

Damage Control Surgery in the Era of Damage Control Resuscitation

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Abstract and Introduction

Abstract

Damage control surgery (DCS) is a concept of abbreviated laparotomy, designed to prioritize short-term physiological recovery over anatomical reconstruction in the seriously injured and compromised patient. Over the last 10 yr, a new addition to the damage control paradigm has emerged, referred to as damage control resuscitation (DCR). This focuses on initial hypotensive resuscitation and early use of blood products to prevent the lethal triad of acidosis, coagulopathy, and hypothermia. This review aims to present the evidence behind DCR and its current application, and also to present a strategy of overall damage control to include DCR and DCS in conjunction. The use of DCR and DCS have been associated with improved outcomes for the severely injured and wider adoption of these principles where appropriate may allow this trend of improved survival to continue. In particular, DCR may allow borderline patients, who would previously have required DCS, to undergo early definitive surgery as their physiological derangement is corrected earlier.

Introduction

Over the last two decades, public health measures and better pre-hospital care have led to an increasing number of seriously injured patients surviving their initial accident and arriving in hospital.^[1] These injured patients often have injuries to multiple body cavities, massive haemorrhage, and near exhausted physiological reserve. Management of these cases has changed significantly in the last decade with the emergence of a new paradigm termed damage control.

A combination of acidosis, hypothermia, and coagulopathy (the so-called lethal triad) may preclude definitive surgical repair of all injuries in one sitting and it is in this subset of patients that 'damage control surgery' (DCS) is advocated. DCS is a treatment strategy of temporization; prioritizing physiological recovery over anatomical repair. Its use is associated with dramatically increased survival of the most seriously injured patients.^[2] Damage control resuscitation (DCR) is a newer development within the damage control paradigm, and describes novel resuscitation strategies aimed to limit the physiological derangement of trauma patients. This review will discuss the principles and application of DCS in the current era of DCR.

Damage Control

Stone and colleagues were the first to describe a technique of 'truncated laparotomy' for patients with clinically evident coagulopathy and retrospectively reviewed its efficacy in 1983.^[3] A decade later, Rotondo and colleagues popularized the term 'damage control laparotomy', retrospectively reviewing the management of patients undergoing laparotomy for exsanguinating penetrating injuries [requiring urgent transfusion of >10 units of packed red blood cells (PRBC)]. They identified a subset of maximally injured patients (major vascular injury with two or more visceral injuries) in which survival was markedly improved in the DCS group.^[2] DCS limits the goals of the initial operation to control of haemorrhage and limitation of contamination rather than definitive repair of all injuries; prioritizing physiology over anatomy.

In modern trauma practice, it is inconceivable that DCS should be practiced separately from DCR; the two strategies are integral to each other and DCS should be the endpoint of DCR with surgical control of haemorrhage. DCS was originally described by Rotondo and colleagues in 1993 as a three-phase technique. This was later modified by Johnson and Schwab^[4] to include a fourth, pre-theatre phase:

- Part zero (DC 0) emphasizes injury pattern recognition for potential damage control beneficiaries and manifests in truncated scene times for the emergency services and abbreviated emergency department DCR by the trauma team. Rapid-sequence induction (RSI) of anaesthesia and intubation, early rewarming, and expedient transport to the operating theatre are the key elements.
- Part one (DC I) occurs once the patient has arrived in theatre and consists of immediate exploratory laparotomy with rapid control of bleeding and contamination, abdominal packing, and temporary wound closure.
- Part two (DC II) is the intensive care unit (ICU) resuscitative phase where physiological and biochemical stabilization is achieved and a thorough tertiary examination is performed to identify all injuries.
- Part three (DC III) occurs once physiology has normalized and consists of re-exploration in theatre to perform definitive repair of all injuries. This may require several separate visits to theatre if multiple systems are injured and require operative treatment.

Indications for Damage Control

Appropriate patient selection for DCS is critical. Attempts at primary definitive surgical management in patients with severe physiological compromise will almost inevitably lead to poor outcome or unplanned abbreviation of the procedure. In contrast, excessively liberal use of DCS may deny patients with adequate physiological reserve the benefits of effective early management and condemn them to unnecessary extra procedures with attendant morbidity and potential for mortality. There are published data to guide patient selection^[5] but no single 'physiological threshold' has been defined. Over liberal application of DCS has significant resource implications for theatres and ICU and may increase the risk of intra-abdominal infection, fistula formation and abdominal wall hernias.^[6-8]

If not identified before operation by mechanism or injury pattern, indications to change to a damage control strategy are primarily those of physiological derangement; significant bleeding requiring massive transfusion (>10 units PRBC); severe metabolic acidosis (pH<7.30); hypothermia (temperature <35°C); operative time >90 min; coagulopathy either on laboratory results or seen as 'non-surgical' bleeding; or lactate >5 mmol litre⁻¹.^[9-13]

Overall, it is estimated that ~10% of major trauma patients might benefit from DCS but there is no single factor that predicts who these patients are. However, the later that the decision to damage control is made, the less successful the outcome is likely to be.

Damage Control Part Zero (DC 0)

Damage control part zero is the earliest phase of the damage control process. It occurs in the pre-hospital setting and continues into the emergency department. The emphasis is on injury pattern recognition (to identify patients likely to benefit from damage control), followed by DCR and rapid transfer to theatre of identified patients.

For the emergency services, truncated scene times and early notification of the receiving hospital trauma team are the priorities; 'scoop and run' rather than 'stay and

play'. Blood products and tranexamic acid (TXA) are increasingly used in the pre-hospital environment and may be widely available to paramedic crews in some areas of the UK.^[14,15] The increasingly widespread presence of pre-hospital doctors, particularly with air-ambulances, may allow RSI to be performed in the pre-hospital phase where necessary. The recent initiation of major trauma networks in England is another major step forward in trauma care, putting in place bypass protocols that allow ambulances to proceed directly to major trauma centres (rather than the nearest hospital) if certain injury patterns or physiological abnormalities are present in trauma patients.^[16]

Once in hospital, emergency department DCR and rapid assessment of the trauma patient is the goal. Gaining large-bore i.v. access, RSI (if not performed already), chest drainage if indicated, prevention of hypothermia, DCR, and expedient transport to the operating theatre are the key elements of DC 0 in the trauma bay.^[4] Broad-spectrum i.v. antibiotics and tetanus prophylaxis should be administered where appropriate and theatres should be placed on standby; allowing the preparation of cell-saver devices, appropriate instrument trays, and rapid patient transfer if required.

Damage Control Resuscitation

The deleterious effects of excessive fluid resuscitation on haemostasis have been recognized for many years and delayed fluid resuscitation^[17] or permissive hypotension^[18] have long been advocated. A more recent development was the recognition of an endogenous coagulopathy in a large proportion of severely injured trauma patients on arrival in hospital. This 'acute traumatic coagulopathy' is present in the most severely injured patients and is associated with poor outcomes.^[19] Its discovery promoted interest in resuscitation strategies that directly target coagulopathy. Modern resuscitation after major haemorrhage therefore incorporates permissive hypotension and early treatment of anticipated coagulopathy with blood products: DCR.

DCR primarily has its origins in the military's experience of management of major haemorrhage during recent conflicts in Afghanistan and Iraq. In 2007, Holcomb and colleagues described DCR as 'a proactive early treatment strategy that addresses the lethal triad on admission to a combat hospital'.^[20] Hodgetts and colleagues chose a broader definition, which incorporated the pre-hospital management and the primacy of haemorrhage control in exsanguinating haemorrhage. They defined DCR as: 'a systematic approach to major trauma combining the <C>ABC paradigm with a series of clinical techniques from point of wounding to definitive treatment in order to minimize blood loss, maximize tissue oxygenation, and optimize outcome'.^[21]

The main elements of DCR are:

- <C>ABC resuscitation
- Permissive hypotension
- Limitation of crystalloid with early use of blood and blood products
- Early use of TXA
- DCS (DC I)

There is emerging evidence supporting the use of DCR. An observational study of patients undergoing damage control laparotomy demonstrated an association with improved survival for patients undergoing DCR when compared with historic controls.^[22] Furthermore, there is evidence from patients with major peripheral vascular

injuries that using DCR might result in more favourable perioperative physiology and lessen the need for DCS.^[23,24]

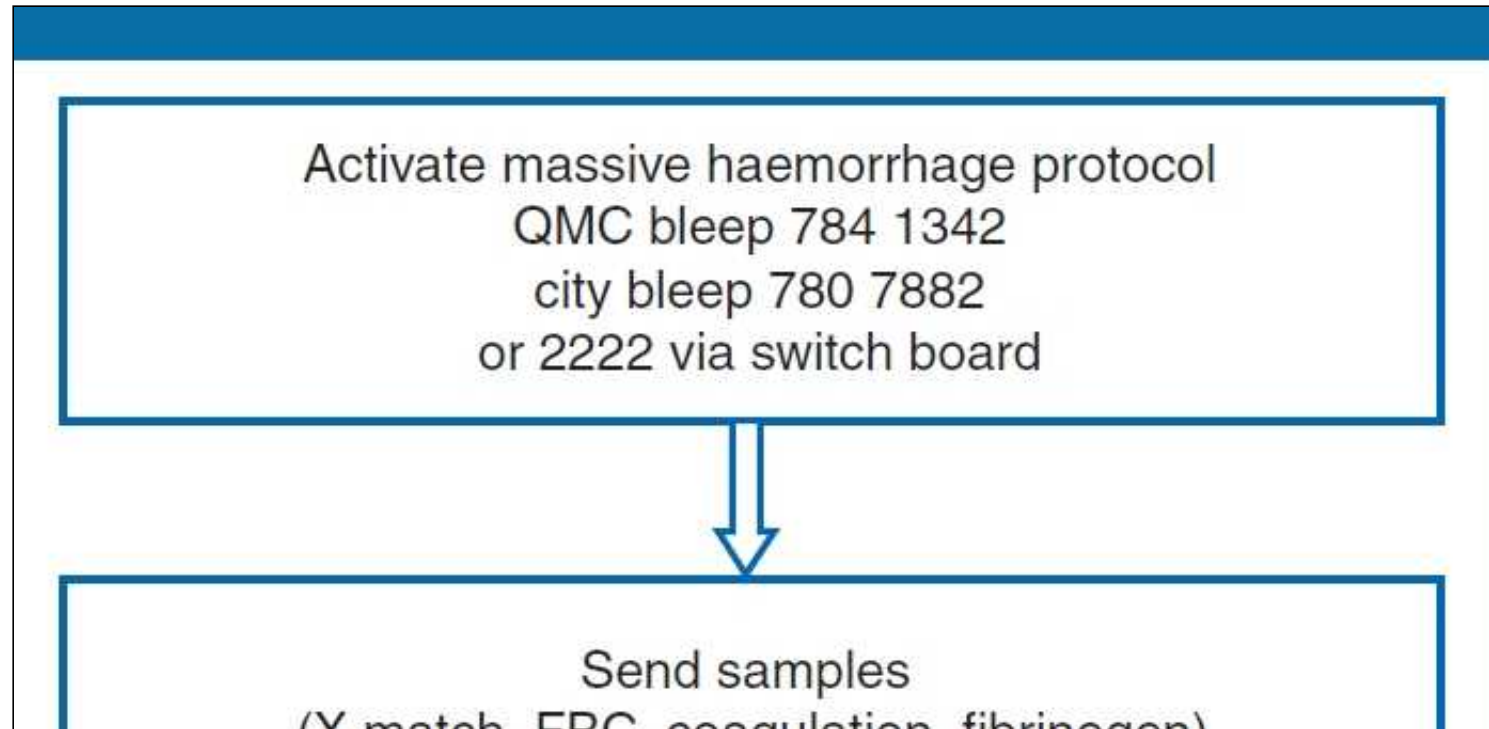
Early use of Blood and Blood Products

In addition to using blood earlier in the resuscitation effort, attention is given in DCR to the ratio of blood components that are used in transfusion, to directly target coagulopathy. A higher ratio of fresh frozen plasma (FFP) to PRBC has been associated with survival benefit in trauma patients.^[25–28]

The optimal ratio of blood, FFP, platelets, and other products have not yet been defined though the first prospective study of transfusion ratios in trauma haemorrhage, the PROPPR (pragmatic, randomized optimal platelet and plasma ratios) trial is due to report imminently.

Massive Transfusion Protocols

Protocolized administration of blood products has also been shown to reduce mortality and morbidity in major trauma patients requiring massive transfusion.^[29] As a consequence, major trauma centres in the UK should have a massive transfusion protocol in place, designed to prevent delays in accessing appropriate blood products for exsanguinating patients. An example of the protocol in place in our centre is provided in Figure 1. The exact protocols used in different centres may show some local variation but in essence, all should have available an initial pack of non-cross-matched blood for immediate use in the unstable patient. Once bloods for cross-match have been taken, further group specific or fully matched components are provided (depending on the time frame in which they are required) in a protocolized fashion, designed to prevent clotting factor depletion and coagulopathy during early massive transfusion. Beyond a certain point, further products are provided and given in a bespoke fashion, guided by the results of bedside, or laboratory tests of coagulation.



(A match, FBC, coagulation, fibrinogen)

use ROTEM if available

Collect and transfuse Pack 1

Instigate resuscitation and haemorrhage prevention measures

Tranexamic acid (1 g i.v. bolus, then 1 g over 8 h)

Correct acidosis and hypothermia

Contact haematologist (may be initiated by blood bank)



Collect and transfuse Pack 2 accordingly

Enquire about available blood results but **DO NOT WAIT**

for results to before transfusing

use ROTEM results as a guide if available

Send repeat samples

check ABG, K⁺, Ca⁺⁺

Patient still bleeding?

Send for Pack 3

Liaise with haematologist



Collect haemorrhage Pack 3 and transfuse accordingly

Check available blood results

Send repeat samples

Use ROTEM as a guide if available

Patient still bleeding?

Discuss with consultant haematologist

Further component require authorization from
consultant to haematologist

Transfusion targets

Hb 70–90 g litre⁻¹

Platelets $>75 \times 10^9$ litre⁻¹

PT/PTT $<1.5 \times$ normal

Fibrinogen >1.5 – 2.0 g litre⁻¹

Figure 1.

Massive transfusion protocol currently in use for adult trauma patients at Queen's Medical Centre, Nottingham, UK. Pack 1: 4 units PRBC. Pack 2 and all subsequent packs: 6 units PRBC; 4 units FFP; one pool platelets; two pools cryoprecipitate.

Imaging

For the rapid work-up of penetrating trauma in the unstable patient, minimal diagnostic X-rays are required. A chest X-ray after intubation might be considered to confirm tube placement and identify haemo-, pneumothorax, or both that might compromise the patient during transport to theatre. Plain films may also be useful to confirm the presence or absence of residual foreign bodies. In blunt trauma, spinal precautions are observed throughout resuscitation, obviating any role for immediate spinal imaging. Similarly, in the shocked patient early empirical pelvic stabilization with a pelvic binder (or equivalent) may render pelvic X-rays superfluous initially. It must be emphasized at this stage that if damage control measures truly need to be undertaken, the patient may not be stable enough to undergo a before operation trauma CT. In reality, the majority of trauma patients can be stabilized sufficiently in the emergency department to survive their trip through the CT scanner and timely contrast enhanced CT is without doubt an extremely useful diagnostic adjunct to the primary and secondary surveys, particularly in multiple injuries.^[30,31] In the unstable patient, however, any delay to the operating theatre may be detrimental and CT may have to be bypassed.

Damage Control Part One (DC I)

The primary objectives of the initial laparotomy are haemorrhage control, limitation of contamination (and subsequent secondary inflammatory response), and temporary abdominal wall closure. All of this is done by the most expedient means possible and aims to restore physiology at the expense of anatomical reconstruction. DCR should be on-going throughout DC 0 and DC I and is indeed an integral part of the damage control strategy.

Preparation

The operating theatre should be forewarned of a major trauma patient's arrival to allow adequate preparation and rapid intervention once the patient arrives. Cell salvage suction equipment, instrument trays consisting of a standard laparotomy set, vascular, and chest instruments (including a sternal saw) should all be immediately available. A large supply of laparotomy pads must also be available for the initial packing. It is useful to have a trolley stocked with damage control equipment available in or immediately adjacent to theatre, reducing the time runners need to spend fetching equipment.

The patient is placed in a 'cruciform' position on the table; supine upper extremities abducted at right angles on arm boards. Positioning of the electrocardiogram leads and monitoring equipment must not limit the options for surgical exposure. In anticipation of the need for a median sternotomy, resuscitative left thoracotomy, or bilateral tube thoracostomy, no leads or tubing should be present on the anterior or lateral chest wall. The patient is prepped from chin to mid thighs, extending down to the table laterally should thoracotomy be necessary. A urinary catheter and nasogastric/orogastric tube are inserted at this stage if not done already. Surgery should not be delayed

for the insertion of arterial or central venous lines in the unstable patient. These can be placed during the procedure, either by the anaesthetist or members of the surgical team if in the prepped region.

Incision

The best incision for abdominal exploration is the vertical midline extending from the xiphoid process to the pubic symphysis. In the setting of a suspected severe pelvic fracture, the inferior limit of this incision initially might be curtailed to just below the umbilicus, allowing for continued tamponade of a potential large pelvic haematoma. In addition to giving good abdominopelvic exposure, a midline incision has the advantage that it can be easily extended superiorly, laterally, or both to give exposure to the chest (via thoracotomy or sternotomy) and laterally in the subcostal regions to give better access to the upper abdomen if required.

Haemorrhage Control

Once the peritoneum is entered, the first step is haemorrhage control. Large clots should be removed manually and then a large hand-held retractor is used sequentially around the periphery of the abdomen to provide space for the packing of all four quadrants. Surgeons on opposite sides of the table alternate between retraction and packing as appropriate. The cell salvage suction should be in place to maximize autologous blood capture and return. While packing the abdomen, the surgeon is assessing the degree and location of the most significant injuries. In penetrating trauma, knowledge of the trajectory of the projectiles may aid in assessing potential sites of major bleeding or organ injury. Adequate packing should provide a good degree of haemorrhage control for most venous or solid organ bleeding. If the patient remains profoundly hypotensive after packing, a significant arterial source of haemorrhage is likely and control of aortic inflow should be obtained. Manual occlusion of the aorta at the diaphragmatic hiatus can be performed quickly to control abdominal exsanguination and give the anaesthetic team some time to catch up with volume replacement; this manoeuvre also has been shown to augment cerebral and myocardial perfusion.^[32] If prolonged occlusion is necessary, or if surgical hands need to be freed, a vascular clamp can be placed on the supra-coeliac aorta after minimal dissection in the abdomen or alternatively, the descending thoracic aorta if a thoracotomy is performed. Once clamped, the time should be noted as severe visceral ischaemia will develop unless the clamp can be removed, or at least placed more distally, within a short period of time. In practice, it is desirable to move the clamp down the aorta sequentially as access and haemorrhage control is gained distally.

Between occlusion of the aorta and intra-abdominal packing, the majority of significant bleeding should be controlled. Once exsanguinating haemorrhage has been stopped, a table-mounted retractor is placed to provide maximal exposure and packs are removed in a sequential fashion, beginning in the areas least likely to harbour the source of major haemorrhage.

For major vascular injuries, damage control options are either vessel ligation or placement of temporary intravascular shunts in critical arteries.^[33–36] Shunting for venous injury has also been used and has been shown to improve arterial flow in a limb in animal models compared with ligation.^[37] Primary venous shunting with subsequent repair of proximal limb veins has also been shown to reduce amputation rates compared with ligation,^[38] particularly in the context of concurrent arterial injury. It should be remembered however, that ligation of almost any major vein is usually a survivable procedure if required.^[39] Definitive reconstruction of complex arterial injuries should be avoided in unstable patients as these procedures can be lengthy. If limb circulation has been compromised for a significant period of time, fasciotomy is necessary once haemorrhage is controlled.

Prolonged repair of solid organ injuries must also be avoided in unstable patients. Splenic, renal, and pancreatic tail injuries are managed best with total or partial resection. Bleeding from liver lacerations after blunt trauma can be torrential and difficult to manage but in the damage control situation is dealt with primarily by packing. On-going bleeding from deep hepatic parenchymal injury may need to be controlled by the Pringle manoeuvre (temporary hepatic vascular inflow occlusion by compression of the porta hepatis within the lateral edge of the gastrohepatic ligament). Formal liver resection or finger fracture to expose deep intraparenchymal bleeding

vessels for suture ligation or clip application is rarely needed, even in severely injured patients, and is best performed by surgeons with experience of this technique.^[40]

Other strategies can be used to deal with larger, actively bleeding liver parenchymal disruptions; placement of topical haemostatic agents (such as microfibrillar collagen, Tachosil™, or fibrin glue) on the liver injury itself may provide additional haemostatic support.^[41] Where available, angio-embolization can be a useful technique for the treatment of bleeding vessels deep within the liver parenchyma. Even when haemostasis seems to have been achieved, some centres will routinely proceed to angiography after initial laparotomy in complex hepatic injuries and frequently find previously unsuspected bleeding or arterio-venous fistulae.

Contamination Control

The second priority in a damage control laparotomy is to control the spillage of intestinal contents or urine from hollow viscus injuries. Simple bowel perforations, limited in size and number, may be primarily repaired using a single-layer continuous suture. More extensively injured bowel segments can be resected using a linear stapler. To save time, reconstruction, stoma creation, and feeding tube placement are avoided at this stage and the intestine is left in discontinuity. In high-energy injuries, the extent of bowel wall injury is often not apparent at the initial operation; this can cause delayed bowel ischaemia and perforation, threatening anastomoses and stomas. Therefore, bowel viability is always re-assessed during DC III.

Biliary and pancreatic ductal injuries can be managed initially by simple drainage to form controlled fistulae. Definitive repair or resection is delayed until physiological restoration is achieved as the anastomotic leak rate from complex reconstructive procedures in compromised patients is unacceptably high. Drains are brought out laterally through the flank at the mid-axillary line and intra-abdominal packs are carefully placed so as not to cause kinking of these tubes.

Urinary contamination of the abdominal cavity is less serious than that caused by bile, pancreatic juice, or bowel content but injuries to the urinary tract may still be encountered. Most injuries to the bladder may be suture-repaired primarily and then drained with a Foley catheter. Larger defects may require formal reconstruction by a urologist as part of DC III but during the damage control phase, packing, and catheter drainage is an acceptable solution. Ureteric injuries can be repaired primarily over a stent but in an unstable patient can simply be drained to the abdominal wall (with a paediatric feeding tube into the proximal lumen) or even tied off, with the patient then requiring nephrostomy insertion if they survive.

Once all vascular and viscus injuries have been controlled, intra-abdominal packing is performed. Packing should be sufficient to provide adequate tamponade without impeding venous return or arterial blood supply.

Abdominal Closure

Abdominal closure is the final step before transfer to the ICU. In all damage control cases, fascial closure is not recommended at the initial laparotomy. Reperfusion injury and on-going capillary leakage during resuscitation will cause intestinal and abdominal wall oedema to develop and potentially cause intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS). In this situation, a number of different methods of temporary abdominal closure have been described, from the simple home-made solutions (e.g. the Bogota bag, Opsite™ sandwich) to custom made commercial devices, mostly using some form of topical negative pressure therapy (e.g. Abthera™). All rely on the same basic principles of preventing visceral adherence to the abdominal wall while attempting to allow drainage of the oedema and maintaining some tension between the skin and fascial edges to prevent retraction and allow secondary closure at a later date.

Further Procedures

Damage control part I cannot be considered complete until all surgical bleeding is arrested and as mentioned previously, patients will sometimes require an interventional radiological procedure to achieve haemostasis. Uncontrolled surgical bleeding may not respond to packing alone and interventional radiology (IR) techniques are useful to halt bleeding in complex hepatic, retroperitoneal, pelvic, or deep muscle injuries that, because of location, are not amenable to surgical control or would require lengthy surgical exploration in the setting of coagulopathy.^[42] It may be possible to perform endovascular interventions in the operating theatre using either mobile imaging or a hybrid endovascular theatre. If not, the patient may have to be transferred to the interventional radiology suite. It is essential that DC II strategies be initiated and maintained during the time the patient spends undergoing endovascular interventions. Appropriate monitors, suction devices, respiratory support, patient, and fluid warming devices, and also capable nursing personnel must be available as the IR suite is transformed into an extension of the surgical ICU.

Damage Control Part Two (DC II)

The goal of DC II is to reverse the sequelae of hypotension related metabolic failure and support physiological and biochemical restoration. Simultaneous treatment of all physiological abnormalities is essential and as a result, the first several hours in the ICU are extremely labour intensive and often require the collaborative efforts of multiple critical care physicians, nurses, and ancillary staff.

One of the keys to physiological restoration is the establishment of adequate oxygen delivery to body tissues. Invasive monitoring devices are generally used to guide fluid administration and normalize haemodynamics. The exact monitoring methods used will vary according to local protocols and preferences but multiple options are available (e.g. trans-oesophageal Doppler, trans-thoracic echocardiography, lithium dilution, pulmonary artery catheters, etc.). Most try to measure or estimate the cardiac output and its response to fluid challenges. All techniques have their advantages and disadvantages and, by and large, will trade accuracy of measurement for level of invasiveness.

To date, the exact hemodynamic endpoints that patients must attain after severe injury in order to reliably survive remain controversial. Moreover, resuscitating patients to arbitrary endpoints of normal or supranormal haemodynamic and oxygen transport variables have not been shown to predict survival. Abramson and colleagues, however, did show that serum lactate clearance correlates well with patient survival and that the ability to clear lactate to normal levels within 24 h was paramount to ensuing patient survival.^[43]

Immediate and aggressive core rewarming not only improves perfusion, but also helps reverse coagulopathy. All of the previously mentioned warming manoeuvres initiated in the trauma bay and operating theatre should be duplicated in the ICU. Gentilello showed that failure to correct a patient's hypothermia after a damage control operation is a marker of inadequate resuscitation or irreversible shock.^[44]

An aggressive approach to correction of coagulopathy is paramount in DC II. Standard therapy to correct coagulopathy includes reversal of hypothermia and administration of FFP, which is rich in Factors V and VIII. Repletion of clotting factors with FFP continues until laboratory measurements of coagulation are normal. Platelet levels also should be followed and corrected accordingly. Likewise, fibrinogen levels should be assessed and, if necessary, cryoprecipitate infused. All blood products should be warmed before infusion. Where available, bedside testing of the coagulation system (e.g. with rotational thromboelastometry) and protocolized massive transfusion policies allow guided use of different blood components and may improve outcomes and reduce transfusion requirements.^[29]

During DC II, a complete physical examination or 'tertiary survey' of the patient should occur. This should include relevant imaging studies where appropriate and the patient should also proceed to CT scan to detect occult injuries if stable enough. In cases of blunt trauma, completion of the spinal survey is imperative. Peripheral wounds are addressed and vascular integrity of all injured limbs is assessed frequently. Recruitment of consultants for all definitive repairs should occur early in this

phase, and both the extent and priority of repairs must be established.

The exact timing of reconstruction and abdominal closure (DC III) is dependent on the individual patient. The goal is to resuscitate the patient to within normal physiological parameters; for some patients, this may only require 12 h while many more will require 24–36 h. One should keep in mind that if a patient does not normalize haemodynamically or lactic acid or base deficit fail to improve, the patient should be taken back to the operating theatre earlier for re-exploration. Generally, two subgroups of patients are seen in DC II who require 'unplanned' re-operation before physiological restoration.

Unplanned Re-operation

The first is the group of patients who have ongoing transfusion requirements or persistent acidosis despite normalized clotting and core temperature. These patients are usually found to have ongoing surgical bleeding or a missed visceral injury that was not treated adequately during the initial damage control operation and have a very high mortality rate.^[2,45]

The second group requiring unplanned return to the operating theatre have developed ACS. ACS is the endpoint of a disease spectrum of IAH, defined as a pathological, sustained increase in intra-abdominal pressure >12 mm Hg. ACS is IAH sufficient to cause organ dysfunction. It is defined as sustained or repeated IAP >20 mm Hg in the presence of new single or multiple organ system failure.^[46] Normal intra-abdominal pressure is 2–7 mm Hg. Vigilant monitoring of intra-abdominal pressure is mandatory to recognize IAH and treat it expediently before ACS develops. This is done by intermittently transducing a urinary bladder pressure through the urinary catheter as described by Kron and colleagues.^[47]

Clinically, ACS is characterized by a tensely distended abdomen; elevated peak airway pressure and impaired ventilation, associated with hypoxia and hypercarbia; decreased urine output; increased systemic vascular resistance; and decreased cardiac output.^[48] ACS has a reported incidence of 6% in patients with severe abdominal, pelvic trauma, or both undergoing emergency damage control laparotomy.^[49] However, this incidence has been shown to be reduced by the use of DCR strategies.^[29] Management of the open abdomen with vacuum pack closure does not preclude the development of ACS^[50] and the best treatment of ACS is prevention. Medical and anaesthetic measures to reduce the volume of the intra-abdominal contents (colloid rather than crystalloid resuscitation to decrease gut oedema, nasogastric drainage, or bowel purgation) or increase abdominal wall compliance (optimal analgesia and sedation including complete neuromuscular block if necessary) can ameliorate the consequences of IAH. Continuous haemofiltration has been shown to reduce the circulating cytokine load in patients with significant systemic inflammatory response syndrome (SIRS) and reduce both IAH and mortality.^[51] Surgical treatment consists of opening the patient's abdomen to relieve the pressure. If ongoing blood loss is suspected as the cause of the increased intra-abdominal pressure, this best is performed in the operating theatre, as long as the patient can tolerate the necessary transport. The alternative is to open the abdomen at the bedside in the ICU under sterile conditions. Occasionally, adequate decompression can be achieved without extensive operative intervention by incising the external drape of the vacuum pack to allow for further expansion of the neo-abdominal wall before placement of a new sterile cover.

Damage Control Part Three (DC III)

Timing of DC III is critical as it will likely have the most impact on achieving traditional measures of 'successful outcomes' (e.g. hospital length of stay, surgical site infections, anastomotic leaks, etc.). Before transitioning to DC III, the team should ensure that adequate resuscitation and physiological optimization has been achieved. Patients should be normothermic, have normal coagulation studies and also a normal pH and lactate. With focused, critical care management and resuscitation one may obtain this physiological state within 24–36 h.^[2,4] Aside from ongoing pathology necessitating unplanned return to theatre outlined above early progression to DC III may

be warranted in certain other circumstances, for example, to salvage an ischaemic limb because of shunt occlusion. Early re-operation is also advisable for bowel that has been interrupted at several sites, resulting in a closed-loop obstruction.

Operative Game Plan

A thorough discussion and detailed 'hand-over' should occur before DC III if the restorative surgeon did not perform the original DC I laparotomy. In the operating theatre, the temporary abdominal dressing is prepped into the field before removal and subsequent exposure of the abdominal contents.

All packs are irrigated copiously and removed carefully to avoid clot disruption or further visceral damage. As with DC I, the surgeon must be prepared to accept failure if bleeding is encountered on pack removal. When repeated attempts to control the bleeding using local haemostatic measures fail, immediate repacking is the safest course of action to prevent massive blood loss and recurrent physiological deterioration. Alternatively, during the initial and subsequent explorations, the packs may be wrapped in a non-adherent material such as loban™ to obviate the need for 'teasing' them off clot, bowel serosa, or liver parenchyma.

After successful pack removal, a complete re-examination of the abdominal contents should occur, with particular attention paid to any previous repairs made during DC I. Significant injuries are often overlooked, or only partially defined, during the rapidly performed initial laparotomy in an exsanguinating, unstable patient. Additional sites of bleeding are controlled, vascular repairs are performed, and intestinal continuity is restored.

Abdominal Closure

Once all of the repairs are completed, formal abdominal closure without tension is the challenging final step in the planned re-operation sequence. If gentle adduction allows the fascial edges to approximate, a standard fascial closure should be possible. However, persistent oedema within the retroperitoneum, bowel wall, and abdominal wall often renders primary closure impossible. Should the peak airway pressure increase by >10 cm H₂O during temporary fascial approximation, then the fascia should be left open and the temporary abdominal closure device replaced.

In this case, the patient is returned to the ICU where aggressive diuresis should be considered in an attempt to decrease bowel and body wall oedema as haemodynamically tolerated. During this period, the patient undergoes frequent and regular abdominal washouts, re-inspection, and careful replacement of the abdominal closure device to prevent fistula formation. This may occur at the bedside if personnel and resources are available. The majority of damage controlled open abdomens can be closed primarily within 1 week, especially if there is no sign of intra-abdominal infection. If fascial closure is not achieved after 7 days, the surgeon faces a number of alternatives to cover the abdominal defect, but these will leave the patient with a large ventral hernia that may be repaired at a later date.

Conclusions

DCS and resuscitation have been associated with improvements in survival for the severely injured trauma patient. An abbreviated operation to attain control of haemorrhage and enteric contamination and also aggressive resuscitation allows one to improve the patients' physiology, albeit at the expense of anatomical repair in the short term.

DCR used during the initial phases of damage control has further been associated with improved mortality rates and reduced incidence of complications in major trauma patients. It may reduce the requirement for DCS as patients' better physiological condition after DCR allow them to better withstand early definitive surgery.

Sidebar

Editor's Key Points

- Damage control strategies prioritize physiological and biochemical stabilization over the full anatomical repair of all injuries.
- Damage control strategies are useful for a subset of trauma patients and are not appropriate in all cases.
- Selection criteria for damage control management include the mechanism of injury and the degree of physiological derangement.

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Declaration of interest

None declared.

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