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Indications for the Appropriate Use of Damage Control Surgery and Damage Control Interventions in Civilian Trauma Patients

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In patients undergoing emergent operation for trauma, surgeons must decide whether to perform a definitive or damage control (DC) procedure. DC surgery (abbreviated initial surgery followed by planned reoperation after a period of resuscitation in the intensive care unit) has been suggested to most benefit those injured patients more likely to succumb to the "vicious cycle" of hypothermia, acidosis and coagulopathy, and/or postoperative abdominal compartment syndrome (ACS) than the failure to complete all organ repairs. However, currently there exists no unbiased evidence to support that DC surgery benefits injured patients. Further, the procedure is associated with substantial morbidity, long durations of intensive care unit and hospital stay, increased healthcare resource utilization, and possibly a reduced quality of life among survivors. Therefore, it is important to ensure that DC laparotomy is only utilized in situations where the expected procedural benefits are predicted to outweigh the expected procedural harms. In this manuscript, we review the comparative effectiveness and safety of DC surgery when used for different procedural indications. We also review recent studies suggesting variation in use of DC surgery between trauma centers and the potential harms associated with overuse of the procedure. We also review published consensus indications for the appropriate use of DC surgery and specific abdominal, pelvic, and vascular DC interventions in civilian trauma patients. We conclude by providing recommendations as to how the above list of published appropriateness indications may be used to reduce overuse of DC surgery and guide medical and surgical education, quality improvement, and surgical practice.

Keywords: *Damage Control Surgery; Damage Control Interventions; Indications; Wounds and Injuries*

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INTRODUCTION

In patients undergoing emergent operation for trauma, surgeons must decide whether to perform a definitive or damage control (DC) procedure [1–4]. In contrast to definitive laparotomy, DC laparotomy includes an abbreviated initial operation that aims to rapidly control the "compelling source" of hemorrhage and/or contamination using what Feliciano originally termed "rapid conservative operative techniques" (now also referred to as DC interventions) [5–8]. The patient is subsequently admitted to the intensive care unit (ICU) after temporary abdominal closure (TAC) for ongoing resuscitation before returning to the operating room for additional surgery and/or primary abdominal fascial closure (i.e., fascia-to-fascia re-approximation within the index hospitalization) [1,5,6].

DC surgery has been suggested to most benefit injured patients more likely to die from physiological exhaustion secondary to the "vicious cycle" of hypothermia, acidosis and coagulopathy, and/or postoperative abdominal compartment syndrome (ACS) than the failure to complete all organ repairs [6,9,10]. However, currently there exists no unbiased, randomized evidence to support that DC surgery significantly benefits injured patients [1,5]. Further, the procedure is associated with substantial morbidity, long lengths of ICU and hospital stay, increased healthcare resource utilization, and possibly a reduced quality of life among survivors [11–15].

Therefore, it is important to ensure that DC surgery is only utilized in situations where the expected procedural benefits are predicted to outweigh the expected procedural harms [2,3]. However, several studies have reported that the procedure may presently be overused [3,16,17], which is concerning as overuse of DC laparotomy has increasingly been reported to be associated with increased morbidity and mortality [18,19]. Our group has therefore suggested that injured patient outcomes may improve with more selective use of DC laparotomy [2–4].

In this article, we review the comparative effectiveness and safety of DC versus definitive trauma surgery when used for different procedural indications. We also review studies that suggest significant variation in use of DC laparotomy among trauma centers and the potential harm associated with overuse of the procedure. Finally, we review results of recent studies conducted by the Indications for Trauma Damage Control Surgery International Study Group. Their work created a list of pre- and intraoperative clinical scenarios that nine experts in trauma surgery and a large cohort of surgeons who regularly operate on injured patients in level-1 to -3 trauma centers agreed appropriately indicated use of DC surgery in civilian trauma patients [1–4,6]. We conclude by providing recommendations on how to use the above list of published appropriateness indications to reduce overuse of DC surgery and guide medical and surgical education, quality improvement, future research, and surgical practice.

COMPARATIVE EFFECTIVENESS AND SAFETY OF TRAUMA DC SURGERY

Although one study began enrolling patients as early as 2016, to date no randomized controlled trial (RCT) that compares DC and definitive surgery in trauma patients has been completed [1,20,21]. A Cochrane systematic review of DC laparotomy for abdominal trauma conducted in 2012 identified a small number of observational studies and no RCTs [1,21]. In June 2016, Harvin et al. began enrolling patients aged 16 years or older undergoing emergent laparotomy (defined as admission directly to the operating room from the emergency department within 90 min of arrival) into a pragmatic, single-center, parallel group, pilot RCT comparing DC and definitive laparotomy [20]. Inclusion criteria require that the attending surgeon must believe that one or more predefined potential indications for DC laparotomy exist [20]. Results of this RCT were originally expected in 2020.

Another systematic review conducted by our group in 2018 identified two cohort studies [22,23] that evaluated outcomes associated with implementation or utilization of indications for DC surgery [24]. Rice et al. reported that, when compared with minor deviations, moderate or major deviations from a protocol that suggested using DC surgery for patients with a temperature <35°C, lactate >4 mmol/L (or greater than twice the upper limit of normal), or corrected pH <7.3 were independently associated with a significantly reduced survival at 90 days [22,24]. Asensio et al. developed a guideline that suggested use of DC surgery in patients who received more than 4 L of packed red blood cells (PRBCs), more than 5 L of PRBCs and whole blood combined, or a total operating room fluid (PRBCs and whole blood, other blood products, and crystalloid) volume replacement of more than 12 L; had a temperature <34°C, serum [HCO3-] ≤15 mEq/L, or arterial pH ≤7.2 during operation; were found to have a thoracic or abdominal vascular injury or complex hepatic injury requiring packing; required emergency department or operating room thoracotomy; or developed intraoperative coagulopathy or dysrhythmias [23,24]. In this study, use of this guideline was associated with a significantly decreased unadjusted odds of intra-abdominal abscesses, extra-abdominal infections, and abdominal fistulae; a significantly increased unadjusted odds of abdominal closure; and significantly reduced unadjusted lengths of ICU and hospital stay [23,24].

We also identified 14 other cohort studies [18,19, 25–36] that compared outcomes of patients treated with DC versus definitive laparotomy in different clinical situations [24]. Stone et al., Rotondo et al., and Chinnery et al. reported a significant improvement in unadjusted survival with use of DC or staged laparotomy instead of definitive laparotomy for those that developed a coagulopathy during operation, received

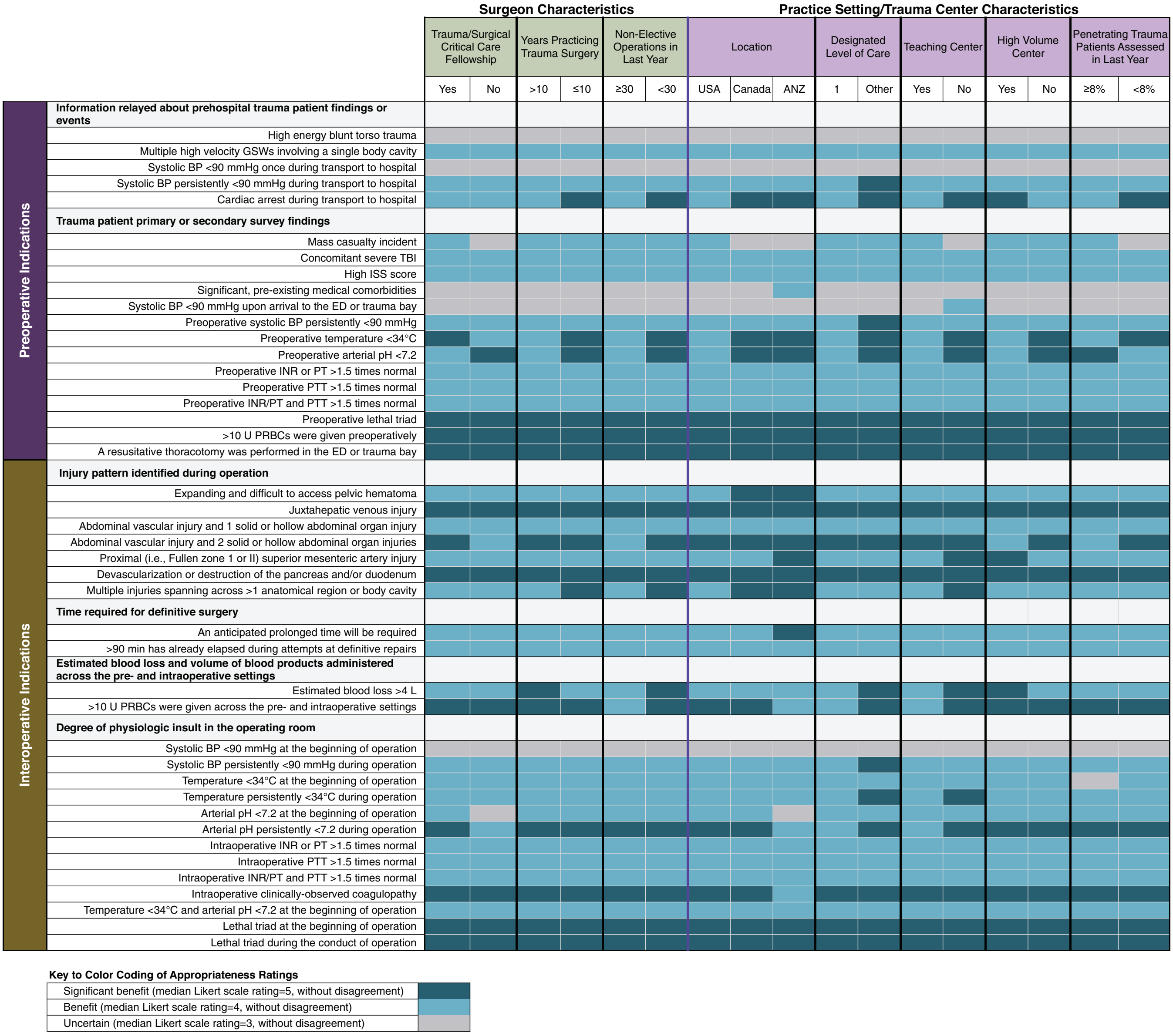

Figure 1 Color map of respondents' appropriateness ratings of published candidate pre- and intraoperative indications for use of damage control surgery stratified by surgeon- and trauma center-level characteristics. ANZ indicates Australia and New Zealand (i.e., Australasia); BP, blood pressure; ED, emergency department; GSWs, gunshot wounds; INR, international normalized ratio; ISS, injury severity scale; PT, prothrombin time; PTT, partial thromboplastin time. Interpolated median values halfway between two integers were rounded up. 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 reprinted from reference [4], copyright (2016), with permission from Elsevier. The Creative Commons license does not apply to this content. Use of the material in any format is prohibited without written permission from the publisher, Elsevier.

more than 10 U PRBCs and had one or more major abdominal vascular and two or more abdominal visceral injuries, or had combined abdominal vascular and pancreas gunshot injuries, respectively [25–27]. However, because the type of surgery (DC or definitive laparotomy) for the patients enrolled in these and the other 11 cohort studies identified by the systematic review mentioned above were not randomly assigned, these studies are likely confounded by indication [6]. This confounding occurs because surgeons choose to perform DC laparotomy based on patient, provider, and hospital characteristics, and these characteristics likely influence outcomes [37].

Therefore, very little valid or unbiased observational studies exist to support use of DC over definitive surgery in different clinical situations.

VARIATION IN AND POTENTIAL OVERUSE OF TRAUMA DC LAPAROTOMY BETWEEN CENTERS

Several authors have recently reported data suggesting that a variation in use of DC laparotomy may exist

Table 1 Reported descriptions of thoracic, abdominal/pelvic, and vascular interventions identified as constituting damage control [44].

Intervention	*Description*
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).
Staged pancreaticoduodenectomy [46–49]	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 [50]*	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 [50]	When neither transurethral nor 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 [51–53]	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 [54]	Both internal iliac arteries are ligated using heavy, permanent sutures during laparotomy.
Vascular damage control interventions	
Balloon catheter tamponade [55–59]	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 [60, 61]	After an embolectomy and administration of local intravascular heparinized saline, the defect in the injured artery and/or vein is bridged with a Pruit-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).

*GIA, gastrointestinal anastomosis; TA, thoracoabdominal. *In contrast to resuscitative packing (where packs are used to check intraoperative bleeding for a short period of time), therapeutic packing refers to prolonged (intra- and postoperative) use of packs to tamponade hemorrhage [5]. Table and Table legend reproduced from reference [44], with permission from Wolters Kluwer Health, Inc. The Creative Commons license does not apply to this content. Use of the material in any format is prohibited without written permission from the Publisher, Wolters Kluwer Health, Inc. Please contact permissions@lww.com for further information.*

Table 2 Highest rated candidate indications for use of damage control surgery in civilian trauma patients.

Indications
Injury pattern identified during operation
A difficult to access major venous (intrahepatic, retrohepatic, retroperitoneal, or pelvic) injury
A major liver or combined pancreaticoduodenal injury with hemodynamic instability in the OR
A combined pancreaticoduodenal injury with massive hemorrhage from the head of the pancreas
Devascularization or massive disruption of the duodenum, pancreas, or pancreaticoduodenal complex with involvement of the ampulla/proximal pancreatic duct and/or distal CBD
Inability to control bleeding by conventional methods
Amount of resuscitation provided
A large volume of PRBCs (median >10 U) or PRBCs, other blood products, and crystalloids combined (median >12 L) were administered preoperatively or across the pre- and intraoperative settings
Degree of physiological insult
Hypothermia, acidosis, and/or clinical or laboratory coagulopathy in the pre- or intraoperative settings*
Persistent intraoperative cellular shock†
Development of intraoperative ventricular arrhythmias
Need for staged abdominal or thoracic wall reconstruction
Inability to close the abdominal or thoracic wall without tension because of visceral edema‡
Signs of an abdominal or thoracic compartment syndrome developed during attempted abdominal or thoracic wall closure
Need to reassess the extent of bowel viability after a period of further resuscitation in the ICU

*CBD, common bile duct; ED, emergency department; ICU, intensive care unit; OR, operating room; PRBCs, packed red blood cells. *Hypothermia, acidosis, and clinical and laboratory coagulopathy were most commonly defined in the literature and the appropriateness rating study as a temperature <34°C, pH <7.2, a PT and PTT >1.5 times normal, and the absence of visible blood clots during operation/diffuse oozing from all injured tissues. †Cellular shock is defined as an oxygen consumption index <100 mL/min/m², lactate >5 mmol/L, pH <7.2, base deficit >15 mmol/L, and core temperature <34°C. ‡Surgeons may also not be able to close the thoracic wall without tension because of the presence of resuscitative intrathoracic packing.*

among trauma centers or that the procedure may currently be overused [3,4,6]. In a recently reported post-hoc analysis of the PROPPR randomized trial, DC surgery was used for 33% to 83% of patients requiring urgent laparotomy across 12 of the participating institutions [38]. Interestingly, although there was no significant adjusted mortality difference among these centers, the unadjusted risk of sepsis and ventilator-associated pneumonia was higher among those treated with DC laparotomy [38]. Therefore, some have suggested that decreasing use of DC among individual trauma centers may not necessarily influence injured patient mortality but may decrease their morbidity [38].

Variation in use of DC across trauma centers could relate to increasing use of the procedure for indications other than those previously suggested to be appropriate or validated in the literature [1,6,24]. In support of this, one retrospective cohort study by Hatch et al. reported that one in five patients who received DC laparotomy at a level-1 trauma center between 2004 and 2008 failed to have at least one traditional indication for use of the procedure [1,6,39]. In this study, only 33% of the patients who underwent DC laparotomy were acidotic, 43% hypothermic, and 48% coagulopathic on arrival at the ICU after operation [1,6,24,39]. Although the ideal rate of use of DC during emergent laparotomy is presently unknown, it was estimated in one cohort study to range between 19% and 27% across six American, level-1 trauma centers [40].

Some evidence suggests that overuse of DC laparotomy may be associated with increased morbidity and mortality [3,4,18,19,39,41]. Martin et al. reported that, when compared with patients with a severe abdominal injury who underwent therapeutic definitive laparotomy, use of DC laparotomy in patients with an arrival systolic blood pressure (BP) >90 mmHg, no severe traumatic brain injury (TBI) (head Abbreviated Injury Scale score <3), and no combined abdominal injuries was independently associated with significantly increased odds of major postoperative complications and a significantly increased adjusted length of hospital stay [18]. In another propensity-matched cohort study, Harvin et al. reported that use of DC instead of definitive laparotomy [for intra-abdominal packing (68%), second-look laparotomy (6%), hemodynamic instability (15%), to expedite postoperative care or intervention (8%), abdominal compartment syndrome prophylaxis (1%), contamination (1%), or other/unclear reasons (1%)] was associated with a significantly increased incidence of gastrointestinal (GI) ileus and bleeding, abdominal fascial dehiscence, superficial surgical site infection (SSI), and death [19]. Finally, in a follow-up study by Harvin et al. in 2019, injured patients who underwent DC laparotomy across six American, level-1 trauma centers and were judged by majority faculty vote to have been candidates for definitive laparotomy were matched 1:1 with those who underwent definitive trauma laparotomy at these centers using propensity scores [42]. In this study, for those whom surgeons had equipoise

Table 3 Indications for use of thoracic, abdominal/pelvic, and vascular damage control interventions that were rated to be appropriate by a panel of experts.*

Indication(s) For
Abdominal/pelvic DC interventions in patients undergoing laparotomy
Therapeutic perihepatic packing†
An expanding or ruptured extensive subcapsular hematoma
An extensive bilobar hepatic parenchymal injury
A juxtahepatic venous injury
An 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‡
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
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 difficult to access anatomical location or vessel in the OR§
Significant, ongoing bleeding from a deep or transfixing hepatic parenchymal wound in the OR
Temporary intravascular shunting
An 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 abdominal vascular injury requiring operation during a mass casualty incident or to a hospital with little experience with surgical management of vascular trauma

*CBD, common bile duct; DC, damage control; ED, emergency department; IR, interventional radiology; OR, operating room; PRBCs, packed red blood cells. *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 [3]. †In contrast to resuscitative packing (where packs are used to check intraoperative bleeding for a short period of time), therapeutic packing refers to prolonged (intra- and postoperative) use of packs to tamponade hemorrhage [5]. ‡A large volume of PRBCs was most often defined in the literature as >10 or >12.5 units. §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, and the distal branches of the internal iliac artery in the pelvis. Reproduced with permission from reference [44], with permission from Wolters Kluwer Health, Inc.*

regarding use of DC or definitive laparotomy, definitive laparotomy was associated with a significantly higher probability of fewer hospital-free, ventilator-free, and ICU-free days, suggesting that use of definitive laparotomy in this setting may decrease hospital resource utilization [42]. However, the two groups demonstrated a similar probability of major abdominal complications [42].

PUBLISHED APPROPRIATENESS INDICATIONS FOR USE OF DC SURGERY AND DC INTERVENTIONS IN CIVILIAN TRAUMA PATIENTS

We previously hypothesized that variation in use of DC surgery among trauma centers may occur when surgeons are uncertain which operative profile is best across the large number of varying clinical situations encountered in practice [4,6,43,44]. This uncertainty is likely exacerbated by the limited available data evaluating the effectiveness and safety of DC surgery and DC interventions and the risks of bias associated with existing evidence on the topic [4,6,43,44]. Further, conducting RCTs evaluating DC laparotomy is difficult for many reasons, most importantly the lack of equipoise among surgeons regarding its likely superior outcomes when used instead of definitive laparotomy in certain clinical situations (e.g., a juxtahepatic venous injury) [45]. Despite this, however, surgeons must decide when to use DC (or specific DC interventions) over definitive surgery (or specific definitive surgical interventions) in their practices [6,44].

In 2013, Roberts et al. and the Indications for Trauma Damage Control Surgery International Study Group began a program of research to develop evidence-informed indications for the appropriate use of DC surgery and DC interventions in civilian trauma patients [1–5,44]. We first conducted a scoping review that aimed to identify a comprehensive list of the reported indications for use of DC surgery and DC interventions and examine the content and evidence on which these indications were based [2,24,44]. 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)" [3]. This study identified 270 peer-reviewed articles that reported 1,107 indications for DC surgery and 424 indications for 16 different DC interventions (see Table 1 for our previously published definitions of abdominal, pelvic, and vascular DC interventions) [2,24,46–61]. Of note, bilateral internal iliac artery ligation should only be performed in carefully selected patients, given the risk of pelvic ischemia associated with this intervention (which may lead to bilateral buttock claudication or necrosis, vasculogenic impotence, colorectal ischemia or necrosis, and spinal cord injury).

We subsequently conducted a qualitative content analysis to synthesize the above published indications into 123 codes representing uniquely reported indications for DC surgery and 101 codes representing uniquely reported indications for 16 different DC interventions [3, 44]. An international panel of nine different trauma surgery experts located in the United States ($n = 3$), Canada ($n = 1$), the United Kingdom ($n = 1$), Finland ($n = 1$), Australia ($n = 1$), and South Africa ($n = 2$) then rated 101 (82%) of the unique indications for DC surgery and 78 (77%) of the unique indications for DC interventions to be appropriate for use in surgical practice [3,44]. The highest rated indications for DC surgery and those rated to be appropriate for the individual DC interventions are listed in Table 2 and Table 3, respectively [3,44].

We then surveyed the opinions of 366 surgeons who regularly treat injured patients in the United States, Canada, Australia, and New Zealand on the appropriateness of many of the indications for DC surgery rated in the previous expert appropriateness rating study [4]. Of the 366 surveyed surgeons, 201 (56%) responded and rated 15 (78.9%) preoperative and 23 (95.8%) intraoperative indications to be appropriate for use in their practices [4]. Ratings of appropriateness were consistent across subgroups of surgeons with different training, experience, and practice settings, suggesting that practicing surgeons have relatively consistent opinions regarding use of DC surgery in certain clinical scenarios (see Figure 1 for a color map of respondents' appropriateness ratings reported in this study stratified by surgeon- and trauma center-level characteristics) [4]. Nearly 90% of the respondents also agreed that injured patients who present with physiological derangements that significantly improve or reverse during operation were candidates for definitive instead of DC laparotomy [4].

As the above studies did not measure how surgeons actually practiced, their assessments of appropriateness may have reflected idealized practices [4,62]. We therefore recently reported the results of a study that sought to determine the accuracy of the above-published appropriateness indications for predicting use of DC surgery among patients undergoing emergent laparotomy at a large, level-1 trauma center in the United States [62]. In this study, two published preoperative indications (a systolic BP persistently <90 mmHg or core body temperature <34°C) produced moderate changes in the pre-test probability of patients undergoing DC laparotomy [62]. Five published intraoperative indications produced large and often conclusive changes in the pre-test probability of conducting DC during emergent laparotomy, including the finding of a devascularized or completely disrupted pancreas, duodenum, or pancreaticoduodenal complex during operation; an estimated intraoperative blood loss greater than 4 L; administration of more than 10 U PRBCs in the pre- and/or intraoperative period; and a systolic BP persistently <90 mmHg or arterial pH persistently <7.2 during operation [62]. Many of the indications that produced large shifts in the pre-test probability of conducting DC laparotomy were uncommonly encountered in practice (i.e., their incidence was <2%) [62]. Finally, a small number of published appropriateness indications were independently associated with the conduct of DC laparotomy even after adjusting for the simultaneous presence of other indications, suggesting that some surgeons may choose to conduct the procedure when they encounter certain *single* clinical findings [62].

IMPLICATIONS OF RECENT RESEARCH AND RECOMMENDATIONS

In recent years, wide variation has been reported in the rates of use of DC laparotomy among North American trauma centers [3,16,17]. This variation may be explained by several factors, including differences in surgeon equipoise regarding the benefit of the procedure

Table 4 Unadjusted and adjusted odds of performing damage control laparotomy by published pre- and intraoperative appropriateness indications.

Published Appropriateness Indication	*OR for Performing DC Over Definitive Laparotomy (95% CI)*	
	Unadjusted	*Adjusted**
Preoperative indications		
Information relayed about prehospital trauma patient findings or events		
The patient suffered a successfully resuscitated cardiac arrest during transport to hospital	2.13 (0.13–34.11)	0.60 (0.036–10.17)
Trauma patient primary or secondary survey findings		
The patient presented with a concomitant severe TBI	5.51 (3.69–8.22)	1.99 (1.11–3.57)
The calculated ISS score of the patient was >25	4.57 (3.49–5.97)	3.14 (2.06–4.79)
The patient's preoperative systolic BP was persistently <90 mmHg	7.12 (4.32–11.71)	4.31 (2.09–8.88)
The patient's preoperative core body temperature was <34°C	5.45 (1.35–21.94)	1.31 (0.19–8.89)
The patient's preoperative BD was >15 mmol/L or lactate was >5 mmol/L	3.82 (2.89–5.06)	2.90 (1.93–4.35)
The patient presented with a coagulopathy on rTEG†	1.35 (1.05–1.75)	0.97 (0.66–1.43)
>10 U of PRBCs were given to the patient preoperatively	1.40 (0.95–2.07)	1.11 (0.49–2.53)
Intraoperative indications		
Injury pattern identified during operation		
The patient is found to have an abdominal vascular injury and a major associated abdominal solid or hollow organ injury	3.77 (2.62–5.41)	2.78 (1.61–4.82)
The patient is found to have devascularization or disruption of the pancreas, duodenum, or pancreaticoduodenal complex requiring a pancreaticoduodenectomy	Perfectly predicted use of DC	Perfectly predicted use of DC
Multiple blunt or penetrating injuries spanning across more than one anatomic region or body cavity that each require surgery	4.21 (2.57–6.91)	1.53 (0.73–3.22)
Time required for surgery		
>90 min has already elapsed during the index operation	0.56 (0.43–0.74)	0.37 (0.26–0.53)
Estimated blood loss and volume of blood products administered across the pre- and intraoperative settings		
The patient's estimated blood loss is >4 L	20.07 (10.21–39.46)	4.16 (1.60–10.83)
>10 U of PRBCs have been given to the patient across the pre- and intraoperative settings	18.95 (12.46–28.80)	7.84 (4.78–12.86)
Degree of physiological insult in the operating room		
The patient's systolic BP was <90 mmHg at the beginning of the operation	4.36 (3.11–6.13)	1.16 (0.71–1.91)
The patient's systolic BP was persistently <90 mmHg during the operation	35.64 (4.69–270.89)	5.01 (0.42–59.72)
The patient's core body temperature was <34°C at the beginning of the operation	3.30 (1.67–6.53)	2.46 (0.50–12.20)
The patient's core body temperature was persistently <34°C during the operation	3.34 (1.33–8.39)	0.43 (0.065–2.85)
The patient's arterial pH was <7.2 at the beginning of the operation	7.03 (5.03–9.83)	2.27 (1.42–3.63)
The patient's arterial pH was persistently <7.2 during the operation	32.28 (9.89–105.34)	3.26 (0.73–14.50)
The patient's core body temperature was <34°C and arterial pH <7.2 at the beginning of the operation	7.40 (2.37–23.12)	0.86 (0.11–6.54)

*BD, base deficit; BP, blood pressure; DC, damage control; ISS, injury severity scale; OR, odds ratio; PRBC, packed red blood cell; rTEG, rapid thromboelastography; TBI, traumatic brain injury; U, units. *Adjusted for the simultaneous presence of other pre- or intraoperative indications in order to determine the independent influence of that individual indication on the decision to conduct DC over definitive laparotomy. †Defined as an activated clotting time ≥128 s, K-time ≥2.5 min, α-angle ≤56°, maximal amplitude ≤55 mm, or lysis at 30 min ≥3% [64]. Table and Table legend reproduced from [62], copyright (2020), with permission from Elsevier.*

in different clinical situations and the lack of valid data supporting that DC laparotomy improves survival in severely injured patients. The possible overuse of DC laparotomy across these trauma centers is concerning as some recent data suggest that when DC is used instead of definitive laparotomy in patients in whom surgeons have equipoise between the two, use of DC laparotomy is associated with increased resource utilization [42]. Other studies have also suggested that use of DC instead of definitive laparotomy when DC laparotomy is not indicated may be associated not only with increased resource utilization, but with higher morbidity and possibly mortality [18,19].

Table 4 summarizes those published indications that have been rated to be appropriate for use in practice by experts and practicing surgeons [62]. We also provide estimates of the unadjusted and adjusted (i.e., adjusted for the simultaneous presence of the other indications listed in the table) odds of undergoing DC laparotomy for each of these different indications [62]. Although the intraoperative findings of an expanding or difficult-to-access pelvic hematoma or juxtahepatic venous injury were previously rated to be appropriate indications for use of DC laparotomy in our expert appropriateness rating study [3] and cross-sectional survey of practicing surgeons [4], we do not yet have data on their ability to predict use of the procedure in practice [62]. Despite this, experts and practicing surgeons strongly suggest using DC surgery in these situations.

The indications listed in Table 4 may be used to educate surgical trainees on the appropriate, yet limited use of DC laparotomy and guide trauma center quality improvement practices aimed at reducing inappropriate use of the procedure. The group at the Red Duke Trauma Institute at Memorial Hermann Hospital-Texas Medical Center recently reported a decrease in the rate of use of DC laparotomy from 39% between 2011 and 2013 to 23% between 2013 and 2015 using a multifaceted quality improvement initiative that included audit and feedback for every DC laparotomy case [63]. The indications listed in Table 4 may also be used to guide the development of prospective observational and randomized studies aimed at understanding in which clinical situations DC laparotomy may offer a survival benefit over definitive laparotomy in injured patients. In our opinion, it is now time for these studies to be conducted.

CONCLUSIONS

Although DC surgery may benefit select, critically injured patients, it may currently be overused in some trauma centers. This is concerning as some studies have reported that overuse of this technique may be associated with increased healthcare utilization, morbidity, and potentially mortality. The published DC surgery appropriateness indications outlined in this manuscript may be used to reduce overuse of DC surgery and guide medical and surgical education, quality improvement, future research, and surgical practice.

Ethics Statement

(1) All the authors mentioned in the manuscript have agreed to authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.
(2) The authors declare that they have read and abided by the JEVTM statement of ethical standards including rules of informed consent and ethical committee approval as stated in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Author Contributions

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