Dermal Fenestration With Negative Pressure Wound Therapy: A Technique for Managing Soft Tissue Injuries Associated With High-Energy Complex Foot Fractures

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ABSTRACT

Military casualties can sustain complex foot fractures from blast incidents. This frequently involves the calcaneum and is commonly associated with mid-foot fracture dislocations. The foot is at risk of both compartment syndrome and the development of fracture blisters after such injuries. The amount of energy transfer and the environment in which the injury was sustained also predispose patients to potential skin necrosis and deep infection. Decompression of the compartments is a part of accepted practice in civilian trauma to reduce the risk of complications associated with significant soft tissue swelling. The traditional methods of foot fasciotomy, however, are not without significant complications. We report a simple technique of dermal fenestration combined with the use of negative pressure wound therapy, which aims to preserve the skin integrity of the foot without resorting to formal fasciotomy.

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Improvised explosive devices (IEDs) are the signature weapon used by the insurgents against coalition troops in the recent conflicts in Iraq and Afghanistan (1). IEDs encompass a wide variety of devices from crudely made devices, using home-made explosives, to complex explosive systems involving military grade explosives capable of causing multiple fatalities and severe injury.

Studies from the UK and US Joint Trauma Registries have shown that most combat wounds are located in the extremities (2–5). In some instances, when the lower limb has not been immediately traumatically amputated by the blast itself, explosions can result in severe injuries to the calcaneum by acceleration of the vehicle floor, with the forces transmitted to the foot (6).

Open calcaneal fractures after blast injury are associated with a poor prognosis and often lead to a high rate of amputation (7). However, even in closed injuries, significant soft tissue injury can occur. Fracture blisters and soft tissue swelling are common complications of any acute calcaneal fractures, preoperatively or postoperatively (8,9). Varela et al (10) reported an incidence of 10.9% fracture blister formation in all calcaneal fractures. Our experience with managing military casualties with closed hindfoot and mid-foot fractures has always been complicated by the presence of extensive soft tissue blistering and swelling. The timing of calcaneal fracture surgery is contentious. It has been suggested that surgery should be delayed >72 hours to avoid wound complications (11). However, others have advocated very early operative intervention to avoid the edematous phase that begins at around 6 hours after injury (10,12).

However, UK military casualties injured while on duty undergo initial resuscitation and fracture stabilization in a field hospital (role 3), where internal fixation is not within current UK military practice. Transfer to a UK hospital (role 4) for definitive treatment by aeromedical evacuation, precluding the option of early definitive surgery and the possibility of avoiding swollen soft tissue and its inherent potential complications.

The major concern regarding fracture blisters is their progression to full dermal necrosis, which subsequently requires complex plastic surgical reconstruction. The cosmetic appearance of free tissue transfer to the foot is seldom welcomed by the patient and inevitably reduces their ability to wear normal footwear (13). In addition, complex plastic reconstruction results in an insensitive tissue transfer, which is not ideal in a weightbearing structure (14). Many of the calcaneal fractures have poor functional outcome, leading to elective amputation. Our
strategy has been to avoid free tissue transfer, which has a high risk of being discarded with the limb at a later amputation (15).

Strategies have been used to prevent and treat fracture blisters, although most investigators have agreed that compression and elevation are key in the initial stage, further treatments of fracture blisters include aspiration, de-roofing, application of silver sulfadiazine, and even leaving the blister intact and simply covering it with loose dressings (16,17).

Significant soft tissue swelling can result in compartment syndrome of the foot. Although usually a rare complication of foot injuries, it has been described after crush and blast injuries, in particular, if the Lisfranc joint, Chopart joint, or the calcaneum is involved (18–20). Ritenour et al (21) reported that combat casualties have an increased risk of developing acute compartment syndrome owing to the high-energy mechanism of injury. Their data showed a higher fasciotomy rate in military casualties compared with civilian trauma data (21). Treatment by decompression is debatable, and current expert opinion within the UK Defence Medical Service has advocated a high index of suspicion and intervention (22).

Negative pressure wound therapy (NPWT) has been used widely in the management of trauma wounds in recent years. In particular, it has been used in large, complex, and exudative wounds sustained by coalition forces from IEDs in the recent conflicts in Iraq and Afghanistan (23,24).

We describe an innovative technique that combines decompression of soft tissue swelling and application of NPWT as a part of the strategy to prevent soft tissue swelling and fracture blisters in closed complex foot fractures from progressing to full dermal necrosis or compartment syndrome.

Surgical Technique

We describe our technique using photographs from 2 of our patients. Patient 1 was a 41-year-old male soldier who had sustained right closed calcaneum and pilon fractures (Fig. 1) in an IED explosion during a foot patrol. Patient 2 was a 25-year-old male soldier with left complex ankle and mid-foot fractures sustained from an IED explosion (Fig. 2). Both patients were aeromedically evacuated from Afghanistan to a UK hospital to undergo fracture fixation surgery 3 days after their initial injury.

During the first trip to the operating theater in the United Kingdom, fracture fixation was performed with dermal fenestration in both patients. Dermal fenestration involves multiple stab incisions of 0.2 cm (Fig. 3) at the site of the fracture blisters and swollen areas (Figs. 4 and 5) of potential blister formation using a no. 15 scalpel blade. The scalpel was used in the line of the cutaneous nerves to reduce the risk of damage to these structures. The depth of the incision should be no more than the thickness of the skin to reduce the risk of vascular injury. Within 30 minutes of performing fenestration, it will be clearly seen that the overall size of the foot has been reduced, with many points of punctate hemoserous oozing. We performed this technique concurrent with definitive fracture management in the presented patients and at separate trips to the theater before fracture fixation in other patients.
Before application of the NPWT, the wound and surrounding skin are meticulously cleaned to allow formation of a closed seal under vacuum. The use of tincture of benzoin at the skin adjacent to the wound can enhance adhesiveness to prevent leakage at junctional areas. Kerlix™ gauze (Covidien, Farmington, CT) is then laid onto the wound bed, covering all the areas of skin and blister that underwent dermal fenestration. A drain is then placed onto the gauze, followed by a film to complete the seal and produce a closed wound environment. The pressure of the V1STA (Smith & Nephew, London, UK) is set at 80 mm Hg. The absence of leaks is ensured by checking the maintenance of the pressure on the machine.

On removal of NPWT in our patients, the soft tissue appeared healthy, with minimal scarring from the dermal fenestration (Figs. 6 to 8).

Discussion

Severe axial loading is exerted on the lower extremities either by explosions occurring from beneath or when the casualty is thrown off the ground and lands on their feet. Ramasamy et al (25) demonstrated in their study that the environment (i.e., mounted and dismounted) in which the explosion occurs has an effect on the type of blast injury seen. Also, although the structure of a vehicle can mitigate the peak overpressure (primary) and moving object (secondary) related injuries, the tertiary blast effect and lower extremity fractures are more common in an enclosed environment such as a vehicle owing to movement and displacement of the vehicle’s occupants.

More than 70% of explosive combat injuries are located on the extremities (1), causing a mixture of traumatic injuries at the scene. These include complete traumatic amputation, nonviable but attached limbs, and attached and viable but extremely complex bony and soft tissue injuries. Calcaneal fractures are not uncommon and are
often associated with multiple other injuries in the military setting. Ramasamy et al (25) noted a rate of associated spinal injuries in the combat zone similar to the rate of 21% noted in falls from a height >2 stories of a building in the civilian setting. As discussed, infection is a serious complication of calcaneal fractures. In military open fractures, a higher rate of infection can be anticipated owing to contamination of the wounds resulting from the austere environment, propulsion of fragments and dirt deep into the tissue planes, and severe comminution of fractures owing to the significant forces present in explosive injuries.

IEDs causing calcaneal fractures can occur when dismounted (soldier on foot patrol) or mounted (in a vehicle). Ramasamy et al (6) described the modern “deck-slap” injury of calcaneal blast fractures from vehicle explosions, in which, on detonation of the device, the vehicle floor slams into the sole of the foot. If the calcaneal injury is at that point not an open one, a high chance still exists of it becoming so by the external explosive forces causing crushing of the soft tissue, the severity of the fracture itself, the dirt of the Afghanistan environment, limited hygiene, and poor nutritional status of the combat soldier who lacks his normal diet and has been expending more calories than he takes in. IED-related calcaneal fractures, therefore, have a high infection and amputation rate and only a few casualties are able return to preinjury military duties (6).

Most fracture blisters are thought to form within 24 hours (10). Initial swelling mainly results from the hemorrhage from torn blood vessels, leading to hemorrhosis or hematoma. After 6 hours, interstitial edema appears due to the increased vasodilation and yet decreased perfusion to traumatized tissue. This edema separates the epidermis from the dermis; fluid then fills the deficit to form the fracture blister. A case also exists for fracture blisters being more common in the area of the ankle (than at other anatomic locations) because of the unique differences found in ankle skin. Zirm (12) described flattened epidermal papillae over the malleoli, signifying a lack of arterioles between the rete ridges. Furthermore, the amount of subcutaneous fat is sparse and well-formed adipose or muscular layers are lacking. The skin is relatively thin, a collection of veins is present medially, and fewer hair follicles are present in this area. Hair follicles are thought to aid re-epithelialization in healing of split-skin graft donor sites and might help anchor the dermis to the epidermis—so their relative lack in this area might be a factor in blister formation. Although the calcaneum lies below true ankle skin, it is in close proximity and shares some of the features of ankle skin described.

Advocates for early intervention for calcaneal fractures believe that surgery within 6 to 8 hours of injury for patients with fractures at high risk of developing blisters is beneficial. Rapid surgical decompression during open reduction can release the soft tissue and drain the subcutaneous hematoma. Fixation of bleeding fracture surfaces can result in swelling reduction and provide an improved environment for soft tissue viability. Definitive surgery for complex orthopedic injury is not appropriate in a deployed field hospital. Surgery undertaken at a role 3 (field) hospital should be performed with regard to later reconstructive options and function preservation (26). Hence, rapid surgical decompression should not occur unless foot viability is absolutely at threat.

Foot fasciotomy is not without complications. The main indication for foot fasciotomy is impending or obvious compartment syndrome characterized by severe unrelenting pain. The aim is to reduce the morbidity of the contractures associated with muscle necrosis from the microvascular compromise resulting from the increased pressure in closed compartments (27). However, one of the main concerns with the fasciotomy procedure is wound closure. Myerson (18) reported on a series of 14 patients. Of these patients, 11 required split-skin grafting and 3 achieved delayed primary closure (18). Other complications included bleeding, nerve injury, and wound infection. Established foot compartment syndrome without decompression will lead to contractures and toe deformities; however, controversy exists regarding the significance of these complications compared with the morbidity associated with foot fasciotomy (28).
NPWT works by applying subatmospheric pressure to a wound filter material placed onto the wound bed (i.e., to the fenestrated and blistered areas over the calcaneum) and covered by an airtight seal to draw exudate to the canister collection device. It acts as a closed sealed wound device that maintains aseptic conditions as far as is possible and avoids soiled dressings. This is perhaps particularly pertinent for soldiers who being cared for in a working aircraft undergoing aeromedical repatriation back to the United Kingdom from Afghanistan. The dermal fenestration technique with the NPWT device can also help to mitigate swelling, remove exudate, maintain wound cleanliness as best as possible, prevent general wound de- dervation, and provide functional wound splinting. All these factors are extremely useful in the military setting regarding wound protection in the field hospital and during transport back to the United Kingdom. This technique can also be applied to civilian calcaneal fractures with the threat of, or actual, blister formation.

We, therefore, propose the dermal fenestration and topical NPWT technique as a method of preventing blisters in calcaneal fractures deemed to have a high potential for blister formation and in managing already evident calcaneal fracture-associated blisters. It can also obviate compartment syndrome and the subsequent need for foot fasciotomies. Our technique can be performed either before or during definitive surgery to prevent deterioration of the soft tissue insult and to prevent or reduce postoperative wound and compartment complications.

In conclusion, this technique is minimally invasive and has demonstrated good soft tissue results in our patients. We have since used this technique on several other military patients. In future work, we will report on a case series with longer term follow-up of patients treated using this technique and integrating this technique as a part of our protocol in the treatment and prevention of blister formation in IED-related complex foot fractures.

References
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