Soft Tissue Coverage of Combat Wounds

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Warfare-related open fractures with large soft tissue defects create a significant reconstructive challenge. The objective of this article is to review current and evolving treatment strategies for soft tissue coverage of warfare-induced extremity wounds. A review of previously published literature and current data evaluating combat-injured personnel requiring extremity flap reconstruction performed by a single surgeon within the National Capital Area from 2004 to 2009 was performed. Collected data reviewed included injury patterns, methods of reconstruction, and success rates. Seventy-five (59 pedicled flaps and 16 free) extremity reconstructions employing flaps (34 fasciocutaneous, 34 muscle, and 7 adipofascial) were performed in the subacute time period between 7 days and 3 months. One hundred percent of the wounds were associated with open fractures. Early postoperative infections (<6 weeks from reconstruction) occurred in 10 patients (13%). Total flap loss occurred in two flaps (2.8%) and partial flap loss occurred in six flaps (8.3%). Two patients underwent early limb amputation after flap failure. Two additional patients underwent delayed amputation. Flap success was 97% and limb salvage rate was 94%. Based on the location of the extremity wounds, a reconstruction guide for flap type was created. Modern military limb reconstruction strategies in carefully selected patients with soft tissue defects have resulted in low flap loss rates and high limb salvage rates despite reconstruction in the subacute period between 7 days and 3 months. This limb salvage protocol is likely applicable in high-energy civilian motor vehicle accidents or industrial trauma when highly contaminated wounds are present.. (Journal of Surgical Orthopaedic Advances 19(1):29–34, 2010)

Key words: extremity trauma, flap, free tissue transfer, limb salvage, war wounds

The National Capital Region (National Naval Medical Center, Walter Reed Army Medical Center) continues to treat injured personnel supporting Operation Iraqi Freedom and Operation Enduring Freedom. Optimal reconstruction of massive soft tissue and bone defects of the extremities secondary to modern military conflicts remains controversial. The management of these injuries is unique for three reasons: 1) heavy bacterial contamination of wounds, 2) definitive reconstruction in the subacute period, and 3) multiple concurrent injuries.

For these unique extremity injuries, no standard protocol exists and reconstructive strategies are continually evolving. The principle of early radical debridement and wound coverage with vascularized tissue is followed. Other wound reconstruction principles may be used; however, the timing and type of flap reconstruction for these lower extremity battlefield injuries is generally based on anecdotal experience and surgeon judgment.

Evidence in the civilian literature indicates that early wound coverage provides better outcomes and that subacute reconstruction is plagued with high complication rates (1–7). Despite this, multiple factors including concurrent injuries, intercontinental medical evacuation, heavy wound contamination, and systemic illness have necessitated that war extremity wounds be reconstructed during the subacute time period between 7 days and 3 months (8–13). We reviewed the types of soft tissue reconstruction and outcomes of extremity battle injuries requiring flap reconstruction during this subacute time period.

Method of Reconstruction

Extremity-injured patients were initially treated with serial debridement until the wounds appeared clinically healthy with viable tissue. Between operative wound evaluations, negative pressure wound therapy (NPWT) [vacuum-assisted closure (VAC) therapy, KCI Licensing, Inc., San Antonio, TX] was applied to the wounded extremity. Uniplanar external fixation was placed far

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forward in the theater of operation and modified as necessary along the evacuation route. Wounds were reconstructed based on the judgment and experience of the plastic and orthopaedic surgeon. A standard reconstructive strategy based on the location of the wound evolved over time (Figs. 1 and 2).

Artificial skin substitutes were not used in isolation with this cohort of patients because of their underlying fractures. Many patients did, however, have wounds requiring both flap and artificial skin substitute wound reconstruction. Skin substitutes such as Integra Bilayer Matrix Wound Dressing (Integra Life Sciences, Plainsboro, NJ) were also commonly used in wounds without underlying fracture during this same time period. Following incorporation of the dermal analog, a split-thickness skin autograft was performed, significantly limiting donor site morbidity (14) (Figs. 3 and 4).

Physical and occupational therapy commenced upon transfer to the inpatient care ward and was modified according to the specific reconstruction and overall status of the patient. The uniplanar external fixation was converted to multiplanar ringed external fixation or internal fixation as indicated after soft tissue reconstruction was considered successful. When open reduction and internal fixation of fractures was deemed necessary, it was performed on the day of or the day proceeding flap coverage.

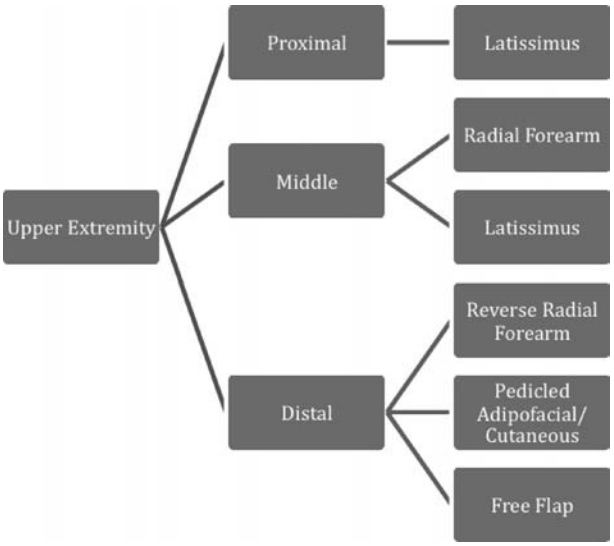

FIGURE 1 Upper extremity flap reconstruction of choice based on location of injury.

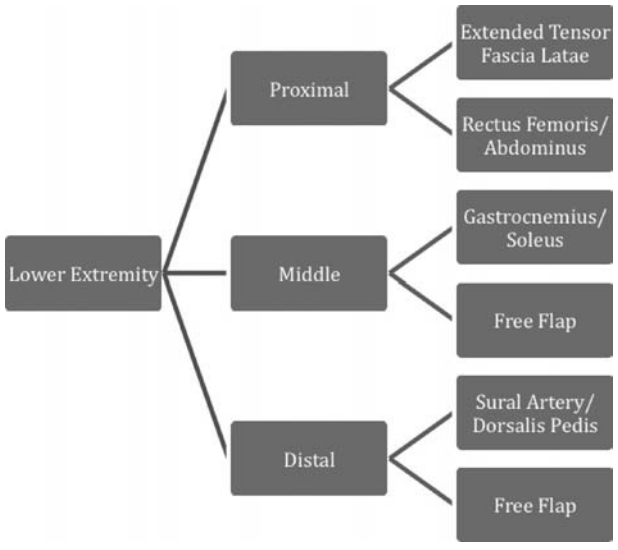

FIGURE 2 Lower extremity flap reconstruction of choice based on location of injury.

Outcomes

Seventy-five (59 pedicled flaps and 16 free) extremity reconstructions employing flaps (34 fasciocutaneous, 34

FIGURE 3 Large soft tissue wound to thigh with exposed muscle fascia (no underlying fracture).

FIGURE 4 Soft tissue wound with Integra placed onto the wound.

muscle, and 7 adipofascial) were performed. Over 70% of all injuries were associated with an improvised explosive device blast. Thirty-five upper and 40 lower extremity flaps were performed. One hundred percent of injuries were associated with regional open fractures managed with NPWT prior to reconstruction. Average number of prereconstructive irrigations and debridements was five. Average time to reconstruction was 21 days. Forty percent of all wounds were cultured positive at admission, of which 69% were associated with *Acinetobacter* species. Postoperative early infections occurred in 10 flaps (13.9%). Total flap loss occurred in two flaps (2.8%) and partial flap loss occurred in six flaps (8.3%). Two patients underwent early limb amputation after flap failure. Two additional patients underwent delayed amputation. These two patients went on to heal their fractures and had no soft tissue flap complications but were unsatisfied with their residual limbs and their level of function and thus desired elective transtibial amputations. Flap success was 97% and limb salvage rate was 94%.

Discussion

Byrd et al. (10) documented the necessity of early radical debridement and early (<5 days) vascularized soft tissue coverage of grade III extremity injuries. However, his model for civilian injuries does not recognize the evolution of care for modern battlefield injuries. To ensure the best medical care to injured military personnel, echelons of medical care have been developed, each with increasing medical capabilities. Early care is focused on life, limb, and eyesight preservation. The next stage of treatment involves transportation to major hospitals for definitive surgical treatment. In our patient population, it is not possible logistically to provide flap coverage within 72 hours from the time of injury. In most instances, our patients have not yet reached the level V treatment center by this time. Due to the high soft tissue contamination and often delayed appearance of progressive muscle necrosis in these high-energy blast injuries, early flap coverage within 7 days has not been performed at our institution.

We have demonstrated that this delay in reconstruction does not unfavorably affect outcomes. If surgeons adhere to the established principles of creating a clean wound bed and using healthy vascularized coverage, infection and flap failure can be minimized. Compared to the body of orthopaedic and plastic surgical literature, our experience demonstrated low flap failure rates and reasonably low rates of infection (10–12, 15). This represents a significant improvement in management of devastating open extremity fractures in the subacute period.

Even with heavy wound colonization prior to flap coverage, our results indicate an acceptable postoperative infection rate (13.9%) and a low flap failure rate (3%). Bermudez et al. (8) reported significantly worse outcomes with a similar cohort of patients from the Colombian conflict in which they had a 12.5% free flap failure rate. Even the landmark article on early soft tissue coverage by Godina (11), which reported the lowest flap failure rates and infection rates with early flap coverage (<72 hours from time of injury), reported significantly higher rates of infection and flap failure if reconstruction was performed during the subacute time period. Godina reported a 0.75% flap failure rate, 1.5% infection rate, and a union time of 6.8 months in limbs reconstructed within 72 hours of injury. In the subacute period, however, he reported a 12% flap failure rate, 17.5% infection rate, and a 12.3-month time to union.

Despite poor results obtained by many for flap coverage in the subacute time period, there has been limited civilian literature to support that adequate results can be obtained during this time period. While most clinicians would prefer to provide early wound coverage, this is often not possible. Yaremchuk et al. (16) found no negative effects with soft tissue wound coverage at an average of 17 days in patients with severe open IIIB tibia fractures. They reported this in 1986, the same year as Marco Godina's landmark article on early flap coverage. More recently, in a review of delayed flap coverage of both upper and lower extremity open fractures, Steiert et al. (17) found a low rate of both infection and flap failure performed in the subacute time period.

It is uncertain what variables allow for the successful flap coverage of wounds during the subacute time period. Clearly success in this time period is attainable, yet high rates of infection and flap failure during this time period are frequently reported. This is obviously a complicated clinical question with a complex multifactorial answer and is not likely readily answered by the current literature. Yaremchuk reported that the true zone of an injury is often not readily apparent at the initial or even a "second look" debridement. He stated that the zone of injury is often far more extensive than originally thought and that only through serial debridements was the true zone of injury adequately appreciated. He concluded that in high-energy wounds, the delay in wound coverage and serial debridements had a positive rather than a negative effect on the clinical outcomes.

Steiert et al., in a more recent review, agreed with the difficulty of identifying the true zone of injury during the early time period, yet they also highlighted the advances in wound care over the past 20 years and specifically discussed the use of the NPWT (VAC therapy, KCI Licensing, Inc., San Antonio, TX) device as a significant contributor to the overall success of flap coverage in this subacute time period. In contrast to these results, however, a recent review of IIIB open tibia fractures at a level one trauma center within the United States revealed an overall

infection rate of 36% when flap coverage was provided in the first 7 days after injury. When coverage was delayed beyond 7 days, the infection rate soared to 57%. Their treatment protocol included NPWT application to open wounds, following initial debridement and stabilization, and then repeat irrigation and debridement procedures in the operating room every 48 hours until definitive soft tissue coverage (18).

Clearly the variables that allow for successful soft tissue coverage in this subacute time period are not fully understood and a thorough analysis of the preceding papers reveals a significant shortcoming in the reporting of open fracture data. Although most authors support a multidisciplinary approach to the management of these injuries, the data are often published in a plastic surgery or an orthopaedic surgery journal without adequately addressing the composite nature of the limb salvage protocol. In many reviews of open fractures requiring flap coverage, the exact timing and type of both the initial and definitive fracture stabilization are not clarified. This makes it very difficult to understand the implications of early versus delayed soft tissue coverage and the overall limb salvage protocol.

It is our opinion that the successful coverage of these open fracture wounds is achieved within the subacute time frame for a variety of reasons. We agree with Yaremchuk that the evolution of the zone of injury in severe extremity trauma is undeniable. This evolution is even more pronounced with a blast-induced injury and progressive necrosis of tissue is sometimes readily apparent even after the second or third debridement at the level V institute in the United States. Another likely contribution to the success of this limb salvage protocol was the avoidance of internal fixation when possible and the timing of the definitive fracture treatment, which was usually coincident with or after the time of soft tissue coverage. This frequently occurred greater than 48–72 hours after flap coverage.

Likely the greatest contributor to the success of this limb salvage protocol in the subacute time period is the orthoplastic approach to the treatment of these injuries. Daily consultation between the orthopaedic surgeon and plastic surgeon who treated the patients in this review was imperative. Both surgeons were present in the operating room for a majority of the initial debridements and were almost always both present at the time of definitive debridement before soft tissue coverage. All bone fixation and soft tissue procedures were thoroughly timed and planned by both the plastic and orthopaedic surgeon with the best overall outcome in mind, as opposed to the usual interest in selective flap success or fracture union.

Free and pedicled flaps have been used with equal success for extremity reconstruction in a civilian model as well as in our reported experience (6, 13). Despite this success, it is necessary to acknowledge that pedicled tissue transfer occurred 3.7 times more commonly than free tissue transfer in our military cohort. While we have had good success with free tissue transfer in carefully selected patients, it is imperative in the management of these complicated patients that the ladder of soft tissue reconstruction be acknowledged. In this patient population with multiple extremity injuries, the simplest and least morbid solution to coverage is selected to ensure that the optimal overall outcome is achieved. Recently, in the civilian reconstruction of extremity injuries there has been a trend toward early and more common free tissue transfer over pedicled transfer due to the improved technical skills and surgical abilities of microvascular surgeons. Despite the potential benefits that have been noted with this management (19–21), we are less likely to advance up the soft tissue ladder of reconstruction without adequate reason when a very reliable pedicled flap will provide a successful outcome (Figs. 5–7).

Conclusion

Reconstruction of extremity war injuries begins with aggressive forward resuscitative care and stabilization of the trauma patient. After serial care at increasingly more supported medical environments, definitive management occurs at the level V military treatment facility. Aggressive forward care coupled with rapid air transport has allowed increasingly complex care to occur at the home military facility but has also created a new set of challenges with regards to limb salvage versus amputation. Specifically, optimal timing of definitive wound closure or coverage in coordination with fracture stabilization and the optimal types of flaps for lower extremity reconstruction have yet to be determined.

FIGURE 5 Twenty-year-old US Marine with open periarticular elbow wound status post multiple irrigations and debridements and open reduction and internal fixation.

FIGURE 6 Same patient with latissimus flap raised.

FIGURE 7 Latissimus flap transferred as a pedicled flap providing coverage of the open wound. (Split-thickness skin graft to be performed over flap).

In addition to practicing established concepts from prior military conflicts, incorporating treatment with novel flap reconstructions has led to improved outcomes.

The ultimate goal for extremity reconstruction for a civilian or a soldier is return to function. Active duty military personnel represent a highly motivated group. Our outcomes of limb salvage have shown that the current practice protocol is successful even with devastating heavily contaminated war injuries in the subacute period.

Decision making in the management of combined major skeletal and soft tissue trauma is a complex process. Our experience with timing and choice of flap reconstruction was related to each individual case. The importance of performing soft tissue coverage prior to or simultaneously with the definitive fixation cannot be overstressed in these complex open combat wounds. The avoidance of internal fixation or intramedullary nailing of these complex fractures may also contribute to improved outcomes and relatively low infection rates.

Every injury is to some degree unique and, therefore, any conclusions based on this review would still need to be interpreted in the context of the patient and the particular wound characteristics at presentation. Details of long-term data such as fracture union rate, return to duty, global function of salvaged limbs, patient satisfaction with limb salvage, and average cost are currently being collected. The current experience supports limb salvage even in the subacute period in carefully selected patients.

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