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Wartime Soft Tissue Coverage Techniques for the Deployed Surgeon

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ABSTRACT Background: Since the start of the conflict in the Middle East in 2001, military orthopedic surgeons have faced complex orthopedic injuries including high-energy soft tissue wounds, traumatic amputations, and open fractures. Although orthopedic surgeons are well trained in the management of osseous injuries, the treatment of soft tissue injuries can be technically challenging and unfamiliar. Early washout, debridement of devitalized tissue, external fixation of bony injuries, and antibiotic therapy remain the foundation of early wound management. However, these unique extremity injuries have no standard plan of care, and definitive treatment options continue to evolve. The following report highlights the typical cases seen in the wartime setting and offers possible solutions for the associated soft tissue injuries. Methods: A single orthopedic surgeon at a Role 3 combat support hospital performed all cases in this series. This study is a report of the cases that the orthopedic surgeon encountered while deployed and the various techniques that can be used to manage the complex wounds seen in a deployed setting. Findings: Twelve patients were included in this report and the data are shown. Of the 12 patients, 6 were injured by an improvised explosive device (IED), 4 were injured by a high-velocity gunshot wound (HVGSW), 1 was injured by a gunshot wound (GSW), and 1 was injured in an auto versus pedestrian motor vehicle crash. The wound sizes ranged from 10 to 300 cm^2. All patients required more than one irrigation and debridement before wound closure. There was a successful outcome in 11 of the 12 patients. The only patient without a known successful outcome was lost to follow up. Six patients were treated with split thickness skin graft (STSG) alone. Four patients were treated with STSG plus an additional means of coverage. One patient was treated with a random flap and one patient was treated with a full thickness skin graft. Integra was used in two of the patients. Each of the patients in whom integra was used had exposed bone and had a successful outcome with respect to tissue coverage. Discussion: This study details different soft tissue coverage techniques that must be learned and possibly employed by the deployed surgeon. Limitations of this study include its retrospective nature and the selected sampling of cases. At initial presentation, the management of war wounds secondary to high-velocity gunshot wounds and improvised explosive devices can be quite daunting. Adhering to firm surgical principles of thorough and meticulous debridement is the foundation of later soft tissue reconstructive options. Once the tissue is deemed clear of infection and contamination, there are myriad treatment options utilizing flaps, synthetic materials, and skin grafting. These are relatively straightforward techniques that the general orthopedic surgeon can utilize while deployed in a combat setting. In the end, it is critical for deployed surgeons to learn multiple techniques to provide definitive soft tissue coverage in a wartime theater.

BACKGROUND

The improvised explosive device (IED) is a major cause of casualties, accounting for 63% of all combat fatalities during Operation Enduring Freedom (OEF).[1] The North Atlantic Treaty Organization (NATO) defines an IED as a device fabricated in an improvised manner incorporating destructive, lethal, noxious, or pyrotechnic or incendiary chemicals and designed to destroy or incapacitate.[2] Explosive devices have accounted for 81% of all combat injuries in OEF with 82% of all extremity fractures being open.[3,4] Despite the high incidence of IED usage, improvements in battlefield trauma management and protective armor have resulted in an increased soldier survival rate.[5,6] Although injured soldiers in Vietnam had a survival rate of 76.4%, this has improved to 92.0% in the Afghan and Iraqi conflicts as of 2011.[6,7] This improved survival has resulted in a population of patients with mangled extremities and large soft tissue defects.[3] As many combat support hospitals lack the resources and technical skills that a plastic surgeon or microvascular surgeon offer for soft tissue coverage, early evacuation to a higher echelon of care is routinely performed. These advanced procedures are performed in a delayed manner. Military personnel are evacuated to higher levels of care, but local nationals will receive their definitive soft tissue coverage in theater.[8]

Since the start of the conflict in 2001, military orthopedic surgeons have faced complex orthopedic injuries including high-energy soft tissue wounds, traumatic amputations, and open fractures. Although orthopedic surgeons are well trained in the management of osseous injuries, the treatment of soft tissue injuries can be technically challenging and unfamiliar. Early washout, debridement, external fixation, and antibiotic

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therapy remain the foundation of early wound management. However, these unique extremity injuries have no standard plan of care.[9] The application of vacuum-assisted closure (VAC) devices has replaced wet to dry dressings until definitive coverage is possible.[10,11] VAC devices provide soft tissue defects with a clean, temporizing method for wound stabilization. This treatment plan is suitable for military personnel who are transported to larger medical centers, but the Afghan national army and local civilians rely on the treating physicians of coalition hospitals for definitive care.[8] The mechanism of injury for Afghan nationals is like that of coalition forces, with IEDs and gunshot wounds (GSW) causing many soft tissue injuries.[8]

Treatment of large extremity wounds consists of a coordinated team approach. For definitive coverage of large wounds, the use of split thickness skin grafting (STSG), bio-artificial dermal substitute, and local, rotational flaps have provided the mainstay of treatment.[12–14] The clinical experiences and lessons learned in wartime should not remain overseas. Instead, the principles developed during combat wound management can be applied and utilized in the domestic setting when managing similar traumatic injuries. This report chronicles the experiences of a single orthopedic surgeon working at a Role 3 hospital during OEF. It highlights the use of soft tissue management techniques that do not require the technical skills of a plastic or microvascular surgeon. It is critical for deployed surgeons to learn these techniques to provide definitive coverage in a deployed setting.

METHODS

This article describes the work of a single orthopedic surgeon at a Role 3 hospital in Afghanistan. This surgeon performed all 12 cases in the series. This series describes and details some of the more complex cases that the surgeon encountered while deployed and the techniques that can be used to manage the complex wounds seen in this setting. It details the unique aspects that the deployed environment presents to surgeons with limited resources who must still care for local nationals not transferred to a higher level of care.

FINDINGS

Twelve patients were included in this series and the data are shown in Supplemental Materials, Table 1. Of the 12 patients, 6 were injured by an improvised explosive device (IED), 4 were injured by a high-velocity gunshot wound (HVGSW), 1 was injured by a GSW, and 1 was injured in an auto versus pedestrian motor vehicle crash. The wound sizes ranged from 10 to 300 cm^2. All patients required more than one irrigation and debridement before wound closure. There was a successful outcome in 11 of the 12 patients with one patient being lost to follow up. Six patients were treated with split thickness skin graft (STSG) alone. Four patients were treated with STSG plus an additional means of coverage. One patient was treated with a random flap and one patient was treated with a full thickness skin graft. Integra was used in two of the patients. Each of the patients in whom integra was used had exposed bone and had a successful outcome with respect to tissue coverage.

RECOMMENDATIONS

IEDs used in Afghanistan are characterized by high explosive content, causing blast waves that accelerate surrounding debris, creating heavily contaminated wounds (Fig. 1). This high-energy injury can result in traumatic amputations and open fractures of the lower extremities. After the primary and secondary survey, the deployed surgeon must plan the extent of debridement. Debridement of a heavily contaminated wound requires several trips to the operating room to ensure removal of debris and devitalized soft tissue. When debriding high-energy wounds, adhering to important principles can facilitate future wound coverage and functional outcome. These principles include preservation of viable tendons and neurovascular structures and utilizing the four “C’s” when determining muscle viability (color, contractility, consistency, and capacity to bleed). Preservation of osseous length through external fixation or splinting and temporary wound coverage with wet to dry dressings or vacuum-assisted closure are two critical principles in orthopedic wound care. If the patient is to be transported to a higher echelon of care, definitive management should not be attempted. In general, adhering to the above principles help by leaving viable, large soft tissue flaps and preserving osseous length to facilitate the definitive management of these complex injuries.

FIGURE 1. Coalition soldier who sustained a complex lower extremity fracture including the talus, midfoot, calcaneus, and distal tibia. Initial presentation before debridement with eventual transtibial amputation as the anterior tibial and posterior tibial arteries were severed.

The debridement of HVGSWs is far more complex than those of low-velocity handguns (Fig. 2A–C). The soft tissue wounds created by assault rifles leaves a large wound bed of necrotic tissue. As more tissue becomes devitalized, repeat operative intervention becomes necessary to maintain healthy tissue margins (Fig. 3). Leaving nonviable tissue increases infection risk and can delay definitive care. Debridement of high-energy wounds is an art that requires patience, adherence to surgical principles, and foresight. A balance between debriding nonviable tissue and preserving vital structures must be employed.

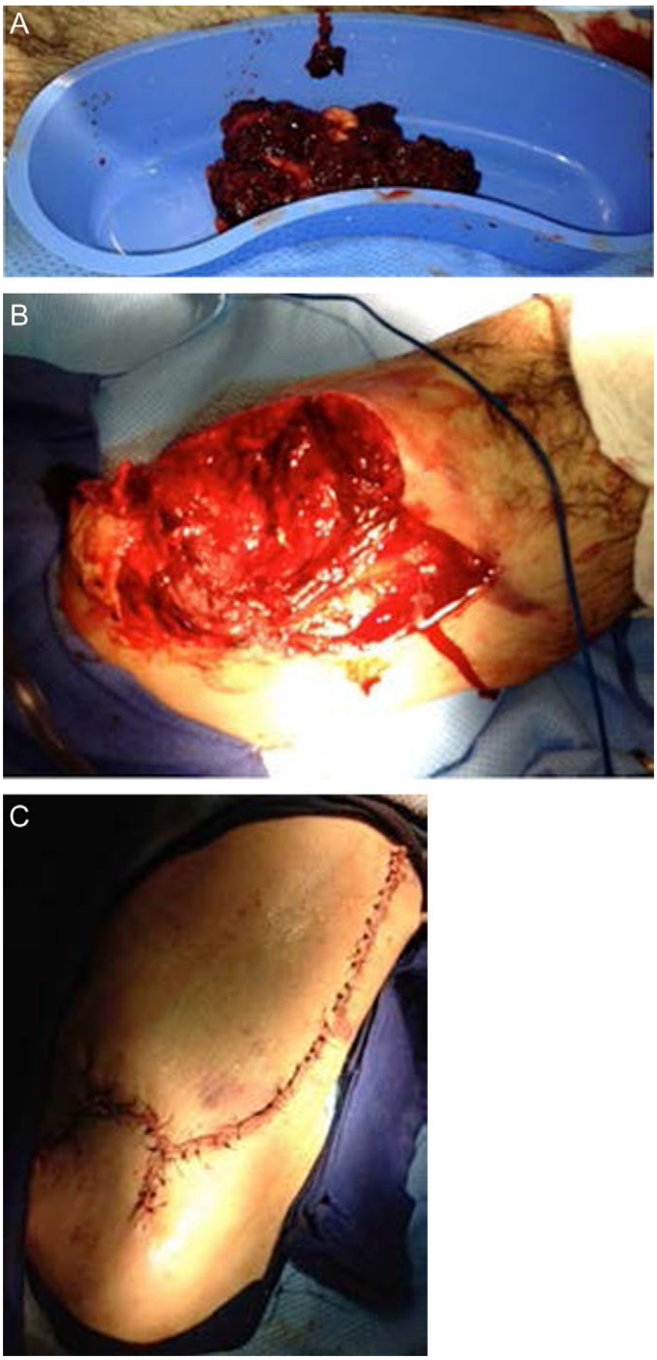

FIGURE 2. (A) Kidney basin demonstrating necrotic tissue removed. (B) Coalition soldier with proximal left thigh wound from 0.762 round, with extensive soft tissue destruction of sartorius, vastus, and rectus muscle bellies. (C) At the third debridement, patient was amenable to a tension-free closure with local rotation flap.

Generally, small wounds <10 cm are washed with 3 L of fluid. Four to eight liters are used for wounds >10 cm and 9 L or more for those with heavy contamination. Bulb irrigation or the use of large bore cystoscopy tubing with gravity flow irrigation is favored over pulsatile lavage. These recommendations are based on the Army institute of Surgical Research, Clinical Practice Guidelines. The use of antibiotics in irrigation has not been found to be superior to plain saline irrigation.[15]

The utilization of negative pressure wound therapy (NPWT) has revolutionized the management of war wounds. Before application of the foam sponge and negative pressure dressing, hemostasis should be achieved. The operating surgeon should not place direct pressure over the sponge, as this can hinder the seal. It is helpful to seal the least dependent zone of the wound first and then connect the standard wall suction tubing to the NPWT dressing until the remainder of the wound is sealed. The last area to seal is the dependent zone. Finally, application of an adhesive covering will immediately create a seal.[16]

Soft tissue injuries caused, by IEDs or HVGSWs, require a thorough debridement before application of NPWT. The deployed surgeon must be mindful when applying these devices since transport can be over 8 h. Civilian surgeons caring for large wounds with NPWT must also be mindful of an intact seal, because, if the seal is compromised, an anaerobic environment is created.[16] This can lead to increased bacterial replication and colonization (Fig. 4). If doubt exists on the ability to obtain or maintain a negative pressure environment, the surgeon should abort use of NPWT and consider wet to dry dressings.

Antibiotic impregnated PMMA beads offer the benefit of delivering high local concentrations of antibiotics while decreasing the risk of systemic toxicity. Indications for antibiotic beads include open fractures, traumatic amputation, osteomyelitis, and large soft tissue defects.[17]

The concurrent use of NPWT and antibiotic beads is often seen in the deployed setting. Although some evidence exists showing decreased antibiotic availability when NPWT is used with PMMA antibiotic beads, the levels eluted are still above the minimal inhibitory concentration.[18] When using PMMA beads with NPWT, the treating surgeon can place Adaptic over the beads or close the deep tissue and then cover the wound with a reticulated foam to decrease the antibiotics lost in elution. Heat-stable antibiotics amenable to the PMMA mixture include vancomycin, gentamycin, tobramycin, and cefazolin.[17] Antibiotic impregnated cement is also integral to the management of bony defects. Utilizing the induced membrane technique, the pseudomembrane that is created by the PMMA cement is rich in growth factors that promote osteogenesis. Stage 1 uses a standard cement spacer that is placed over an intramedullary device, external fixator,

FIGURE 3. Patient with dismounted IED injury with traumatic above knee amputation that was transferred from a Role 2 forward operating base. Patient had a debridement performed before 24 h. Here is seen an evidence of myonecrosis of the anterior thigh musculature. These areas must be sharply debrided to healthy bleeding muscle tissue.

FIGURE 4. Patient with a dismounted IED injury, complex bilateral lower extremity soft tissue injuries, pelvic trauma, and major thoracic injuries. Thoracic injuries necessitated clamshell thoracotomy. Patient is positioned prone here. Note the extensive contamination from debris forced into wound. Multiple vacuum-assisted machines are needed in this case in order to attain a negative pressure environment.

or plate depending on wound type. Stage 2 occurs when autogenous bone is grafted into place in the formed pseudomembrane capsule (Fig. 5).[19]

The application of external fixation for unstable injuries is pivotal in the management of high-energy injuries. Benefits include pain relief, control of blood loss, monitoring soft tissue injury, and reducing infection risk. Thorough knowledge of external fixation principles will limit complications while limited experience and poor understanding of the local anatomy may result in neurovascular injury and joint sepsis.[20] The initial treating surgeon should place the pins away from any future incision sites for definitive management. To avoid future contamination, all planned incisions should be drawn out and avoided with the temporizing external fixation.

Split thickness skin grafting (STSG) is a useful technique in both the deployed and the civilian settings. The donor skin serves as a scaffold for dermal regeneration. The importance of thorough debridement cannot be overstated before definitive closure. The recipient tissue bed must be well vascularized and preferably over viable muscle to allow tissue in growth. Shear forces on the skin graft and hematoma formation both negatively affect graft incorporation. Meshing of skin grafts at a 1:1.5 ratio allows for greater coverage of a wound bed, less donor morbidity, and allows egress of fluid to help prevent failure.[16] The placement of NPWT over STSG has been shown to improve graft survival and is better suited for large areas of grafting.[21,22] Negative pressure is set to continuous 75 mm Hg for 3–5 d. The longer duration improves graft take but can also stimulate granulation tissue. The authors prefer xeroform application over the wound with a non-adherent dressing that is left in place for 5–7 d. It is gradually removed as the donor site re-epithelializes.

Creating a viable soft tissue bed over exposed tendon or bone is challenging. Advances in dermal regeneration templates have allowed surgeons without microvascular training to manage these wounds. The Integra dermal regeneration template (Integra Lifesciences, Plainsboro, NJ, USA), was used in clinical application in the early 1980 s for the treatment of burn wounds.[23] An available formulation at our Role 3 hospital is a bilayer dermal substitute consisting of a deep dermal layer with a collagen–glycosaminoglycan biodegradable matrix and a superficial layer of semipermeable silicone. The dermal layer consists of cross-linked bovine tendon collagen and glycosaminoglycan, which provides a scaffold for infiltration of recipient fibroblasts. Histologically, host fibroblasts infiltrate the deep dermal layer and synthesize a neodermis, which is histologically similar in appearance and structure to normal dermis.[24]

After the proposed wound bed is thoroughly debrided and amenable for coverage, an appropriately sized integra graft is selected. Any irregularity of wound edges should be fixed to the donor bed with absorbable suture. This prevents crack formation at the junction of the wound bed and integra margin. The Integra is fixed to the wound bed with suture or staples and small pores in the silicone allow fluid egress. A non-adherent dressing is placed over the perforated silicone layer. NPWT is applied for 14 or more days. Recent evidence supports keeping the therapy longer, as it may promote neodermis formation.[14] Once a stable wound bed has been created, a STSG 0.008–0.010 in. in thickness is used for definitive coverage as it is the belief of the authors that utilizing STSG of slighter thickness is far more difficult and

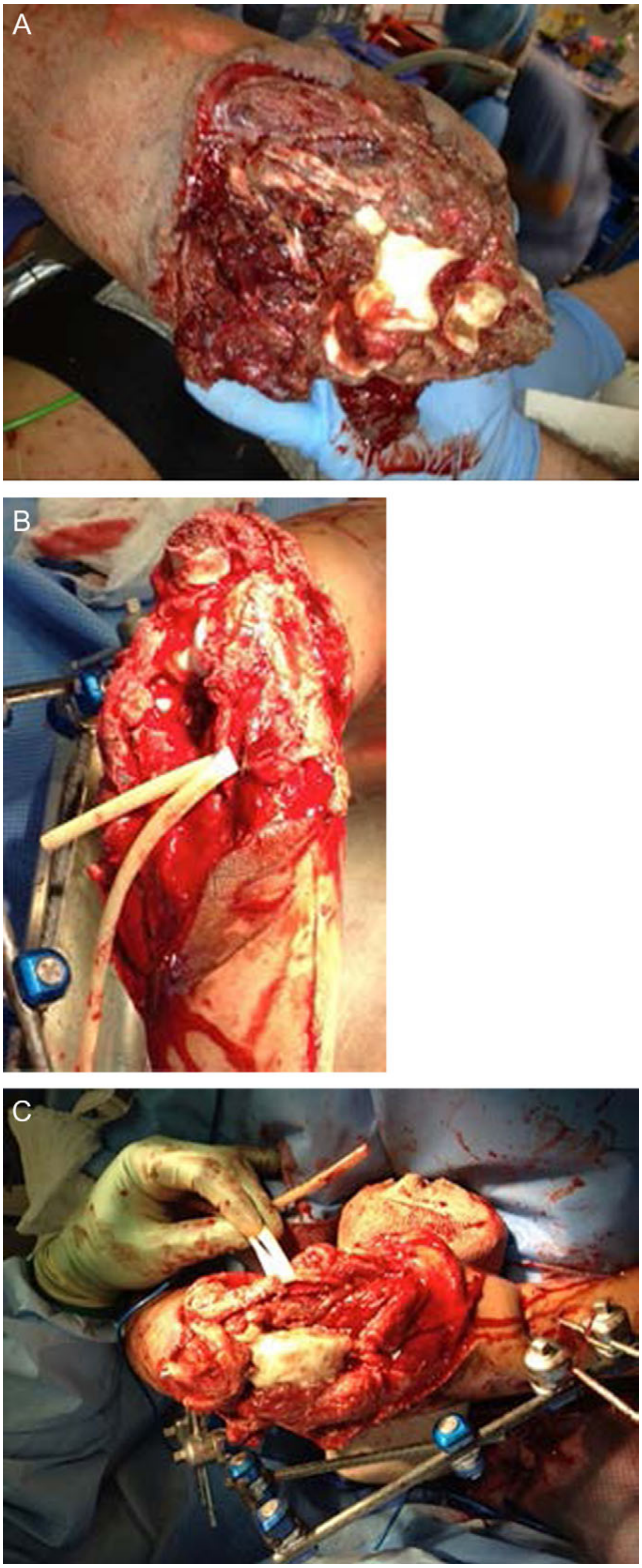

FIGURE 5. (A) Patient with complex proximal ulna fracture, with gross contamination after IED injury. (B) Patient had 4 cm of bone loss in the proximal ulna. (C) He was staged after repeat debridements with cement spacer, intramedullary fixation, and supplementary external fixation.

risks tearing. Standard use of NPWT in the setting of the STSG is then utilized as previously described (Fig. 6).

Definitive wound coverage with local rotational flaps offer an excellent option in the setting of large tissue defects. Adhering to principles including skin bridges, tension lines greater than 7 cm, and knowledge of the cutaneous vascular supply permit rotational flaps. The pedicle must be large enough to increase the number of vascular connections as flap circulation is supplied in a diffuse manner via microvascular connections. In general, the greater the number of vascular connections, the increased viability of the flap. The flap should be no longer than three times the width to maximize the perfusion (Fig. 2 and Supplemental Materials Figure 1). When sewing the flap over the defect, it must be free of any tension as this can decrease circulation and lead to flap necrosis. Blanching of the flap suggests excessive tension and requires revision. In cases where excessive tension exists, and no other rotational pattern is available, the authors recommend mobilization of the flap as close as possible, covering vital structures. The uncovered regions can be managed with negative pressure therapy or wet to dry dressings.

Choosing the correct method of coverage for these complex wounds is difficult. The initial intervention will always involve irrigation and debridement and ensuring hemodynamic stability in the setting of larger vascular injuries. The surgeon should decide if repeated irrigation and debridement will be needed and if an external fixation device is appropriate for temporary fixation of any fractures. Decisions on NPWT and the use of antibiotic impregnated beads or cement can also be made at this junction. Once nonviable tissue has been removed, and stable wound margins are present, the decision for definitive coverage is made. If exposed tendon or bone exists, a dermal substitute should be considered as previously detailed and left on until a viable wound bed is created. Once a viable wound bed is present (either initially or after placing a dermal substitute), skin grafting versus a flap for definitive wound coverage is the final step in the initial reconstructive process for the deployed surgeon.

DISCUSSION

Traumatic wounds in the deployed setting are unlike those commonly seen in a civilian setting. Military forces injured in theater will continue to the US and Europe and receive definitive care at major medical facilities. The local population does not have this option. Definitive soft tissue and osseous management is left to the deployed surgeon. The goal with the local national population is to provide definitive care for their wounds. The concern about how far up the reconstructive ladder to proceed comes into play for the deployed surgeon. One study surveying deployed surgeons found that they felt operating on local nationals "improved their readiness, benefitted the local population and contributed to counterinsurgency operations."[25] So long as military facilities have

FIGURE 6. (A–F) The patient shown is a 30 yr-old coalition soldier after mounted IED injury with traumatic below the knee amputation, and contralateral degloving of anterior and lateral leg with exposed tendon and bone. (B–E) Serial debridements, after third debridement, the patient is amenable to Integra placement followed by STSG once the wound bed is ready. The silicone layer usually changes to a deep crimson red. (F) Clinical appearance at 6 mo.

the capability and resources to care for local nationals most of them will. Causey et al. evaluated local nationals who were referred for humanitarian trauma care in Afghanistan in 2009. They found that the main reason for acceptance or rejection was only bed availability.[26] In settings where the deployed surgeon can operate and perform humanitarian work, the evidence would suggest that they are willing and able to.

Our primary success rate with the coverage techniques described was 100%. Of the 12 wounded patients, we had 6 mo follow up on 11 patients with 1 patient lost to follow up (Wound 2). The results are detailed in Table 1. Our sample size of patients with bio-dermal substitute was small ($n = 2$). Furthermore, the availability of bio-dermal substitute in the deployed setting was limited. Nevertheless, the initial incorporation rate was successful in both patients. There were no signs of gross infection. The patients went on to eventual coverage with split thickness skin grafting. Similar success in the treatment of exposed tendon and bone in those wounded in a wartime setting was found in a recent series by Helgeson.[14] A total of 16 traumatic wounds with exposed tendon or bone were managed with Integra and NPWT followed by skin grafting. The authors of this series were successful in 15 of 16 patients. They attribute success in part to the use of NPWT. The mean time in our patients between Integra placement and STSG was 14 d.

All patients in our facility had at least two operative debridements before definitive coverage. Further debridements were performed in patients that had gross contamination. The use of NPWT appeared to hasten the time to formation of granulation tissue and led to faster incorporation of grafts. These observations are supported by similar accounts in the literature.[14,21,22]

Limitations of this study include its retrospective nature and the selected sampling of cases. The experiences described provide a guideline for the forward deployed surgeon. In civilian centers, large open wounds with exposed tendon and bone are typically covered with free tissue transfer. The zone of destruction in war-wounded patients and resultant inflammation from free tissue transfer precludes its use here. Furthermore, the surgeon did not have microvascular and free tissue transfer training.

CONCLUSION

At initial presentation, the management of war wounds secondary to HVGSWs and IEDs can be quite daunting. Adhering to firm surgical principles of thorough and meticulous debridement is the foundation of later soft tissue reconstructive options. Once the tissue is deemed clear of infection and contamination, there are myriad treatment options utilizing local random flaps, the use of Integra, and split thickness skin grafting. These are relatively straightforward techniques that the general orthopedic surgeon can utilize while deployed in a combat setting.

SUPPLEMENTARY DATA

Supplementary data are available at *Military medicine* online.

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