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ORIGINAL ARTICLE

Damage control strategies in the management of acute injury

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Abstract Traumatic injury is the leading cause of death worldwide. The rapid evaluation and correction of injuries in these patients is paramount to preventing uncontrolled decompensation and death. Damage control strategies are a compendium of techniques refined over decades of surgical care that focus on the rapid correction of deranged physiology, control of contamination and blood loss, and resuscitation of critical patients. Damage control resuscitation (DCR) focuses on the replacement of lost blood volume in a manner mimicking whole blood, control of crystalloid administration, and permissive hypotension. Damage control laparotomy controls gastrointestinal contamination and bleeding in the operative suite, allowing rapid egress to the intensive care unit for ongoing resuscitation. Pelvic packing, an adjunct to DCR, provides a means to control hemorrhage from severe pelvic fractures. Temporary vascular shunts restore perfusion, while resuscitation and reconstruction are ongoing. Taken together, these strategies provide the trauma surgeon with a powerful arsenal to preserve life in the transition from injury to the shock trauma room to the intensive care unit.

Keywords Damage control · Hemorrhage · Resuscitation

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Introduction

Globally, trauma is a leading cause of death, responsible for one in every ten deaths annually, or nine deaths every minute [1]. The care of the injured patient focuses on rapid evaluation and resuscitation, correction of damaged systems, and minimization of overall morbidity. Despite mature trauma systems, patients arriving alive to the medical center may deteriorate into an irrecoverable spiral of blood loss, physiologic derangement, and death. In an effort to interrupt this spiral, damage control strategies have been developed to improve initial resuscitation and rapidly control blood loss and contamination. Though few of these strategies are truly novel to modern surgical care, they have received renewed prominence in light of ongoing combat medicine endeavors of the last three decades. Renewed research in these arenas has demonstrated significant survival benefit to the most severely injured patients with the use of damage control strategies.

In this article, we will review the utility of damage control strategies from the shock trauma bay to the intensive care unit. Damage control resuscitation (DCR) strategies are used to support patients from the moment of admission. Damage control laparotomy (DCL) and pelvic packing are designed to quickly address catastrophic injuries of the torso and to facilitate rapid egress from the operative suite. Finally, we will discuss damage control adjuncts uniquely adapted to major vascular injuries.

Damage control resuscitation

DCR arose to address the problems associated with traumatic coagulopathy and over-resuscitation with crystalloid products prior to surgical control of bleeding [2]. The concept of DCR encompasses permissive hypotension, limitation of crystalloid usage, and the early transfusion of blood products in ratios approximating one unit of packed red blood cells (PRBC) with one unit of fresh frozen plasma and one equivalent of platelets [2]. While this strategy is designed to limit bleeding and prevent traumatic coagulopathy, it is not always evident which patients will benefit from DCR. Historically, matched ratio resuscitations (1:1:1) have been studied retrospectively by investigating patients requiring massive transfusions, which has traditionally been defined as ten or more units of blood transfused over 24 h. The massive transfusion definition has no utility in defining patients in real time, when rapid identification can result in early institution of DCR. Rather, in recent years, we have found the concept of the critical administration threshold (CAT) to be more useful in the prospective identification of critically injured patients at the highest risk of mortality. CAT is defined as the transfusion of three or more units of PRBC in a 60-min period and has proven to be predictive of increased mortality in a retrospective study [3]. The identification of patients who are CAT+ in the shock trauma room may be a rapid means to recognize those requiring DCR.

The most controversial aspect of DCR remains the 1:1:1 resuscitation strategy. The genesis of this approach arose from recent combat experience with whole blood. While the transfusion of whole blood is not a new concept, it had largely fallen out of favor due to the advent of component blood-banking in the 1970s. More recent combat experiences in austere environments revealed logistical challenges in transporting and storing plasma and platelets. In medical situations in which these stores were rapidly depleted, physicians turned to ‘walking blood banks’ or real-time donation and transfusion of warm, whole blood rich in all components. Anecdotal experience and subsequent study demonstrated that patients did well with the receipt of fresh whole blood and the concept evolved to 1:1:1 transfusions of components to mimic whole blood, without the logistic and infectious risks of real-time donation [4, 5]. The concept rapidly penetrated civilian trauma management and, though subsequent research has been largely retrospective and occasionally contradictory, the burden of evidence indicates a conferred survival benefit with 1:1:1 resuscitation [6–9].

The primary benefit of the 1:1:1 resuscitation appears to be the reversal of acute traumatic coagulopathy from acquired abnormalities in anticoagulation activation [6]. In addition to the replacement of oxygen-carrying capacity and volume with PRBC, some evidence points to survival benefits associated solely with the transfusion of clotting factors found in plasma, as well as the reported effects that plasma may have on modulating direct endothelial response [10–12]. Carefully identifying patients for DCR is important, however, as the transfusion of blood products, especially plasma, can be deleterious. In addition to transfusion reactions, the administration of plasma has been associated with sepsis due to bacterial contamination, transfusion-related acute lung injury, and acute respiratory distress syndrome (ARDS) in some massively transfused patients [2, 13, 14].

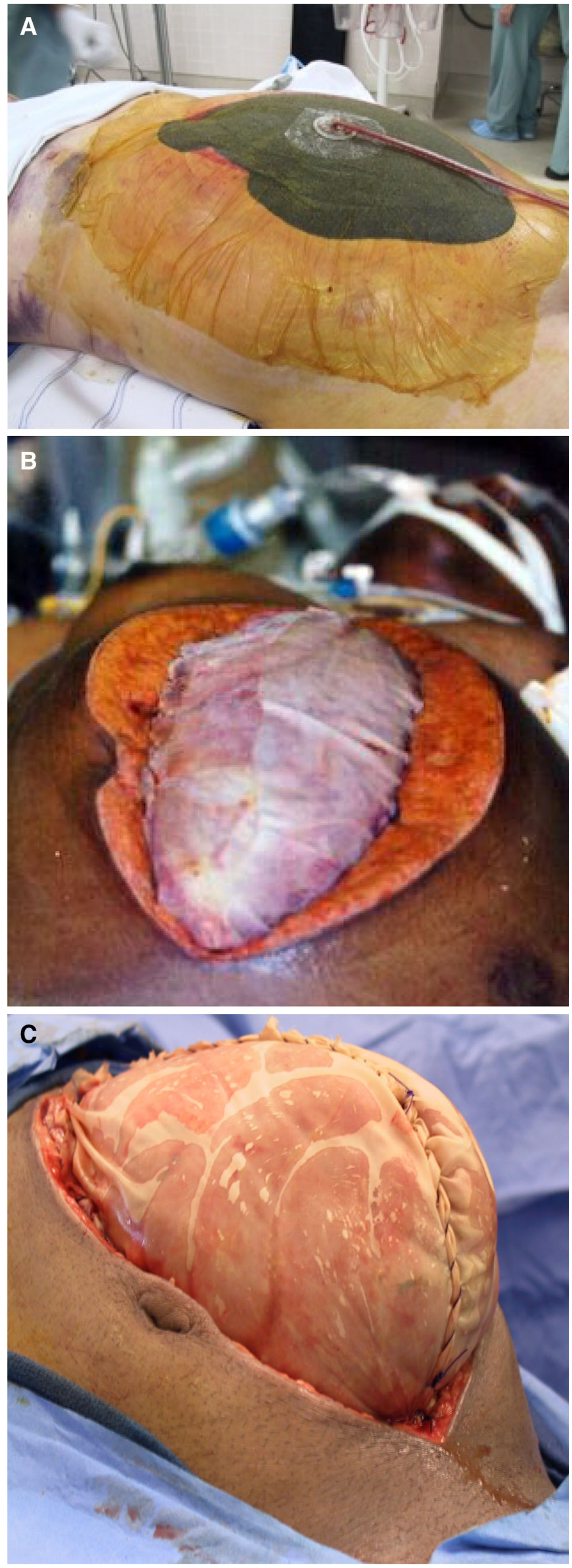
The remaining pillars of DCR include permissive hypotension and limited use of crystalloids for resuscitation. The initial description of permissive hypotension involved penetrating trauma and emerged from Houston in the mid-1990s. Subsequently, evidence supports goal mean arterial pressures of 50 mmHg. Judicious use of permissive hypotension has resulted in decreased transfusion requirements, decreased post-operative coagulopathy, and diminished rates of early post-operative death [15, 16]. Conversely, the use of large volumes of crystalloid for the resuscitation of trauma patients emerged as the standard of care in the 1960s and 1970s [17]. Crystalloid use, in some cases defined as little as 1.5 L given in the emergency department alone, has resulted in worsened arterial oxygen levels, increases in inflammatory response to hemorrhagic shock via cytokine release, and increased rates of anastomotic leaks of the colon [2, 7, 18–20]. Therefore, DCR strategies also stress limiting the volume of crystalloid products infused in the critically injured.

Damage control laparotomy

Damage control strategies are continued in the transition from the shock trauma room to the operative suite. DCL is a strategy designed to manage patients in extremis who require emergency surgery. Initially described by Stone et al. in 1983, and refined by multiple studies over the subsequent three decades, DCL advocates for rapid control of hemorrhage and contamination, temporary closure of the abdominal cavity, and transition to the intensive care unit for further resuscitation. Definitive surgical repair waits until acidosis and coagulopathy have been corrected and normothermia has been achieved [21, 22]. The primary goal of DCL is to prevent rapid physiologic deterioration in the operative suite, much as with DCR. In this case, DCL is designed to prevent what has been commonly described as the ‘bloody vicious cycle;’ or the onset of coagulopathy, acidosis, and hypothermia [23].

The evolution of DCL has rested on the identification of triggers indicating that the patient is in danger of developing the ‘bloody vicious cycle’ as noted above. As such, common triggers have relied on alterations in the patient’s temperature, pH, and evidence of coagulopathy, as indicated by international normalized ratio and prothrombin time (PT) measurements. Though variations exist from

Fig. 1 Examples of temporary abdominal closures. **a** Negative pressure abdominal dressing (KCI Wound V.A.C.). **b** Cassette cover. **c** Temporary Vicryl mesh



study to study, the presence of hypothermia, defined as a core temperature <34 °C, is a key trigger. Acidosis has most conservatively been defined as a pH < 7.2 and coagulopathy is often identified as abnormal bleeding intra-operatively [24, 25]. Additional triggers may include large volume transfusions (often defined as greater than ten units) or significant blood loss, decrements in serum bicarbonate levels, elevations in PT and partial thromboplastin time, and use of large volumes of crystalloid [24, 26, 27]. All authors agree that earlier institution of damage control management in the operating room results in improved patient outcomes, however. This has held true since Stone's first description in 1983, in which damage control principles resulted in 35 % survival in a group generally found to suffer 100 % mortality [21].

Upon admission to the intensive care unit, the patient undergoes aggressive resuscitation aimed at rewarming and correction of coagulopathy. The return to the operating room for restoration of gastrointestinal continuity, unpacking of the abdomen, and a second-look laparotomy may occur as soon as the patient is adequately resuscitated, though, in practice, tends to occur between 48 and 72 h. In some studies, with early institution of DCL intra-operatively and early definitive surgery when resuscitation is complete, a 93 % facial closure rate is possible [28]. In many clinical situations, management of the open abdomen may be as difficult as management of the initial traumatic insult. Significant tissue destruction or contamination may require repeated explorations and washouts. Massive resuscitations may lead to visceral edema preventing fascial closure, or too-aggressive closure may result in abdominal compartment syndrome [29]. Conversely, delays in closure may increase the risk of 'loss of domain,' with subsequent giant ventral hernias, occurrence of enteroatmospheric fistulas, anastomotic leaks, and intra-abdominal sepsis [30, 31].

In light of these risks, aggressive management of the open abdomen in the short term is very important. As multiple operations tend to predispose patients to fistula formation and abdominal sepsis, limiting laparotomies to the fewest possible will be protective [30, 31]. The incidence of fascial closure also improves if the volume of resuscitation, especially with crystalloid usage, is controlled [31]. When possible, fascial closure by post-injury day 5 has proven to be protective against fistula formation. The American Association for the Surgery of Trauma (AAST) Open Abdomen Registry also found that delaying attempts to close fascia until after post-injury day 10 rarely resulted in successful fascial closure [31].

While every effort should be made to close the fascia, overly aggressively early closure does increase the risk to the patient of abdominal compartment syndrome, especially if resuscitation is ongoing at the time of closure [29]. Multiple adjuncts exist to prevent fascial retraction if early closure is not possible. Initially, temporary abdominal closure was achieved via some variation of the Bogota bag or with blue towel closure. In current practice, the use of negative pressure abdominal dressings is most common and is associated with an approximately 60 % fascial closure rate in one meta-analysis (Fig. 1) [32]. Other methods commonly used include retention sutures and the Wittmann patch. All of these methods have low associated mortality and low fistula rates, and are considered safe in the trauma population [32].

In some cases, despite all efforts, it is not possible to achieve delayed primary fascial closure. Patients with an open abdomen who develop severe systemic inflammatory response syndrome are at great risk of failure of fascial closure, as are those with large-volume crystalloid resuscitation and anastomotic leaks [29]. In patients in whom the fascia cannot be closed, it is imperative to apply a skin graft to the abdominal contents as early as possible. Early grafting protects bowels from damage secondary to drying, increases the strength of the abdominal wound, and decreases proteinaceous losses that may contribute to malnutrition [29]. A temporary absorbable mesh may be used in the short term to promote wound care and granulation, but the use of prosthetic meshes long term is discouraged, as they are associated with fistula formation [29]. Patients left with a giant ventral hernia following trauma must undergo abdominal wall reconstruction remotely, usually 6–9 months following injury.

Pelvic packing

Life-threatening hemorrhage occurs in 1–4 % of pelvic fractures, and mortality in this subset can exceed 40 % [33–35]. Evaluation of the pelvic fracture has traditionally relied on plain radiographs, followed by computed tomography to define the extent of injury and to assess for active extravasation of contrast or large retroperitoneal hematomas. In cases where ongoing hemorrhage is suspected, angioembolization has been the traditional adjunct to achieve hemostasis. However, in the unstable or marginally stable patient, the interventional radiology suite is suboptimal for large resuscitations, not to mention time delays associated with starting the procedure. In addition, 90 % of patients with unstable pelvic fractures have associated injuries, 50 % of which have a component of major hemorrhage [34]. Diversion to interventional radiology may delay therapy for these injuries as well.

In light of these issues, unstable patients may not be candidates for angioembolization. Pelvic packing is an excellent damage control strategy in these situations. Transabdominal pelvic packing was first described in the 1960s but had poor success rates [34]. In the late 1990s and early 2000s, reports emerged from Hanover and Zurich, respectively, regarding the packing of the preperitoneal pelvic space for hemorrhage control following pelvic fracture [36, 37]. By packing the extraperitoneal pelvis, control of arterial, venous, and bony hemorrhage is possible, not just arterial control as seen with angioembolization (Fig. 2) [33]. An added benefit is that this procedure occurs in the operative suite, where other injuries may be addressed, external fixation of the pelvis may occur for added stability, and where resuscitation may continue in a more controlled fashion.

When selecting for the unstable pelvic fracture patient, pre-peritoneal pelvic packing has shown decreases in mortality as great as 80 % [33]. Some patients may still require angioembolization for arterial injuries, but this can occur in a more controlled fashion. As with other damage control strategies, unpacking may be considered when the patient is fully resuscitated, but typically occurs at 48–72 h. The main morbidity specifically attributed to pelvic packing has been infections of the deep pelvic space. In one study, rates were found to be 8 % overall if the pelvis was packed once. In patients who required multiple pelvic repacking events on subsequent explorations, the incidence of pelvic space infection rose to 47 % [33]. Overall, pelvic packing is a safe and effective damage control strategy, especially when combined with other modalities, such as external fixation of the pelvis and angioembolization.

Damage control of vascular injuries

Major vascular injuries represent another arena in which damage control strategies are assisting with the salvage of critical patients. Major hemorrhage is a leading cause of early post-injury death but is also potentially preventable [38]. As such, considerable attention has been focused on control and correction.

The use of tourniquets have waxed and waned from favor in the control of extremity vascular injuries in civilian trauma care. In recent military conflicts, however, tourniquets have emerged as front-line tools for hemorrhage control, with exsanguination from extremity injuries no longer being the primary cause of preventable deaths [39]. As such, tourniquets should be routinely used to control hemorrhage resulting from vascular injuries to the extremities. This approach is in agreement with the opinion of the majority of trauma surgeons and tourniquets are

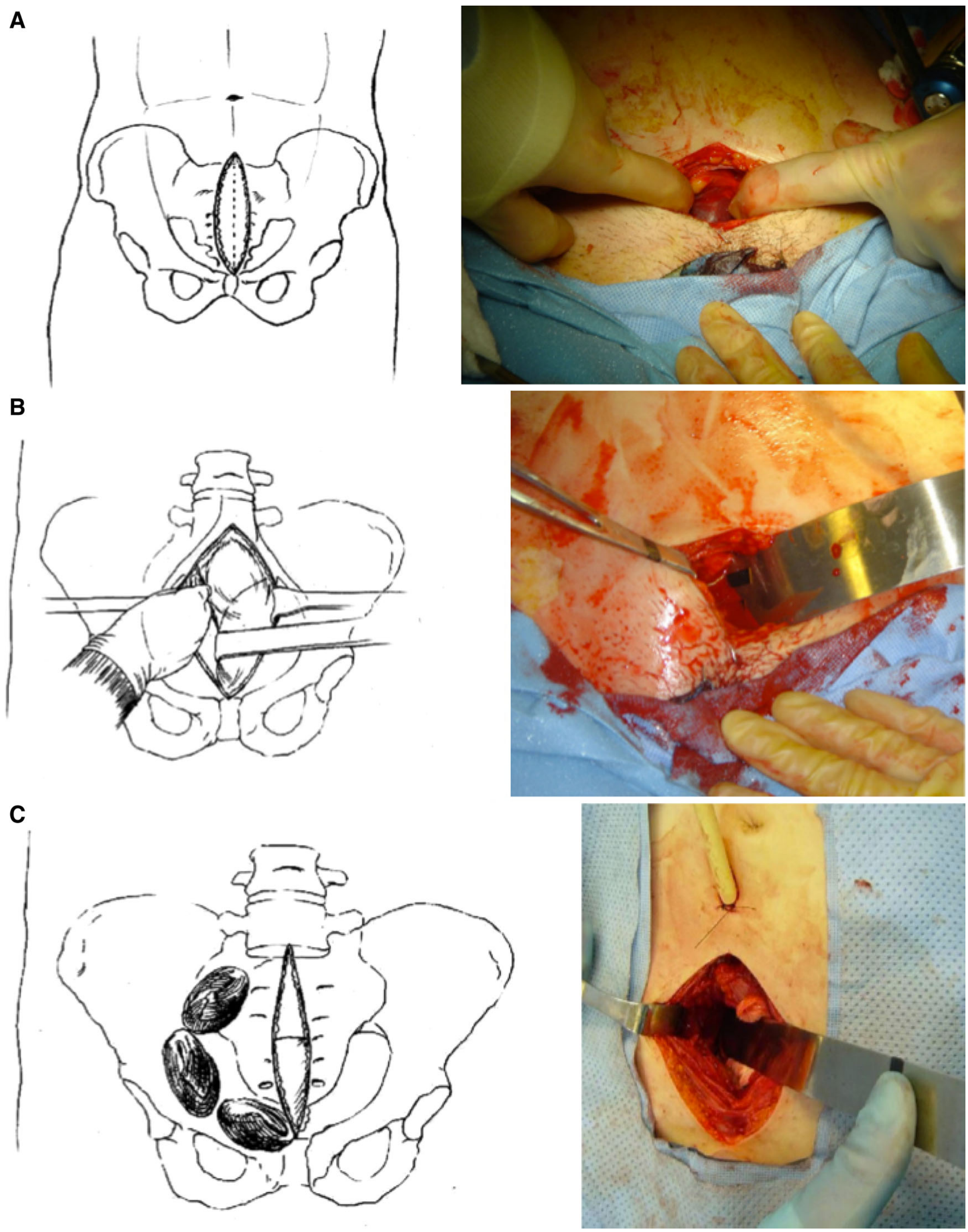


Fig. 2 The approach for pelvic packing with permission from the Journal of Trauma [33]

increasingly stocked with the equipment of pre-hospital providers [40].

Once patients arrive at a trauma center, the earliest possible restoration of perfusion is paramount for limb and life salvage. The use of the temporary vascular shunt has proven to be a versatile option to restore perfusion. First described at the beginning of the 19th century, the temporary use of shunts was employed as a bridge by French medics in the 1950s [41]. Temporary vascular shunts were used more successfully in the 1970s in the Vietnam conflict and have now become widely used in both military and civilian settings [42]. A benefit of the shunt includes ease of placement, even in settings where reconstruction is not possible (Fig. 3). Further, shunts are

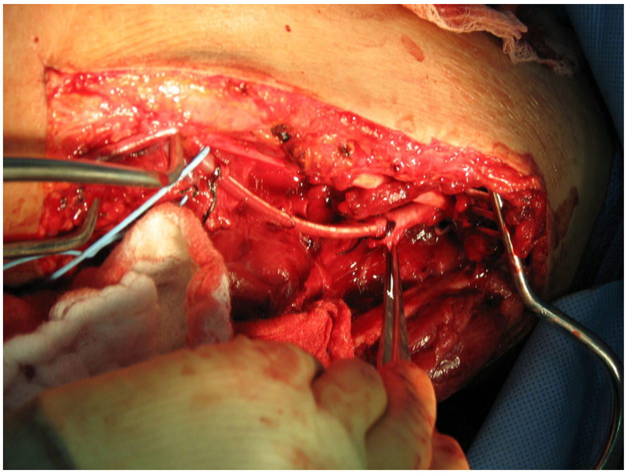


Fig. 3 Temporary arterial shunt in situ

useful to maintain perfusion not only during transport to higher levels of care, but also to delay vascular reconstruction until a patient has been appropriately resuscitated or to allow stabilization of fractures prior to vascular repair.

The success of the shunt is enhanced by proper technique. Thrombectomy should be performed with embolectomy catheters prior to placing the shunt, to remove clot and to ensure adequate inflow and outflow. If possible, systemic heparinization may enhance patency, but is not mandatory. Fasciotomies should be considered in cases of prolonged warm ischemia time, if evidence of extremity compartment syndrome exists or if close monitoring of compartment pressures is not possible [42]. Potential conduits may include standard Javid or Argyle shunts, Pruitt-Inahara shunts, pediatric chest tubes, sterile endotracheal suction catheters, sterile nasogastric tubes, intravenous extension tubing, or pediatric feeding tubes [43]. When placed, attempts should be made to match the shunt size to the vessel size, and intraluminal overlap should be limited to approximately 2 cm proximally and distally [44]. The shunt should be placed in-line to promote patency and prevent dislodgment, and the native vessel should be secured to the shunt with 2-0 silk ties.

Recent studies have demonstrated patent shunts after in situ dwell times of over 12–70 h [43, 45]. Most commonly, shunts have been used in transport, in which dislodgement rates were extraordinarily low, and for brief periods intra-operatively to facilitate other procedures [43]. Multiple studies have demonstrated no increase in amputation rates with the use of shunts, with limb salvage rates ranging from 74 to 100 % [43–45]. In cases in which the limbs were lost, the majority of amputations were due to soft tissue or nerve damage done by the initial injury and not due to vascular occlusion. Some studies have demonstrated an improved shunt patency rate in proximal vessels compared to distal vessels. Additionally, shunting and reconstruction of venous injuries also improves limb salvage [42].

A relatively new technology for the control of distal major vascular injuries, as well as resuscitation of patients in extremis, has been the use of the resuscitative endovascular balloon occlusion of the aorta (REBOA). Placed via percutaneous access or cut-down of the femoral artery, the balloon is passed without fluoroscopic guidance, over a wire, to the distal thoracic aorta [46]. The current literature is limited, however; both animal studies and case reports in humans have demonstrated that it is effective in stopping distal hemorrhage and raising central pressures [47, 48]. Experience with this technology is increasing and further studies will likely elucidate better indications for the use of REBOA, as well as outcomes.

Conclusion

Damage control strategies are reserved for patients in the most dire of circumstances. The guiding principle of all these strategies is rapid control of the life-threatening situation with a pause, prior to repair, to allow resuscitation and restoration of normal physiology. Though counterintuitive at times, over 30 years of evidence has demonstrated significant improvements in patient survival. Ongoing research will result in refinement of these techniques. The ultimate goal is the development of damage control strategies that can be deployed earlier in pre-hospital settings to halt exsanguination rapidly and to prevent the 'bloody vicious cycle' before it is even able to begin.

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