The Evolution of Damage Control in Concept and Practice

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Abstract

Keywords

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- lethal triad

Damage control surgery (DCS) began as an adjunct approach to hemorrhage control, seeking to facilitate the body's innate clotting ability when direct repair or ligation was impossible, but it has since become a valuable instrument for a broader collection of critically ill surgical patients in whom metabolic dysfunction is the more immediate threat to life than imminent exsanguination. Modern damage control is a strategy that combines the principles of DCS with those of damage control resuscitation. When used correctly, damage control may improve survival in previously unsalvageable patients; when used incorrectly, it can subject patients to imprudent risk and contribute to morbidity. This review discusses the evolution of damage control in both concept and practice, summarizing available literature and experience to guide patient selection, medical decision-making, and strategy implementation throughout the preoperative, intraoperative, and early postoperative periods.

Modern damage control combines the principles of damage control surgery (DCS) with those of damage control resuscitation (DCR) to achieve a more holistic management strategy in surgical patients suffering from life-threatening metabolic derangements. There is no Level I prospective evidence to support DCS,¹ but subjective and objective experience is rapidly expanding because of perceived benefits in a cohort of patients previously deemed unsalvageable. Implementing an optimal damage control strategy requires an understanding of the converging principles of both DCS and DCR to optimize patient selection and medical decision-making.

Early Retrospectives

Primitive damage control strategies were first described early in the 20th century,² but for nearly 80 years, its indications had been limited to the management of surgical bleeding that could not be directly sutured, ligated, or cauterized such as that from deep within the liver, retroperitoneum, or pelvis.^{3–5} The approach emphasized the principle of hemorrhage control through compression, either directing pressure with surgical packing or facilitating gen-

eral tamponade through abdominal closure in the face of ongoing, nonsurgical bleeding.⁶

It was not until a landmark study in 1982 that we began to better understand the underlying metabolic processes that impair hemorrhage control in severely injured patients and contribute significantly to their mortality risk. In that study, Kashuk and colleagues observed an overall mortality rate of 37% in 123 patients with major abdominal vascular trauma. Eighty-nine percent of deaths were attributed to hemorrhage, but of those, 51% had exsanguinated after satisfactory repair of their vascular injuries. The last page of that article contains a rudimentary sketch illustrating for the first time how hemorrhage and tissue hypoxia contribute to a *Lethal Triad*. "These findings," the authors conclude, "suggest that coagulopathy, hypothermia and acidosis are complicating factors which demand as much attention by the surgeon as the initial resuscitation and operative control classically emphasized."⁷

Ten years later, Burch and colleagues described an approach of abruptly curtailing efforts to achieve definitive surgical repair of traumatic injuries when confronted with clinical or laboratory evidence of severe metabolic

derangement.⁸ In the authors' view, the metabolic demands of ongoing surgery were contributing to these patients' "impending death." The following year, Rotondo and colleagues defined *damage control* as "the initial control of hemorrhage and contamination followed by intraperitoneal packing and rapid closure... resuscitation to normal physiology in the intensive care unit and subsequent definitive re-exploration."⁹ When evaluated in the small subset of their most severely injured patients, this strategy was associated with a reduction in mortality from 89% to just 23%, and their three-stage model still serves as the foundation for a continuously refined concept of damage control.

Utilization of DCS slowly expanded throughout the 1990s despite only marginal demonstrated benefit. Comprehensive reviews of more than 1,000 damage control patients between 1976 and 1998 demonstrated a persistent mortality rate of greater than 50%.^{10,11} In the absence of an effective way to interrupt the vicious cycle of the Lethal Triad, the observed benefit was likely related to the abbreviation of the physiologic insult of prolonged surgery and anesthesia. Longer periods of corporal exposure associated with definitive surgery led to greater degrees of hypothermia while demanding higher doses of sedation, prolonged muscle relaxation, and greater volumes of resuscitation. All of these factors prohibited DCS from realizing substantially improved outcomes.

Damage Control beyond Surgery

The absence of a reliable method of correcting the life-threatening metabolic consequences of the Lethal Triad limited the early application and success of DCS. Physiologically, packed red blood cells (PRBCs) have a mean pH of 6.79 (± 0.1) when stored for an average of 6.7 days (± 3.8),¹² and they must be transfused with normal saline, which itself has a pH of 5.5 and dilutes the endogenous buffering capacity of plasma.¹³ Lactated Ringer has a less acidotic pH of 6.5, and in patients with normal physiology, lactated Ringer has an alkalinizing effect because the metabolism of lactate produces bicarbonate.¹⁴ Hemorrhaging patients, however, are incapable of metabolizing the already-increased lactate load generated by tissue hypoperfusion. Conventional resuscitation strategies based on large volumes of these components will therefore consistently exacerbate acidosis, accelerating rather than interdicting a patient's metabolic deterioration.

Over the last decade, the concept of DCR has emerged, often used in conjunction with the principles of DCS. DCS combined with DCR results in improved 24-hour and 30-day survival compared with DCS alone.¹⁵ When evaluating the clinical evidence pertaining to damage control, it is important to distinguish between strategies that incorporated the principles of DCR from those that did not. In modern practice, each should be considered a vital component to the comprehensive management of critically ill and injured surgical patients. DCR includes elements of permissive hypotension, fluid restriction, and fixed-ratio blood product resuscitation that approximate the restoration of intravascular volume with whole blood.

Permissive or controlled hypotension balances the risk of inadequate circulating volume against those of exacerbating hemorrhage with increased blood pressures, hypothermia, and dilution of clotting factors. Interventions intended to restore normal physiologic blood pressures are associated with worse outcomes in bleeding patients,^{16,17} except for those with concomitant head injuries, in whom brain hypoperfusion has been associated with higher morbidity and mortality.¹⁸ Permissive hypotension limits interventions intended to augment blood pressure, such as fluid boluses and vasopressor infusions, to only a target systolic blood pressure of greater than 70 mm Hg or a mean arterial pressure greater than 50 mm Hg.

Fluid restriction is an element of controlled hypotension, but can also be categorized independently based on the targets and restrictions of prescribed interventions. Higher volumes of crystalloid in patients requiring damage control laparotomy have been associated with increased risk of bacteremia, acute respiratory distress syndrome (ARDS), and acute renal failure.¹⁹ Higher ratios of crystalloid relative to PRBCs in the first 24 hours of admission have also been associated with greater mortality and higher rates of ARDS, multisystem organ failure, and abdominal compartment syndrome.^{20,21} Fluid-restrictive strategies minimize crystalloid infusion to less than 2 L throughout the emergency room and operating room (OR) resuscitation.

The concept of fixed-ratio blood product resuscitation was first proposed by Hewson and colleagues in 1985, but the recommendation was an unvalidated theoretical response to their observations regarding dilutional coagulopathy and subsequent hypoperfusion.²² Their theory would go unexamined for nearly 20 years until a 2006 study of combat casualties in Iraq showed a significant mortality advantage in patients who received higher ratios of fresh frozen plasma (FFP) relative to PRBCs.²³ Further studies demonstrated additional benefit of higher ratios of platelets and cryoprecipitate in a similar patient population.^{24,25} The concept of a proactive, fixed-ratio resuscitation approximating a 1:1:1 relationship of PRBCs:FFP:platelets:cryoprecipitate was validated in civilian populations, and has been shown to be effective in patients requiring more than 10 units of PRBCs in the initial 24 hours,^{25,26} in patients requiring less than massive quantities of blood products,²⁷ and in patients who have already begun to demonstrate metabolic derangement in the form of coagulopathy and acidosis.²⁸ Massive transfusion protocols that utilize plasma early in fixed-ratio resuscitation are associated with more reliable restoration of normal temperature, coagulation, and acid-base status.²⁹ Though fixed-ratio blood product resuscitation has been associated with increased risk of multisystem organ failure and ARDS in some studies, its mortality benefit persisted in this population despite these complications.³⁰

Who Will Benefit from Damage Control?

No study to date has identified prospective criteria for which DCS would offer a definite survival benefit. Most early studies merely identified risk factors for "imminent demise,"

recommending that operative procedures be aborted in patients demonstrating such signs so that all institutional and physiologic resources could be focused on correcting the patient's metabolic deterioration. These signs of imminent demise included an injury severity score over 25, pH below 7.2, body temperature less than 34 degrees, systolic blood pressure less than 70 mm Hg, estimated rate of blood loss greater than 15 mL/minute, OR blood requirement of 4 L, and OR fluid replacement over 10 L.^{8,31,32} Incorporation of many of these criteria into a prospective damage control algorithm that did not include DCR failed to demonstrate a mortality benefit.³³

In recent years, survival in damage control patients has benefited significantly from increased experience^{11,34} and coordination with improved resuscitation strategies.^{15,35} As a result, indications for damage control have expanded. A recent review by a panel of experts identified 123 different indications for DCS in the literature,³⁶ expanding beyond the trauma population to incorporate any critically ill patient suffering from life-threatening metabolic derangement. In addition to trauma, damage control has been shown to offer a mortality benefit in patients suffering from abdominal sepsis, ischemic bowel, necrotizing pancreatitis, and unanticipated intraoperative hemorrhage.³⁷

Initial patient selection should focus on maximum sensitivity, applying DCR to any patient that might benefit from damage control and tolerating potential over-utilization of DCR. In the most comprehensive review available, 17.6% of damage control cases were determined based on preoperative indicators, most commonly hemodynamic instability, hypothermia, acidosis, and coagulopathy.³⁶ Other considerations in preoperative patient selection include mechanism of injury, surgeon experience, and institutional capability. Patients with high-velocity gunshot wounds, blast injuries, concomitant severe thoracic injuries, or complex pelvic fractures should be considered for damage control,³⁸ as should patients included in a mass casualty situation where surgical demands exceed available resources.

Patients with severe head injuries have been excluded from studies of DCS because of the potentially conflicting implications of hypothermia and permissive hypotension on patient outcomes compared with patients without head injuries. These patients might benefit from a modified damage control strategy that incorporates target cerebral perfusion pressures and hypertonic solutions to reduce brain edema, but no such strategy has, to date, been proposed and validated.

90 Minutes or Less: Temporizing Techniques in Damage Control

Once in the OR, the initial stages of laparotomy for hemorrhage do not differ significantly whether one is anticipating a single definitive procedure or staged damage control. Both should consist of wide preparation of the patient from nipples to knees, broad abdominal exposure through a vertical midline incision, and thorough packing of all four quadrants with initial efforts to control hemorrhage

and minimize contamination. Use of suction should be minimized in the initial stages so as not to disrupt thrombus. DCSs should be concluded in operative times of less than 90 minutes, so an assessment of the patient's metabolic status, using both objective and subjective criteria, should occur approximately 60 minutes into the operation, and a decision of definitive versus staged approach should be made at that time.

The most common intraoperative indication for damage control is the assessed degree of physiologic insult, designated in 38.8% of cases.³⁶ Intraoperative interval assessments should include evaluation of ongoing resuscitation requirements, estimated rate of active bleeding, trend in core body temperature, laboratory evaluation of hemoglobin and pH, and anticipated duration of surgery if the definitive approach was selected. Weighing all of these factors, the surgeon must decide whether the patient is at significant risk of mortality and whether that risk is attributable more to metabolic derangement or to surgically correctable disruption of anatomy.

In limiting laparotomy to no more than 60 to 90 minutes, several injuries will require temporization to expedite closure and transfer to the intensive care unit (ICU). Surgical packing is effective in controlling liver, retroperitoneal, and pelvic hemorrhage, though postoperative angiography and embolization can be important adjuncts if the patient fails to respond to optimal resuscitation. A bleeding spleen should not be preserved in a damage control scenario, given the risk of further hemorrhage. Small vessel mesenteric bleeding should be controlled by directed ligation; electrocautery is often less effective in metabolically compromised patients.

Perhaps the most daunting injury in a damage control scenario is major vascular disruption. The celiac axis and splenic artery may be ligated with limited morbidity. Common hepatic artery ligation is unlikely to cause hepatic ischemia as long as the portal vein is intact. Gallbladder necrosis may occur, but cholecystectomy can be performed at the time of definitive surgery. Ligation of the superior mesenteric artery, superior mesenteric vein, or portal vein will likely result bowel ischemia. Similarly, ligation of the common or external iliac artery will cause significant ischemia of the lower extremity. Primary repair or shunting of these vessels should be considered in the damage control setting with ligation reserved as a life-preserving last resort. Iliac ligation should be accompanied by ipsilateral lower leg fasciotomies, which can be performed after abdominal closure. Definitive primary repair, patch angioplasty, or bypass may be performed at the secondary procedure. An internal iliac artery or vein can be safely ligated with minimal morbidity. Ligation of common or external iliac veins should be considered if direct pressure or primary venorrhaphy cannot arrest the hemorrhage in a damage control setting, though this may be associated with significant lower extremity edema. Revision or venous bypass can be considered in a subsequent, nonacute setting.

Because of their proximity to the aorta, exposing and repairing renal vascular injuries can be dangerous and time consuming. A stable, perinephric hematoma can be packed

and observed. A pulsatile, expanding perinephric hematoma is a sign of arterial hemorrhage that will require exploration even in a damage control scenario. Manual confirmation of the presence of an uninjured contralateral kidney justifies nephrectomy in the damage control setting; on-table intravenous pyelogram is not necessary. The proximal left renal vein can be ligated without complication; however, ligation of the distal left or any segment of the right renal vein will cause congestive nephropathy and subsequent renal ischemia, and thus nephrectomy is preferred.

Urinary extravasation, whether from renal parenchyma or the collection system, can simply be drained at the initial procedure. It is not necessary to open Gerota fascia simply to drain or examine for urine leaks. An intact Gerota fascia will facilitate hemostasis, assuming the hematoma is not pulsatile or expanding, and a contained collection of urine can be addressed with delayed percutaneous drainage or treatment at the follow-up operation. A partially disrupted ureter can be temporized with a double-J stent. A transected ureter can be cannulated with either a pediatric feeding tube or a ureteral stent secured to the open end of the ureter by a ligature and brought out to a separate incision in the abdominal wall. The distal ureter can be tagged if easily identified. In either case, definitive repair can be deferred to the subsequent operation.

Perforated bowel including the stomach can be controlled in several ways. Small perforations can be rapidly repaired primarily. If the viability of long segments of bowel is questionable, it is preferable to control spillage and plan to reassess at the second-look laparotomy. Spillage can be controlled with expedited primary repair or multiple limited resections. Balancing the risk of multiple anastomoses against that of a more extensive resection can be considered once the viability of the entire bowel is determined after the patient's condition has stabilized. Proximal bowel perforations in the duodenum and proximal jejunum can be controlled with primary repair or temporary tube enterostomy secured by a purse-string suture. Bowel discontinuity with proximal drainage through an orogastric tube is well tolerated for the 24-hour period before the second-look laparotomy.

Distal pancreatic disruption with a visible duct should be treated with combined splenectomy and distal pancreatectomy with ligation of the visualized pancreatic duct. There is no role for spleen preserving distal pancreatectomy in damage control. Proximal pancreatic injuries or those in which the duct is not visible can be treated with wide-local, closed-suction drainage, typically with one large bore drain placed superior and another inferior to the pancreas in the lesser sac. Proximal resection, such as the dreaded *Trauma Whipple*, can be deferred until the follow-up operation, if necessary.

Extraperitoneal bladder injuries can be treated with catheter drainage alone, whether transurethral or suprapubic. Massive intraperitoneal bladder disruption can be temporarily controlled with wide local drainage. Definitive repair can be delayed until a subsequent operation so that the entire urinary system, specifically the distal ureters and,

if necessary, the urethra, can be appropriately evaluated. It is important to note disruptions of the urinary system because of their impact on measured urine output during resuscitation.

Numerous methods of temporary abdominal closures have been described. The range of options include skin closure only, using towel clips or running suture; a vacuum pack/Bogota bag using bowel protection, closed suction drainage, and loose subcutaneous packing covered by an occlusive dressing; a Wittmann patch using Velcro sheets sutured to the fascial edges; or a formal intraperitoneal Vacuum-assisted closure device (Wound VAC, KCI, San Antonio, TX). Additional adjuncts are also being marketed. Available literature comparing various methods is limited and subject to significant bias and operator variability.

A temporarily closed abdomen is not the same as open abdomen; abdominal compartment syndrome can be associated with temporary closures as most methods are intended to prohibit fascial and/or skin retraction, thus limiting the expansive capacity of the abdominal cavity. Bladder pressure, urine output, and trends in airway pressures can be used as indicators of increased abdominal pressure. DCR is associated with a significantly lower risk of abdominal compartment syndrome compared with conventional resuscitation regardless of whether temporary or definitive closure is implemented.³⁹ If the patient's condition is deteriorating despite optimized DCR, consider angiography and embolization if liver, pelvis, or retroperitoneal bleeding was present on laparotomy, or it may be necessary to accelerate the second-look laparotomy to assess for substantial tissue necrosis or other sources of hemorrhage.

Post-Damage Control: Timing and Minimizing Subsequent Procedures

Timing of the take-back operation should consider several variables. Ideally, a patient should return for definitive surgery within 24 hours. Once their condition has stabilized and they no longer suffer from severe metabolic derangement, definitive management of all surgical injuries should be completed with as few procedures as possible. Temporization or further staging is not necessary in patients not at risk for acute demise. Specialization or institutional constraints may prohibit all definitive repairs from being completed in a single procedure, but communication and coordination across specialties should seek to minimize the impact of these logistical constraints.

Definitive fascial closure should be attempted once there is no other indication for abdominal procedures. One study of 499 patients at 14 trauma centers demonstrated that after 24 hours, every additional hour delay in take-back resulted in a 1.1% reduction in the success of primary fascial closure.⁴⁰ Patients closed at the first take-back have significantly lower risk of pulmonary, wound, infectious, and noninfectious complications.⁴¹ If definitive closure cannot be achieved, serial closure using interrupted, figure-of-8 0-PDS sutures or fascial closure adjuncts is advisable. Patients in whom complete fascial closure is not achieved by day 7 are unlikely

to achieve complete primary closure during their initial hospitalization.⁴² Those patients in whom the fascia is primarily closed have shorter ICU and hospital stays and improved physical, emotional, and general health on long-term follow-up compared with those requiring subsequent closure procedures.⁴³ Primary skin closure is associated with a higher risk of surgical site infection compared with healing by secondary intention, but it is not associated with an increased risk of fascial dehiscence. Skin closure at the time of fascial closure can spare up to 85% of carefully selected patients the morbidity of a chronic open wound.⁴⁴

Too Much of a Good Thing

There is concern that DCS is overused at some institutions. Expert opinion assessed the appropriateness of 17.9% of reported indications as “uncertain.”³⁶ In an examination of their own experience, Higa and colleagues observed a 76% reduction in the use of DCS over a 2-year span. This more deliberate utilization resulted in an improvement in mortality of damage control patients from 21.9 to 12.9% and yielded an estimated institutional cost saving of \$2.2 million.⁴⁵

If one examines the raw data reported but not discussed by Rotondo and colleagues in their original 1993 publication advocating damage control, one can see that within their 46-patient cohort, DCS was associated with a significantly higher mortality than definitive laparotomy in those patients who were not considered part of the “maximum injury subset” (64% DC vs. 23% DL, $p = 0.0327$ by this author’s calculation of their reported data using a two-sided Fisher exact test).⁹ Twenty years later, low-risk damage control patients continue to have higher morbidity and 30-day mortality rates compared with similar patients who had undergone single-stage procedures.⁴⁶

Just as published experience prior to the dissemination of DCR must be evaluated differently than that published since, so too must we re-evaluate the subjective assessments that inform our patient selection for DCS. Some patients may present with severe metabolic derangement that quickly resolves with disciplined DCR. A definitive, single-stage procedure in patients no longer at risk of “imminent demise” may reduce their long-term morbidity and mortality.

Conclusion: A Prospective Perspective

Damage control is a strategy of managing critically ill and injured patients for whom metabolic derangement is of greater life-threatening importance than incomplete restoration of normal anatomy. It incorporates principles of both DCS, which abbreviates the physiologic insult of prolonged operations and anesthesia, and DCR, which interdicts metabolic decompensation characterized by the Lethal Triad. Incorporating management principles of permissive hypotension, fluid restriction, and fixed-ratio blood product resuscitation with surgical techniques of hemostasis, contamination control, and injury temporization can effectively decelerate patient decline and restore compensation for severe metabolic and physiologic insults. This holistic ap-

proach to critical illness and injury has evolved over a century and does improve outcomes in a carefully selected population of our most vulnerable patients. Overuse of DCR appears to be associated with tolerable risk of morbidity, given its significant benefit on overall mortality, but overuse of DCS can result in added morbidity and mortality in patients who could have reasonably withstood a single, definitive initial operation. Education, experience, and collaboration will enable further refinement of damage control strategies including more-directed patient selection.

Conflict of Interest

This article represents the opinions of the author alone and does not represent official views of the Department of Defense, the Department of the Army, or any of his affiliated institutions.

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