35 °C, lactate >4 mmol/L (or more than twice the upper limit of normal), or corrected pH <7.3 were independently associated with improved survival [54, 55]. Finally, Asensio et al. reported that implementing a guideline that suggested the use of DC surgery for patients with 1 of 12 different clinical findings/events (transfusion >4 L PRBCs or >5 L PRBCs/whole blood combined; total OR fluid replacement >12 L; OR patient temperature ≤34°C, serum [HCO3-] ≤15 mEq/L, or arterial pH ≤7.2; a thoracic or abdominal vascular injury or complex hepatic injury requiring packing; those requiring ED or OR thoracotomy; or patients that develop intraoperative coagulopathy or dysrhythmias) was associated with a decreased unadjusted odds of infections, an increased unadjusted odds of abdominal wall closure, and a reduced unadjusted length of ICU and hospital stay [54, 56].

As DC surgery became widely adopted worldwide in the 1990s and 2000s, it was increasingly reported to be associated with a number of potentially severe and often resource-intensive complications considered by some (at least initially) to be "diseases of survivorship" [1, 54, 57, 58]. DC surgery and open abdominal management have been reported to be associated with an ~10–25% risk of an intra-abdominal abscess or abscesses, a mean of approximately five reoperations, an ~15% risk of readmission to hospital, and an ~8% risk of subsequent surgical procedures, especially those relating to massive or complex ventral herniae [54, 59–61]. Development of an enteroatmospheric fistula, defined as an enteric fistula in the middle of an open abdomen, occurs in approximately 5% of patients with an open abdominal wound and is considered to be a "surgical nightmare" by international surgical opinion leaders [54, 61, 62]. Defining characteristics include the absence of a fistula tract, the lack of well-vascularized surrounding tissue, a low probability of spontaneous closure, and the spillage of

enteric content directly into the peritoneal cavity [8, 54, 62, 63]. These fistulae are difficult to control and may result in repeated episodes of intra-abdominal sepsis, long lengths of ICU and hospital stay, significant costs to the health-care system, and an elevated risk of mortality [54, 64]. Moreover, although many patients can ultimately have their abdomen closed after DC laparotomy, those who cannot are often managed with a "planned ventral hernia," in which a split-thickness skin graft or mobilized native skin flap is used to cover the granulated viscera of the open abdomen, resulting in a massive and complex abdominal wall hernia that may be repaired using a components separation technique in 6–12 months [54, 65]. Possibly because of the above complications, survivors of open abdominal management have been reported to suffer from decreased physical functioning, a reduced quality of life (at least in the short term), and an increased incidence of depression and post-traumatic stress disorder [54, 66–69].

2.4 Variation in and Potential Harm Related to Overuse of DC Surgery Between Trauma Centers

Several authors have recently reported data suggesting that a variation in the use of DC laparotomy may exist across trauma centers or that the procedure may be overused [57, 70]. DC was used in 9% of patients undergoing emergent laparotomy at a level 1 trauma center in the United States in 2008 as compared to a relatively consistent rate of 29–37% in trauma patients at a different American level 1 center between 2004 and 2010 [54, 71, 72]. This variation in the use of DC across trauma centers could relate to increasing use of the procedure for indications other than those that have been previously studied or suggested to be appropriate in the literature [16, 54]. In support of this, one retrospective cohort study reported that one in five patients who received DC laparotomy at a level 1 trauma center between 2004 and 2008 failed to meet at least one of the traditional indications [16, 73]. In this study, only 33% were acidotic, 43% hypothermic, and 48% coagulopathic upon arrival to the ICU from the OR [16, 54, 73].

Variation in rates of use of DC surgery across trauma centers is concerning as accumulating evidence suggests that overutilization of the procedure for inappropriate indications may be associated with increased morbidity and mortality [57, 58, 70, 73–75]. In one retrospective cohort study conducted at a level 1 trauma center between 2005 and 2009, the use of DC instead of definitive laparotomy in trauma patients without severe head injury, a systolic blood pressure (BP) >90 mmHg, and no combined abdominal injuries was independently associated with a three times increased odds of major postoperative complications and a 10-day longer length of hospital stay [16, 75]. Further, in a propensity-matched cohort study conducted at the same trauma center, the use of DC instead of definitive laparotomy (for packing, hemodynamic instability, or intra-abdominal contamination; to facilitate a second look laparotomy, expedite postoperative care/interventions, or prophylax against ACS; or for other/unclear reasons) in injured patients was associated with a 13% increased probability of postoperative ileus, a 4% increased probability of postoperative gastrointestinal bleeding, an 11% increased probability of fascial dehiscence, a 19% increased probability of superficial surgical site infection, and an 18% increased probability of perioperative death [58].

Several other authors and I have therefore suggested that clinical outcomes and health system costs may improve with more selective use of DC surgery, especially given that DC resuscitation may effectively prevent or treat hypothermia, acidosis, and coagulopathy in trauma patients [1, 70]. In support of this, Higa et al. observed that the rate of use of DC decreased from 36 to 9% among trauma patients undergoing emergent laparotomy between 2006 and 2008 despite similar patient demographics and Injury Severity Scale (ISS) scores among the patients managed between these time periods [71]. This decline in the rate of use of DC laparotomy was associated with a significant improvement in primary fascial closure rates (50% in 2006 versus 86% in 2008), perioperative mortality (22% in 2006 versus 13%

in 2008), and total hospital costs ($44,312 in 2006 versus $32,992 in 2008) among patients undergoing emergent trauma laparotomy [54, 71].

2.5 Published Consensus Indications for Use of DC Surgery and DC Interventions in Civilian Trauma Patients

Variation in the use of DC surgery between trauma centers may occur because surgeons are frequently uncertain which operative profile is best in varying clinical situations [15, 70, 76]. This uncertainty is likely exacerbated by the fact that limited data exists on the effectiveness and safety of DC surgery and DC interventions [15, 70, 76]. These procedures are also difficult to study, especially considering the multitude of potential clinical situations that may be encountered by surgeons who (routinely or uncommonly) perform emergent thoracic, abdominal, and/or peripheral vascular operations on injured patients across level 1, 2, and/or 3 trauma centers [15, 70, 76]. Despite this, however, surgeons must decide when to use DC (or specific DC interventions) over definitive surgery (or specific definitive surgical interventions) in their practice [15].

Therefore, the indications for trauma damage control international study group and I initiated a program of research in 2013 to determine the specific clinical situations in which the expected survival benefit of conducting DC surgery (or a specific DC intervention) is likely to exceed the expected risk of negative consequences [15, 16]. We first conducted a scoping review to synthesize the literature on DC surgery and DC interventions, identify a comprehensive list of their reported indications for use, and examine the content and evidence upon these indications were based [15, 54, 77]. An indication was defined as "a clinical finding/scenario that advised use of DC surgery (or a DC intervention) over definitive surgery (or a definitive surgical intervention)" [57]. This study identified 270 published, peer-reviewed articles (58% of which represented original research) that reported 1107 indications for DC surgery and 424 indications for the 16 different DC interventions previously listed in Table 2.1 [54, 77].

We used qualitative research methods to synthesize the above indications into 123 codes representing unique indications for DC surgery and 101 codes representing unique indications for DC interventions [15, 57]. Within these codes, we included summarized or commonly used decision thresholds for reported indications with cutoffs (e.g., temperature or pH <X) [15, 57]. In an expert appropriateness rating study, an international panel of trauma surgery experts (n = 9 surgeons) then rated 101 (82.1%) of the coded indications for DC surgery and 78 (77.2%) of the coded indications for DC interventions to be appropriate for use in surgical practice [15, 57].

In 2014, we subsequently surveyed 366 surgeons who treat injured patients in level 1–3 trauma centers in the United States, Canada, Australia, and New Zealand to determine their opinions on the appropriateness of many of the indications rated in the expert appropriateness rating study [70]. In total, 201 (56.0%) of the surveyed surgeons responded [70]. These respondents rated 15 (78.9%) preoperative and 23 (95.8%) intraoperative indications to be appropriate for use in their practices [70]. There was substantial agreement between the opinions of practicing surgeons with different training, experience, and practice settings on the appropriateness of reported candidate indications for the use of DC surgery (Fig. 2.1) [70]. The reduced list of candidate indications for DC surgery that were rated to be appropriate by both experts and practicing surgeons (in both the expert appropriateness rating study and the survey of practicing surgeons) is listed in Table 2.2 [57, 70].

Nearly all agreed that the expected benefits of DC surgery outweighed the expected risks when adults requiring emergent operation were found to have (1) persistent hemodynamic instability (systolic BP <90 mmHg) in the preoperative setting or during operation (or if they were reported to have a successfully resuscitated cardiac arrest during transport to hospital), (2) persistent hypothermia (core body temperature <34 °C) or acidosis (arterial pH <7.2) during operation, or (3) hypothermia, acidosis, and clinical (absence of

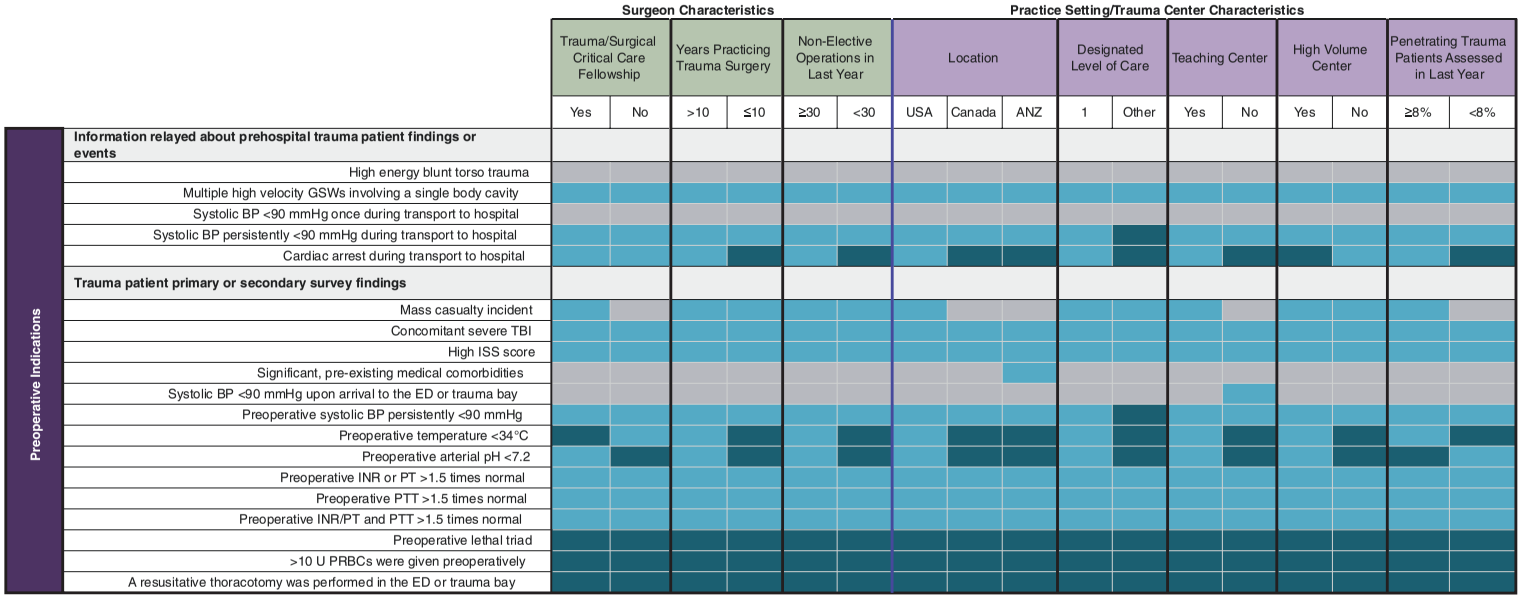
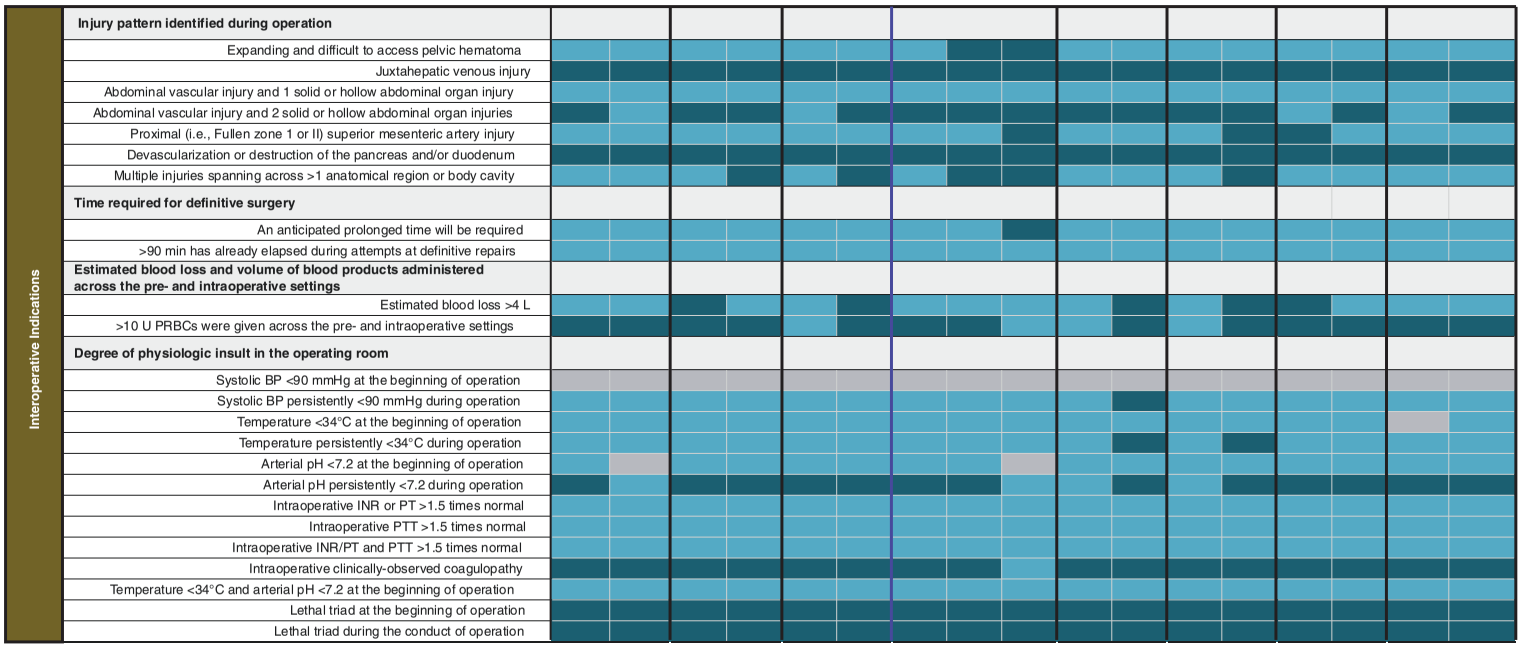


Fig. 2.1 Color map of respondents' appropriateness ratings of published candidate pre- and intraoperative indications for the use of damage control surgery stratified by surgeon- and trauma center-level characteristics, where ANZ indicates Australia and New Zealand (i.e., Australasia); BP, blood pressure; ED, emergency department; GSWs, gunshot wounds; INR, international normalized ratio; ISS, Injury Severity Scale; PT, prothrombin time; and PTT, partial thromboplastin time. Interpolated median values that lied halfway between two integers were rounded upward. Disagreement was defined as at least 33% of respondents rating the indication as 1–2 (significant harm-harm) on the Likert Scale and at least another 33% rating it 4–5 (benefit-significant benefit). Figure and figure legend reproduced with permission from reference [70]



Key to Color Coding of Appropriateness Ratings

Significant benefit (median Likert scale rating=5, without disagreement)	
Benefit (median Likert scale rating=4, without disagreement)	
Uncertain (median Likert scale rating=3, without disagreement)	

Fig. 2.1 (continued)

Table 2.2 Published candidate indications for the use of damage control surgery in adult civilian trauma patients that were rated to be appropriate by a panel of experts and the majority of practicing surgeons

Indication
Degree of physiologic insult in the pre- or intraoperative settings
• Persistent systolic BP <90 mmHg or a successfully resuscitated cardiac arrest during transport to hospital
• Persistent systolic BP <90 mmHg in the preoperative setting or during operation
• Preoperative core body temperature <34 °C, arterial pH <7.2, or INR/PT >1.5 times normal (with or without a concomitant PTT >1.5 times normal)
• Core body temperature <34 °C and arterial pH <7.2 at the beginning of operation
• Persistent core body temperature < 34 °C or persistent arterial pH <7.2 during operation
• INR/PT and PTT >1.5 times normal or a clinically observed coagulopathy during operation
• Core body temperature <34°, arterial pH <7.2, and laboratory-confirmed (INR/PT and/or PTT >1.5 times normal) or clinically observed coagulopathy in the preoperative setting, at the beginning of operation or during the conduct of operation
Estimated blood loss and amount or type of resuscitation provided
• Estimated blood loss >4 L in the operating room
• >10 U of PRBCs were administered to the patient in the pre- or pre- and intraoperative settings
Injury pattern identified during operation
• An expanding and difficult to access pelvic hematoma
• A juxtahepatic venous injury
• An abdominal vascular injury and at least one major associated abdominal solid or hollow organ injury
• Devascularization or destruction of the pancreas, duodenum, or pancreaticoduodenal complex with involvement of the ampulla/proximal pancreatic duct and/or distal CBD

Where *BP* indicates blood pressure, *CBD* common bile duct, *INR* international normalized ratio, *PT* prothrombin time, and *PTT* partial thromboplastin time
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visible blood clots during surgery) or laboratory [international normalized ratio (INR)/prothrombin time (PT) or partial thromboplastin time (PTT) >1.5 times normal] coagulopathy in the preoperative setting or during operation [54, 57, 70]. They also agreed that injured patients with physiologic derangements that improve or reverse during resuscitation and operation were candidates for definitive closure of their injured cavity at the end of the index operation [70]. These findings suggest that surgeons likely believe that unless patients present with or develop the entire lethal triad or have hypotension, hypothermia, and/or acidosis that persists during DC resuscitation (including the emergent operation for rapid hemorrhage control), it is likely frequently safe to perform a definitive (instead of DC) operation (provided that the other scenarios listed in Table 2.2 have not been encountered) [70].

Published indications that were independent of patient physiology and assessed to be appropriate by experts and the broader surgical community included an estimated blood loss >4 L, the administration of a massive transfusion (>10 U) of PRBCs, and the identification of one of the four different injury patterns during operation [57, 70]. The assessment of massive blood loss or requirement for massive transfusion as appropriate indications for DC surgery is not surprising as DC surgery has long been used as a strategy to improve the increased morbidity and mortality associated with exsanguination in trauma patients [78–80]. Further, the above injury patterns assessed to appropriately indicate the use of DC are characteristic of those that (1) often result in exsanguination during exposure and attempts at definitive repair (juxtahepatic venous injuries), (2) require urgent transport to the angiography suite for embolization soon after they are discovered intraoperatively (an expanding and difficult to access pelvic hematoma), (3) are complicated by competing management priorities (hemorrhage and contamination) or multifocal hemorrhage (an abdominal vascular injury

and at least one major associated abdominal solid or hollow organ injury), or (4) require a pancreaticoduodenectomy (devascularization or destruction of the pancreas, duodenum, or pancreaticoduodenal complex) [70, 81, 82].

Table 2.3 provides a list of the indications for the use of DC interventions that were assessed by the expert panel to be appropriate for use in the ED or OR setting [15]. Interestingly, several of the indications for the use of DC surgery and intraoperative DC interventions were identical or nearly identical [15, 54, 57]. Experts assessed these identical or nearly identical indications to have a similar appropriateness for use in practice

Table 2.3 Indications for the use of thoracic, abdominal/pelvic, and vascular damage control interventions that were rated to be appropriate by a panel of experts[a]

Indication(s) for
Thoracic DC interventions in patients undergoing thoracotomy
Rapid lung-sparing surgery (pneumonorrhaphy, pulmonary tractotomy, and pulmonary wedge resection)
Whenever possible when an emergent thoracotomy is required for thoracic trauma
Pulmonary tractotomy
Through-and-through pulmonary parenchymal injuries that do not involve the hilar structures
Rapid, simultaneously stapled pneumonectomy
An irreparable main bronchus injury and significant hemodynamic instability in the OR
Therapeutic mediastinal and/or pleural space packing
Inability to control bleeding with conventional methods (due to a coagulopathy or for other reasons)
Temporary thoracic closure
Signs of thoracic compartment syndrome develop during attempted thoracic wall closure[b]
Hypothermia, acidosis, and coagulopathy in the OR
Temporary thoracic closure with a silo/Bogotá bag
Signs of thoracic compartment syndrome develop during attempted thoracic wall closure en masse or with towel clips
Abdominal/pelvic DC interventions in patients undergoing laparotomy
Therapeutic perihepatic packing
An expanding or ruptured extensive subcapsular hematoma/hematomata
An extensive bilobar hepatic parenchymal injury
A juxtahepatic venous injury
A AAST grade III–V liver injury and a concomitant severe traumatic brain injury or multiple other concomitant solid and/or hollow abdominal organ injuries
Administration of a large volume of PRBCs preoperatively or across the pre- and intraoperative settings in a patient with a liver injury[c]
A liver injury with hemodynamic instability, hypothermia, acidosis, and/or coagulopathy in the OR
Inability to control hepatic bleeding by conventional methods
To facilitate transfer of a patient from a hospital with little experience with (or resources for) management of major liver injury to a level 1 trauma center
Staged pancreaticoduodenectomy
Devascularization or massive disruption of the pancreas, duodenum, or pancreaticoduodenal complex with involvement of the ampulla/proximal pancreatic duct and/or distal CBD (especially when there is an associated massive hemorrhage from the head of the pancreas/pancreaticoduodenal complex)
Temporary abdominal closure/open abdominal management
Coagulopathy (especially when combined with hypothermia and acidosis) in the OR
Administration of a large volume of crystalloids or PRBCs preoperatively or across the pre- and intraoperative settings
Inability to close the abdominal fascia without tension
Signs of abdominal compartment syndrome develop during attempted abdominal wall closure

(continued)

Table 2.3 (continued)

Indication(s) for
Need for a planned relaparotomy to remove intra-abdominal packs or reassess the extent of bowel viability
Extraperitoneal pelvic packing
Significant hemodynamic instability in the ED in patients with a pelvic fracture where IR is not immediately available
Severe pelvic trauma with massive, ongoing hemorrhage in the OR
Evidence on ongoing massive hemorrhage in patients with a pelvic fracture despite pelvic angioembolization
Vascular DC interventions
Balloon catheter tamponade
Significant, ongoing bleeding from a neck or supraclavicular fossa wound in the ED
Significant, ongoing bleeding from a difficult to access anatomical location or vessel in the OR[d]
Significant, ongoing bleeding from a deep or transfixing hepatic parenchymal wound in the OR
Temporary intravascular shunting
An extremity vascular injury requiring operation and a life-threatening injury in another anatomical location that requires surgery
An extremity or abdominal vascular injury requiring operation and an anticipated prolonged operative time with a suboptimal response to resuscitation
An extremity or abdominal vascular injury requiring operation and hypothermia, acidosis, and coagulopathy in the OR
Presentation of a patient with an extremity or abdominal vascular injury requiring operation during a mass casualty incident or to a hospital with little experience with surgical management of vascular trauma

Where CBD indicates common bile duct; DC, damage control; ED, emergency department; IR, interventional radiology; OR, operating room; and PRBCs, packed red blood cells

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[a]Where hypothermia, acidosis, and coagulopathy have most commonly been defined in the peer-reviewed literature as a temperature <34, pH <7.2, and a PT or PTT >1.5 times normal and the absence of visible blood clots during operation/diffuse oozing from all injured tissues [57]

[b]Suggested signs of thoracic compartment syndrome in this setting have been reported to include sudden cardiopulmonary failure, hemodynamic instability, or increased airway pressures (with resultant difficulty with ventilation)

[c]Where a large volume of PRBCs was most often defined in the literature as >10 or >12.5 units

[d]Difficult to access anatomical locations have been reported to include the head, zone III of the neck, the angle of the mandible, and the trunk while difficult to access vessels have been reported to include the carotid artery behind the pharynx; the carotid artery or internal jugular vein at the base of the skull; the internal maxillary artery; the second, third, and fourth portions of the vertebral artery; or the distal branches of the internal iliac artery in the pelvis

[15, 54, 57]. Thus, surgeons may believe that in certain intraoperative circumstances, one or more specific DC interventions should be preferentially performed when patients are selected to undergo DC surgery [54]. These include extraperitoneal pelvic packing (severe pelvic trauma and an expanding and difficult to access pelvic hematoma or massive, ongoing hemorrhage in the OR), therapeutic perihepatic packing (a juxtahepatic venous injury), and staged pancreaticoduodenectomy (devascularization of massive disruption of the pancreas, duodenum, or pancreaticoduodenal complex) [15, 54, 57, 70]. Finally, the expert panel suggested that DC surgery and TAC/open abdominal management were appropriate when patients have been administered a large volume of crystalloid fluids and/or PRBCs, when the abdominal wall is unable to be closed without tension at the conclusion of laparotomy, or when signs of post-injury ACS develop during attempted abdominal wall closure [15, 54, 57].

The above indications may be used as a type of consensus opinion to guide surgical practice in the current era of DC resuscitation [70]. They may also be used to educate surgical trainees and surgeons on the appropriate use of DC surgery and DC interventions in practice, to guide trauma

center quality improvement practices regarding choice of operative profile (through morbidity and mortality rounds, audit and feedback, and other mechanisms), and to design future (adjusted/propensity-matched) prospective observational and experimental studies focused on examining outcomes between patients treated with DC (or a specific DC intervention) versus definitive surgery (or a specific definitive surgical intervention) [54].

2.6 Summary

Modern trauma DC integrates the stages of DC surgery into the process of DC resuscitation. Although widely believed to improve survival when appropriately indicated, there is limited evidence supporting a benefit of DC surgery in injured patients [1, 16]. Further, the procedure is associated with a number of potentially severe and often resource-intensive complications [1, 57, 58]. Several studies have recently reported data suggesting that a variation exists in the use of DC laparotomy across trauma centers or that the procedure may be overused [57, 70]. These and other studies have also suggested that overutilization of the procedure may be associated with increased morbidity and mortality [57, 58, 70, 73–75]. The list of indications identified as being appropriate by both experts and practicing surgeons described in this chapter may be used to guide practice and reduce variation in the use of DC surgery until results of appropriately designed prospective studies become available in the future [54].

Disclosure I have no conflicts of interest to declare.

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