Challenges of treating modern military trauma wounds

The war being fought in Iraq (2003–2009) and Afghanistan (2006–present) is unconventional in that British forces are predominantly engaged in counterinsurgency tactics as part of an asymmetric war (Belmont et al, 2010). While US and coalition forces have numerous technological advantages over the enemy in terms of weapons, armour, transportation and a high level of organisation, they face unconventional weapons and tactics in accordance with a less organised opposition. As a result, the patterns of injury most often encountered in wounded soldiers reflect the enemy's dependence on improvised explosive devices (IEDs), mines and rocket-propelled grenades (RPGs) (Gosselin, 2005).

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KEY WORDS
Explosion-related injuries
Military medical support
Contamination
Topical negative pressure (TNP)

The types of war wounds produced by high energy weapons present very different medical and surgical challenges to those previously encountered on the battlefield and to those seen in the civilian setting. Explosion-related injuries create challenges on numerous levels, which will be discussed in this paper based on experience of these wounds at the UK role 4 facility, The Royal Centre for Defence Medicine (RCDM), Queen Elizabeth Hospital, Birmingham University NHS Trust.

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Modern war wounds

Gunshot wounds are still frequently seen in injured soldiers, however explosion-related injuries are now the most common type of injury (Weil et al, 2006). The catastrophic trauma that occurs as a result of explosive devices is devastating in contrast to other forms of battle injury. It would therefore be expected that the mortality rate associated with such injuries is much higher today than in previous wars. However, this has not been the case. The mortality associated with war wounds has significantly declined due to a number of factors (Calhoun et al, 2008):

- Improvements in body armour have resulted in lower rates of thoracic injury
- Field medical units provide a high quality of immediate care resulting in better pre-hospital chances of survival
- Transportation from the war zone to role 4 facilities may often be achieved within 24 hours of the incident (NHS Choices, 2010).

It is therefore understandable that increased injury-severity scores are being seen in soldiers who survive such catastrophic injuries (Kelly et al, 2008).

The destructive extent of an explosion is dependent on the nature of the device and the proximity of the soldier when it detonates (Champion et al, 2009). In contrast to other forms of weapon (i.e firearms), explosive devices have the capacity to injure multiple victims simultaneously by a variety of different mechanisms. Detonation of an explosive device results in the instantaneous conversion of explosive material to a high pressure gas. The supersonic expansion of this gas creates a blast wave through space that compresses air at its leading edge forming a high-pressure shock wave, the 'overpressure' (Sakorafas and Peros, 2008). The negative pressure void created in the wake of the overpressure sucks debris into the air, which is then caught and propelled outwards by the 'blast wind' — the mass outward movement of air that follows the overpressure. There are five classes of injury associated with explosive devices, however as victims of blast injuries have multiple wounds involving different bodily systems, injury patterns tend to become less distinct (Champion et al, 2009; Wolf et al, 2009).

Primary blast injury results from the overpressure as it passes through the body; specifically at air-fluid interfaces, i.e. the tympanic membrane, lungs and bowel (Weil et al, 2006), where the rapid compression/expansion and acceleration/deceleration forces cause significant tissue damage. The extent of primary injury is dependent on the distance of the victim to the explosion epicentre, the size and type of device, and the environment in which the explosion occurs (Champion et al, 2009). The damaging extent of blast waves in an enclosed space is much greater due to the multiplying effect of deflected waves off walls and objects (Wolf et al, 2009).

Secondary explosive injuries are due to high-energy penetrating fragments from the device casing, or often in the case of improvised explosive devices (IEDs), from fragments such as rusty nails and scrap metal placed within the device to increase its destructive capacity (Ramasamy et al, 2009). While these penetrating wounds are ballistic in nature, they differ significantly to those caused by bullets. The irregular shape of fragments causes them to lose speed through the air so that their trajectory through the tissues is slower and much more tortuous than that of a streamlined bullet. While these factors may initially result in a less severe injury than that of a high-velocity bullet, blast fragments are more numerous and carry much more debris into the wounds leading to extensive wound contamination (Covey, 2002). It is this secondary mechanism of blast injury that causes catastrophic trauma to extremities and results in bone and soft-tissue damage and loss.

Tertiary explosive injuries describe blunt trauma resulting from translocation of the victim into the ground and other structures, or injury secondary to being hit by flying objects. Crush and penetrating trauma may result from this mechanism of injury.

Quaternary explosive injuries involve other mechanisms associated with explosions such as burns, inhalation of toxic gases, and injury from environmental contaminants. The category described as quinary injuries is a relatively recent addition and allows for the purposeful addition of radioactive or bacterial substances to IEDs, creating a 'dirty bomb'. These are increasingly being seen in acts of terrorism (Leissner et al, 2006).

Injuries resulting from explosive devices are consequently both multiple and complex. In the majority of cases, victims of explosive injuries on the battlefield present with heavily contaminated extremity trauma involving massive destruction of soft-tissue and bone. Less obvious effects of this type of injury include microvascular damage in the area surrounding trauma, which later affects reconstruction and healing. The management of such injuries requires a holistic approach by a multidisciplinary team and is complicated by the need to rapidly transport the injured soldier from the battlefield back to the UK.

Phases of management

From the moment that a soldier is injured there are medical management protocols set in motion, the efficacy of which greatly determines the casualty's outcome and further management prospects. Military medical support is organised in four tiers: roles 1 to 4 (Medical support, 2007). Each level is supported and resupplied by the role above it with role 4 being the RCDM in the UK.

Before deployment, all military personnel are issued with and are trained in the use of field dressings, morphine and a one-handed application combat tourniquet. (MacDonald, 2010). By administering immediate self or buddy first-aid treatment in the field, blood loss may be minimised and the chance of survival is improved before treatment by a trained role 1 medic. There are roughly five trained medics to each platoon of approximately 30 soldiers on patrol. These medics constitute the role 1 facility and play a similar role to that of paramedics in the civilian world — providing battlefield life support (management of catastrophic bleeding, airway, breathing and circulation) (Hodgetts et al, 2007). Medical provision at forward operating bases (FOBs) is a role 2 facility, which provides both everyday and emergency care to patrols operating from the FOB. It also serves as a point of primary retrieval via helicopter by a medical emergency response team (MERT) to the role 3 facility field hospital at Camp Bastion. Here, consultant lead emergency, intensive care and surgical facilities employ methods of damage control, resuscitation and surgery. The aim is to restore physiological function (as opposed to anatomical function) (United States Department of Defense, 2004) and limit the lethal triad of coagulopathy, hypothermia and metabolic acidosis encountered as a result of prolonged operative time and persistent bleeding in multiply injured soldiers (Baer et al, 2009; MacDonald, 2010).

One of the key principles in optimising the survival of acutely injured soldiers is damage control resuscitation (DCR), which begins at role 2 facilities and is continued at the role 3 field hospital. Damage control surgery, an aspect of DCR, occurs at the role 3 facility in three distinct phases in order to maximise chances of survival:

- Primary operation and haemorrhage control
- Critical care
- Planned re-operation (United States Department of Defense, 2004a).

The principle of damage control surgery relies on further definitive management at the next level of care in the UK.

Challenges of wound management

Blood loss and fluid resuscitation

Despite advances in mechanisms of limiting blood loss, the catastrophic trauma encountered in soldiers who survive injury by ballistic or explosive weapons is devastating and requires early fluid resuscitation and blood transfusion to maximise chances of survival. The aim of administering fluid and blood components is to restore organ perfusion by increasing circulatory volume and consequently cardiac output and blood pressure.

However, a compromise must be reached between maintenance of organ perfusion and avoidance of re-bleeding by disrupted thrombus formation. This tradeoff is achieved through 'permissive hypotension' (Holcomb and Spinella, 2010), an aspect of DCR that is extremely effective in maintaining this balance.

Currently, 8–10% of military patients undergo massive transfusion (Doran et al, 2010), defined as more than 10 units of blood in 24 hours. Implications of this life-saving measure include immunological compromise, dilutional coagulopathy, acidosis and hypothermia. Hence the need for post-resuscitative intensive care in order to normalise the effects of aggressive resuscitation. In most medical settings, whole blood is rarely transfused in circumstances when fractionated blood components are readily available. However, while there is still uncertainty regarding the most effective resuscitative fluid for the combat casualty, whole blood has been postulated to be clinically superior to component therapy in trauma patients requiring massive transfusions (Holcomb and Spinella, 2010).

Analgesia

Pain control in both the pre-hospital and hospital settings is extremely important, as its physiological and psychological effects are closely tied to patient outcome. Pain activates the sympathetic nervous system resulting in the release of catecholamines into the circulation. Tachycardia, peripheral vasoconstriction and increased oxygen demand are but a few of the systemic effects of this cascade and, in the severely injured patient, aggravate the effects of hypovolaemia (Mackenzie, 2004). Furthermore, uncontrolled pain can induce a hypercoagulable state as a result of decreased fibrinolysis (Looker and Aldington, 2009). The effects of uncontrolled pain on the immune system result in immunological compromise which, compounded by gross contamination of wounds and massive blood transfusion, affects the prospects of wound healing (Middleton, 2003).

Beyond its physiological importance, pain greatly influences the casualty's cooperation with care. The nature and severity of wounding necessitates that pain is controlled throughout the care pathway, namely; efficient aeromedical evacuation, multiple injury assessments, surgical procedures and further rehabilitation. Furthermore, the circumstances of wounding carry a heavy psychological burden, which are inextricably linked with the physical pain of the incident.

There is a wide evidence basis to suggest that continuous peripheral nerve blockade is an effective method of pain management in patients with extremity injury (Connor et al, 2009; Hughes and Birt, 2009). It may be started soon after injury at the role 3 facility in Afghanistan and provide continued pain relief throughout numerous surgical procedures. Neurovascular assessment of the limb should be performed before nerve blockade.

Nutrition

Soldiers are typically fit and young, however, having spent weeks and months in extreme conditions without great access to high-caloric fresh produce and often with poor living conditions, their nutritional state is suboptimal. Having sustained and survived a traumatic injury, these soldiers rapidly become nutritionally deplete due to the hypercatabolic and hypermetabolic state that occurs in response to injury. Lean tissue proteins are mobilised in an effort to support accelerated protein synthesis and maintain an up-regulated immunological response required in the process of wound healing (Jacobs et al, 2009). It is therefore imperative that aggressive nutritional support is started early in the patient's care. There is a wide evidence basis to suggest that early enteral feeding started soon after the patient is haemodynamically stable is associated with better outcomes (Mochizuki et al, 1984).

Figure 1. Heavily contaminated limb secondary to blast injury.

The preferred route for provision of enteral nutrition at RCDM is via nasojejunal tube. This method is associated with fewer complications and sooner attainment of nutritional goals (Jacobs et al, 2009). It also results in fewer interruptions with ongoing surgical procedures when compared to nasogastric feeding.

Contamination and debridement

Wounds sustained in combat are heavily contaminated. The mechanism of explosion-related injury drives mud and dust deep into the tissue planes, which, if not removed, potentially contaminates un-injured healthy tissue. Fragmentation from the device itself and other debris such as clothing, plastic and even foreign human material are commonly found in military wounds (*Figure 1*), hence excision of debris and non-viable tissue from the wound is a key life and limb-saving measure.

In contrast to healthy muscle, dead muscle is dusky and unable to contract or bleed. However, the differentiation between non-viable and traumatised tissue is made difficult by the microvascular trauma that tissues in the vicinity of the wound will have sustained during the injury process (Sakorafas and Peros, 2008). Ideally, debridement of wounds should be performed by senior specialist surgeons and approached with the planning of later reconstruction in mind.

Initial debridement of military wounds occurs as part of damage control surgery and is therefore limited to removal of necrotic tissue and foreign contaminants. Early evacuation of debris is essential to avoid infection becoming established. However, potentially viable tissue is not excised initially in order to avoid enlarging the wound unnecessarily. At a definitive care facility, serial debridement performed over several days determines the extent of the zone of injury (Heller and Levin, 2001), and allows the patient to recover between procedures.

Figure 2. Strikethrough seen in conventional dressings.

Debridement by sharp excision with use of a tourniquet is recommended in extremity injures to minimise blood loss in an already compromised patient and to maintain a field where tissues may be easily visualised (Taylor et al, 2009). Application of a tourniquet may limit the surgeon's ability to differentiate between viable and non-viable tissue by inhibiting bleeding in viable tissue. However, this should not greatly affect the experienced surgeon's ability to accurately excise necrotic tissue. High-pressure irrigation has been shown to propagate bacteria into tissues, leading to higher rates of bacterial retention and infection (Hassinger et al, 2005). It is therefore not recommended for debridement of such injuries. The Versajet™ Hydrosurgery System (Smith and Nephew) is commonly used in the debridement of embedded foreign material from the surface of military wounds at the RCDM.

As a result of multiple contaminated soft-tissue and bone injuries, massive blood transfusion and fungal infection, soldiers are immunologically compromised. While early surgical debridement of contaminated war wounds forms the basis of infection prevention, prompt broad-spectrum antibiotic therapy is an essential adjunct and should be started as soon as possible after wounding (United States Deparment of Defense, 2004b). Once at a definitive care facility (RCDM), wounds are routinely swabbed, biopsied and cultured to tailor antibiotic provision based on microbial sensitivity.

Fungal infection is commonly seen in war wounds and must be considered in patients with prolonged pyrexial episodes. Antifungal treatment should be started in patients who are suspected of fungal wound infection while awaiting fungal analysis of tissue samples (United States Department of Defense, 2004b).

Dressings

After initial debridement, current practice at the role 3 facility in Afghanistan is to dress wounds with dry fluffed gauze and crepe bandages. This dressing remains in place while the soldier is transported via Aeromed to the UK. Wound exudate is absorbed by the gauze, which hardens to form an eschar. Removal of these dressings serves secondarily to debride the wound, however, due to the extensive nature of the injuries sustained by these soldiers and the overwhelming amount of exudate produced, these dressings often show 'strikethrough' on arrival in the UK (*Figure 2*). This poses a risk of infection to both the patient and the healthcare professionals involved in their care.

At the RCDM all postoperative dressings applied to the wound are topical negative pressure (TNP) dressings, employing the gauze based Chariker-Jeter system. TNP is heavily relied upon in the management of multiply wounded soldiers and

Figure 3. Topical negative pressure dressing enables functional splinting of the hand.

will soon replace conventional dressings used at the role 3 facility in Afghanistan. It enables the wound to be left open for a longer period of time, until conditions are optimal for reconstruction, yet without progression to a chronic wound (Schlatterer and Hirshorn, 2008). Application of negative pressure to the wound bed creates an optimal environment for wound healing through a variety of mechanisms (Preston, 2008; Jeffery, 2009; Fang et al, 2010). Extravascular fluid accumulation in injured tissues results in decreased end-capillary pressure and increased risk of further tissue necrosis. By actively draining exudate and inflammatory mediators from the wound bed, angiogenesis is promoted and tissue viability and granulation tissue formation is enhanced (Morykwas et al, 1997; Preston, 2008). The sealed, negative-pressure environment reduces the risk of further contamination and has also been shown to decrease bacterial load (Morykwas et al, 1997). Furthermore, the vacuum-induced rigidity of the dressing enables protection and splintage of the hand in upper limb injuries (*Figure 3*), making additional splints unnecessary.

Delayed primary closure and reconstruction

The benefits of delayed primary closure of war wounds were first realised in the 1700s by Scottish surgeon John Hunter (Gosselin, 2005). By delaying wound closure, swelling of the surrounding tissues is given time to subside, which avoids the development of ischaemia. Furthermore, exudation of serum is permitted and a closed anaerobic environment is avoided, making infection less likely (Gray, 1994).

Key factors that determine the timing of sub-acute definitive wound closure are the overall condition of the patient, bacterial status of the wound, stability of bony elements, and adequate coverage of vital structures (i.e. vessels, nerves and tendons) (Heller and Levin, 2001; Kumar et al, 2010). Before considering soft-tissue reconstruction the patient must be apyrexial — there should be no sign of wound infection and exudate should be minimal. The patient should be physiologically stable, in an optimal nutritional state and not be receiving inotropic support (Taylor and Jeffery, 2009).

Reconstruction of soft tissue wounds may be achieved with grafts, local tissue transfer or free tissue transfer (Tintle et al, 2010). In many cases the use of TNP enables complex soft-tissue injuries to be reconstructed with grafts, which are less complicated and require less operative time. In the absence of graft donor sites, skin substitutes may be used with the intention of revision at a later date. Careful consideration must be taken with the use of local tissue transfer, as the zone of injury often extends well beyond the area of trauma, particularly in blast injuries, and poor microvascular circulation will affect flap survival. Free tissue transfer from distant donor sites is safer, however the lack of donor sites in those with multiple injuries and the requirement for the patient to be systemically healthy make this method impractical in many cases.

Summary

Soldiers currently fighting in Afghanistan are sustaining multiple, highly contaminated injuries as a result of blast and ballistic weapons. The improved pre-hospital medical and surgical management of these casualties has resulted in astonishing rates of survival, yet a subsequent increase in wound severity. The management of such injuries requires a multidisciplinary approach throughout structured phases of care in order to achieve maximal recovery. Resuscitative measures and initial operative procedures to control haemorrhage and limit infection greatly influence future wound management and reconstructive outcomes. Attention to analgesia, nutritional and psychological state are essential in promoting optimal wound healing. The use of TNP has revolutionised surgical management of combat injuries by preparing the wound bed to enable uncomplicated sub-acute reconstruction. Further steps to improve wound care in injured soldiers will undoubtedly contribute to future advances in this field. **WUK**

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Key points

- Victims of explosive injuries on the battlefield present with heavily contaminated extremity trauma.
- Continuous peripheral nerve blockade is an effective method of pain management in patients with extremity injury.
- Before reconstruction, the patient should be physiologically stable, in an optimal nutritional state and not be on inotropic support.
- The use of TNP has revolutionised surgical management of combat injuries by preparing the wound bed to enable uncomplicated subacute reconstruction.