MINI-SYMPOSIUM: BULLET AND BLAST INJURIES

(ii) Initial medical and surgical management

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Summary
This paper sets out the basic principles of the initial medical and surgical management of those affected by blast, mine and ballistic injury. The principles are unchanged since the American Civil War—and many come from pre-history; put simply: Resuscitate, Penicillin, Anti-Tetanus, Debride, Wash, Fasciotomise, Pack, stabilise, Leave—open and alone!

Introduction
Limb wounds are common in all walks of life, accidents in the home, on the roads and in industry. In our western society, the well-nourished victim is transported with extreme rapidity by a dedicated ambulance service to a local hospital with a well-staffed operating theatre where a highly trained medical team will perform a familiar surgical operation. Thence they will go to a clean, plumbed, well-lit ward with dedicated and trained nursing staff where they will receive seamless holistic, rehabilitative care whilst the state cares for the needs of their family and home.

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There are those who would say that our medical management of blast, gunshot wounds (GSW) and mine injuries should not differ significantly from this secure civilian norm: that our normal protocols for wound closure, limb stabilisation and post-operative care may be safely applied, wherever in the world we are. Sadly, this perceptual error is repeated at the start of every new conflict and even during established conflicts when new medical staff arrive, keen to show that being a good doctor can overcome ‘old-fashioned’ wound care protocols.

We must have a different mindset when we deal with these injuries. The most reliable civilian analogue of war and conflict wounds would be those that occur in slurry covered farmyards or sewage pits. Where civilian wounds are contaminated on average by a single bacterial species, wounds of conflict harbour between four and six. Thus, wounds greater than 6 h old need to be treated as infected...
rather than contaminated. The life should be saved first, then the limb. If all wounds were treated in such a fashion, then articles like this would not be necessary.

Military surgeons, unfortunate civilian surgeons caught up in conflict zones, and those who now volunteer for overseas service with Non-Governmental organisations (NGOs) such as Médecins sans Frontieres and the Red Cross will find themselves living ‘above the shop’, in-danger, with limited resources and little or no back-up. They will be expected to operate on severely mangled limbs or wounds of unexpected severity. Small simple wounds will not heal and patients will sell their drugs to pay for food for their family. Malnutrition will be rife, clean water unavailable—and all this, often from the day that they arrive in that country.

History

Wounding agents are largely unchanged since the Vietnam war. The multiple penetrating wounds, blast trauma and burns seen from today’s improvised explosive devices (IEDs), car bombs, suicide bombs and rocket propelled grenades (RPGs) are little changed from those encountered by the French in Dien Bien Phu, the British in Northern Ireland or the Coalition Forces in Iraq and Afghanistan.

The anatomical distribution of these military wounds has remained essentially unaltered.

<table>
<thead>
<tr>
<th>Conflict</th>
<th>Penetrating limb wounds (%)</th>
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<tbody>
<tr>
<td>WW1</td>
<td>70</td>
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<tr>
<td>WW2</td>
<td>75</td>
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<tr>
<td>Vietnam</td>
<td>74</td>
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<tr>
<td>Gulf War 1 (UK)</td>
<td>71</td>
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<td>Afghanistan</td>
<td>61</td>
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The selective availability of munitions is a determinant of wounding pattern. In year one of the Soviet War in Afghanistan, 60% of injuries were GSW. Five years later, as the Mujahadeen captured or acquired explosives, mortars and mines, blast accounted for over 70% of all injuries. In general though, roughly 1/3 of all injuries presenting to a conflict hospital of any sort will be from blast injury (RPG/Mine/IED) and 1/3 will be ballistic (GSW/Grenade) trauma. The remainder will be RTAs, burns and other injuries.

We may think that we have made major steps in our care of the war-injured patient. This is untrue as despite substantial improvements in resuscitation (including novel haemostatic techniques—QuikCLOT, HemoCon, Factor V11a), ‘far-forward damage-control’ surgery, front-line intensive care and critical care evacuation, advances in body armour, vehicle armour and basic first aid—the battlefield surgical salvage rates from our current campaigns in Iraq and Afghanistan remain exactly the same as in WWII and Vietnam—3.5%.

As armour has improved, so have sighting and offensive weapon capabilities. A current trick in Iraq is for a sniper to quietly shoot out the radiator of a vehicle. When the occupant gets out to check why the engine has overheated—he is shot in the exposed infra-axillary gap in the body armour when he lifts his hands and the bonnet above his head (Fig. 1). The resulting trans-mediastinal wound is rapidly fatal. There is now newer body armour to counter this threat (Enhanced CBA), which has upper arm cuffs. Unfortunately, this item is heavy and cumbersome and thus disliked by troops.

Mine injuries themselves are emotive, disabling events. Whilst they can be life threatening, most mines are not designed to kill. The PMA-3 mine, ubiquitous in Bosnia, contains just 35g of Tetryl explosive. The PMN mine, favoured in Afghanistan contains 240g of TNT. Anti-tank mines require much higher pressures to set the mine off. However, it is not uncommon for some to bury anti-tank mines with anti-personnel mines on top. In total, 3kg pressure triggers the smaller mine whose explosion activates the larger device.

It is estimated that there are 110 million landmines across 64 countries worldwide. Although there are well publicised mine clearance programs, mines are continually being laid. There are 600,000 victims of landmines in Afghanistan, one in 50 of the population. One third are female. There are still 10,000,000 mines in Afghanistan. Removal is said to occur ‘limb by limb’ with even the most diligent of the agencies only able to achieve 99.6% clearance.

The military ethos of mine-laying is denial of ground. This may be to delineate border areas such as in Egypt. They also act against the morale of the fighting troops.

In a section of eight men, if one is shot dead, the remaining seven members of the group are likely to fight back all the harder. If one man suffers traumatic amputation of a leg after a mine strike, at least two men will have to carry him (if not four) and one will have to render

Figure 1 Non-enhanced body armour vulnerability.
first-aid. As soldiers generally do not fear death, merely disability, the fighting spirit of the two remaining soldiers not directly involved in the care of the casualty is not generally improved by the screams of the injured man. There is also the concept of ‘mine starvation’. Agricultural production falls by over a third in mined areas, due to land denial, the inability of the amputee farmer to till the soil and a general lack of investment. Mines may purposefully be sown on riverbanks to deny a population fresh water. Further deaths are then caused by the infantile diarrhoea, malnutrition and iodine deficiencies that result. Because vaccination teams do not visit the area, there are outbreaks of polio and measles amongst the villagers. Prosthetic fitting charities report two types of provision in the most heavily mined areas; callipers for the polio epidemic survivors and artificial limbs for the minestrike victims. Finally, mines do not disappear. Mines laid in Libya in 1942 still kill. The concept of mine marking is specious. Soil and sand erode. Snow melts. Those mines left on riverbanks are washed downstream to kill again. Cluster munitions are often brightly coloured and attractive to children who pick them up—so-called ‘butterfly bombs’. They continue to maim and blind long after the fighting troops have gone. For every two mine victims who reach hospital, there are three who died of shock, sepsis, blood loss and gangrene. There are now 100,000 minestrike amputees in Angola.

Initial medical management

Village first aid—Villagers should be trained in first aid. This should mean some provision of basic equipment with advice on bandaging/compressive wrapping, intramuscular antibiotic administration and mouth-to-mouth resuscitation. Simple written tourniquet protocols are appropriate for mine injuries, but these must be clear as pre-hospital transfer times often average 6–9h. Splintage of the injured limb relieves pain for transport. Pentazocine (50mg p.o.) or morphine (10mg i.m.) are useful for pain control. Local barbers, shopkeepers and pharmacists are the best group to target. Local drivers and car owners should be offered bonuses and incentives for bringing blast and bullet victims to medical care. This simple approach should also apply to western agencies in the resuscitation room. Pressure dressings and well-padded tourniquets are useful when there is traumatic amputation—a pneumatic theatre tourniquet being the best type. Antibiotics (Benzylpenicillin 2.4g i.v., Flucloxacillin 2g i.v. given as a loading dose with half these doses given qid for at least 2 days) may be given intravenously. Tetanus toxoid booster and immunoglobulin (Tetanus Immunoglobulin of Human Origin—HTIG, 500 units i.m.) for the non-vaccinated individual is also necessary. Crystalloid is administered intravenously to maintain a palpable radial pulse.

The most important factor in this initial care is not to be distracted in any way by the catastrophic limb injury. Although limb bleeding can be troublesome, an unrecognised chest injury such as a pneumothorax will kill the patient just as surely as exsanguination. Similarly unrecognised perineal or rectal injury—common in lower limb mine strikes may also be ultimately fatal. This is covered in the resuscitation section of this mini-symposium.

Initial surgical care

Mine injury

If primary debridement is radical, there is no need for serial (piecemeal) debridement. This is the basic tenet of all surgery for mine injuries and is the core principle of the treatment protocols of the International Committee of the Red Cross (ICRC). Mine injuries are dirty and bacterially contaminated. The tissues are impregnated with organic matter, dirt and debris, often quite proximal to the injury up the intermuscular and interfascial tissue planes. By comparison, ballistic wounds
are relatively clean—minestrike surgery is difficult and time consuming.

Four patterns of wounding are recognised from mines:

I. Mine stand (30%)—The victim stands on a mine producing a mangled foot (including the hindfoot) with evidence of proximal blast injury several centimetres up the leg (Fig. 2a). There may be blast injury to the contra-lateral leg (Fig. 2b). The anterior and lateral compartments fare badly but the posterior compartments of the leg normally flap back and are relatively spared. Transtibial amputation with a long posterior flap is the general rule.

II. Fragmentation injury (50%)—a mine explodes at distance and secondary projectiles cause injury. In a Claymore type mine or grenade, this will be from multiple ball-bearing or preformed notched wire fragments (Fig. 3).

III. Mine pick up (5%)—This usually causes significant hand and forearm injury. Blindness from globe penetration is common. Penetrating chest injury must be ruled out (Fig. 4).

IV. No recognisable pattern (15%)—Often seen when smaller mines and anti-tank mines are used in conjunction, or where there has been an explosion in a confined space.

General or Ketamine anaesthesia is used. For type I and III injuries, the majority of the contaminated distal limb is placed in an sterile impermeable stockinette bag and a crepe wrap applied. The remainder of the limb is prepped and draped. Use of an uninflated proximal pneumatic thigh tourniquet is very reassuring at this stage. Generally, it is best to operate without a tourniquet—this will prevent any further tissue damage. If or when substantial bleeding(577,827),(816,857) encountered, the tourniquet can be inflated in a matter of seconds and released again when the bleeding is controlled. Using a skin marker pen and ruler it is then determined what skin and bone are available—a preoperative X-ray may be useful in the stable patient (Fig. 5). In total, 12–15 cm of stable tibia and a further 12–15 cm of posterior skin flap beyond this ideal. Less than 5 cm of tibia is does not usually produce a functional result.

Because the anterior and lateral compartments are tightly bound down to the tibia and fibula—they do not survive blast injury well. They are often severely contused and contaminated. They are best dealt with by resecting them transversely at the site of bony election. This makes a rapid, definitive and simple single surgical step as opposed to slow piecemeal distal to proximal nibbling.
Figure 6  Amputation sequence: (a,b) initial surgery, protection of soft tissues, (c) stump at 5 days, (d) long healthy posterior flap, (e) fashioning the final stump, (f) closure.
By contrast, the posterior compartment with its overlying skin will have been able to flap back and absorb the shockwave better (the superficial posterior compartment with gastrocnemius especially as it is attached distally only to the tibia) to the tibia and proximally only to the distal femoral condyles). The soleal mass is quite bulky and often needs filleting, but this is not so important at the time of the initial surgery. It is important to check up all tissue planes for grass, mud, pieces of clothing and shoe. Interseptal contamination will extend proximally for many centimetres above the obvious external injury. As each compartment is identified and dealt with, a simple proximal fasciotomy is then performed with curved round-ended scissors.

The tibia should be cut transversely 12–15 cm below the joint line: use a ruler to formally measure this distance. A Gigli saw can be used but a tenon or bone saw is best. The surrounding tissues must be protected. The medullary cavity is curetted and washed out as debris may have been forced into it. The bone edges are bevelled down with a rasp, anteriorly the sharp tibial crest should be smoothed down for a few millimetres. The fibula should be resected some 2 cm proximal to the tibia. This can be done with bone cutters and again, any bony spicules should be removed. Disarticulation of the proximal tibio-fibular joint is not recommended. If access is difficult to the fibula, a small 3–4 cm 'back-cut' may be made on the lateral side of the flap for access (Fig. 6a–f).

If possible, the plane between the gastrocnemius muscle and the skin should be left alone; this avoids damage to the perforating vessels and cutaneous blood supply. Although the muscle itself may have some embedded fragments, the soleus muscle acts as a bodyguard for the gastrocnemius and this plane is usually therefore clean. The three neurovascular bundles are identified. The main arteries are best double ligated with vicryl ties. The veins can be singly ligated. The nerve ends are best cut under gentle traction and allowed to retract proximally: This avoids the possibility of a later painful distal stump neuroma. Although asymmetric flaps can be created and used, the surgical reconstruction of most mine injuries relies on this persistent long posterior myocutaneous flap.

The wound and muscles are then copiously irrigated with sterile saline. However, this is a bulky expensive item and use of potable or bottled water is the norm. The final wash can then be with a few 100 ml of sterile saline or water, but this is not strictly necessary. Fluffy gauze is loosely placed in the wound on top of the gastrocnemius and the skin is curved, without kinking, around the stump. Further fluffy gauze is placed around the stump with a layer of cotton wool and several crepe bandages on top. The last layer should include a Plaster of Paris (POP) backslab to splint the knee in full extension for if a significant flexion contracture develops in a stump, it becomes functionally useless.

The ICRC teaching, in countries where over 25% of all surgical workload may be mine-related, is to leave all dressings in place for 5 days before a return to theatre for delayed primary closure (DPS). Although the dressing may smell and stain yellow-green, it is not the smell of putrefaction, it is the so-called 'good-bad smell' and the patient is otherwise well. Only if the patient deteriorates with pyrexia and the dressing becomes extremely offensive, the ‘bad-bad smell’, is the patient returned to theatre before 5 days.

In low intensity conflict or single patient scenario where circumstances allow, a return to theatre at 48 h may be appropriate, especially in the first few cases performed. This can serve as a feedback as to the adequacy of the initial debridement. There will be an increased requirement for blood transfusion if this is done routinely.

In a third world setting, a high-protein diet with mineral and vitamin supplementation is useful at this stage. Hookworm and helminth infestations can be treated. Children especially, may have been anaemic pre-operatively; transfusion to normocythaemia if logistically possible will aid wound healing. If the patient cannot eat, enteral feeding using locally available resources is a possibility.

At day five, the patient is returned to the operating theatre. Any remaining non-viable areas, foreign matter and debris are removed. These areas should be minimal if the initial surgery was done correctly. Filleting of the bulky soleus may be necessary, sometimes a little of the gastrocnemius belly also until the flap sits nicely over the end of the bone. Two 3.2 mm holes are drilled in the end of the tibia with a hand or power-drill, two sutures are passed through the end of the flap picking up the muscle, which will have the beginnings of the Achilles tendon within it, but not the skin. This myodesis will aid propulsion by firmly attaching the muscle to the bone. The skin is then closed with interrupted 2 'O' nylon mattress sutures over a Penrose drain (the cut-off finger of a glove is a useful substitute). Some attention to peripheral ‘dog-ears’ may be necessary. Fluffy gauze, cotton wool and crepe are used to dress the stump. Again, a backslab is useful to hold the stump in full extension for a day or so.

Physiotherapy begins 24–48 h after wound closure, specifically range of motion and quadriceps exercises. Stump wrapping (Fig. 7) and ambulation on crutches are also commenced at this stage. The drain is pulled on the ward at 48 h. The patient should be ambulating on a prosthetic limb at 12 weeks after surgery (Fig. 8). Re-operation may be

Figure 7 Stump wrapping and physiotherapy, note the split skin grafts to the previously exposed areas on the contralateral leg.
necessary for prosthesis fitting, scar tethering, sinus or sequestrum formation, neuroma, protruding bone spikes and growing bone in children.

Above knee amputation

Through-knee disarticulation is not recommended. Divide the femur 12–15 cm above the joint line of the knee (25 cm below the greater trochanter), bevel and smooth the bone end. The nerves and vessels are dealt with as for BKA. Fashion a 12–15 cm anterior and a 10 cm posterior skin flap such that the final scar will not overlay the point of the stump. This often equates to an anterior cut where the quadriceps tendon inserts into the patella and the posterior cut 3–5 cm proximally. Two or three 3.2 mm drill holes are made in the distal femur and the quadriceps tendon containing anterior muscle group attached to the bone. The skin is closed using 2 '0' nylon over a Penrose drain. A bulky stump always remodels.

Above elbow amputation

There is no optimal level of amputation. The bone should be divided as low as possible. This is usually about 2/3 of the way down the humeral shaft using 5 cm equal anterior and posterior skin flaps.

Below elbow amputation

Above the wrist, the bones are cut cleanly across at equal length. The edges are filed smooth. The flexor and extensor musculature is sewn over the bone ends. In total, 3–4 cm equal length skin flaps are constructed. In the hand, as much useful tissue is preserved as possible, the thumb in particular. Even a short stiff thumb acting as a post is better than no thumb at all. Surplus palmar and dorsal skin can be used to cover bony defects.

Krukenberg amputation: This is used by some agencies where the victim has been blinded as well as losing part of one or both forearms. It provides a chopstick style sensate limb. The skin of the forearm is wrapped around the radius and ulna separately in the distal 2/3 of the forearm. This allows motion between the two bones and a degree of sensate manual dexterity.

Guillotine amputation

The ICRC does not recommend this technique and its associated postoperative care for the following reasons:

I. It shows a lack of understanding of the patho-physiology of mine injury; proximally injured dead muscle and infective debris in tissue planes well above the signs of any external damage will be missed.
II. It is unsuitable in mid limb situations because of subsequent muscle swelling.
III. It will require revision stump surgery if the patient survives.
IV. It may result in an amputation higher than necessary.
V. It produces a non-standard stump that is difficult to fit with a standard prosthesis.

In a guillotine amputation, skin traction is required postoperatively to prevent skin retraction—this is cumbersome, difficult to do and makes transportation difficult. It is better to perform the long posterior flap technique as described above.

Ballistic injury and gun shot wounds (GSW)

There is often much discussion (and confusion) about the following terms; high or low velocity and high or low energy transfer. Quite simply, velocity relates to the projectile: energy transfer to the wound. As discussed elsewhere in this mini-symposium, a high velocity projectile may pass through tissue (Fig. 9) without giving up any of its energy and produce a low energy transfer wound. Alternately it may be significantly retarded or come to rest in the tissue having expended all of its energy and produce a high energy transfer wound. Additionally, a heavy, yet low or intermediate velocity projectile designed to expand or fragment on impact (hollow point bullet) may produce a high energy transfer wound. Therefore, it is best to treat the wound and not the projectile.

Again, the principles of treatment of ballistic injury are not difficult. The ICRC and British Military guidelines are simple and easy to understand:

I. Complete wound excision,
II. Delayed Primary Suture (DPS),
III. antibiotics,
IV. antitetanus vaccine and immunoglobulin,
V. splintage without internal bone fixation.
Effective and early wound excision reduces the mortality and morbidity from these wounds. It reduces the chance of death from sepsis and gas gangrene and the number of operations required to remove remaining dead tissue and allows primary closure to succeed.

**Wound classification**

Simple wound scoring systems are useful, for both documentation and clinical decision making purposes. The ICRC has a simple six parameter scoring system which is shown below:

\[
\begin{align*}
E &= \text{entry wound size in cm} \\
X &= \text{exit wound size in cm} (X = 0 \text{ if no exit}) \\
C &= \text{can the cavity of the wound admit two of the surgeons fingers before surgery?} \\
&= C0: \text{no} \\
&= C1: \text{yes} \\
F &= \text{fracture} \\
&= F0: \text{no fracture} \\
&= F1: \text{simple fracture, hole, insignificant comminution} \\
&= F2: \text{clinically significant comminution} \\
V &= \text{Vital structure injury (dura, pleura, peritoneum, major vessel injury)} \\
&= V0: \text{no injury} \\
&= V1: \text{yes} \\
M &= \text{metallic body} \\
&= M0: \text{no} \\
&= M1: \text{yes, one metallic body} \\
&= M2: \text{yes, multiple metallic bodies} \\
\end{align*}
\]

Thus, a small simple track without fracture and no cavity—a low energy transfer wound might be graded: E1 X0 C0 F0 V0 M0.

A high energy transfer wound with a large exit wound, tissue cavitation and a comminuted femoral fracture might be graded: E1 X5 C1 F2 V0 M1.

The greater the cavity and tissue damage, the greater and more complex the surgery. Wound excision is the technique best suited to these injuries. All the dead and damaged tissue grossly contaminated with bacteria and debris is completely cut away. This leaves behind healthy perfused tissue capable of combating infection as long as the wound is not sutured shut. Thus, single or multiple superficial penetrating fragment wounds (E1 X0 C0 or E1 X1 C0) such as those caused by preformed notched wire fragments in modern grenades and explosive munitions (Fig. 3) do not usually require exploration. The "Death by a Thousand Cuts" or "Swiss Cheese" surgery—an attempt to excise all wounds and fragments through multiple incisions—is not necessary. In regard to the fragments themselves, unless they are intra-articular (where tissue acids such as hyaluronic acid may dissolve lead and other heavy metals causing a lead arthropathy), they need not be removed.

For distal injuries, the placement of a proximal, uninflated pneumatic tourniquet is often reassuring. In more proximal or junctional injuries, a decision needs to be made whether formal proximal vascular control is necessary. The whole limb is scrubbed clean, then prepped and draped. All posterior wounds should be dealt with first. Different tissues respond in different ways to ballistic trauma. Skin is elastic, strong and remarkably resistant to damage. Only skin that is pulped or multiply lacerated e.g. in the typical stellate contaminated fashion, need be removed. It is wise to be conservative with skin—it will be needed later. Only a millimetre or so of the edge need be excised with a sharp knife.

For E1 X1 C0 wounds i.e., simple tracks, this may be all that is necessary (Fig. 10). Skin excision should be followed by wound flossing (use of a single swab opened lengthways passed repeatedly through the wound to remove any small pieces of debris) and copious irrigation. Simple dressings are then applied.

For E1 X4 C1 type larger wounds (Fig. 11a), after the wound edges have been debrided, generous longitudinal incisions (Fig. 11b), in the long axis of the limb but curved over flexion creases are made in the skin. The commonest error is to make these too short. Subcutaneous fat with its poor blood supply, generally high levels of contamination and poor resistance to infection and its associated shredded fascia is generously removed.

Formal fasciotomy is often necessary and if you think about fasciotomy—you should perform it! All compartments should be released in the injured limb. There are four in the lower leg, three in the thigh, two in the arm and three in the forearm. For wound debridement though, the deep fascia is

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**Figure 9** Low energy transfer wound right calf.

**Figure 10** Low energy transfer right thigh, wound flossing.
incised along the length of the skin incision; this then allows the gentle gloved finger to become a diagnostic probe to estimate track size and tissue damage.

If a large area of blue-black clot is encountered — this is a reliable sign that a major vessel has been damaged (Fig. 12). Before further exploration is undertaken, proximal vascular control should be considered. Attention can now be turned to the muscle: all dead muscle must be excised. Dead muscle, contaminated at time of wounding, becomes infected muscle six hours after wounding. The bacteria exit their latent phase and begin actively dividing and invading. If unnoticed, clostridial infection then occurs, the limb threatening injury becomes a life threatening one.

Muscle viability is assessed using the four Cs: Colour, Consistency, Contractility and Capillary bleeding. Healthy muscle is a succulent glistening brick-red colour. It will contract and ooze when cut. If the patient has been given a muscle relaxant (blocking the neuromuscular junction), the normal pinch reaction of muscle may be partly lost. Low intensity diathermy (so as not to char the tissues) can then be used as a diagnostic adjunct.

At its simplest level then, the basic technique is to pick up lumps of muscle with forceps, pinch them, and if they do not contract, excise them with scissors. The lumps should be no bigger than 2 cm² to prevent damage to vital structures or healthy tissue. Small vessels should be carefully and individually coagulated: avoid the tendency to fulgurate large areas. Larger vessels are controlled with vicryl ties.

Frayed tendons are trimmed; pieces of bone without attachment are removed. No attempt is made at tendon, nerve or internal bone repair at this stage. If major vessels are damaged primary repair, vein-patching or reversed saphenous vein grafting are usually necessary. In certain circumstances, it might be better for the inexperienced surgeon to ligate a distal artery and perform wide fasciotomies rather than spend several fruitless hours attempting an unfamiliar arterial repair or graft. This is especially true in multiple casualty situations. Figures from the Second World War indicate that gangrene is not always a foregone conclusion — even in ‘end-artery’ ligation.

It is also important not to open up fresh planes in healthy tissue. Complete metallic fragment removal is unnecessary but all foreign debris, clothing wads, vegetation and dirt must be completely eliminated. At the end of this phase, the wounds are copiously irrigated with bottled or potable water (Fig. 13a). All residual debris and clot is removed. If available, a few 100 ml of sterile normal saline is used for the last wash. The wound is then packed with fluffed up dry gauze. No tight packs or antibiotic soaks (e.g. betadine) are used. The most memorable historical aphorism about this phase is;

Wounds should be packed like a lady’s handbag, that is lightly and with delicate fluffy things.

A gamgee or cotton wool layer is placed over this and several layers of crepe bandage steadily but not tightly applied. The aim is for inflammatory fluid to be drawn out of the wound and into the dressing. Therefore, Vaseline gauze and other occlusive dressings should not be used.

As with mine injuries, the wound is left untouched for 5 days before DPS is undertaken. The previous notes about the ‘good/bad’ smell and the ‘bad/bad’ smell remain extant. The dressing is taken down in theatre under Ketamine/GA, any small remaining devitalised areas are removed and the wounds closed without tension using 2 ‘0’
nylon sutures. If 2 '0' nylon will not close the wound, then it is either not ready for closure or some alternate means will need to be used to achieve skin cover such as a split-skin graft or local flap.

Bony injury

All dead and contaminated bone has to be removed. The prevention of bone sepsis is paramount. In the acute phase it may be life-threatening, in the chronic phase it will prevent formal reconstruction. Even with modern technology, the viability of bone fragments can be difficult to determine. Large cortical fragments with firm muscle attachments are usually fine. Small pieces (<1 cm) with only filamentous strands of tissue holding them in place are best removed. Dirty bone ends are cleaned best by judicious use of bone nibblers back to healthy white punctate bleeding bone. Medullary cavities need to be curetted and irrigated clean. Both ends of the fractured bone need to be delivered into the wound, thus adequate longitudinal incisions and a bone hook are useful. In neglected wounds—the bone may be yellow ('bad teeth') in colour and appearance—this needs to be aggressively resected back to healthy bone.

If there is a suspicion that a fragment of bullet has penetrated or traversed a joint, then that joint must be washed out. X-rays are helpful as they may show air or debris in the joint. Retained metallic fragments, especially if they contain lead need to be removed because of the risk of lead arthropathy. Where there has been damage to the joint, the same rules apply as to bone. Attached osteochondral fragments are retained in place as best as is possible, but it is best not to fix them at the initial debridement stage. After copious irrigation the joint capsule should be closed, if possible, to further reduce the risk of infection. The skin and other structures can be closed at the time of delayed primary suture.

Fracture stabilisation

In total, 35–50% of all limb wounds will have some bone involvement. Such injuries are compound and are frequently infected by the time they reach a surgical facility. Wound debridement should take place as described above, then the wound and fracture must be stabilised and if the limb seems in any way tense, fasciotomy is immediately performed. X-ray is a useful but not essential adjunct.

Realignment and stabilisation

The benefits of realignment and stabilisation of fractures are:
- Provides pain relief and reduces overall analgesic requirements.
- Reduces secondary neurovascular and tissue damage.
- Stabilises the ‘wound organ’ and reduces harmful cytokine release.
- Reduces the chance of fat embolism.
- May convert a stretcher case to a self-care walking casualty.
- Allows for safe and prolonged transport.
- Begins the rehabilitation and healing process.

The stabilisation method used will vary from case to case and limb to limb, but POP remains the safest and commonest method. Although external fixation devices may be available (Fig. 13b), their presence is not an absolute indication for their use. Humeral, tibial and forearm injuries are all suitable for POP splintage. In the tibia, this can be augmented with proximal and distal Steinmann pins to hold the limb out to length when there is significant bone loss (Böhler technique). In all cases, the foot should be incorporated and placed at 90°. This prevents any later equinus deformity.
A fractured femur will require some form of skeletal traction as the pull of the attached muscles causing femoral and tissue shortening may allow for untamponaded intracompartmental haemorrhage. For the femur, placement of a proximal tibial or distal femoral Steinmann or Denham (threaded) pin is optimal. This may be attached to a Thomas splint for transport (Fig. 14) and allows for easy conversion to beam, balanced or Obletz traction for treatment to union.

Well-moulded POP splintage is suitable for tibial fractures; windows may be cut in the plaster for wound care (Fig. 15). External fixation, when available is an alternative and is best suited to the tibia. However, if a patient is likely to be repatriated to a western standard of care facility within a day or so, consideration should be given to avoidance of the technique in uncomplicated fractures as an early pin-site infection can contaminate the medulla and this may then preclude intra-medullary nailing. The ICRC currently uses the AO/ASIF tubular fixator. The US, NL and UK military use the Hoffmann II pattern fixator. The latter has the advantage of self-drilling, self-tapping pins. External fixation is particularly suitable for:

- Unstable fractures with extensive bone loss.
- Fractures with extensive soft tissue loss or burns.
- Vascular injuries requiring repair.
- Polytrauma.
- Casualty transfer/definitive care.

However, external fixation is not without its complications. Pin-site infections, thermal necrosis of bone at insertion, unicortical placement and poor biomechanical placement of the pins will all cause early loosening and failure. Even trained orthopaedic surgeons can have difficulty with fixator placement. It is best learnt as a formal practical skill in a workshop environment. Technical points to consider are:

- General limb realignment before beginning.
- >1 cm stab incisions.
- Avoidance of bony thermal damage.
- Subcutaneous tibial border insertion.
- Bi-cortical placement.
- Avoidance of pin-placement within joint capsule or 3 cm of fracture.
- Two solid pins above, two solid pins below the fracture.
- Pins in the ‘near-far/near-far’ configuration.
- Stable pin/bar configuration.
- Daily pin-site care.

**Fasciotomy**

The technique of fasciotomy is not difficult. It is therefore surprising that many surgeons agonise over the procedure. In the conflict scenario or times of high casualty flow, it may be several days before the surgeon sees the patient again. The message is therefore very simple. If you even think the word ‘fasciotomy’—then just do it. Do not agonise over ‘pain on passive stretch’, ‘moderate but not uncontrollable pain’, ‘weak but palpable distal pulses’.

**Indications for Fasciotomy:**

- Ballistic wounds directly involving the calf.
- Ipsilateral major venous injuries.
- Clinical signs or any suspicion of compartment syndrome.
- Warm ischaemic times in excess of 4–6 h.
- Crush or prolonged entrapment scenarios.
- Major arterial injury, ligation or repair.

Fasciotomy is best learnt as a technical skill. But it is not difficult to do. There is no place for single skin incision fasciotomy or decompression via fibulectomy (the fibula is then lost as a reconstructive aid). There is no place for limited incisions or so-called subcutaneous fasciotomy. Fasciotomy incisions must be generous, correctly placed and include at least a 7 cm skin bridge between incisions.

**Technique**

There are four compartments to release in the lower leg. The guide to the anterior and lateral compartments is the lateral intermuscular septum; this is found about 4–5 cm lateral to the lateral subcutaneous border of the tibia. It may be palpated through the skin. An incision is made which extends from just anterior and 2 cm below the head of the fibula; to 5 cm above and anterior to the lateral malleolus. The subcutaneous fat is
also incised taking care at this stage not to violate the fascia. The lateral intermuscular septum is easily felt.

A 2 cm transverse incision is made at mid incision level in the fascia centred on the septum. The sharp tense edge of the septum as it dives deep between the two compartments is unmistakeable. Long curved scissors used at the outer edges of this transverse cut are then used in a two-pass technique to produce an H-shaped release. The first pass with the tips closed lifts the fascia off the muscle, the second with tips open divides the fascia completely, up to and slightly beyond the skin incision margin. The middle finger of the surgeon's free hand should then be able to pass freely proximally and distally without encountering any remaining fascial leashes or bands.

This technique is used proximally and distally in each compartment. The commonest technical errors are:

- Inadequate skin incisions and failure to confirm the compartment being released, the swollen lateral compartment is then mistaken for the anterior and two incisions are made in the lateral compartment instead. The anterior compartment dies and the leg or the patient is lost.
- Damage to the lateral peroneal nerve. It perforates the lateral septum two-thirds of the way down the leg. It is avoided by angling the tips of the scissors away from the initial incision. In the lateral compartment, the tips are aimed towards the head of the fibula proximally and the lateral malleolus distally. In the anterior compartment, the tips are aimed towards the tibial metaphyseal flare both proximally and distally.

The superficial and deep posterior compartments are released next. A ruler is used to determine a seven centimetre skin bridge between the two releasing incisions. For the posterior compartment, the incision is made one cm behind the medial tibial border from just below the proximal metaphyseal flare to 7 cm above the tip of the medial malleolus. The long saphenous vein and its accompanying nerve are gently retracted. A 2 cm transverse cut is made to identify the thin septum between the superficial and deep posterior compartments. The superficial compartmental fascia containing gastrocnemius and soleus is released proximally and distally using the curved round-ended scissors. The deep compartment is released distally by dividing the flimsy deep fascia over flexor digitorum longus and tibia posterior. This dissection is continued proximally through the soleus bridge—a transverse leash of 2–3 veins where soleus begins its bony attachment to the tibia. Some mobilisation of the soleus off the tibia may be necessary to fully release the proximal fascia over the deep compartment. Again, a finger is used to confirm release. After haemostasis, the wounds are dressed and left open for later DPS.

There is often considerable angst about the techniques for fasciotomy wound closure. The medial wound often contains exposed tibia and therefore should be closed first and directly. The lateral wound is then problematic, if there is residual swelling then a delay of a few more days is reasonable before closure. Skin is viscoelastic and retracts. Consideration, if facilities allow, should be given to skin-stretching techniques. The easiest is to use a skin pulley stitch. An '2' nylon is used in the near-far-far-near configuration, the skin edges opposed and the wound formally closed with 2 '0' nylon. The pulley stitches are removed. However, it needs to be remembered that excessive tension must be avoided. The other common alternative is to place a meshed split-skin graft over the anterolateral defect.

In the upper arm, the two compartments; anterior containing biceps and brachialis, posterior containing triceps, are released via a single lateral incision. In the forearm, the superficial and deep flexor compartments are released through a lazy 'S' incision from the transverse ante-cubital fold, over palmaris longus, down to and including the carpal tunnel. The extensor compartment is released in the pronated arm from the lateral wad down to the centre of the wrist. In the hand the transverse carpal ligament is released on the palmar side and two incisions used to release the interossei on the dorsal side.

In the thigh, the three compartments (anterior/quadriceps, posterior/hamstring, medial/adductor) are released via a two incision technique. A single lateral incision with division of the fascia over the flexor and extensor muscles usually suffices. If there is a penetrating injury, a medial incision over adductor longus releases this side.

Special situations

Suicide bomb incidents

Standard multiple fragment injuries remain the norm. However, the biologic material produced in such explosions presents an added complication as patients will sustain injuries caused by the bone fragments of the bomber. These samples have tested positive for Hepatitis B virus.6 In the non-immune, initial medical treatment of these patients needs to include Hepatitis B vaccination and Hepatitis B immunoglobulin (HBIG 500 units). If there is any suspicion of HIV infection in the bomber, post-exposure prophylaxis (currently Zidovudine 300 mg p.o. b.d., Lamivudine 150 mg p.o. b.d., Nelfinavir 1.25 g p.o. b.d.) should be started immediately. If possible, the remains of the bomber should also be tested.

Junctional injuries

These continue to pose a significant challenge to the orthopaedic surgeon. Proximal thigh and axillary injuries are special cases. The best advice is to have a vascular surgeon in theatre and to ‘double-team’ the case. If in solitary practice, then proximal arterial control is wise. In the thigh, the femoral artery can be controlled, with a circumferential sloop, in the groin crease, if the wound is in the thigh, the femoral artery can be controlled, with a circumferential sloop, in the groin crease, if the wound is in the groin, then extra-peritoneal iliac control is prudent. For complex proximal subclavian injuries, be prepared to undertake a rapid midline sternotomy to gently clamp the intrathoracic right subclavian or brachiocephalic arteries. During resuscitation, a Foley catheter can be placed in a neck or proximal wound and inflated, to tamponade bleeding until formal control is obtained.
Training for blast and ballistic injury

Whilst this mini-symposium is intended to provide a general overview of the pathophysiology, resuscitation, initial treatment and care of victims of ballistic and blast trauma, there is no doubt that practical training is also vital. The Royal College of Surgeons of London runs a twice-yearly ‘Definitive Surgical Trauma Skills’ (DSTS) course. This is a cadaver practical-based course with emphasis on great vessel access and control, amputation, fasciotomy, external fixation and damage control laparotomy for penetrating abdominal trauma. The ICRC runs a twice yearly 2–3 days ‘Surgery for Victims of War’ course. It also runs longer courses for those about to deploy overseas to one of their third world hospitals. The Professorial Department of Military Surgery of the UK Defence Medical Services runs yearly War Surgery courses and Mangled Extremity courses.

References


Further reading