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Demystifying damage control in musculoskeletal trauma

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ABSTRACT

Trauma care has evolved rapidly over the past decade. The benefits of operative fracture management in major trauma patients are well recognised. Concerns over early total care arose when applied broadly. The burden of additional surgical trauma could constitute a second hit, fuelling the inflammatory response and precipitating a decline into acute respiratory distress syndrome, sepsis and multiple organ dysfunction syndrome. Temporary external fixation aimed to deliver the benefits of fracture stabilisation without the risk of major surgery. This damage control orthopaedics approach was advocated for those in extremis and a poorly defined borderline group. An increasing understanding of the physiological response to major trauma means there is now a need to refine our treatment options.

A number of large scale retrospective reviews indicate that early definitive fracture fixation is beneficial in the majority of major trauma patients. It is recommended that patients are selected appropriately on the basis of their response to resuscitation. The hope is that this approach (dubbed 'safe definitive fracture surgery' or 'early appropriate care') will herald an era when care is individualised for each patient and their circumstances. The novel *Damage Control in Orthopaedic Trauma Surgery* course at The Royal College of Surgeons of England aims to equip senior surgeons with the insights and mindset necessary to contribute to this key decision making process as well as also the technical skills to provide damage control interventions when needed, relying on the improved techniques of damage control resuscitation and advances in the understanding of early appropriate care.

KEYWORDS

Damage control – Major trauma – Temporary external fixation

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Trauma care has evolved rapidly over the past decade. Damage control resuscitation (DCR) has revolutionised the care of the most severely injured, in whom immediate life-saving surgery is required to prevent exsanguination and body cavity soiling, and to restore tissue perfusion. Clearly, early definitive operative stabilisation of major fractures would be inappropriate in those with acute coagulopathy, raised intracranial pressure (ICP), persisting significant acidosis or hypothermia. However, the response to DCR can be dramatic, offering the potential to extend surgical options within the first 24–36 hours of admission. Conversely, deterioration may occur intraoperatively, in which case abandonment (which has been planned proactively) of early definitive fixation in favour of temporary external fixation is likely to prove the safest option. This approach, tailoring surgical fracture management to the patient's progress, underpins the emerging philosophy in major trauma and is referred to as safe definitive surgery or early appropriate care.

Evolution of fracture surgery in major trauma

The first damage control intervention was probably the use of the Thomas splint for femoral fractures in the First World War.[1] Initially, these injuries carried a mortality rate of 80%, with a large proportion of deaths occurring close to the frontline, on their way to or at the casualty clearing stations. After the introduction of the Thomas splint to the field ambulances, this early mortality fell to 20%.

In the early half of the 20th century, polytrauma patients were usually considered too ill to undergo surgical procedures to stabilise major fractures. By the 1970s, however, results started suggesting that early skeletal stabilisation had a beneficial effect on pulmonary function and

postoperative complications.[2,3] The concept of early total care emerged and was supported in a prospective randomised study published by Bone *et al* in 1989, which showed a decrease in morbidity and mortality with early fixation of femoral shaft fractures in multiply injured patients.[4] Thanks largely to the work published by Pape and his team in Hannover, a better understanding of the 'second hit' phenomenon developed, which was perceived at the time to be caused by the additional burden of major surgery (ie femoral nailing).[5]

Studies of markers, mediators and effector cells of the systemic inflammatory response pointed towards exacerbation by definitive fracture surgery. Interleukin-6 (IL-6) in particular was found to correlate with the systemic inflammatory response syndrome (SIRS).[6] The finding that staged definitive fracture surgery, after temporary external fixation, was not associated with further elevation of IL-6 supported the damage control orthopaedics (DCO) approach.[7] Similar findings in terms of neutrophil priming and activation along with monocyte dysfunction were also observed.[8–10]

Indeed, some patients given early total care developed a higher rate of complications, specifically acute respiratory distress syndrome (ARDS), SIRS and multiple organ dysfunction syndrome (MODS), which are spectra of the same underlying physiological condition. These are catastrophic autoimmune sequelae of major trauma and were thought to be a direct consequence of the second hit of femoral nailing. DCO was adopted by Pape's team, who saw an overall reduction in morbidity and mortality in Hannover,[11] and a stratified approach emerged, popularised in the 2000s. Patients were divided into three groups: stable patients, suitable for early total care; unstable patients, suitable for DCO; and borderline patients who need further evaluation to determine their category. For those in whom a second hit was anticipated, a three-stage protocol was advocated:

1. Initial rapid temporary stabilisation using external fixation
2. Resuscitation in an intensive care unit
3. Subsequent definitive reconstructive surgery when the patient's condition has optimised

Concerns over exacerbating the systemic inflammatory response to injury by performing reconstructive surgery (particularly for major fractures) led some clinicians to regard days 2–5 following injury as a 'no-go zone' for definitive fixation of major fractures.[5,7,12] This corresponds to the phase of relative immunosuppression recognised in the original one/two-hit model, described subsequently as part of the compensatory anti-inflammatory response syndrome.[13]

It might be obvious when a patient is physiologically unstable because of hypotension, tachycardia or (worse still) presence of the lethal triad of hypothermia, acidosis and coagulopathy. The presence of severe thoracic, abdominal or head injuries or bilateral femur fractures was also proposed as a way of identifying patients as borderline and therefore suitable for DCO. In a retrospective review of 22,882 patients with femoral shaft or distal femoral fractures, 472 had sustained bilateral femoral fractures.[14] Associated injuries were common, present in 41.1% (9,214 patients) of those with unilateral fractures and 80.5% (380 patients) of those with bilateral fractures. Isolated unilateral fractures had a 30-day mortality rate of 3.4%, which rose to 12.8% with associated injuries. This compared with a mortality rate of 9.8% for those with bilateral femoral fractures, rising to 31.6%.

No physiological data were presented to illuminate the decision making behind the selection of femoral fracture management. Indeed, causality cannot be ascribed to the method of fracture management as this was presumably selected on the basis of the right choice for the patient at that time. However, overall, the lowest mortality (22%) was seen in those undergoing bilateral femoral nailing.

It now seems clear that the dogma of a second hit effect by femoral nailing (perceived in the past as being damaging to the lungs) has been overemphasised. It is likely that much of the 'second hit' phenomenon observed in the 1990s and 2000s was related to the liberal use of large volumes of crystalloid for resuscitation as opposed to the mode of fracture stabilisation. This aligns with early evidence emerging from general surgery, regarding strategies to deal with exsanguinating abdominal injury, refined by recent military experience and encapsulated as the philosophy of DCR.[15,16]

Defined as a series of techniques from the point of wounding to definitive treatment to minimise blood loss, maximise tissue oxygenation and optimise outcome, this philosophy has produced dramatic improvements in survival. Fluid resuscitation now centres on the use of component blood products to replicate whole blood replacement within consistent massive haemorrhage policies. Bleeding is controlled surgically before blood pressure is restored above a target systolic pressure of 90mmHg. Sympathomimetics are not used. In fact, vasodilation accompanying general anaesthesia is a key part of the strategy to restore tissue perfusion as rapid transfusion proceeds; volumetric flow is more important than simple pressure. Surgery is an integral part of this resuscitation, aiming to control bleeding, avoid body cavity soiling, debride wounds and enable decompression for compartment syndrome. When patients respond well, it is possible to extend surgical intervention but this is a team decision and not a case of mission creep.

To date, no large scale study reappraising the changes in inflammatory markers, mediators or effector cells in the era of DCR has been published. In one small series of pelvic injury patients dominated by those requiring massive transfusion on admission, definitive fracture surgery was executed on a pragmatic basis when the patient was felt to be on a trajectory for recovery.[17] Despite patients undergoing surgery in the 'no-go zone', no significant exacerbation of the inflammatory response was seen either in terms of IL-6 levels or clinical problems.

In a study performed by Xiao *et al* of major trauma patients who required transfusion with blood products because of hypotension or acidosis, an 'unexpected genomic storm' was identified, affecting circulating leucocytes.[18] This manifested itself within hours of injury and

was sustained, showing dysregulation in the pro and anti-inflammatory facets of the response from the outset rather than in a sequential pattern as postulated previously.

These data show that inflammatory/immune dysfunction manifests itself at a genomic level very rapidly and the severity of the response is linked with recovery. The question of surgery in the damage control phase of patient management was not addressed in the study by Xiao *et al*[18] and its findings should therefore be interpreted with care, before implying that this could be taken as evidence that injudicious early surgery cannot lead to a second hit. The long-term neuroendocrine and catabolic effects of major trauma are also now better recognised, with persisting inflammation linked with the latter,[19] and long-term suppression of endogenous anabolic hormones underpinning these processes and offering a potential therapeutic target.[20,21]

Furthermore, there is increasingly compelling evidence that early definitive fixation of fractures (femur, spine, pelvis) leads to shorter intensive care unit stays, and lower rates of MODS and ARDS.[22] To this end, suitable physiological markers have been sought to discriminate patients not yet suitable for definitive surgery from those who are adequately resuscitated and can have their orthopaedic injuries definitively treated.

Serum lactate levels have been shown to be a reasonable indirect measure of tissue perfusion or occult hypoperfusion.[23,24] The traffic light system proposed by O'Toole *et al* is based around serial lactate measurements within the first 24 hours of injury:[25]

- Lactate >2.5mmol/l = RED: Stop definitive surgery – DCO if this level persists beyond 24 hours
- Lactate 2.5–2.0mmol/l = AMBER: Management depends on lactate trend
- Lactate <2.0mmol/l = GREEN: Suitable for early femoral nailing

Importantly, this serum lactate trend can also be used during surgery to determine whether a change in strategy is needed where a patient is showing early signs of deterioration. In order to achieve the required level of teamwork and communication, surgical teams should emulate the human factors approach employed by the Defence Medical Services at Camp Bastion.[26] This approach was developed to aid in the management of the most severely injured patients but it can be applied readily to any major trauma situation.

The first of three elements is the 'command huddle' in the emergency department, in which a joint decision is reached between the trauma team leader, surgeons, anaesthetists and the theatre lead regarding transfer of the patient to theatre, via computed tomography (CT) as appropriate. The second element, the 'snap brief', is performed on arrival in theatre to ensure that all members of the theatre team know what is about to happen and why. The surgeon outlines the surgical plan. The anaesthetist states the patient's temperature, blood pressure, blood volume given so far, blood gas information, clotting information and any other issues, and confirms that antibiotics and tranexamic acid have been given. The 'sit reps' (situation reports) make up the third element, occurring between surgeons and anaesthetists every 10–30 minutes in theatre as circumstances can change rapidly.

Depending on the surgical progress and the patient's clinical condition, it may be possible to extend the scope of the original surgical plan or it may prove necessary to abbreviate it. This is a joint decision but the patient's changing physiology is the principal factor.

Serum lactate levels must not be taken as the final deciding factor for treatment. There are other situations that demand a less invasive surgical approach and in which damage control is still indicated, even in the event of normal lactate levels:

- *Severely contaminated high energy open fractures or dislocations with possible ischaemic tissue (eg following crush or blast injury)*
  Even after timely debridement and fasciotomy for compartment syndrome or following vascular reconstruction, it is likely that there will be muscle that is of dubious viability and that cannot necessarily be identified at the first surgery. Damage control surgery in this context is a safe and sensible option since further dead muscle debridement is likely, meaning soft tissue cover would be delayed.
- *Traumatic brain injury with raised intracranial pressure*
  There is relatively limited evidence regarding the effect of orthopaedic surgery on ICP in the context of an injured brain. However, neurosurgical caution is likely to trump early definitive orthopaedic care in the context of raised ICP following trauma. Increasing use of direct ICP monitoring (despite some reservations about its superiority to management based on CT and clinical assessment)[27] can further act as a guide to care and is now more common.

Conclusions

An algorithm for deciding on the optimal strategy for skeletal stabilisation of major orthopaedic injuries in severely injured patients is essential for achieving the best outcomes for individual patients. The stable/unstable/borderline concept is now somewhat dated and unhelpful since resuscitation is a dynamic process over time rather than a static snapshot of physiology. Understanding trauma physiology is key. Patients should be aggressively resuscitated, using haemostatic ratios of blood products, and with the emphasis on restoring tissue perfusion, clotting and haemostasis rather than on restoring a normal blood pressure. Crystalloid administration for volume replacement should be completely avoided in the acute situation. A minority of major trauma patients need staged DCO. Early appropriate care can be applied safely within the first 24 hours although this can be extended until lactate normalises.

Major fractures should be stabilised, with those of the femur, spine and pelvis currently assuming the highest

priority. Lactate can be monitored intraoperatively so that the 'limit' of appropriate surgical intervention can be determined in real time. A well trained team repeatedly monitoring patient physiology will ensure the best possible outcome. The novel *Damage Control in Orthopaedic Trauma Surgery* course (held at The Royal College of Surgeons of England) aims to equip senior surgeons with the insights and mindset necessary to contribute to this key decision making process as well as the technical skills to provide damage control interventions when needed. This course relies on the improved techniques of DCR and advances in the understanding of early appropriate care to enable orthopaedic surgeons to offer improved treatment options in managing severely injured patients.

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