

Blast and Ballistic Injury: Principles of Management

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Foreword

Prof Tim Briggs, BOA President, and Kate Brown

The 14th century heralded the advent of gunpowder and a change from purely penetrating wounds to ballistic injuries. Since then, military surgery has taught us much about the management of blast and ballistic wounding patterns. Early examples include Ambroise Pare’s treatment of open fractures with reduction and stabilisation at the Battle of Turin, the formalisation of debridement by Desault and the introduction of true Damage Control Surgery by Baron Jean Larrey during the Napoleonic Wars. More recently, the development of antisepsis with Lister’s carbolic acid and Sir Alexander Fleming’s discovery of penicillin came from the First and Second World Wars respectively. We continue to revisit the surgical lessons learnt from our military history and never has that been so pertinent than during the recent conflicts in the Middle East. The tempo of war has now changed from the traditional format of enemy lines to a more blurred, almost guerilla-style fighting. Military personnel undergo attacks not only from traditional ballistic weapons but also from Improvised Explosive Devices (IEDs). The injuries that result from these weapons are devastating, causing significant polytrauma in multiple casualties. Research from the operational theatre has served to assess and understand how the surgical management principles taught are borne out in practice and what is their clinical effectiveness.

Professor Jon Clasper’s expert opinion on the management of blast and ballistic injuries outlines the most current guidelines, drawing together contemporaneous evidence coupled with personal clinical and academic experience in the field. He describes the principles of wound management, in particular how to assess for viability. There is continuing argument as to how aggressive this should be which can be confusing for the more inexperienced surgeon. He outlines which antimicrobials should be used, and describes why gram-negative therapy is often not indicated. How to assess, bind and debride pelvic injuries is described and what the common pitfalls are including mal-placement of the binder and where to inspect for contaminating debris. How fasciotomies should be performed is delineated and when they should be performed. Finally, the topic of amputations is reviewed. This is a highly sensitive issue with significant implications. Whether or not they can be objectively scored is examined and the method by which the amputations should be performed.

These principles are just as relevant in civilian practice as in the theatre of war. Although more prevalent in the United States, gun crime is still a significant contributor to all-cause trauma in the United Kingdom. With the advent of Major Trauma Centres, the majority of these patients will be managed in hospitals with experience in such injuries. However, this will not always be the case and smaller more peripheral hospitals will need guidance. Blast weapons have been used on numerous occasions, most notably recently in the tube bombings July 2005 and the Boston marathon bomb April 2013. Even large MTCs are less experienced in such wounding mechanisms.

About the Author

Prof Jon Clasper MBA DPhil DM FRCSEd(Orth) FRCS FHEA

Professor Clasper qualified from Glasgow University in 1986 and completed his basic surgical training in the Armed Forces. His higher surgical training included a year at the Major Trauma Centre in Baltimore, USA, as well as 3 years at Oxford. His clinical post is as Consultant Trauma and Orthopaedic Surgeon at Frimley Park NHS Foundation Trust.

As Defence Professor in Trauma and Orthopaedics, he is responsible for the orthopaedic research focus of the British military. This is a joint post between the military and the Royal College of Surgeons of Edinburgh, and was established in June 2009 to complement the Defence Professor of Surgery within the Academic Department of Military Surgery and Trauma.

Jon was one of the founding members of Imperial Blast, a multidisciplinary group of clinicians, scientists and engineers collaborating to study the effects of high strain rates on biological structures. Following significant funding, this initiative has now developed into the Royal British Legion Centre for Blast Injury Studies at Imperial College.

Jon is the author of a number of book chapters, and of specific papers on trauma and upper limb surgery. He has gained doctorates in both Medicine and Philosophy.

In 2010 Jon was appointed as a Visiting Professor in Bioengineering at Imperial College London.

Jon has deployed on many operational tours including Northern Ireland, Sierra Leone, Bosnia and Kosovo. He served in both Gulf Wars, and has deployed to Afghanistan 3 times.

His clinical and academic experience in both military and civilian settings pertain him to be an authority on the management of blast and ballistic injuries.

Introduction

The aim of this short guide is to outline the principles in the management of blast and ballistic injuries. Whilst once the domain of the military, with the global rise in terrorism, particularly suicide bombers, it is likely that more civilian surgeons will be exposed to these wounds. Although the principles in the management of these injuries are similar to the management of civilian open fractures, some of the injuries, particularly the blast pelvis or traumatic amputations will be alien to most people. In addition the technique of amputations for trauma will not be familiar to most orthopaedic surgeons.

Management of the Ballistic Wound

The principles of wound care are similar to civilian trauma, although some techniques do differ. Antibiotics, although an important factor, are secondary to early surgery and should not be considered as an alternative form of treatment. Neurovascular and radiological assessment should be undertaken prior to debridement when possible.

Debridement

General Principles

Clothing and gross debris should be removed.

Pre-operative washing of the limb with copious volumes of warmed soap/detergent solution is essential to remove skin contamination and fully identify all injuries.

Where practical all wounds should be photographed prior to debridement. Photographs allow further wound management to be planned. Pre-operative photographs are also an invaluable tool for demonstrating the rationale for amputation to casualties post-operatively.

The wound should be debrided by each layer around the full circumference of the wound in a methodical manner. Macroscopically non-viable tissue should be excised.

Initial wound debridement should be achieved through sharp dissection using scissors or scalpel. While the use of diathermy to control bleeding is acceptable its use to excise muscle and to assess contractility is not recommended as it leaves points of dead burnt muscle which may predispose to infection.

The use of a pneumatic tourniquet will limit blood loss during debridement and improve visualisation of the operative field, however, it may compromise the assessment of muscle viability and add further ischaemic stress to already damaged but viable tissue.

In the case of amputations formal flaps should not be fashioned at the initial debridement as this may involve the sacrifice of viable muscle, which may be required for reconstruction but all viable skin in continuity should be preserved. (1) (See also Amputations Section).

Technique

Skin

At the initial debridement it is likely that the wound edges will be traumatised. However, skin is resilient and debridement should be restricted to obviously non-viable tissue. When debridement of skin is performed there is no requirement to excise to bleeding dermis as skin perfusion may be altered by hypotension, and by transient vasoconstriction which can be associated with ballistic injury. Similarly small flecks of embedded contamination are not an indication for excision.

Extension of traumatic wounds may be necessary to allow access to the underlying zone of injury. Wound extensions should facilitate fasciotomy and any subsequent procedures. Skin incisions should be in the

long axis of limbs except where they cross the flexor surfaces of joints where they should be placed obliquely to reduce the risk of scar contractures.

Fat/fascia

Debridement of fat and fascia should be limited to macroscopically damaged tissue to avoid undermining skin, which is reliant on its attachment to fat and fascia for its blood supply. Injudicious debridement of this layer may compromise the use of fascio-cutaneous flaps during reconstruction.

Fasciotomies of muscle compartments are required to expose the underlying zone of injury, to treat actual or impending compartment syndrome and to reduce the risk of occult compartment syndrome occurring during evacuation or where prolonged sedation is anticipated. Where performed, fasciotomies should be along the full length of the muscle compartment (see fasciotomy section).

Muscle

The 4 C's of colour, contractility, consistency and capillary bleeding may not be reliable indicators of microscopic muscle damage. Altered consistency correlates moderately well with microscopic muscle damage but colour variation, contractility and capillary bleeding correlate more weakly (2). In the absence of other criteria they should be used together to judge how much macroscopically damaged muscle should be excised. In situations where serial marginal debridement is to be carried out it is suggested that muscle which is traumatised but not clearly non-viable is left for subsequent reassessment.

Blood vessels/Nerves and Tendons

Traumatised nerves, tendons and blood vessels should be clearly documented in the operation note.

Primary vascular reconstruction may be necessary in some proximal limb wounds with associated vascular trauma. However, reconstruction of divided nerves and tendons should not be undertaken at the initial debridement.

Divided blood vessels should be ligated unless reconstruction is required. Divided nerves and tendons can be tagged/marked with sutures, however this should not add to the existing damage to the structure.

In the absence of clinical signs of vascular injury it is not necessary to identify major blood vessels beyond the zone of injury at the time of initial debridement.

Bone

Exposed cancellous bone should be curetted and contaminated cortical bone trimmed with bone nibblers. Periosteum should be preserved where possible. Bone in continuity should be preserved even where stripped of all periosteum and soft tissue.

Bone fragments with soft tissue attachments which are absent or very tenuous should usually be discarded.

Prior to irrigation of the wound a final circumferential check of the debrided wound to confirm adequacy and check for haemostasis should be performed.

Irrigation

Fluid constituents

Wounds should be irrigated with warmed sterile saline where available. Where resources are limited warmed drinking water is an adequate alternative (3,4). Antiseptic, antibiotic and soap solutions are associated with higher rebound bacterial counts at 48 hours (5) and should be avoided. In addition antiseptic solutions are associated with cytotoxicity (6,7) and reduced microvascular blood flow (8), and antibiotic solutions are associated with wound healing problems without a reduction in the rate of positive wound cultures (9,10).

Fluid Delivery

Irrigation should be via low-pressure systems such as syringe, giving-set or cutting the corner off a bag of fluid. High-pressure pulsatile lavage systems are associated with damage to cortical bone (11), periosteal stripping (12), muscle damage and propagation of bacteria into tissues (13). Even low-pressure pulsatile lavage strips periosteum (12) and demonstrates a higher rebound bacterial count at 48 hours (5).

Fluid Volumes

Suitable volumes for irrigation of wounds are 9L for massive energy wounds such as those caused by close proximity blast/explosions, 6L for high-energy ballistic wounds and 3L for lower energy narrow channel ballistic wounds (14) or superficial soft tissue wounds.

Dressings

At present there is no evidence that any specific dressings are associated with any reduction in extremity war wound infection rates.

Negative pressure wound therapy (NPWT) is being commonly used on military casualties in Birmingham. This technique appears effective, but evidence is limited at present.

Interval to reassessment/closure

Ballistic wounds caused by penetrating projectiles should be reassessed, usually with a plan to achieve wound closure at around 5 days. There is no requirement for an earlier reassessment or dressing change if the debridement is considered complete and the casualty remains well and apyrexial.

If tissue of doubtful viability was left at the initial debridement the casualty should be returned to the operating theatre at around 48 hours for assessment of viability, further debridement if necessary and application of new dressings.

Close proximity blast/explosion wounds

These devastating injuries represent a new challenge; in previous conflicts many casualties did not survive long enough to reach hospital.

The debridement of these wounds is extremely challenging. It is unlikely to be achieved in a single surgical episode due to the physiological frailty of the casualty as well as the complex and contaminated nature of the wound. Debridement may initially be limited to removal of grossly dead tissue rather than the layer-

by-layer procedure described above but each opportunity to reduce the burden of wound contamination should be taken. This can be a concurrent activity during life-saving damage control surgery.

A philosophy of serial marginal debridement should be adopted (15). This describes the process by which, at each visit to the operating theatre, the traumatised tissue within the extensive zone of injury is reassessed and debrided or left as appropriate. At each procedure it may be possible to carry the debridement deeper into the track of the most complex wounds and remove devitalised tissue where appropriate.

Low energy soft tissue wounds

While every wound must be explored, not all need the full surgical debridement described above.

Narrow channel soft tissue wounds

A low energy narrow channel wound is characterised by entry and exit wounds of less than 1cm, no wound cavity, no swelling of intervening tissue and no other signs of injury to important structures. In this situation it is sufficient to excise the entrance and exit wounds and irrigate the connecting channel.

Superficial soft tissue wounds

Small superficial wounds that do not penetrate the deep fascia do not require any formal surgical intervention. The wounds should be scrubbed, irrigated with normal saline and left to heal by secondary intention. The casualty should be given oral antibiotics and dressings should be changed every 48 hours.

Antimicrobials

Although responsible for decreasing the infection burden of combat injury, the widespread use of antimicrobial agents has also created the latest challenge in wound care: multi-drug resistant bacteria. Antimicrobial agents are merely an adjunct to wound care, to be chosen and administered only after due consideration. This notion of selecting therapy to target agents posing the greatest threat to those recently injured has been discussed by Hutley and Green (16).

- Intravenous antibiotics should be commenced within three hours of injury with as narrow a spectrum as wounding pattern allows.
- Routine Gram-negative cover for all wounds is discouraged.
- Recommendations for agent of choice and duration of cover differ, however regardless of choice, duration should be short (48-72 hrs) following initial procedure with a subsequent short course to cover wound closure at which point antibiotics are stopped.
- Co-amoxiclav is appropriate for extremity wounding, and visceral injury
- Any further antibiotic therapy should be guided by clinical and microbiology assessment. Tetanus immunisation status should be addressed.

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Pelvic Injuries Following Explosions

Improvised explosive devices (IEDs) have become the weapon of choice in Afghanistan, and were responsible for 60% of coalition forces' fatalities in 2009 and 2010. This period has also seen the emergence of one of the most challenging injury patterns seen in trauma (1), the unstable pelvic fracture, with severe perineal trauma, and associated severe limb injuries often with traumatic amputations.

The increased survival in the current conflict in Afghanistan has been well documented, and this is related to an integrated systematic approach to military trauma, from improved training and pre-hospital care to after-event clinical governance review (2). This, together with improved personal protection (body armour) has resulted in early survivors with injuries that were universally fatal in previous conflicts. These casualties bleed to death, rapidly, and the initial treatment is therefore focused on controlling catastrophic haemorrhage (3). This applies particularly to the management of traumatic amputations, but is challenging when the injuries are very proximal.

Pre-hospital Care

If available, and if enough limb remains, a tourniquet should be immediately applied proximal to the injury.

If this is not effective or possible, direct pressure at the site of bleeding is effective, but can be difficult to maintain, particularly when casualties have to be moved. The military and some ambulance services carry topical haemostatic agents, which should be considered.

All casualties with severe limb injuries, particularly traumatic amputations, are assumed to have pelvic fractures, and a pelvic binder should be applied. Care must be taken to position the binder correctly, even if wounds are present. Binders that are too high do not effectively close the pelvis (4).

Resuscitation requires vascular access. Peripheral venous access is frequently impossible particularly if all 4 limbs have been injured. Intraosseous devices such as the EZIO[®] (Vidacare[®], Shavano Park, Texas, USA) and FAST-1[™] (PyngMedical, Richmond, BC, Canada) are used by the UK military. The EZIO[®] is usually inserted into the proximal tibia or iliac crest, but when the patient has sustained traumatic lower extremity amputations, or iliac placement is contraindicated by the presence of pelvic injuries, the humeral head is an alternative site.

Hospital Phase

The hospital reception and initial assessment of casualties with proximal traumatic extremity amputations requires communication, preparation, organisation and leadership.

Key preparations include the immediate availability of an operating theatre and operating room staff, and notification of the blood transfusion laboratory. Delay will kill these casualties; it must be minimised.

The anteroposterior pelvic radiograph is the key investigation in identifying the unstable pelvic ring, even with the binder in place. If there is radiological evidence of a pelvic fracture, and the patient is responding to resuscitation, CT scanning should be performed prior to removal or loosening of the binder.

Non-responders, or transient responders require proximal surgical control, and should be taken immediately to the operating theatre. If delays are likely operating in the Emergency Department should be considered.

If a clear need for operative proximal vascular control is identified prior to the arrival of the patient, the trauma team is relocated to the operating theatre, and the casualty taken straight there, bypassing the ED.

Whilst some of this may seem aggressive, this approach has been adopted by the military, with demonstrable success. Patients with severe pelvic injuries who have arrived at hospital undergoing cardio-pulmonary resuscitation, have left hospital alive.

Resuscitation

Techniques are discussed in detail elsewhere (5).

Surgical Strategy

The initial surgical management is focused on gaining control of haemorrhage. The proximal extension of the zone of injury is usually worse than external appearances suggest.

Amputation below mid-thigh level can usually be managed with a combination of tourniquet and, if necessary, surgical control at common femoral artery level.

If the injury is more proximal but unilateral, an extraperitoneal approach with control at external iliac level should be considered.

With bilateral and more proximal injuries, immediate laparotomy and control at the level of the distal aorta or iliac system can be achieved more rapidly, and limits blood loss from both the amputation sites and pelvic injuries.

Laparotomy can be performed with a pelvic binder still applied, and following proximal control of bleeding, conversion to an external fixator, if indicated, should be performed at this stage.

Debridement of bilateral lower extremity wounds should ideally be performed by two teams working concurrently, to minimise ischaemic injury and on-table time. Contaminating debris is frequently found forced into intermuscular planes and around neurovascular bundles.

Proximal vascular control is maintained until debridement is complete rather than released immediately after femoral vessel ligation, as additional blood loss may worsen any coagulopathy.

Many patients with high traumatic amputations caused by IEDs also sustain extensive perineal injuries, which can present complex management dilemmas. Faecal diversion should be considered, but is the subject of some debate. Vascularised testicular remnants should be preserved. Scrotal and penile injuries are debrided and, where possible, closed. Urethral injuries are treated with urethral and/or suprapubic catheterisation.

Contamination often extends through the sacro-iliac joint into the paraspinal muscles, it is usually impossible to debride this at the first operation due to the severity of the injuries in an unstable casualty. Whilst not ideal this has to be accepted as part of the damage control nature of the surgery.

Wounds should be inspected every 48 hours and debrided as necessary.

For patients with associated upper limb injuries, the policy in military casualties evacuated to Birmingham is to try and optimise the upper limbs by early internal fixation as appropriate before re-debriding the pelvis. Functional recovery should be optimised, rather than delaying upper limb reconstruction by constantly destabilising the patient attempting to clear the pelvic contamination first.

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Compartment syndrome and Fasciotomy

Introduction

Acute Compartment Syndrome (ACS) is more common with ballistic and blast injury.

The diagnosis is clinical, although pressure monitoring can be used if the condition is anticipated or suspected and accurate clinical examination is not possible, such as with a head injured patient (1). As pressure monitoring has not been shown to be more accurate than clinical monitoring (2), it is not indicated in a conscious patient if regular assessment is possible.

Regular re-assessment is required as there may be a delay in presentation, with a recent paper reporting a mean delay between injury and fasciotomy of 22 hours even in monitored patients (3). Even though the development of ACS may be delayed, once the diagnosis has been made, fasciotomy must not be delayed. It has been reported that a delay in treatment is associated with an adverse outcome and an increase in complications such as amputation and even death (4).

General Principles

Fasciotomy can be associated with a high rate of complications (5), and in many cases this is due to technique rather than the underlying injury.

Unfortunately most of the following guidelines below have had to be relearned in recent conflicts. They represent what we believe to be current best practice. They are meant to guide, particularly for the relatively inexperienced, and should not be regarded as superior to any other published guides:

- **Following diagnosis, fasciotomy should be carried out as soon as practical** due to the increase in complications with delay (4).
- **All compartments should be decompressed.** In the lower leg failure to decompress the deep posterior is relatively common and missed compartment syndrome is associated with a high complication rate (5).
- **Full length incisions must be performed.** A common error is the incision is too short; usually the decompression appears adequate but post-operative muscle swelling leads to ACS recurrence due to the tourniquet effect of tight skin and fascia at the extremes of the incision.
- **Incisions should be placed with regard to later reconstructive options.** If the medial incision to decompress the lower leg (see below) is placed too posteriorly the perforating vessels may be damaged, limiting the options for local flaps.
- **All planned incisions must be pre-marked, including possible surgical extensions prior to any incision being made.** It should be noted that significant swelling may obscure the normal anatomical features.
- **In most circumstances any associated fracture should be reduced and stabilised.** Most fasciotomies are carried out through a longitudinal skin incision. If the incision is performed in the presence of an unstable displaced fracture, particularly with rotational abnormalities, the final incision, after reduction of the fracture may expose bone, or again compromise reconstructive options.
- **Un-necessary exposure of the bone by the fasciotomy incision must be avoided** as this will also compromise reconstructive options, possibly necessitating flap rather than split skin graft coverage.

If the medial incision to decompress the lower leg (see below) is placed too anteriorly, the subcutaneous surface of the tibia may be exposed. The upper tibia may also be exposed due to failure to appreciate the flare of the proximal tibia.

Anatomical Locations

Upper arm

This has 2 compartments; the flexor containing the biceps and related muscles, and extensor containing the triceps. Both can be decompressed by a single longitudinal incision, which may be possible through an open wound.

If exposure of the vessels is also required, the incision can be placed medially.

A lateral longitudinal incision can be used to avoid exposing the artery, but if external fixation is also required, closure of a lateral wound may be compromised.

Forearm

The forearm has superficial and deep flexor compartments and an extensor compartment, and release can be performed through a single curved volar incision, and several incisions have been recommended (6,7).

However, for the inexperienced, it is advisable to carry this out through 2 separate incisions to avoid inadequate release and compromising potential wound closure options.

The following method is suggested:

- Identify both epicondyles and identify the midpoint of a line joining the 2. Mark a 2nd point midway between the 1st point and the medial epicondyle. In other words this is a point $\frac{1}{4}$ of the way along a line from the medial to lateral epicondyles.
- At the proximal wrist crease mark a point in line with the ulnar border of the ring finger.
- A straight incision should be made joining these points.
- This incision will not allow adequate access to the lateral muscles, and to decompress these, a separate incision is made. For this a straight, longitudinal incision is made along a line joining the lateral epicondyle of the humerus with the radial styloid. An incision along the proximal $\frac{1}{3}$ to $\frac{1}{2}$ of this line is made.
- If extension into the palm is required to release the carpal tunnel, a short transverse incision is made in the proximal wrist crease to a point marked in line with the radial side of the ring finger.
- The incision is then extended longitudinally into the palm. To avoid contractures transverse or oblique incisions should always be used when the flexor surface of a joint is crossed.

Hand

The compartments of the hand contain the small muscles that provide fine motor control of the digits. Missed or untreated compartment syndrome of the hand can be devastating for hand function, with only very limited reconstruction options being possible. Unlike with the foot, there is no debate amongst hand surgeons of the need to decompress the hand.

The compartments that require release are:

1. The thenar eminence
2. The hypothenar eminence
3. The interossei and lumbricals
4. The adductor pollicis

The thenar and hypothenar eminences are released via longitudinal incisions along their radial and ulnar borders, respectively. Up to 50% of patients may have separate compartments within the thenar eminence and this should be reviewed by direct inspection.

The interossei are approached via 2 longitudinal incisions on the dorsum of the hand, the first over the 2nd metacarpal and the second over the 4th metacarpal. The incisions are deepened either side of the metacarpals and care should be taken to leave the paratenon of the extensor tendons undisturbed. This allows release of not only the interossei but also, via the radial extension of the first incision, the adductor pollicis muscle that is deep to the 1st dorsal interosseus.

Thigh

The thigh contains 3 compartments, flexor, extensor and a medial adductor compartment. In most situations release of the anterior and posterior compartments through a single lateral incision may be sufficient, but penetrating injuries to the thigh may require release of the medial compartment particularly when associated with a vascular injury. This will require a separate (medial) incision.

Lower leg

There are 4 compartments; anterior and lateral, and superficial and deep posterior compartments. Failure to release the deep posterior compartment is the most common error in lower limb fasciotomy, and occurs when releasing the soleus muscle from the posterior aspect of the tibia is mistaken for releasing the compartment. The posterior tibial artery is located between the 2 posterior compartments, and this can be used as a landmark during surgery. A 2 incision technique should be used in the lower limb, decompressing the posterior compartments through a single medial skin incision approximately 1-1.5 cm (1 finger breadth) posterior to the medial border of the tibia. Incisions too anterior will leave exposed bone, and incisions too posterior may damage the perforators and compromise subsequent plastic surgical options.

The anterior and lateral compartments can be decompressed through a single lateral incision. There should be a 5-7cm skin bridge between these two incisions, which should be drawn with an indelible marker prior to incision as the surface anatomy may be altered by the first incision. Traumatic wounds should be incorporated into the skin incisions where practical to avoid leaving two inadequate skin bridges each side of the wound. Again these should be marked on the skin prior to any incisions being made.

The lateral compartment can be decompressed through the intermuscular septum between the anterior and lateral compartments and indeed this method is the recommended standard of care in civilian open fracture management in the United Kingdom (8). However, the lateral compartment may also be decompressed through its overlying deep fascia (9). Both techniques require only a single skin incision. The advantage of the former is that it avoids undermining skin and fat and so preserves its blood supply and theoretically the use of a lateral fasciocutaneous flap. The latter technique perhaps provides a more independent decompression of the lateral compartment.

Foot

The main indication for fasciotomy is to reduce the morbidity associated with muscle necrosis. With the foot, there is some controversy regarding the significance of the complications, when compared to the morbidity associated with the procedure.

The diagnosis of compartment syndrome of the foot remains challenging and the sequelae of missing or not adequately treating can be disabling and painful (10). However the operative management of compartment syndrome can be complicated by developing infection of the wounds and fracture sites especially if there is a need operative fixation and the wounds are likely to require skin grafting for closure (11). The complications associated with missing or not decompressing a foot with compartment syndrome includes contracture and toe deformities (12). It is the level of disability from these deformities that is the focus of the debate as to whether to decompress or not. 2 dorsal incisions are made centred over the 2nd and 4th metatarsals.

The adductor compartment is released through the 1st webspace. The posterior extent of the incision is approximately 3cm anterior to the back of the heel, and 3cm above the sole of the foot.

Dressings and Re-inspection

Wounds should be re-inspected if any increase in pain is noted and routinely at 3-5 days as early cover / closure leads to better mobilisation.

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Amputations

Indications

The presence of a vascular injury that required repair in a physiologically unstable patient was the main factor in patients who required an amputation in one study (1). This is unsurprising when considering the prolonged time needed for revascularization will not be tolerated in a patient who is critically unwell.

Given the advances that have been made in limb salvage techniques, then anatomical indications for amputation, such as 'unreconstructable' should not be used, unless the case has been discussed with a specialist centre.

The presence of a numb sole of foot has, traditionally, been quoted as an indication for amputation. However, recovery of protective sensation has been reported in 50% of civilian trauma patients (2), and has also been noted in 90% of UK military patients.

Scoring systems

Several scoring systems have been developed to help the decision to amputate after severe lower limb trauma. However, none of these scores have been fully validated in subsequent studies, and they must only be considered as guides; none relate to specific to blast and ballistic injury mechanisms.

Brown et al reported the largest study investigating the use of the Mangled Extremity Severity Score (MESS) specifically in ballistic lower extremity injuries (1). In their study, 9 patients (10 limbs) with a MESS 7 had limbs that were successfully salvaged, resulting in a positive predictive value of 64.3% if the MESS criteria of 7 had been used for amputation. This equates to one in three legs being unnecessarily amputated. The authors concluded that the MESS could not be used to determine the need for primary amputation in individual patients.

General Principles

A trauma amputation should be considered an extension of debridement, rather than a definitive procedure in its own right.

When the foot remains viable, debridement of the wound, rather than amputation should be performed. This approach retains the possibility of reconstruction, even when significant foot injuries have occurred (3).

In 2007 the Limb Trauma Working Group of The Academic Department of Military Surgery and Trauma held a consensus meeting to discuss amputations from military trauma (4). The output of this meeting was a series of recommendations, which are noted in Table 1, and expanded below.

Whenever it is practical to do so, the decision by the admitting consultant to perform an amputation should be discussed with a colleague who should, if possible, perform his or her own clinical assessment of the patient, and this discussion should be clearly documented.

Pre-operative radiographs

These should be obtained unless the resulting delay would compromise the care of the casualty. Radiographs may help to identify significant proximal contamination as well as the extent of bony injury that may influence limb salvage (5).

Technique

A guillotine amputation, defined as skin, soft tissue and bone all cut at the same anatomical level utilising a circumferential skin cut, should be avoided. A guillotine amputation is not a significantly quicker amputation and will sacrifice viable tissue and subsequent stump fashioning can be technically challenging. An exception to this guidance may be considered if the amputation is required for extraction of a trapped casualty when access to the patient and limb is limited.

Medial and lateral longitudinal incisions should be used to extend the wounds and allow adequate exposure, but this is dependent on individual circumstances, particularly pre-existing wounds.

At initial debridement all viable tissue should be preserved even if bone length appears excessive, or excess soft tissue is present. This is to avoid compromising definitive closure, particularly if further skin or soft tissue necrosis occurs.

Definitive flaps should not be performed at the initial debridement. This may result in the excision of viable tissue, which could be required for definitive wound closure, particularly if further excision is required or non-standard flaps are necessary. Definitive flaps are created at the time of wound closure, usually 2-5 days later.

Management of the bone

Bone should be cut at the most distal soft tissue levels as excising bone more proximal than soft tissue may compromise the vascularity of the distal soft tissue and subsequent wound closure. Any bone protruding beyond soft tissue will require excision and the absence of soft tissue attachments may compromise its blood supply and predispose to infection.

Definitive bone levels should be determined at the time of wound closure not the initial debridement.

Amputation should not to be carried out at the level of any fracture unless this is the appropriate skin/soft tissue level. Viable bone distal to a fracture site may be reduced and fixed at definitive closure to allow for a better functional outcome.

Articular fragments should not be excised if soft tissue attachments remain.

Through Knee Amputations

One area of controversy is the place of through knee amputations, which may be indicated following trauma. Although traditionally it was felt that these had little place, modern prosthetics result in a better functional result than a trans-femoral amputation, and the cosmetic result is acceptable. Although it has been reported that through-knee amputation result in a worse outcome when compared to above-knee (6), others have stated that the more distal the level, the better the walking independence and functional outcome, and have noted that disarticulations result in end-bearing stumps (7). This opinion has been

confirmed by the Defence Rehabilitation Centre at Headley Court, who probably have more experience with through knee amputations than any other centre in Europe.

The amputation is performed through the joint and the distal femoral condyles should not be excised. The Gritti-Stokes technique of attaching the decorticated patella to the distal condyles should not be performed.

Wound Closure

No part of the wound to be closed at initial surgery; even if closed without tension, post-operative/injury oedema will occur and this may result in soft tissue swelling, ischaemia and necrosis.

Bone does not have to be covered by soft tissue at the time of the initial debridement, instead soft tissue can be folded across and a moist dressing applied.

No attempt should be made to prevent skin retraction as this may result in ischaemia of deep tissues and further swelling resulting in further skin loss.

Table 1. Guidelines for Immediate Amputation following Military Trauma

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.	Bone should be cut at the most distal soft tissue level.
Radiographs should be obtained prior to amputation.	Amputation should not be carried out at the level of any fracture unless this is the appropriate skin/soft tissue level.
Neurological dysfunction should not be part of the limb salvage algorithm.	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.

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