Trauma resuscitation and the damage control approach

Nathan West

Rob Dawes

Abstract

Haemorrhage remains the biggest killer of major trauma patients. One-third of trauma patients are coagulopathic on admission, which is exacerbated further by other factors. Failure to address this results in poor outcomes. Damage control resuscitation is current best practice for bleeding trauma patients, and encompasses damage control surgery and damage control radiography. This review provides a summary of the latest concepts in the rapidly evolving field of trauma resuscitation management.

Keywords Damage control; massive haemorrhage; resuscitation; trauma

Introduction

Damage control (DC) was first termed to describe measures taken by a ship's crew to reduce damage that immediately threatened the integrity of the hull, and enabled return to port for definitive repairs. DC has been traced to the British Royal Navy as early as the 1600s.

Rotando and colleagues[1] were credited as the first to use the term DC in the medical literature to describe improved survival in exsanguinating, penetrating, abdominal trauma using damage control surgery (DCS), comprising haemorrhage control, peritoneal decontamination and packing and rapid closure rather than definitive laparotomy, although similar strategies had previously been documented.

Resuscitation aims to restore physiological normality to the acutely unwell and, may incorporate various techniques, including surgical and radiological intervention.

Damage control resuscitation (DCR) encompasses techniques to restore physiological balance to the major trauma patient, and describes a systematic approach to minimize haemorrhage, prevent coagulopathy and maximize tissue oxygenation to optimize patient outcome. DCR incorporates the concepts of both DCS and Damage Control Radiology (DCRad).

The concept of DCR was initially used in military situations to describe approaches to the management of the severely injured trauma patients and has evolved significantly in the last two decades.[2] Early resuscitation now employs a horizontal team approach, where rapid restoration of physiology has primacy over definitive surgical repair ('operating on physiology, not anatomy'). This philosophy has increasingly been adopted in the civilian environment.

DCS describes the specific, systematic surgical approaches focussing on normalizing physiology from the dual insults of injury and surgery, as opposed to providing immediate definitive repair.[3,4] DCRad incorporates diagnostic and interventional radiological solutions used to treat severely injured patients.[5]

Recent history of trauma care

Advances in trauma care commonly occur during warfare, where high numbers of seriously injured soldiers are treated, although a landmark change was the introduction of the Advanced Trauma Life Support® (ATLS) programme in 1978. ATLS was originally targeted at doctors with little expertise in trauma and provides a structured system for recognizing life-threatening problems and instigating appropriate interventions. The ATLS 'Airway, Breathing, Circulation, Disability, and Exposure' (ABCDE) mantra is familiar the world over. Whilst it is likely this approach has saved many lives over the years, with the advent of regional trauma networks and experience gained from large recent military campaigns, an approach that reaches beyond ATLS is now required in civilian practice.

DCR is a more recent evolution enhancing resuscitation of major trauma. Over the last decade, DCS and DCR have evolved significantly as increasing experience has driven clinical innovation.

Pathophysiology

Acute traumatic coagulopathy and trauma-induced coagulopathy

Haemorrhage remains the leading cause of death in both civilian and military trauma and considerable research has improved our understanding and treatment of massive haemorrhage. Initially, the 'bloody vicious triad' of acidosis, hypothermia and coagulopathy with increased consumption of platelets and clotting factors together with dilution by crystalloids was thought to produce trauma-induced coagulopathy (TC). Subsequently, a much more complicated picture is now emerging.

In 2003 Brohi and colleagues identified the existence of acute traumatic coagulopathy (ATC)[6] ATC is a complex and multifactorial endogenous process occurring after severe injury in approximately a third of patients and independently predicts death and prolonged ICU stay. Hypoperfusion and poor tissue oxygenation are thought to be the main drivers and the onset of ATC is fast, commonly within 30 minutes of injury. Worsening coagulopathy may develop from enzyme and platelet dysfunction, produced by hypothermia, acidosis and serum dilution, which can be intensified during the resuscitative phase particularly if a large amount of crystalloid is given. ATC is exacerbated by these factors, and collectively these processes constitute TC. Our currently incomplete understanding of haemostasis was summarized recently by Cohen et al.[7] and an overview is displayed in Figure 1.

Hypothermia

Hypothermia has many systemic effects including reduced respiratory function and cardiac output. Enzyme kinetics slow down; below 33°C coagulation efficacy is approximately 50%

***Nathan West** BA BSc MB BCh is a Trainee in Anaesthesia at The Ed Major Critical Care Unit and Department of Anaesthesia, Morriston Hospital, Swansea, UK. Conflicts of interest: none declared.*

***Rob Dawes** BM FRCA FIMC RCSEd MCEM is an Anaesthetic and Pre-hospital Critical Care Consultant in the Department of Anaesthesia, Morriston Hospital, Swansea, UK; Emergency Medical Retrieval and Transfer Service CYMRU. Conflicts of interest: none declared.*

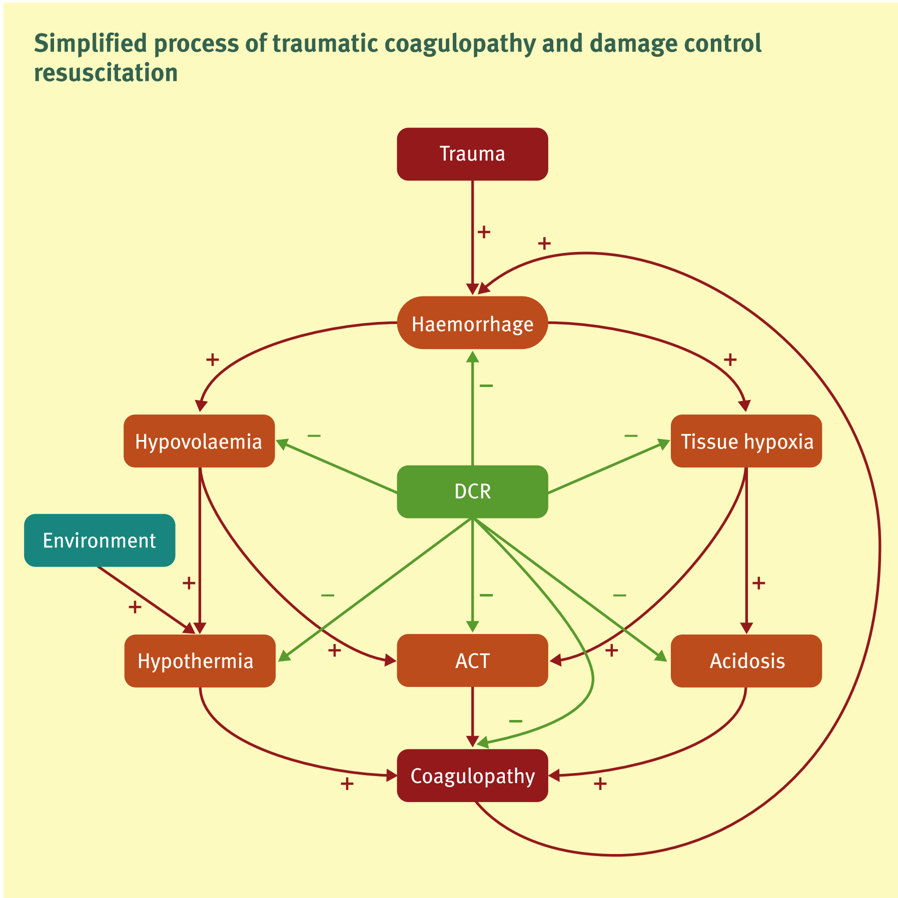


Figure 1

that of 37°C despite normal levels of clotting factors. Hypothermia inhibits the coagulation cascade, increases fibrinolysis and reduces platelet number and function due to morphological changes which decrease platelet aggregation, alter platelet surface molecule expression, and increase platelet sequestration in to the liver and spleen.

Acidosis

pH changes effect coagulation by reducing enzymatic conversion of coagulation factors into their active forms, particularly thrombin generation, and by alteration of platelet activity through decreasing platelet count and modification of calcium ion binding site morphology.

As our understanding of the pathophysiology of severe injury and TC has evolved so our treatment strategies have also adapted.

Changing paradigms

ABC becomes <C>ABC

The most important treatment for haemorrhage is to stop it. Recognition that compressible haemorrhage from extremity wounds kills rapidly (but can be treated with minimal training and equipment) resulted in changing the dogma of ABCDE to <C>ABCDE, where <C> denotes Catastrophic Haemorrhage.[2] This utilizes field dressings, tourniquets and topical haemostatic agents in a stepwise fashion. It follows that severe internal bleeding must also be arrested in a timely manner, and hence early invasive interventions such as DCS and DCRad are an essential part of DCR.

Fluid resuscitation

Fluid resuscitation in the 1970s focussed on initial high-volume replacement with crystalloid, followed by packed red blood cells (PRBC). ATLS has long advocated this strategy, and despite increasing evidence of harm, still advocates replacing each 1 ml of blood loss with 3 ml of crystalloid, up to 2 litres (adult) or 20 ml/kg (paediatric) of crystalloid. Uncontrolled crystalloid infusion in trauma patients has been termed the 'vicious salt water cycle' due to its association with serious complications such as acute lung injury, abdominal compartment syndrome, worsening coagulopathy, and (in shocked burns patients) reduced end organ perfusion. Ley and colleagues[8] demonstrated that crystalloid infusion of 1.5 litres or more in trauma patients was an independent risk factor for mortality.

Mature trauma systems now replace blood with blood products from the outset, although the exact ratio and quantity of products is still under investigation. Some trauma systems (mainly military) utilize whole blood transfusions for resuscitation, although most advanced civilian trauma systems are still reliant on PRBC, fresh frozen plasma (FFP), platelets (Plt) and cryoprecipitate (Cryo). These are typically given in an empirical manner initially, according to local policy.

Damage control resuscitation

The key tenets of DCR are controlling the bleeding (including DCS and DCRad), hypotensive or novel hybrid resuscitation, haemostatic resuscitation, and massive transfusion.

Controlling the bleeding

Effective DCR starts at the point of injury. A range of interventions from direct pressure, haemostatic agents and tourniquets to stem bleeding, to more advanced strategies offered by some services, such as pre-hospital resuscitative endovascular balloon occlusion of the aorta (REBOA) and abdominal aorta junctional tourniquet (AAJT).

During the primary survey any ongoing bleeding should trigger rapid intervention to stem further haemorrhage. Where necessary tourniquets, pelvic binders and distraction/splinting of long bone injuries should be instigated. Prompt decisions to move to the operating theatre or radiology suite should be made for severe ongoing haemorrhage; if not then multi-slice computed tomography can provide essential information which often guides intervention (see DCS and DCRad sections below).

Hypotensive and novel hybrid resuscitation

Hypotensive resuscitation describes targeting a lower blood pressure until definitive haemostasis is achieved. This approach is a trade-off between adequacy of tissue perfusion, versus normalizing coagulopathy and gaining haemostasis. Reduced crystalloid volumes are less likely to create dilutional coagulopathy, and reduced pressures are less likely to dislodge formed clots. Tissue oxygen delivery and clearance of metabolic waste must, however, be maintained at a level compatible with life. Hypotensive anaesthesia is a well-established practice for minimizing bleeding in many surgical situations. Animal models of uncontrolled haemorrhagic shock with both penetrating and blunt trauma have demonstrated benefit using targeted lower mean arterial pressures (MAP) of 60–70 mmHg whilst bleeding is ongoing. Human data have added further weight to this approach and suggested both shorter bleeding times and improved mortality. However, extended hypotension increases tissue hypoperfusion and adds to ATC. A military research strategy of 'novel hybrid resuscitation'[9] (NHR) has shown improved outcomes with a targeted systolic blood pressure of 80–90 mmHg or palpable radial pulse for the 60 minutes post-injury, increasing to 110 mmHg with volume boluses. Initial data are promising but large-scale human data are awaited.

Massive transfusion protocols and haemostatic resuscitation

Various definitions of massive haemorrhage exist including:

- the requirement for ten or more units of PRBC within 24 hours of admission
- replacement of a whole blood volume within 24 hours
- replacement of 50% volume within 3 hours
- Ongoing blood loss of 150 ml/minute or greater.

Massive transfusion (or haemorrhage) protocols (MTP) were designed to provide a systematic way of dealing with the coagulopathy resultant on sole administration of PRBCs without additional coagulation factors such as plasma or platelets. However, empiric MTPs do not necessarily provide the best solution for traumatic haemorrhage.

MTPs typically rely on standard blood tests which take time to process (and are often inadequate in a dynamic resuscitation). Coagulation assays in particular do not give enough factor specific information and have limited use in this context. Currently the best empirical blood product administration is controversial. PRBC alone provides little haemostatic capability. High volumes of FFP are independently associated with serious complications including multi-organ failure and acute respiratory distress syndrome. FFP takes time to thaw, and so many MTPs start with PRBC only. FFP and platelets/fibrinogen then follow. PRBC and FFP without platelets and cryoprecipitate (or fibrinogen concentrate) give no clear benefit, so incorporating equivalent ratios at an early stage appears vital. High Plt:FFP:PRBC ratios confer a survival advantage, but whether that is at 1:1:1 or 1:1:2 is not clear despite recent investigation.[10] A typical DCR strategy involves empirically giving blood products initially at ratios of 1:1:1:1 Cryo:Plt:FFP:PRBC to approximate whole blood equivalence, followed by a conversion to specific goal directed therapy guided by thromboelestography (see below).

Keeping the lethal triad at bay

Once haemostasis is achieved a targeted volume resuscitation ('vasodilate and fill') approach begins, still using rapidly infused warmed blood products at 1:1:1:1 ratios. This shifts the resuscitation focus towards restoring end organ perfusion and oxygenation, and eradicating acidosis. Vasopressors should be avoided where haemorrhagic shock exists to avoid further peripheral acidosis and facilitate faster base deficit (BD) clearance. BD provides an indirect indicator of hypoperfusion, and forecasts transfusion requirements, which also correlates with mortality; it therefore makes it an effective resuscitation marker.

Active methods to prevent and reverse hypothermia undertaken, including warming fluids, warming the environment (operating theatre, CT scanner, resuscitation room), warmed air convection devices and heated mattresses. It is important not to forget to cover the patient's head and to use warmed irrigation fluids for body cavities.

Giving antifibrinolytic agents

The CRASH-2 trial[11] provided evidence that early administration of tranexamic acid (TXA) reduced the risk of death in bleeding trauma patients by approximately one-third. The protocol was 1 g over 10 minutes as a loading dose, then a further 1 g as an infusion over 8 hours. Administration of TXA should ideally be started within 1 hour of injury, and within 3 hours to avoid harmful effects. TXA has now become incorporated as standard practice in UK trauma care.

Point of care testing (POCT)

Point of care testing has also advanced in recent years and it is now feasible to provide this facility cost effectively in major centres. Viscoelastic coagulation tests are dynamic tests which analyse the kinetics of the whole coagulation process and allow for identification of targeted therapeutic interventions (see POCT article in Surgery, Feb 2013 issue). Such tests may facilitate individualized treatment strategies and can reduce total blood product requirement. There are three systems in widespread commercial use: ROTEM® (rotational thromboelastometry), TEG® (thromboelastography) and SONOCLOT®. Definitive outcome advantages are yet to be demonstrated so it seems unlikely that widespread adoption of its use will take place outside major centres at the moment.

Correcting for electrolyte imbalances

As massive transfusion progresses correction of electrolyte disturbances is required, specifically hyperkalaemia and hypocalcaemia. Regular checks should be undertaken. Hyperkalaemia development is independently associated with PRBC administration. This is exaggerated when older PRBC are given or when infusion under pressure occurs. Administration of calcium (providing myocardial protection) and an insulin–dextrose infusion (to encourage potassium to move intracellularly) should be instigated if hyperkalaemia is detected.

Hypocalcaemia is a common problem in severe trauma, in part due to citrate, a calcium-chelating agent, which is added to donated blood to facilitate storage. As massive transfusion progresses so ionized calcium levels are depleted, and regular replacement is required to maintain a level of more than 1 mmol/litre. In addition to bestowing cardio-protective properties, calcium is an essential cofactor in the normal coagulation process, effecting both platelet activation and the clotting cascade. Furthermore, low levels of ionized calcium are associated with an increase in mortality in critically ill patients.

Damage control surgery (DCS)

DCS focuses on rapid control of haemorrhage, removal/minimizing the effects of gross contamination, and facilitating the return of normal physiology. DCS should be time limited (less than 90 minutes) and applicable to most anatomical zones including maxillofacial, neck, thoracic cavity, pelvic, and major extremities. This initial short intervention is at the expense of providing definitive repair, which is delayed until the patient is physiologically stable. DCS may involve a single visit to the operating theatre, or a multi-phased approach with pauses whilst physiology is restored to acceptable levels.

Preparation of the patient is important as injuries to different anatomical zones may require multiple surgeons working concurrently to facilitate expedient surgery. The anaesthetist(s) may have difficulty directly accessing the patient during the surgical phase, so adequate vascular access and monitoring must be obtained, along with attempts to minimize heat loss. One effective method involves placement of the patient in a cruciform position with arms out on boards, ECG leads posteriorly, preparation from chin to mid-thigh, urinary catheter and naso/orogastric tube inserted, ideally on a heated mattress, with ambient temperature and humidity high.

Abdominal DCS commonly involves laparotomy with midline incision and techniques such as clamping, packing, vascular ligation or shunting to allow flow, closure or resection of hollow viscous injury, debridement of contaminated or unsalvageable tissue and placing of drains. The high risk of developing pressure-related complications, such as intra-abdominal hypertension and abdominal compartment syndrome, means that many surgeons now prefer to leave a laparostomy with a temporary abdominal closure, such as a vacuum dressing; definitive closure is delayed until several days later, when a re-look laparotomy can be safely undertaken.

Thoracic DCS typically includes unilateral or bilateral anterolateral thoracotomy or median sternotomy incisions to provide adequate access. Common procedures include pulmonary resection, lobectomy, pneumonectomy, non-anatomic resection, wedge resection and tractotomy. Major vascular, cardiac, and tracheo-oesophageal injuries may also warrant procedures. Additional thoracic procedures of note which are not exclusively undertaken by surgeons and may be undertaken at early stages of the resuscitation include finger thoracostomy, intercostal drain insertion and resuscitative thoracotomy. These should therefore also be viewed as DCS procedures.

Extremity DCS includes reduction and stabilization (often with external fixation) of severe fractures, and debriding grossly contaminated extremities. DCS for other zones is necessarily determined by anatomy essential to preserve life. For example where severe maxillofacial and/or neck injury exists a tracheostomy may be an appropriate early part of the DCS strategy.

An in-depth discussion of all DCS techniques is beyond the remit of this article.

Damage control radiology

DCRad incorporates both diagnostic and therapeutic procedures.

Diagnostic DCRad (dDCRad) involves multidetector computed tomography (MDCT) to quickly find life-threatening injury and haemorrhage, identify or exclude head and spinal injury, and facilitate decision-making for further treatment options.[6] In the UK MDCT is the diagnostic imaging of choice, and due to its high sensitivity and specificity, often negates the requirement for X-rays and ultrasound. Furthermore, the dogma that previously prevented transfer of unstable patients to the CT scanner is challenged by evidence that it is precisely these patients who stand to gain most benefit.[6] Protocolized dDCRad imaging is undertaken, of which the default scan for a severely injured patient is head-to-thigh contrast enhanced MDCT. Experienced senior radiologists are able to quickly discern and deliver a primary survey style report to expedite appropriate trauma team decision making, including whether to go to the operating theatre, the angiography suite or the intensive care unit. A more detailed report can be delivered later.

Whilst there may be a role for incorporating skilled ultrasound assessment in the resuscitation room, this should not be done at the cost of causing delay to either MDCT or the operating theatre (OT). Current UK guidelines support the use of extended focussed assessment sonography in trauma (eFAST) for aiding with triage decisions where resources are low, such as in multiple casualty incidents. eFAST may also help in the rapid assessment of thoracic injury prior to MDCT in both the resuscitation room and the pre-hospital phase. Examples of this might be to identify large pneumothoraces or significant pericardial effusions (requiring finger thoracostomy, or suggesting imminent resuscitative thoracostomy respectively).

Therapeutic DCRad (tDCRad) relies upon having an appropriate on-site service available within 30–60 minutes, which is not available in many UK hospitals receiving major trauma. Minimally invasive techniques such as arterial balloon occlusion, occlusive embolization and vascular stenting are feasible in the tDCRad context and have become important for certain complications, such as contained aortic transection, traumatic pseudoaneurysms, arterial pelvic haemorrhage, and organ preservation (splenic, renal and hepatic).

Limitations of DCRad include the erroneous security of a false-negative MDCT result and the utility of tDCRad in those with multiple bleeding sites (time may be problematic) or in special populations such as the very young or the elderly (where small vessels or vessel fragility may increase likelihood of failure/injury). Furthermore, success of tDCRad techniques rely partially on the presence of an ability to form clots, so DCR must be an ongoing concern before and during these interventions.

Sequence of damage control

DC has classically been described in distinct phases, and the four-phase approach described by Lamb et al.[4] serves well to conceptualize the surgical priorities. However, resuscitationists should regard DCR as a seamless process; 'resuscitation' is ongoing from start to finish, and different tools (dDCRad, tDCRad, DCS) may be utilized once or more at different stages of treatment, depending on patient need (Figure 2). Often these tools are in a specific chronological order, for example ED reception before MDCT before DCS, but this is not fixed, and maintaining flexible capability allows for issues to be prioritized and addressed in order to achieve the aims set out above (see Damage Control Resuscitation).

Who needs DCR?

Expedient identification of appropriate patients and subsequent activation of DCR is required to minimize mortality. Several criteria have been suggested for guidance on who requires a DC approach, yet different trauma systems have highly variable capabilities. Definitive standards appropriate for all still remain to be elucidated. Essentially a DCR approach should be adopted for any patient suspected to have major haemorrhage, including those with pathophysiological indicators following traumatic injury or with haemorrhage requiring more than four PRBC units in the first 4 hours.

Rotondo's DCS indications are a particularly useful guide (Table 1).

Whilst these criteria assist decision-making they are not specific tests. Development of local protocols and early involvement of experienced senior decision makers are vital elements to implement a successful DCR strategy.

Hypotension is deleterious for brain-injured patients, so a different strategy with higher target blood pressures is warranted if isolated head injury is present. Evidence for DCR in cases where both significant haemorrhage and severe head injury are present is currently lacking, and so current strategies often consist of a combination of DCR principles with higher initial systolic or mean arterial pressure targets to maintain cerebral perfusion pressure.

Endpoints of DCR

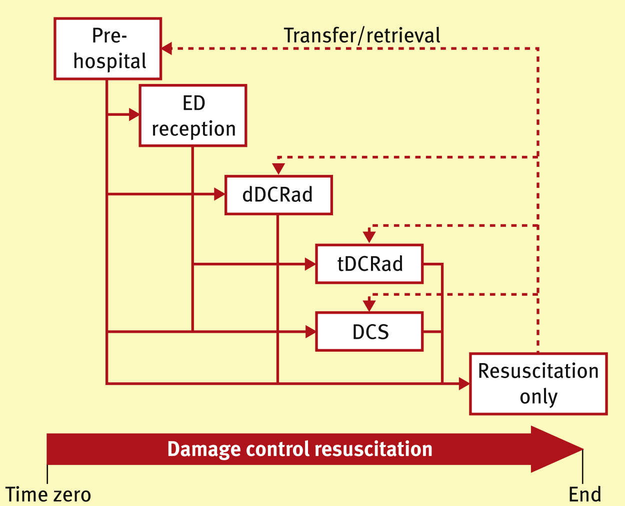
Perhaps the most challenging part of DCR strategy is understanding when to cease. DCR aims to restore physiology. Exact endpoints for trauma resuscitation remain the focus of much debate. Clearly resuscitation continues whilst there is ongoing haemorrhage. Once haemostasis is achieved the classical approach, normalizing physiology is pursued. Many resuscitationists now recognize that further target-focussed resuscitation must continue until tissue hypoxia is diminished. Key endpoint parameters therefore include:

- pH
- base deficit
- core temperature
- coagulation (ideally with both POCT and laboratory tests)
- haematocrit.

Outcomes of DCR

As DCR continues to evolve, data increasingly demonstrate improved outcomes.[9] Specific benefits include improved

Damage control resuscitation sequence



DCS, damage control surgery; dDCRad, diagnostic damage control radiology; ED, emergency department; tDCRad, therapeutic damage control radiology.

Figure 2

Indications for damage control resuscitation

Conditions	High-energy blunt trauma
	Multiple torso penetration
	Haemodynamic instability
	Presenting coagulopathy and/or hypothermia
Complexes	Major abdominal vascular injury with multiple visceral injuries
	Multifocal or multicavity exsanguinations with concomitant visceral injuries
	Multiregional injury with competing priorities
Critical factors	Severe metabolic acidosis (pH $\leq$7.3)
	Hypothermia (temp $\leq$35°C)
	Resuscitation and operative time >90 minutes
	Coagulopathy as evidenced by development of non-mechanical bleeding
	Massive transfusion required ($\geq$10 PRBC units)

Adapted from ref. 1. PRBC, packed red blood cells.

Table 1

mortality, improved tissue perfusion, reduced acidosis, lower risk of rebleeding, and reduced volumes of both crystalloid and blood products. From a surgical perspective, well-implemented DCR can reverse a deteriorating physiological trajectory, and in some cases facilitates longer surgical times than initially predicted. However, it is clear that such complex physiology is still not fully understood, and there is considerable room for improvement with current approaches.

Decision-making and resource implications

A key, perhaps *the* key, component of effective DCR is accurate and timely decision-making and availability of appropriate resources. Senior staff, working in a highly trained, multidisciplinary, horizontal hierarchy team is a successful model used by the UK military.

Many civilian centres have adopted a similar horizontal team approach, although the civilian hospital trauma team typically consists of the following core members:

- trauma team leader (TTL)
- trauma resuscitationist (anaesthetics/intensive care) with advanced airway, vascular access, resuscitation (and increasingly procedural) skills
- airway assistant (operating department practitioner or equivalent)
- primary survey doctor (emergency medicine/general surgery)
- procedures doctor (general surgery/trauma and orthopaedic)
- procedures nurse (emergency medicine nurse)
- scribe
- runner.

Additional specialists may be invited/required depending on pathology (e.g. burns and plastics, cardiothoracics, maxillofacial, neurosurgery, obstetrics, paediatrics).

Ideally the TTL should be an experienced consultant with an in-depth knowledge of trauma. TTLs are commonly emergency medicine specialists. It is the TTL's responsibility to coordinate overall strategy, process information and make appropriate timely treatment decisions in consultation with senior members of relevant specialities. TTLs must coordinate communications with other departments of interest (specialists, operating theatres, haematology, laboratories, radiology) to facilitate seamless care.

The reality can be somewhat different. It is not unusual that out of hours in many hospitals there is no consultant present during the early resuscitation. Teams of junior doctors who continually change with each shift and each new rotation, assemble as *hot teams* who may have little understanding or knowledge of each others' capabilities or limitations. In order to maximize success it is vital that a common approach, structure and language be employed. Increasingly local and national courses in crew resource management (CRM or human factors and non-technical skills) are being taught to improve trauma team performance under stress.

Tips and tricks for practitioners

For trauma team leaders

- Keep overall control and good situational awareness. Those with specific tasks may become task orientated. Your role is to see beyond this and ensure the successful implementation of the overall strategy.
- De-escalate any conflict between team members and direct all team communications solely through you. Refocus the team if required.
- Anticipatory activation of MTPs when pre-hospital information suggests severe bleeding will get the process mobilized and facilitate earlier blood product availability.

For trauma resuscitationists

- Preparation is a key. Set up and check your equipment and monitoring, and draw up your drugs before the patient arrives where possible. Ensure you have an experienced assistant, and ideally a further pair of experienced hands to assist where necessary. Prime the rapid infusion system if there is any suggestion it may be required, and (with the TTL) delegate an operator.
- Transfer to CT, angiography, operating theatres and ICU will be under your supervision. Take everything you may need and plan for the worst eventuality. Do not take non-essential personnel as they often complicate situations.
- Encourage the TTL to activate the MTP at the earliest opportunity when you feel it may be required.

For trauma surgeons and interventional radiologists

- Get senior help early on. Unstable trauma patients decompensate quickly; when invasive resuscitative intervention is required you are unlikely to have time to wait for your consultant to arrive from home.
- Use proactive communication to keep your TTL and resuscitationists up to date with progress, concerns and any revisions in strategy. They will be second-guessing you to provide optimal resuscitation. The British military have adopted a 'ten in ten' principle, where the surgeon updates the anaesthetist for 10 seconds every 10 minutes.

For intra-osseous infusion and paediatric resuscitations

- Choose the humeral intra-osseous (IO) route in preference to the tibial route as flow rates are faster and delivery is more proximal.
- When delivering high flow through IO needles the IO bore limits flow rates, which can trigger infusion system pressure alarms and cease delivery. A three-way tap with a one-way valve proximally and a 60-ml syringe on the side port allows warmed fluid to be drawn and infused without altering the three-way tap position.
- For paediatrics this provides an efficacious way of delivering precise volumes of warmed blood product in a controlled manner.

Special populations

DCR evidence is primarily from military populations (young healthy adults). A growing body of research addresses the applicability of DCR to other population groups including children and the elderly. These groups have different physiology and it is possible that modifications are required to provide optimal treatment. Recent conflicts have involved treatment for high numbers of paediatric casualties. Although the military have specific paediatric algorithms, the lack of randomized controlled trials for this population remains a barrier to elucidating best practice.

The elderly with multiple co-morbidities have decreased physiological reserve, particularly cardio-respiratory. Patients are less able to tolerate hypovolaemia or the ensuing aggressive volume resuscitation without developing complications (e.g. hypoxic tissue injury, ischaemic myocardium, cardiac overload, acute lung injury, pulmonary oedema etc). Caution must be exercised to ensure adequate physiological tolerance, whilst adhering to DCR principles. Older patients are more likely to take anticoagulant medications and could require haemostatic reversal such as prothrombin complex concentrate. In this subgroup, where vitamin K antagonists are relatively common, the international normalized ratio (INR) coagulation test still has a useful role to play.

The future

Some of the interesting areas under investigation include the following:

Red blood cells

Separated PRBC may decrease oxygen delivery through disturbing regional blood flow control and altered oxygen affinity.[12] Older PRBC units do not provide the same erythrocyte functionality or survival. Improvements could be made to the current systems where fresher PRBC units are provided first. Furthermore, the investigation of whole blood therapy and novel oxygen carrying products may also yield interesting results.

Lyophilized plasma/fibrinogen and prothrombin concentrate

Dried concentrated clotting factors have shown good shelf-life and stability, which increases their portability to austere and pre-hospital scenarios. As availability increases and costs decreases this will give more scope to ameliorate TC at an earlier stage.

Suspended animation physiology

An emerging concept (successful in animal models and undergoing human studies) is emergency Preservation and Resuscitation for Cardiac Arrest from Trauma (EPR-CAT). Rapid hypothermia is induced (<10°C) for up to 60 minutes whilst life-saving surgical repair is undertaken in patients with non-survivable cardiac arrest from traumatic exsanguination. Trial results are due in 2017.

Extracorporeal membrane oxygenation (ECMO)

The use of ECMO is becoming increasingly widespread. This therapeutic rescue intervention has the capability to preserve blood oxygenation, whilst rewarming and correcting acid–base abnormalities in patient groups who were previously catastrophic. Its use in trauma may become more accessible and convey a survival advantage to some of the most serious cases.

Enhanced pre-hospital critical care

Enhanced pre-hospital services are still in their relative infancy although established military systems (e.g. MERT) show considerable improvements in patient outcomes. They offer several advantages over conventional ambulance and air ambulance services including:

- critical care capability quickly to the point of injury
- on-scene senior decision-making skills
- transportation of patients to the most appropriate care centre.
- DCR en-route
- the ability in some centres to bypass the emergency department for operating theatres or CT scanning.

Summary

The science of trauma and its treatment are rapidly evolving fields. Considerable improvements in patient outcomes have been demonstrated with the introduction of concepts such as DCR. Survival is now possible from injuries where it may have been unfathomable as little as 20 years ago. This review presents a simplified summary of the current concepts in trauma resuscitation. ◆

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