Improvised Explosive Devices: Pathophysiology, Injury Profiles and Current Medical Management

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Abstract

The Improvised Explosive Device (IED), in all its forms, has become the most significant threat to troops operating in Afghanistan and Iraq. These devices range from rudimentary home made explosives to sophisticated weapon systems containing high-grade explosives. Within this broad definition they may be classified as Roadside explosives and blast mines, Explosive Formed Pojectile (EFP) devices and Suicide bombings. Each of these groups cause injury through a number of different mechanisms and can result in vastly different injury profiles.

The "Global War on Terror" has meant that incidents which were previously exclusively seen in conflict areas, can occur anywhere, and clinicians who are involved in emergency trauma care may be required to manage casualties from similar terrorist attacks. An understanding of the types of devices and their pathophysiological effects is necessary to allow proper planning of mass casualty events and to allow appropriate management of the complex poly-trauma casualties they invariably cause. The aim of this review article is to firstly describe the physics and injury profile from these different devices and secondly to present the current clinical evidence that underpins their medical management.

Introduction

The Improvised Explosive Device (IED) has become synonymous with current conflicts in Iraq and Afghanistan, and has been the leading cause of death and injury amongst Coalition troops [1-5]. The US Department of Defence defines them as *"devices placed or fabricated in an improvised manner incorporating destructive, lethal, noxious, pyrotechnic or incendiary chemicals, designed to destroy, disfigure, distract or harass and often incorporate military stores…"*[6]. This broad definition encompasses a wide spectrum of devices ranging from rudimentary home-made explosives to sophisticated weapon systems containing high grade explosives. Within this generic definition, IEDs can be classified as roadside explosives and blast mines - usually formed from conventional military ordnance, Explosive Formed Projectiles (EFP) (Penetrator) devices and suicide bombings.

The physics and injury mechanism from roadside explosives and blast devices are covered in a separate article in this edition [7]. In this paper, we describe the pathophysiology, injury mechanisms and medical management of the most common IEDs currently in use in the operational theatres of Iraq and Afghanistan in order to inform clinicians who may be responsible for the care of such casualties.

Explosive Formed Penetrators

The use of the EFP has been widely reported in the international media [8, 9], and was a prominent feature of the military operation in Iraq. An EFP is a form of shaped charge weapon that uses an explosive charge to deform a metal plate into a penetrator (Figure 1) [10]. A typical EFP is comprised of a saucer shaped metallic liner (usually copper), a casing, an explosive element, and an initiation train.

Figure 1. A number of EFPs linked in a daisy chain configuration, uncovered in Iraq. (From: MOD archives with permission. Crown copyright)

Following detonation, the explosive products propel a high pressure wave [up to 30 million psi] along the axis of symmetry towards the liner. This high pressure wave then impacts the liner, causing it to collapse and distort on this central axis forming the EFP, as well as simultaneously accelerating it to velocities up to 6600 mph (Figure 2). On impact of the penetrator with the target, a significant amount of kinetic energy is dissipated, causing injury.

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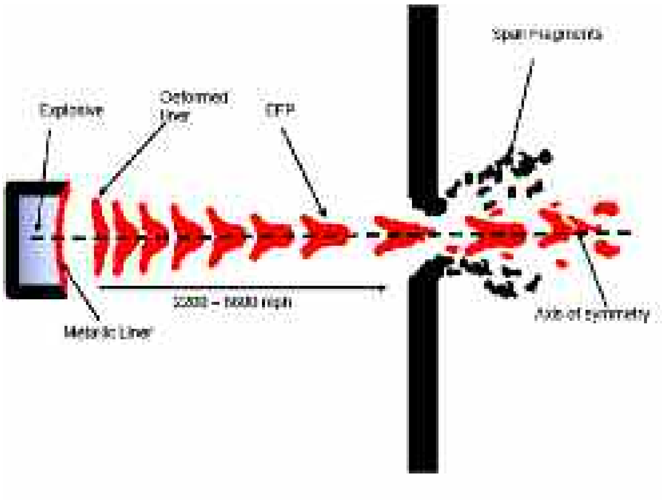

Figure 2. Illustration of the formation of an EFP following detonation.

In a review of 53 casualties from EFP-IED attacks in Iraq 2006, Ramasamy et al, found that injuries from EFPs followed an 'all or nothing' pattern; casualties either die from catastrophic poly-trauma resulting from direct impact, or sustain relatively minor injuries as result of the associated indirect energy dissipation [1]. All the fatalities in that series had a New Injury Severity Score (NISS) of 75, which suggests that regardless of evacuation time or availability of medical resources, these casualties would have succumbed to their injuries, whereas the survivors from the same incident had a median NISS of 4. Despite the close proximity of the vehicles to the explosion in this series, significant primary blast injuries were uncommon and only seen in 3.7% of casualties. This would suggest that the blast component of these devices is not a significant factor in the aetiology of injury. They concluded that casualties caught in the trajectory of the EFP suffered catastrophic injuries whereas those sitting adjacent to the projectiles path suffered relatively less severe injuries. The EFP-IED produces a more focused stream of fragments that cause injury to casualties caught in their path rather than the pattern of more dispersed fragmentation seen with conventional explosive devices. In addition, the types of injuries encountered were predominantly secondary blast injuries related to being hit by the large metallic EFP or large fragments of the EFP (Figure 3).

Suicide Bombings

Figure 3. A traumatic below-knee amputation following an EFP blast.

The goal of suicide bombings is to cause devastating physical and emotional damage. Suicide bombers, often indistinguishable from the civilian population, are able to mobilise the explosive through public spaces in order to cause indiscriminate injury which generates fear, chaos and can bring about a drastic change in everyday behaviour. Targets are usually chosen to amplify and dramatise the effects of the explosion and will include crowded restaurants, busy nightclubs, commuter trains, buses and crowded open public spaces. The modes of deployment can vary from explosive belts carried by a suicide bomber, to bomb-laden cars or pack-animals, to airplanes hijacked and flown into crowded buildings.

Over the years, the devices detonated have become more sophisticated. A review of suicide bombings in Israel has shown that the median number of fatalities per attack has risen from three throughout the 1980s, to nine in 2004 [11, 12]. The authors attributed this effect to the use of high-grade military explosives and the addition of large amount of shrapnel to intensify the effects of penetrating trauma (Figure 4). The activation of the device by the attacker has meant that the device can be detonated at the optimum opportunity to cause maximal injuries.

Figure 4. Multiple fragment wounds following a suicide attack at a festival in Southern Afghanistan [13]. This casualty was close to the bomber at detonation and several bone fragments from the bomber were removed during debridement. This picture was taken 5 days after the initial debridement, where the wounds clear of infection were closed by delayed primary suture.

In both Iraq and Afghanistan, these attacks have become increasingly frequent with a number of high profile attacks recently reported in Southern Afghanistan [13]. In an area where local health care facilities are already limited, these facilities are further degraded as the security situation deteriorates. Below a certain level of safety, it becomes too dangerous for most non-government organisations and international aid agencies to support host nation facilities. This healthcare vacuum has to be filled to some degree by the military medical facilities deployed to the region [14]. Consequently, military medical units should be prepared to experience a huge influx of casualties following a suicide bombing.

Aharonson-Daniel et al [15] analysed the patient and injury characteristics of 1155 people injured by suicide bomber explosions in Israel between 2000-2004. They found that 29.3% suicide bomber explosion victims suffered severe to critical injuries (ISS >16), compared to 10.1% of non-terror explosion victims. They were also more likely to be hypotensive on presentation (6.1% vs 2.6%), have decreased levels of consciousness (8.7% vs 2.4%), and have more than 3 body regions injured (18% vs 5%). They also found these casualties also suffered more internal injuries (32%), open wounds (59%), burns (17%) and nerve and vascular injuries (8% and 4% respectively) compared to non-suicide bombing victims. This translated to significantly more surgical interventions, intensive care requirements and in-patient mortality. The authors considered this to be related to the intentional addition of shrapnel to the explosive package.

The location of the explosion can have a significant effect on

both the severity and spectrum of injuries seen following a suicide attack. Leibovici compared the effects of explosions occurring in open spaces with enclosed spaces. He found that explosions in enclosed spaces were associated with a higher incidence of primary blast lung injury, increased injury severity, increased mortality and severity of burns compared to explosions in open air [16]. Kosashvili et al reported that explosions occurring in buses had the highest rates of overall mortality (21.2%), whilst those caught in enclosed space explosions (eg restaurants) suffered the highest number of severe injuries and required the largest number of surgical interventions; Open spaced explosions caused the largest number of casualties but with the smallest percentage of severe injuries or death [17]. The location of the explosion may also influence infections post-injury. Wolf et al, reported higher rates of candidaemia in casualties injured in an suicide attack in a market. Environmental analysis of the market showed high levels of Candida species and mould in the market and concluded that the candidaemia could be related to the blast facilitating the dispersal and transport of Candida in air, transforming it temporarily to an airborne pathogen [18].
These studies stress the importance of good communication between the incident scene and the receiving medical facility. A good appreciation of the circumstances surrounding the explosion will provide the medical teams invaluable information to allow them to predict the number, severity and spectrum of casualties they are likely to encounter and thereby plan resources appropriately.

Medical management of IED injuries

Initial Management

The principles of treatment for IED injuries remain the same as for any trauma, with the initial aim being to identify and treat any life-threatening injuries. This begins in the battlefield and is encompassed within the principles of "damage control resuscitation" (DCR) that has become part of modern military medical doctrine. It is a systematic approach to major trauma combining the <C> ABC (catastrophic bleeding, airway, breathing, circulation) paradigm with a series of clinical techniques from point of wounding to definitive treatment in order to minimise blood loss, maintain tissue oxygenation and optimise outcome [19-21]. These techniques range from the use of topical haemostatics [22] and tourniquets [23] in the field to an aggressive approach to coagulopathy, hypothermia and acidosis [21, 24] in the field hospital. Damage control surgery is a component of DCR and the timing and type of surgical procedure performed will be dictated by the physiological state of the patient.

Anatomical Pattern of Wounding

As with other fragmentation weapons, IEDs most commonly affect the extremities with upper and lower limbs affected equally [2, 25]. Studies from the UK and the US Joint Theatre Trauma Registries have shown that following explosion, over 70% of combat wounds are to the extremities, with head and neck injuries accounting for 20-25% of wounds with torso injuries seen in less than 10% of combat casualties [1, 3, 26-29]. This may be attributed to the effectiveness of the enhanced combat body armour, which consists of a Kevlar and Nylon woven vest combined with large ceramic plates that cover a large proportion of the torso.

Assessment in the Emergency Department

The clinical evaluation of the limb should involve;

- Addressing wound haemorrhage with direct pressure using a sterile dressing.
- A full neurovascular assessment of the injured limb. If necessary, Doppler ultrasound can be used to assess distal pulses. The location of the pulse should be marked for future examination.
- Assessment of skin and soft tissue damage. If possible photograph the wound, and then cover the wound with a sterile dressing.
- Following adequate analgesia, reduce the fracture if possible and place in a splint. If the fracture is manipulated in the emergency department, ensure that the neurovascular status is rechecked and documented in the medical notes.

The wound should not be irrigated, debrided or probed in the emergency room, if immediate operative intervention is planned. Doing so may further contaminate the tissues and only obvious foreign bodies that are easily accessible may be removed.

Antibiotic Prophylaxis

The prophylactic use of penicillin has been one of the enduring lessons learnt from WWII when sepsis was a major cause of mortality following battlefield injury. Benzyl penicillin has the advantage of being heat stable allowing early field administration as well as being effective against those organisms which are potentially life-threatening, namely Gram positive Clostridia species and anaerobic streptococci [30]. Animal studies by Mellor in 1996 showed that administration of intramuscular benzyl penicillin begun within 1 hour of wounding was effective in preventing streptococcal infections in a pig model of fragment wounds. When this administration was delayed until 6 hours after wounding, the antibiotic was ineffective [31]. Current BATLS guidelines state that antibiotics should be given as soon as possible after wounding and UK Military Surgery Guidelines recommend that for limb, soft tissue and muscle injuries 1.2gm benzylpenicillin should be given on admission and that cefuroxime and metronidazole should be given peri-operatively when a hollow viscus has been punctured [21]. It should be recognised that antibiotic administration is no substitute for early and appropriate surgery in preventing infection [32].

Recently, the US military have issued 400mg Moxifloxacin tablets as part of a combat pill-pack issued to every soldier and is to be administered immediately following wounding. Although the early administration of such a broad-spectrum antibiotic may appear appealing, there is some concern that pre-hospital administration of broad-spectrum antibiotics such as meropenem and gatifloxacin may have attributed to the appearance of significant multi-drug resistant *Acinetobacter baumannii* seen in US casualties [33, 34].

Debridement

The aim of debridement is to render the wound devoid of foreign material and of non-viable tissue, in order to leave a clean healthy bed for soft tissue reconstruction [35, 36]

Wound excision.

Skin is generally very resistant to trauma and has a good capacity to heal. Therefore the wound edges should be excised with care and only enough to leave healthy skin edges.

Wound extension.

The zone of soft tissue injury will often extend far beyond the wound, so the wound will need to be extended proximally and distally to enable full examination of the injured tissue.

Removal of non-viable tissue.

Devitalised tissue especially muscle will provide a focus for infection and needs to be excised. When assessing damaged tissue, look for the "4 C's": Colour - Dead muscle is often dark and discoloured. Consistency - Non-viable tissue has lost its material integrity and would therefore have a mushy consistency. Contractility - Dead muscle will not contract when crushed with forceps or touched with a diathermy probe. Capillary bleeding. Non-viable bone fragments (ie without significant soft tissue connection) should be removed.

Wound toilet.

An essential feature of wound debridement is copious wound irrigation. There are currently no definitive trials assessing the quantity or method of delivery to adequately remove contamination from a wound. Traditionally, 3L has been recommended for Gustillo Type I open fractures, 6L for Type II fractures and 12L for Type III fractures. In terms of method of delivery, although high pressure pulsatile lavage might appear superior for clearing bacteria from a wound, animal studies have indicated that pulsatile lavage might push bacteria deeper into wounds [37]. In addition, high pressure pulsed lavage has been shown to be associated with macroscopic bone and soft tissue damage [38].

The type of irrigation fluid used has also been a source of debate in recent years. Although there are no trials in combat wounds, a multi-centre, prospective, randomised trial undertaken at Level I trauma hospitals compared normal saline versus tap water for irrigation of lacerations. Of the 600 patients in the study the infection rate was 4% and 3.3% in the tap water and saline groups respectively [39]. In field conditions, where supplies of sterilised fluids are limited, the use of potable water as an irrigation agent is unlikely to increase the infection rate.

Other soft tissue structures.

Damaged nerves and tendons can often be left alone and can be repaired at the time of wound closure once the wound is free of infection. Nerve ends can be tagged to aid identification in future surgery; early nerve repair should be considered once the wound is free of contamination. Following initial debridement, the wounds should be lightly packed with a sterile dressing and covered with a bulky dressing to absorb any exudate. Currently, sterile gauze is the dressing of choice in the field hospital, although research is currently being undertaken at Dstl, Porton Down, to investigate the efficacy of different dressing regimens. The wounds should be left unchecked for 2-5 days, unless there are clear signs of infection. Wound closure should only be attempted once the wound is free from infection. This can be achieved in a number of ways from delayed primary closure to free flap reconstructions.

Management of small fragment injuries

While the conventional military approach to the management of penetrating war wounds is by exploration, debridement, excision of dead tissue, and delayed primary closure [40], experimental evidence and clinical experience suggests that selected low energy transfer small fragment wounds may be safely managed non operatively [41-43]. They are treated non-surgically by thorough wound scrub and then left to heal by secondary intention. Patients are then given a one-week course of oral Penicillin V 500 mg qds and Flucloxacillin 500mg qds. The wounds are usually less than 1 centimetre in length, never greater than 2 cm in length, limited to soft tissue, and not associated with a significant wound cavity (defined as inability to probe the wound with a single digit); they should not be grossly contaminated, with no signs of haematoma, underlying soft tissue disruption, comminution of bone or neuro-vascular injury.

Figure 5. A radiograph of the forearm of the same casualty Figure 4. The ball-bearing visible on the X-ray was packed around the explosive. Metallic fragments are frequently packed around the device to increase its effectiveness and have been a feature of several suicide attacks around the world.

The majority of fragments from modern anti-personnel munitions weigh only a few hundred milligrams. (Figure 5) These are initiated at high velocity (greater than 1000 m/s), but their low mass and irregular shape lead to a rapid reduction in velocity. Animal studies have shown that the energy transfer from these fragments to the soft tissues is 25 to 30 J and the soft tissue damage extends only a few millimetres from the entry wound margin. The amount of devitalized muscle amounts to only a few hundred milligrams within the wound track for up to 24 hours and to around a gram by 3 days, with frankly necrotic tissue in the tract. However, by 7 days, the tissue in the tract consists almost entirely of granulation, with little necrosis [44]. These findings are supported by data from the International Committee Red Cross (ICRC) war surgery hospital in Quetta, Pakistan, which showed that out of 866 low energy transfer wounds treated non-operatively there were only 2 instances of wound infection [42]. More recently, a study from the UK Field Hospital in Iraq has shown that over 80% of low energy transfer wounds could be safely treated non-operatively with no complications reported [3].

Compartment syndrome

Compartment syndrome is a limb-threatening condition observed when perfusion pressure falls below intracompartmental pressure in a closed anatomic space. Bleeding, oedema or inflammation may increase the pressure within one of the osteofascial compartments. This leads to decreased capillary flow, which results in ischaemia, oedema and further increase in the pressure of the compartment. A vicious cycle occurs that ultimately leads to the necrosis of the nerves and muscles within the compartment within 12 hours [45]. Once infarcted, the muscles are replaced by inelastic fibrous tissue (Volkmann's ischaemic contracture).

The classical diagnostic features of compartment syndrome are the 5P's; pain, paraesthesia, pallor, poikilothermia, and pulselessness. However most are late signs and are not apparent in ventilated or paralysed patients. One of the most important symptoms is pain out of proportion with the injury. Increasing pain or analgesic requirements despite adequate splintage is a warning sign that compartment syndrome is present. This can be confirmed with pain on passive stretching of the muscles in the suspected compartment. The presence of an open fracture does not infer that all the muscle compartments are adequately decompressed (Figure 6). Clinically, the compartment will feel tense. The use of compartment pressure testing maybe useful in ventilated patients and can also be useful in monitoring trends of compartment pressures [46]. Δp is a measure of perfusion pressure [diastolic pressure – intracompartment pressure]. McQueen found a correlation between a Δp less than 30 mm Hg and the development of compartment syndrome [47]. The management of compartment syndrome is dependent on early diagnosis. Full compartment fasciotomies of the affected limb segment are required and if performed within 6 hours of onset then almost full recovery of limb function can be expected [48].

The majority of current combat extremity injuries are from explosion. Explosions can cause fracture, tissue loss, and vascular injury, all of which place the extremities at risk of developing compartment syndrome. Additionally, in the combat environment, a number of factors may prevent prompt diagnosis of the condition; namely, multiple casualties from a single IED attack may reduce the opportunity for serial examinations, casualties suffering multiple distracting injuries, analgesics, sedation, oedema formation or delayed bleeding into compartments following adequate resuscitation, and application of constrictive splints.

In a study of complications after fasciotomy revision and delayed compartment release in US combat casualties, Ritenour et al found that out of 332 patients undergoing fasciotomies, 17% required a revision procedure. In the revised group, there were statistically higher rates of muscle excision (35% vs 9%) and mortality (20% vs 6%). Those casualties who received fasciotomies after evacuation had amputation rates twice those who had fasciotomies in theatre

(31% vs 15%). The most commonly unopened compartments were the anterior and deep posterior compartment of the lower leg [27]. The authors concluded that there was a need for increased vigilance for compartment syndrome in severely injured patients and they urged the early use of complete fasciotomies and prophylactic fasciotomies in high-risk patients. Due to the paucity of high energy trauma seen in the UK, fasciotomies are not commonly performed in standard NHS orthopaedic practice. In order to prepare operating teams adequately, fasciotomy technique is now taught to all deploying surgeons on the new Military Operational Surgical Training (MOST) course run by the Academic Department of Military Surgery and Trauma (ADMST).

Figure 6. Compartment syndrome of the foot, following an IED blast on a vehicle. This soldier presented with a grossly swollen foot and multiple closed foot fractures. He underwent full compartment fasciotomies of the foot within an hour of injury and the swollen, oedematous muscle compartments are clearly visible. (Photograph courtesy of Surg Cdr M Brinsden, RN).

Management of Skeletal Injury

Fixation of open fractures has a number of beneficial effects including protection against further damage of soft tissue, improved wound care, soft tissue healing and possibly reducing infection [49]. Operative stabilisation of open fractures is the only way thought to be required to eliminate movement and maybe considered to be the only treatment available [50]. Therefore, methods such as plaster are not considered suitable for stabilisation [51]. However, the use of thorough wound excision, together with traction or splintage of ballistic femoral fractures was shown to be an effective treatment over 90 years ago, and during the First World War in deployed forward hospitals, it helped to reduce the mortality of such injuries from 80% to 20% [52]. This method remains as valuable now as then and is used to good effect by UK Military Orthopaedic surgeons in Iraq and Afghanistan, and by the ICRC hospitals (29, 53-55).

In the developed world, innovation and new technology continue to advance medical care but these treatments may not always be appropriate in the military environment, as they often require specialist resources in the post-operative period. With the majority of casualties treated in the current conflict in Afghanistan being local civilians, it is therefore vital that the clinical care provided is appropriate to the technology and clinical care available locally. [56]. Traction and plaster immobilisation is entirely suitable for the treatment of local civilians as this can be carried on in local facilities. This is equally true in military personnel, since nothing should be done in theatre that may compromise future surgical management in the UK.

The use of external fixators in combat fracture management has been a source of considerable debate over the years. Bradford first reported its use on ballistic fractures in US military hospitals during WW2 [57]. They felt its use was indicated in patients with multiple injuries, infected fractures, or to prevent complications during evacuation. However, in a post war report, Cleveland stated that *"its use was associated with a high percentage of both infection and delayed union ... the method was therefore forbidden and removed from the hospitals...'*[58]. More recently, based upon an analysis of the conflict in Somalia, external fixation became the preferred stabilization method for US forces [59]. The advantages of external fixation include facilitation of transportation of wounded patients with fractured extremities, allowing access to soft tissue wounds and thereby enabling effective wound care, and rapid stabilisation of the skeletal system to permit revascularisation procedures. In addition, temporary external fixation may provide systemic benefits similar to those reported in multiply injured civilian patients undergoing "damage control orthopaedics" [60, 61].
However, their use in ballistic trauma is not without complications. Clasper and Phillips prospectively followed up 15 external fixators applied in the management of war injuries during the 2003 Gulf conflict. They found that 13 (86.7%) required early revision or removal due to complications of the injury or the fixator; 67% had instability of the fixator, 20% developed pin site infections refractory to intravenous antibiotics, and 33% developed pin loosening. They concluded that external fixators were associated with a high early complication rate and cautioned against its universal application in war injuries and recommended that if used, multiple pins and bars be utilised to improve the rigidity of the fixator construct and that bridging configurations should be avoided [62]. The indications for the use of external fixation in combat injuries are given in Box 1 [63].

- Unstable fractures, due to severe communition or bone loss where plaster will not maintain adequate stability.
- Severe soft tissue injury, where microvascular anastomosis may be required such as for free tissue transfer.
- Fractures with associated vascular injury, where vascular repair is required.
- Multiple injuries.
- Patients requiring evacuation.

Box 1 The common indications for external fixation in military ballistic trauma

Traditionally there has been no place for internal fixation (intramedullary nails or plate fixation) in the acute management of war injuries, due to the related high risk of infection and complications. The high infection rate after primary intramedullary nailing has been confirmed in animal models [64, 65] and in civilian studies on the management of open fractures when dirty water or agricultural contaminants are present [66].

Amputations

The treatment of severe, leg-threatening injuries often necessitates an immediate or early decision between limb reconstruction and amputation. This initial decision requires a prediction of treatment outcomes on the basis of patient and injury characteristics. Factors that may mitigate towards amputation are in Box 2.

- Irreparable vascular injury,
- Warm ischaemia greater than 8 hours
- Severe crush with minimal remaining viable tissue.
- A severely damaged limb which may constitute a threat to the patient's life.
- Even after revascularization the limb remains so severely damaged that function will be less satisfactory than that afforded by a prosthesis.

Box 2. The factors that suggest that limb amputation may be a reasonable option.

A number of scoring systems have been developed to aid the surgeon in making the difficult decision to amputate. The most commonly used is the Mangled Extremity Severity Score (MESS) [67], where a score of greater than 7 predicts amputation. However the sensitivity of these scoring systems was only 63%. This was confirmed in a study by Brown et al [68], who reviewed 77 UK combat casualties with lower extremity fractures and found that the MESS did not help to decide whether or not an amputation was appropriate. Component analysis of the data did reveal that prolonged hypotension and the presence of an ischaemic limb appeared to be the main indicators for amputation.

The decision to amputate should be made by the most senior surgeon available and ideally should be made by two surgeons and documented clearly in the medical notes. It has previously been thought that the presence of an insensate foot at the time of injury was an indication for amputation. However evidence from the LEAP (lower extremity assessment project) study, has shown that plantar sensation can return and therefore should not be used as a determining factor for amputation [69]. The huge psychological cost of such injuries cannot be underestimated and often patients are unwilling to undergo primary amputation following injury. In these cases, where the patient's physiological state is favourable, initial salvage may be attempted, with amputation occurring at a later stage. The Lower Limb Trauma Working Group within the Academic Department of Military Surgery and Trauma have laid down guidelines on amputations in the field hospital and they are summarised in Table 1 [70].

Pre-Operative	Operative Technique
The examination findings, together with the indications to amputate the limb should be documented	The site of the amputation should be the lowest level possible.
Existing limb salvage scores should not be used.	Guillotine amputations should not be performed.
Where possible, the decision to amputate should be confirmed with a second surgeon.	No fashioning of flaps at initial debridement.
All wounds to be photographed. Radiographs should be obtained prior to amputation.	Bone should be cut at the most distal soft tissue level.
Neurological dysfunction should not be part of the limb salvage algorithm.	Amputation should not be carried out at the level of any fracture unless this is the appropriate skin/soft tissue level.
	No part of the wound to be closed at initial surgery.
	No attempt to be made to prevent skin retraction.
	Through-knee amputation is acceptable if appropriate.

Table 1. Guidelines for Amputations in the Field Hospital Setting [adapted with permission].

Immunisation

The explosive forces that disperse nails and other metal objects embedded in explosive devices may also disperse fragments from the body of the bomber to which the device is attached. Bone, because of its light weight and mechanical properties, makes a highly effective projectile, hence its use in the arrowheads and spearheads of primitive cultures. In a study of casualties from the London July 7th suicide bombings, Wong et al, reported 5 cases of foreign bone implantation in patients treated at the Royal London Hospital [71].This biologic material can not only cause physical injury to bystanders but may also represent a source of severe infectious disease. Braverman et al, reported a case of the removal of a penetrating bone fragment which contained tissue positive for hepatitis B surface antigen [72]. In a review of 12 terrorist suicide attacks in Israel, the bone fragments of 3 suicide bombers were analysed for hepatitis B, C and HIV. Of the 3 tested, 2 were positive for hepatitis B [73].

To combat the possibility of cross infection from implanted foreign tissue, patients treated at the Royal London Hospital following the 7th July 2005 bombings in London were vaccinated against hepatitis B in accordance with recommendations from the Health Protection Agency (HPA) [74]. Table 2 outlines the US Centre for Disease Control guidelines on prophylactic vaccinations following terrorist bombings [75].

Pre-Operative	Hepatitis B	Hepatitis C	HIV	Tetanus
Category 1. Penetrating or non-intact skin exposures.	Intervene	Consider testing	Generally no action	Intervene
Category 2. Mucous membrane exposures.	Intervene	Generally no action	Generally no action	No action
Category 3. Superficial exposure of intact skin.	No action	No action	No action	No action

Table 2. Recommended post-exposure management by risk category and specific pathogen. From: Recommendation for Post-exposure interventions in persons wounded during bombings and mass-casualty events, CDC, 2008 [75].

Conclusions

The IED, in all its forms, has become the most significant threat to troops operating in Afghanistan and Iraq. Its' ability to wound indiscriminately, has meant that the vast majority of its victims are likely to be civilians. The number, severity and spectrum of injuries they cause are closely related to the type and location of the IED employed. An understanding of the types of devices and their pathophysiological effects is necessary to allow proper planning of mass casualty events and to allow appropriate management of the complex poly-trauma casualties they invariably cause.

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