Damage control surgery: current state and future directions

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Purpose of review
Damage control surgery (DCS) represents a staged surgical approach to the treatment of critically injured trauma patients. Originally described in the context of hepatic trauma and postinjury-induced coagulopathy, the indications for DCS have expanded to the management of extra abdominal trauma and to the management of nontraumatic acute abdominal emergencies. Despite being an accepted treatment algorithm, DCS is based on a limited evidence with current concerns of the variability in practice indications, rates and adverse outcomes in poorly selected patient cohorts.

Recent findings
Recent efforts have attempted to synthesize evidence-based indication to guide clinical practice. Significant progress in trauma-based resuscitation techniques has led to improved outcomes in injured patients and a reduction in the requirement of DCS techniques.

Summary
DCS remains an important treatment strategy in the management of specific patient cohorts. Continued developments in early trauma care will likely result in a further decline in the required use of DCS in severely injured patients.

Keywords
damage control surgery, multiple organ failure, resuscitation, shock, trauma

INTRODUCTION

Trauma is the leading cause of death in people aged 1–44 years, with haemorrhage considered the primary cause of preventable death, accounting for 30–40% of fatalities [1]. The primary and definitive repair of severe traumatic injuries in patients presenting with deranged physiology is known to be detrimental to outcome [2,3]. Damage control surgery (DCS) represents a staged management approach for these injured patients who present with severe physiological compromise and whom require surgical intervention [3]. This approach has demonstrated improved survival of critically injured and shocked patients [4–7], and in the context of current trauma care, it is estimated that approximately 10% of patients will require DCS intervention [8–10].

The principles of DCS involve abbreviated surgery to control blood loss and contamination in the abdomen, the simultaneous resuscitation of physiology and delayed definitive surgical care once acceptable physiology has been restored [4,11]. More specifically, DCS has been outlined in five clinical phases [2]: Phase 1 involves identifying the unwell trauma patient based on injury characteristics and presenting pathophysiology. Phase 2 represents abbreviated surgery to control bleeding and contamination, which is closely followed by phase 3, the dynamic reassessment of patient parameters during the operative course. Phase 4 encompasses continued physiological restoration and vital organ support in the ICU through optimization of haemodynamics and the correction of acidosis, hypothermia and coagulopathy. Following patient stabilization, definitive surgical reconstruction is undertaken during phase 5. With the development of early trauma resuscitation techniques, an additional 'Phase 0' has been proposed focussing on goal-directed haemostatic resuscitation without delaying surgery.

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KEY POINTS

- Damage control surgery is a treatment modality, which can be applied for the care of the most severely injured trauma patients with critical physiological derangement.
- The widespread application of DCS to noncritical trauma patients or with easily reversible derangements is not warranted and increases resource utilization and complications.
- Modern resuscitation strategies help reduce the need for frequent DCS use.

Despite its advantages, DCS is associated with significant complications. Trauma patients requiring a staged surgical approach are subjected to multiple operations, prolonged ICU stays and may experience abdominal compartment syndrome, acute respiratory distress syndrome and multiple organ failure [12,13]. In particular, open abdomen management may result in intra-abdominal infection and severe morbidities such as anastomotic breakdown, ventral hernias and entero-atmospheric fistula [14,15]. Clearly, the benefits of DCS very much depend on correct patient selection.

HISTORICAL PERSPECTIVES

The modern history of DCS emerged in the late 1970s from clinical experience with major hepatic trauma [16,17]. Although packing of liver wounds to achieve haemostasis was embraced by Pringle in 1908 [18], enthusiasm for staged laparotomy with primary perihepatic packing became widespread during this period, as numerous clinical reviews began to identify refractory coagulopathy as a barrier to patient survival.

Moore *et al*. [19,20] observed that 82% of deaths following liver trauma were due to uncontrolled haemorrhage and progressive coagulopathy, seemingly exacerbated by hypothermia and acidosis. In addition, more than half of deaths secondary to major abdominal vascular injuries occurred secondary to unrelenting coagulopathy after primary vascular injuries had been addressed. On the basis of these observations, the 'bloody viscous cycle' or 'lethal triad' was proposed, emphasizing hypothermia and persistent metabolic acidosis as key factors promoting a lethal coagulopathic state [2].

In 1981, Feliciano *et al*. [21] reported on the observed merit of temporary laparotomy pad tamponade for postinjury coagulopathy. Nine out of 10 patients with persistent hepatic parenchymal ooze, despite all attempts at surgical control, survived with intra-abdominal packing and delayed removal. This finding led the authors to advocate the technique as a lifesaving manoeuvre in select trauma patients with persistent coagulopathy. Two years later, Svoboda *et al*. [22] reaffirmed the survival benefit of intra-abdominal packing in 12 patients with hepatic injury, hypothermia and persistent coagulopathy.

The original description of staged laparotomy for penetrating abdominal trauma however was outlined by Stone *et al*. in 1983 [5]. In a brief but seminal report, the authors reviewed survival in patients who developed intraoperative coagulopathy during laparotomy for predominately penetrating abdominal trauma. Compared with a historical cohort survival rate of just 7% in 14 patients treated with definitive laparotomy, 65% (11 of 17 patients) survived via 'initial abortion of laparotomy, establishment of intra-abdominal pack tamponade and then completion of the surgical procedure once coagulation has returned to an acceptable level'. In doing so, the authors outlined the fundamental objective of abbreviated surgery in trauma care, acute restoration of physiology and staged anatomical reconstruction. During the decade that followed this publication, abbreviated laparotomy for postinjury coagulopathy became widespread accepted practice [7,23,24] resulting in improved patient survival.

Adapted from a US naval phrase describing salvage techniques for seriously damaged ships [25], the term 'Damage Control Surgery' was first described for trauma management by Rotondo *et al*. in 1993 [4], who outlined a three-phase approach for patients with major abdominal trauma. In a retrospective review of 46 patients with penetrating abdominal trauma requiring laparotomy for exsanguination, overall survival rates were similar in patients managed via definitive laparotomy and a DCS approach, although the authors found that in a subset of 22 maximally injured patients (major vascular injury combined with two or more visceral injuries), those who underwent 'an initial control of haemorrhage and contamination followed by intraperitoneal packing and rapid closure, allowing for resuscitation to normal physiology in the intensive care unit and subsequent definitive re-exploration' showed markedly improved survival (77 vs. 11%, $P < 0.02$).

With the implementation of DCS patients previously regarded as beyond help were now surviving their initial injuries and were being transferred to ICUs for physiological stabilization prior to surgical reconstruction. During the same period, research by Shoemaker *et al*. [26–28] outlining the perceived benefits of supranormal resuscitation resulted in many of these patients receiving excessive volumes

of crystalloid and experiencing subsequent problematic tissue oedema of the lungs and gut during attempts at physiological restoration. The combination of shock, large volume resuscitation, intestinal oedema and a tightly packed and closed abdomen led to increased intra-abdominal pressures and the development of virtual epidemics of abdominal compartment syndrome [29,30]. With an initial reported prevalence of more than 30% [31–33] and mortality rate greater than 60% [24] in the major trauma population, these patients were now surviving their initial injuries but were soon dying from lethal respiratory, renal and cardiac failure due to increased abdominal pressure.

Prospective observational studies soon identified the association between ACS and traumatic shock resuscitation. Through the liberal use of open abdomen surgery and systematic evidence-based modifications to traumatic shock resuscitation techniques, postinjury ACS was essentially eliminated from modern trauma care. In 2011, a prospective review of 81 patients admitted to the ICU with shock and major torso trauma, 0% of individuals developed ACS [34]. The successful prevention of this lethal syndrome is one of the greatest documented achievements of modern postinjury critical care. Over the last 10 years, driven by ACS research, a new addition to the damage control paradigm has formed, damage control resuscitation (DCR). DCR differs from previous resuscitation approaches by attempting an earlier and more aggressive correction of coagulopathy as well as metabolic derangements. It embraces several key concepts, including permissive hypotension, the restriction of isotonic fluid for plasma volume expansion and the early and rapid administration of component transfusion therapy to support correction of postinjury coagulopathy [8]. This strategy begins in the emergency room and continues through the operating room and into the ICU [35].

Contemporary evidence now reflects the benefit of DCS in the context of DCR. DCR restores physiological reserve facilitating more definitive surgical treatment resulting in decreased perioperative complications and improved outcomes [36,37]. DCS is now considered a component of DCR, with both forming a continuum of modern trauma care [38,39].

DCR facilitates the early correction of the 'bloody vicious cycle' of trauma allowing for definitive surgical treatment to be completed at the first operation [40].

In 2011, Cotton *et al.* [41] demonstrated survival benefits in 108 adult trauma patients requiring damage control laparotomy managed with DCR compared with a historical cohort treated with conventional resuscitation methods. Those managed with DCR required less intraoperative crystalloid and blood products and reached the ICU warmer, less acidotic and less coagulopathic (80 vs. 46%, $P < 0.001$). Correspondingly, after controlling for patient age, arrival vital signs and laboratory values, the group noted reduced 24-h and 30-day mortality. DCR was independently associated with a 2.5-fold increased odds of 30-day survival. Similar survival benefits and reduced ICU length of stay have been outlined by Duchesne *et al.* [37] in a review of adult trauma with severe haemorrhage [>9 units intraoperative packed red blood cells (PRBCs)] requiring DCS.

In a 3-year retrospective review of 532 trauma patients requiring laparotomy, Higa *et al.* [42] found that with implementation of DCR and more specific patient selection, the rate of patients requiring DCS laparotomy decreased from 36 to 9% ($P < 0.001$) in a level 1 trauma centre. This shift towards definitive surgery was associated with significant reductions in healthcare costs and resource utilization. In addition, the mortality of those requiring open laparotomy dropped from 22 to 13% ($P = 0.05$). Higher rates of primary abdominal fascial closure in the context of DCR have been subsequently reinforced by additional authors reviewing larger patient cohorts over longer study periods [43,44]. More recent evidence has suggested DCR has also reduced the need for surgical haemostasis by up to 20% in severe hepatic trauma, by directly addressing trauma-induced coagulopathy [45].

With continued advances in early trauma care, in particular DCR strategies, the requirement for a staged DCS approach to the critically injured trauma patient is likely to become less and less necessary.

CURRENT EVIDENCE BASE AND DAMAGE CONTROL INDICATIONS

Although DCS has become a standard in trauma care, it is interesting to note that DCS practice is based on information primarily established from case and observational studies in the absence of higher levels of evidence. Indeed, a Cochrane review in 2013 [46] was unable to validate the benefit of DCS over definitive surgical care in major abdominal trauma. Despite reviewing 2441 individual studies, no published nor pending randomized controlled trials were found. Two additional studies [4,5] (previously outlined) relevant to the research question were excluded, as both were case–control studies with limited patient numbers. The review concluded that quality randomized trials comparing DCS and immediate surgical reconstruction were required to validate its practice.

Despite the accepted advantages of a staged surgical approach, recent evidence has highlighted inconsistencies in the use of DCS across tertiary trauma centres. Watson *et al*. [47] in 2017 described significant variation in damage control laparotomy utilization, ranging from 33 to 88% in severely injured trauma patients across 12 Level 1 trauma centres in North America. Additional evidence has also suggested that the overutilization of DCS in current trauma practice has resulted in increased morbidity and resource utilization [48]. In a review of 925 patients managed at a level 1 trauma centre, Hatch *et al*. [49] found that 20% of patients with open abdomens following initial laparotomy did not have established indications for DCS. These variations have been suggested to be in part, attributable to a lack of consensus among the surgical community regarding indications for its appropriate use [50].

Historically, indications for DCS have been focused on patient factors (medical comorbidities and physiological reserve), injury factors (blunt vs. penetrating torso trauma, peritoneal contamination or major haemorrhage), physiological parameters (primarily focused on the 'lethal triad of trauma' – hypothermia, acidosis and coagulopathy) and treatment factors (resuscitation requirements and the expected duration/physiological effect of definitive care) [51]. Specific trigger points to dictate DCS have been indicated [3] but validated variably.

In 2015, Roberts *et al*. [52] highlighted the significant volume, varying underlying content and lack of original research relating to indications for DCS implementation.

Through a scoping review of the literature from 1950 to 2014, 270 peer-reviewed articles outlining 1099 individual indications for DCS were identified. Although an assessment of study quality nor predictive validity of each indication was undertaken, the authors found most (94.5%) indications to be based on patient characteristics, including their physiology (57.6%), injury characteristics (38.9%) and/or resuscitation requirements (14.3%).

The proportion of described preoperative ($P < 0.001$) and resuscitation-based ($P = 0.001$) indications increased several fold after the year 2000, reflecting the growing opinion damage control strategies should be made early, prior to significant/irreversible physiological compromise [53,54]. Similarly, an increase in indications based on volume/type administered resuscitation fluids reflects our understanding of established morbidity associated with unbalanced blood products and large volume crystalloids [38]. However, only 58% of studies were of original research (75% cohort studies), with only 87 individual indications evaluated by original research (nine indications by more than one study), demonstrating the lack of validated DCS indications in our current evidence base.

Subsequent to this review, Roberts *et al*. [55▪] in 2016 aimed to characterize and evaluate indications for the implementation of DCS in civilian trauma. The group synthesized indications for DCS reported in 175 peer-reviewed articles identified between 1983 and 2014. Citations involving exclusively non-civilian trauma and patients with associated burns, neurological or orthopaedic injuries were excluded from the analysis. One hundred and twenty-three unique indication codes for DCS (36 preoperative and 87 intraoperative) were summated using an abbreviated grounded theory method from 1107 reported indications. An invited panel of nine trauma surgery experts (from United States, Canada

Table 1. Highest rated candidate indications for use of damage control surgery in civilian trauma patients

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 haemodynamic instability in the operating room
A combined pancreaticoduodenal injury with massive haemorrhage 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 physiologic insult
Hypothermia, acidosis and/or clinical or laboratory coagulopathy in the pre or intraoperative settings[a]
Persistent intraoperative cellular shock[b]
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 oedema
Signs of an abdominal or thoracic compartment syndrome develop 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.
[a]Hypothermia, acidosis and clinical and laboratory coagulopathy were most commonly defined in the literature and the appropriateness rating study as temperature <34.8°C, pH <7.2, PT and PTT >1.5 times normal, and the absence of visible blood clots during operation/diffuse oozing from all injured tissues.
[b]Cellular shock is defined as an oxygen consumption index <100 ml/min/m^2, lactate >5 mmol/l, pH <7.2, base deficit >15 mmol/l and core temperature <34.8°C.
Adapted with permission from [55▪].

and Europe) then rated the appropriateness (expected benefit to harm ratio) of the coded indications for use in surgical practice. The indication codes assessed to have the greatest benefit to harm ration (Table 1) included the administration of more than 10 units of PRBCs in the preoperative setting, greater than an accumulative 12l of PRBCs/whole blood/other blood products/crystalloids during the pre and intraoperative period, an inability to control bleeding with conventional methods, the degree of physiological insult as demonstrated by pre or intraoperative hypothermia (<34.8°C), acidosis (pH < 7.2) and/or coagulopathy (prothrombin time and partial thrombolastin time >1.5 x normal and the absence of visible blood clots during operation/diffuse oozing from all injured tissues). Specific injury characteristics and concerns regarding abdominal or thoracic compartment syndrome were also deemed to be indicators to pursue DCS. Interestingly, an anticipated prolonged operative procedure was considered an indication to change tact to DCS only in the context of suboptimal response to resuscitation. This suggests the growing recognition that surgical management must be based on the dynamic response to resuscitation rather than a static snapshot/indicator of patient physiology or injury characteristics at the time of presentation. The authors acknowledged that as the physiological and survival benefits of DCR techniques in trauma care are currently an area of active investigation [56–60] and clinical implementation, indications for DCS so will evolve in the future. Further evidence-based validation of these indicators through original research is required.

DAMAGE CONTROL SURGERY FOR NONABDOMINAL INJURIES AND FOR NONTRAUMA PATIENTS

In the context of trauma, DCS strategies have been widely applied not only to abdominal injuries but also in the treatment of thoracic [61], vascular [62], pelvic [63] and extremity injuries [64,65]. Most literature has focused on damage control orthopaedics (DCO), the staged fixation of major fractures, primarily in the context of femoral shaft factures management. Research has examined the outcomes of primary/definitive intramedullary nailing (early total care/ETC) vs. a staged DCO approach with initial external fixation, resuscitation and optimisation of patient physiology followed by planned reoperation with intramedullary fixation. Whenever possible, ETC has demonstrated better outcomes with less perioperative morbidity. However, for critically injured, nonresponder traumatic shock patients, the abbreviated, less invasive and temporising surgery can be lifesaving and preventing multiple organ failure.

ETC of long bone fractures within 24–48 h was popularized during the 1980s citing a reduction in complications and hospital length of stay associated healthcare costs [66–68]. However, as with many examples in medicine, it was taken out of context and applied to situations when unresuscitated and coagulopathic patients were subjected to femoral nailing directly from emergency department, typically after receiving crystalloid and colloid-based fluids. DCO was subsequently recommended to avoid complications from operating on physiologically exhausted patients [65,69]. However, DCO was soon abused and applied to physiologically noncompromised patients.

In 2007, Pape *et al*. [70] published the first prospective, randomized, controlled analysis examining the outcomes of polytrauma patients with femoral shaft fractures managed via staged fracture stabilization (DCO) or immediate definitive intramedullary fixation. The study found neither stable nor patients with 'borderline' physiology benefited from DCO, which lead to more septic complications, longer hospital and ICU stays. Borderline patients experienced a lower incidence of acute lung injury when managed via staged fixation, but importantly, this did not translate to any benefit in clinically significant adverse outcomes, mortality or resource utilization. These findings were further reinforced by the experience of centres that routinely provided ETC to patients with 'borderline' physiology [71]. The randomized trial by Pape *et al*. [70] encouraged a new era of reflected ETC rather than the rigid application of damage control principles in physiologically uncompromised patients or those who had readily reversible acute physiological compromise. Today, DCO is recommended in the treatment of a specific cohort of patients whom present in physiological extremis or those unstable/borderline patients who do not respond to modern day resuscitation techniques [72–74].

During the last 10–15 years, there have been efforts to translate the physiological compromise seen in acutely injured major trauma patients to the management of acute surgical abdominal emergencies in the nontrauma setting [75–77]. The reports in this context however are rather preliminary, largely retrospective in nature and often confuse the definitions and fundamental principles of DCS [78]. Of note, despite obvious evidence-based limitations, the general trend towards adopting DCS strategies for general abdominal surgical emergencies reflects a similar pattern seen in the early 1990s during the spread and acceptance of DCO in trauma care.

FUTURE DIRECTIVES

The clinical applications of DCS are well ahead of its current evidence base. Unfortunately, it is difficult to undertake randomized trials in situations wherein accepted practice has been implemented prior to establishing high level evidence. Probably, the best way forward may be to categorize trauma patients based on physiological derangement and injury characteristic in prospective cohort studies. Long-term, high-quality prospective cohorts would assist the trauma community in monitoring practice trends and corresponding changes in patient outcomes. Damage control remains essential in the management of patients presenting in extremis or those not responding to resuscitation efforts. However, current evidence trends suggest that the principles of DCS are likely to be required less and less as improved resuscitation techniques allow one-stage definitive surgical care to be implemented in larger patient cohorts.

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- ■ of special interest
- ■■ of outstanding interest

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