Since the beginning of post 9-11 combat operations in Afghanistan and Iraq, more than 2400 soldiers and Marines have been killed. Additionally, over 17000 have been wounded with approximately 8000 of those wounded so severely that they were unable to return to duty. Improvements in ballistic body armor and protective helmets have improved a combatant’s chances of survival and improved the ratio of killed to wounded from 1:4 in World War II, to 1:7 in today’s war. Unfortunately, the combatant’s extremities remain unprotected and consequently the majority of war injuries are sustained in these areas. Approximately 60-70% of non-lethal injuries are now orthopedic in nature.

Although gunshot wounds remain a common occurrence on the battlefield, blast weapons such as rocket-propelled grenades, mortars, and especially Improvised Explosive Devices (IEDs) cause the most devastating injuries. The ability of these weapons to strip away soft tissue, fracture bone and produce contaminated wounds is dramatic. Aggressive surgical management of these wounds along with new techniques have met with some success, yet nearly 600 military members have undergone amputations ranging from fingers to multiple extremities. This current amputation rate is only slightly less than that of the Korean War and about equal to that of the Vietnam War.

Service members returning to either National Naval Medical Center or Walter Reed Army Medical Center undergo an average of 5-6 surgeries from battlefield to final closure, not including delayed reconstructive procedures. The first of these surgeries is usually performed less than one hour from the time of injury and additional debridements are performed during the transportation process. Definitive management occurs back in the continental United States. The mainstay of battlefield wound treatment continues to be multiple aggressive surgical debridements, stabilization of fractures, and delayed closure (either primary, secondary or flap coverage). However, the technique and timing of both debridements and soft tissue coverage continue to evolve. An ongoing dialogue and additional review should prove helpful in maximizing limb functional outcomes and reduce the rate of amputation.
Combat casualty care is a dynamic process that continues to evolve with respect to types of injuries, frequency, timing of treatment, and location of care. Landstuhl Regional Medical Center in Germany has the unique experience in this process since it is the initial receiving facility for all casualties from the combat theaters of operations (Operation Enduring Freedom and Operation Iraqi Freedom) in our continued Global War on Terrorism. A majority of patients arrive to LRMC from theater approximately 12 hrs to 48 hrs from injury and initial evaluation. Length of stay in the theater medical facilities is dependent upon stability of the patient and medical evacuation aircraft availability. Triage upon arrival to LRMC was performed by the designated representative from the surgery department. Casualties with multi-system involvement were assigned to the general surgery service. The Orthopaedic Surgery service was the primary service for patients with isolated extremity injuries and was consulted on all other patients with orthopaedic injuries. All major procedures involving extremity injuries were performed by an orthopaedic surgeon. Since LRMC was the first medical facility outside of a combat zone, patients could be re-assessed in a safer, more stable environment. All patients had an assessment upon arrival to LRMC and, after admission, had a complete re-assessment by the admitting service. Additional injuries were addressed as indicated. All wounds were re-evaluated. Most wounds that required an operative procedure in theater were re-evaluated in the operating room. This repeat debridement and irrigation occurred approximately 24-48 hours from the initial (or most recent) procedure that had been performed prior to departure from theater. It was felt that the wounds should be evaluated in the operating room at LRMC because the improved working conditions in this facility as compared to ‘in theater’ conditions. As well, it was determined that tissue injury and necrosis was continuing during the rapid evacuation process and warranted additional, updated evaluation and treatment. Along with improving the status of the soft tissues of the extremity wounds, evaluation of any bony stabilization was performed. Any adjustment, augmentation, further fixation was performed at that time. Average evacuation time from LRMC to CONUS (continental United States) was approximately 4 days, therefore, LRMC was usually not the facility to provide definitive fixation. Special attention was given to amputees, both upper and lower. With the advent of designated amputee care facilities, and the improved evacuation times, LRMC was not a definitive care facility for amputations. The goal at LRMC was to adequately debride all devitalized tissue and preserve all viable tissue. Flaps, definitive amputation level, prosthetic fitting, etc., would all be performed by the CONUS amputee centers. Non-urgent/emergent orthopaedic injuries (combat and non-combat) were evaluated for stabilization and definitive fixation was performed, if time and resources permitted. The Orthopaedic Surgery Service at LRMC was also responsible for ensuring continued, rapid and efficient evacuation to CONUS. Based upon injury and military unit location, each patient was evacuated to the appropriate military medical treatment facility in the U.S. Continued trauma reassessment, aggressive management of soft tissue injuries and providing adequate bony stabilization for further transport, along with maintaining constant communication with facilities in theater and CONUS, have provided for high quality combat casualty care at LRMC while maintaining the rapid evacuation process to definitive care facilities.
This presentation examines the techniques of wound debridement for extremity war injuries, detailing the common operative techniques and grading the evidence to support those techniques using the US Government Agency for Health Care Policy and Research classification.

The treatment of ballistic wounds in 20th century warfare, carrying on into the 21st century, derived in large part from the experiences of the Great War 1914-18. At the Inter-Allied Surgical Conference in 1917 the extent of surgery appropriate for limb wounds was discussed in detail, and a consensus view was reached (Level C evidence). This emphasized:

- Excision of the skin margin
- Generous extension of the wound
- Exploration through all layers
- Excision of damaged muscle

The French surgeons at that conference popularized the term debridement, initially implying the action of cutting tissues which strangulate the organ or tissue which they cover. The term was adopted into common usage, but was taken, in the English speaking world, to imply a rather more extensive procedure: incision, including excision of the damaged underlying tissues. The Official US Medical History from that war illustrated the procedure, and the techniques would be recognized by all trauma surgeons operating on extremity wounds today.

Ballistic science and clinical practice throughout the last century and into the present have thrown light on the biophysics and pathophysiology of wounds (mainly level B evidence) and have examined the value of the techniques outlined above; for many extremity wounds the principles of management remain unchanged.

The proponents of surgical excision of tissue believe that this process removes or reduces the potential culture medium within the wound, or hold that the residual tissue is better able to mount a biological defence against the contaminating bacteria. In deciding on the amount of tissue to be removed surgeons have relied on the criteria for muscle viability, which have become known as the 4Cs criteria:

- Contraction on being pinched
- Consistency not waxy or “stewed”
- Capillary bleeding when cut
- Colour red not pale or brown

The validity of these criteria has been investigated, and there is evidence for the clinico-pathological significance of consistency, contractility and capillary bleeding (level B evidence). An experimental study has also shown the value of colour in determining blood flow within the muscle (level B evidence).

Extensive experience of handgun wounds in an urban “peacetime” environment has led to questioning of the need for surgical exploration or wound debridement, particularly in these low energy transfer wounds. There is clinical evidence from large series to support the policy of non-operative management of selected wounds (level B evidence) – the question that remains is how best to select these wounds. There is similar evidence from experimental studies and published clinical experience to show that selected small fragment wounds (“shrapnel”) may also be safely managed non-operatively (Level B evidence) – the same question about selection of wounds pertains.

The essence of surgical management of ballistic wounds to the extremities, supported by ballistic and clinical evidence, remains very similar to that promulgated a century ago: skin can be excised with a narrow margin; fascia should be generously released; all layers of the wound should be explored and gross contamination removed; non-viable muscle (according to the 4Cs criteria) should be excised. It is accepted that some low energy transfer wounds will actually consist of little tissue damage and can be safely managed non-operatively, provided that there is confidence in the assessment of the severity of the wound. Questions remain around the safe and effective way to assess wounds and decide on operative versus non-operative management.
Open fractures, particularly those associated with high-energy mechanisms of injury, have long been thought to represent surgical emergencies. Most texts recommend surgical debridement within 6-8 hours of injury. The American College of Surgeons Committee on Trauma in its Resources for Optimal Care of the Injured Patient defines 6 hours as the benchmark for debridement of open fractures in institutions considered trauma centers.

While the urgency of debridement within 6-8 hours of injury seems nearly universally accepted, the data supporting such dogma is lacking. Gustilo and Anderson’s landmark paper in 1976 describing prevention of infection after 1025 open fractures noted that “There is universal agreement that open fractures require emergency treatment including adequate debridement and irrigation of the wound.” Their statement is, however, un referenced. The theory that emergent debridement decreases infection risk seems to have been based on pre-antibiotic era war injury experience and animal data plus information about bacterial doubling times.

There are no Level I studies published in the literature comparing early versus delayed debridement for treatment of open fractures, and such studies would be problematic to design. Multiple factors influence timing of debridement of open fractures including operating room availability, surgeon availability, and the patient’s physiologic status. In the military environment, the patient’s location vis-a-vis the location of the nearest appropriate operating room is an important additional variable. In some combat scenarios, evacuation of wounded soldiers to a medical facility capable of operative debridement of an open fracture may need to be delayed until a safe transport mechanism can be secured. Patient and injury variables further complicate any analysis of the independent effect of timing of debridement on the incidence of any postulated important outcome measure such as incidence of infection. Thus successful design and completion of a prospective randomized comparison between early and delayed operative debridement of open fractures is unlikely to be successful.

Conversely, several series have recently examined results after relatively delayed debridement of open fractures. Skaggs et al reviewed 554 open fractures in 536 consecutive children treated at six centers and found no significant difference between injuries treated within six hours versus those treated after 7 hours. They concluded that in the context of early antibiotic administration, operative debridement of open fractures within six hours of injury offered little benefit as compared to debridement within 24 hours. Noumi et al from Kitasato University in Japan used multivariate analysis to assess the degree to which multiple factors contributed to the incidence of acute infection after intramedullary nailing of open femoral shaft fractures. They determined that only Gustilo type was predictive of infection risk and that only fracture severity as measured by the AO classification was predictive of non-union risk. Timing of operative debridement was not a predictor of either defined adverse outcome.

Khatod et al reviewed 106 tibia open fractures in 103 patients and noted no difference in infection rate when debridement occurred greater than 6 hours after injury as compared to debridement within 6 hours of injury. Regardless, they continued to recommend emergent treatment of open fractures citing inadequate analysis of co-variables and a high rate of loss to follow-up as study weaknesses.

In multivariate analysis, Harley et al found no significant relationship between time to debridement and either infection or nonunion in 241 open long bone fractures when debridement occurred within 13 hours of injury. Similarly, Spencer et al found no increase in infection rate in 142 open fractures when time to debridement exceeded 6 hours. Only one study of by Kindsfater and Jonassen reported an increased incidence of osteomyelitis with delay in debridement of open fractures and that study was biased by dissimilarities between treatment groups.

I and others reviewed the timing of treatment in a subgroup of 315 patients with open fractures enrolled in the LEAP Study. All patients sustained open lower extremity fractures deemed to be limb-threatening by the treating surgeon. Multiple patient, injury and treatment characteristics were recorded prospectively including time of injury, time of admission and time of debridement. Incidence of infection within the first 6 months after injury was the measured outcome. We found a significant relationship in multivariate modeling between incidence of infection and time from injury to admission to the definitive treatment center. Time from injury to debridement did not predict infection in bivariate or multivariate analysis suggesting that something occurring upon admission to the definitive treatment center was associated with a decreased infection risk. Postulated factors included antibiotic administration and aggressive fluid resuscitation. Further examination to define the potential role of these factors was not possible given the data available.

Factors resulting in delays in operative treatment in civilian populations are common and include patient, surgeon and facility variables. Emergent debridement of open fractures may be complicated by additional logistic issues in a combat environment. Overcoming such issues may compromise safety in certain situations. Such compromise would not seem warranted based on available data from civilian populations. Further analysis is indicated to assess the effect of time to debridement on infection risk in open fractures associated with war.
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 conus 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 both upper and lower extremity reconstruction have yet to be determined.

The experience at the National Naval Medical Center from 9/2004 until present with complex lower and upper extremity wounds was reviewed. During that time period 59 flaps were performed for complex wound closure. The distribution by location was 7 craniofacial, 23 upper extremity, 26 lower extremity, and 3 torso flaps. The types of flaps were:

**Upper extremity coverage by region from proximal to distal:**

- Shoulder/Upper arm: Latissimus muscle flap
- Forearm: Local fasciocutaneous flaps (bipedicled, reverse radial forearm)
- Hand: Local fasciocutaneous flaps (bipedicled, reverse radial forearm), Local reverse adipofascial flaps, Reverse cross finger flaps, Finger amputation fillet flaps, Free contralateral radial forearm flaps, Free ATL flaps, Pedicled Abdominal flaps, Pedicled Groin Flap, Pedicled adipofascial flaps

**Lower extremity coverage by region from proximal to distal:**

- Hip/Groin/Sacrum: Oblique skin island rectus abdominus musculocutaneous flaps, Extended TFL musculocutaneous flaps with distal delay
- Thigh/Knee: Pedicled rectus femoris muscle flap, Pedicled Gastrocnemius flaps
- Leg: Pedicled gastrocnemius flaps, Pedicled Soleus flaps, Free rectus abdominus flaps, Free ATL flaps, Peroneal muscle flap
- Foot: Dorsalis pedis flaps, Local Bipedicled skin flaps, Reverse sural artery flaps, Medial plantar flaps, Medial calcaneal flaps, Free serratius anterior flaps, Pedicled adipofascial flaps

Early analysis of the flaps utilized above revealed an infection rate of 5% (3/59), total flap loss 0%, partial flap loss 5% (3/59), failed limb or finger requiring amputation post flap 3% (2/59). Long term data such as fracture union rate, time to ambulation, range of motion and global function of salvaged limbs, patient satisfaction with limb salvage, and average cost are currently being collected. Optimal timing of closure and optimal flap type are yet to be determined.
Little has and should change regarding the principles underlying wound coverage in complex extremity injuries. Achieving wound closure as early as possible with the goal of maximal tissue preservation and, more importantly, optimal functional outcome, must be a constantly sought after goal. That being said, with the epidemic of recent, horrific battlefield extremity injuries in our military population, we have been forced to rethink some of the evolving tactics which have served us well over the last three decades in the treatment of primarily civilian based, low to medium energy trauma. Three components of the current injury profile coming out of Iraq are particularly noteworthy. 1) The massive nature of the extremity injuries being seen and treated, 2) The high rates of infection involving acinetobacter baumannii, and 3) the distance and complexity of triage to tertiary treatment sites. Not since the Vietnam War has there been such an epidemic of devastating war related injuries resulting in the military fighting force. As in that war, aggressive soft tissue, bone and blood borne infections complicated matters further. Interestingly enough, acinetobacter baumannii was one of the most frequently cultured bacteria in that population as well. Triage efficiency has changed drastically with the rapid and deliberate movement of survivable extremity injuries out of theater towards state of the art treatment facilities with minimal delay. Wound coverage must never supersede thorough, repeated, and aggressive debridement. Dressing intervals between debridements are affected by specific treatment modalities including traditional bandages, the wound VAC and nonoperative alternatives such as the whirlpool. Once a patient is stabilized, his or her wound adequately cleaned, necrotic tissue removed and infection appropriately treated, definitive closure should be the first order of business. In the early course of wound assessment, given all of the complications that may occur in the early phases of treatment, the judicious use of primary amputation, as in past conflicts, plays an increasingly important role. As in massively burned patients, interval split thickness skin grafting of those components of a complex extremity wound which only require superficial soft tissue closure should be encouraged. Post traumatic osteomyelitis, nonunions of long bones, infected or otherwise should be treated according to well tested protocols inclusive of rigid fracture stabilization and vascularized tissue transfer. Local muscle flaps, fasciocutaneous flaps or free tissue transfers may play a vital role. Timing of closure will depend on local tissue environments such as edema and perivascular fibrosis, regional factors such as usable vascular inflow and venous drainage, and systemic factors such as sepsis or destabilizing visceral, neurological and thoracic injuries. With well experienced extremity reconstructive surgical expertise, the entire gamut of free tissue transfers should be available. Muscle coverage alternatives include latissimus, serratus, gracilis, and rectus abdominis. Skin flap transfers include parascapular and scapular flaps, radial forearm, groin, DIEP and anterolateral thigh flaps. Vascularized bone transfers are primarily based on the fibula, when available. Smaller transfers may be constructed from the humerus, radius or lateral border of the scapula.

Flaps should be constructed and inset with the idea that they will require subsequent elevation for open reductions and internal fixations, bone grafting, nerve or tendon repairs and further soft tissue reconstruction. Concomitant physical therapy must be instituted when possible to maintain joint motion and prevent loss of muscle mass and flexibility. Nutritional supplementation is routinely overlooked in the firmament of acute care activities and must be constantly kept in focus. Understanding the long term investments that will inevitably be required of the patient and healthcare professionals, an overall strategic plan for recovery, including reintegration into familiar support structures such as family, friends and community should start early. Our initial enthusiasm towards early surgical reconstruction and its technical demands should not deflect us from planning for and working towards the overall goal of maximal functional return of a rehabilitated patient.
Session I: Wound Management A: Presentation 6

Removal of Retained Shrapnel: When and Why?

Meir Liebergall, MD

Background: Civilian shrapnel injuries became widespread during the course of the last decade. In modern warfare they are the most common injury of the musculoskeletal system, accounting for 60-70% of all injuries. Where in the past shrapnel injuries were exclusively found in the combat field, recently these injuries have reached epidemic proportions in major capital cities around the world which have been exposed to terror attacks and crime. Shrapnel injuries are inflicted either by a direct weapon or are secondary to blast explosions which cause fragments and other debris to become flying objects. The acute management of shrapnel wounds depends primarily on the amount of energy carried by the particles and the anatomical location hit by the shrapnel. The tissue damage caused by high velocity bullets or shrapnel is significant and requires thorough irrigation, debridement and if possible, removal of the shrapnel. In the case of low velocity shrapnel, there is a smaller potential for infection, and surgical intervention is not always needed. Removal of shrapnel is not always practical because of its location or size, but peri-articular involvement, proximity to neurovascular structures and shrapnel in contact zone necessitate surgical intervention.

Retained shrapnel carries the potential for local tissue or systemic toxicity inflicted by certain metals, such as lead and depleted uranium projectiles, and biohazards such as organisms like hepatitis, HIV and other potential blood-carried organisms. These biohazards are either deliberately added to the shrapnel or are carried by the blood of other victims at the scene. The literature review confirms many case and small series reports of retained bullets that have caused systemic toxicity, nephropathic disease, male sterility and local tissue complications such as cysts, foreign body granulation tissues and others.

Diagnosis: Plain x-ray films are, in the majority of cases, sufficient for the diagnosis of shrapnel injuries because of their metallic radiopaque nature. A CT scan is needed in order to view the precise position of the shrapnel in relation to anatomic structures. Understanding the exact position of the shrapnel determines the indication and approach for its removal. MRI is usually contraindicated due to the potential of additional tissue damage caused by the shrapnel under influence of the magnetic field.

Treatment: The treatment algorithm is chronologically divided into acute, sub-acute and late phases. In the acute phase, treatment depends upon the amount of energy carried by the shrapnel. In cases of high velocity weapons or shrapnel, or in cases of a low velocity weapon used from a short distance, debridement of the necrotic tissue and irrigation is mandatory, and the shrapnel is usually removed at this stage. In cases of vascular and neurological impairment, a multi-disciplinary team approach is required. In the case of low velocity weapons or shrapnel, the immediate treatment protocol is still debatable, but the trend nowadays is to treat these injuries less aggressively and on an ambulatory basis. The sub-acute phase relates to cases where removal is not immediately performed, but removal is indicated due to the shrapnel's proximity to neurovascular structures, the neural canal or peri-articular placement.

Late removal is indicated in cases where the shrapnel become locally or systemically symptomatic due to the dissolving of the metal in the shrapnel. Another indication nowadays is when an MRI is indicated for other unrelated medical reasons.

Surgical Removal: Detection and tracking of shrapnel during its removal remains a challenge. There is a constant tradeoff between soft tissue damage during dissection and the benefit gained by removing the shrapnel. For this reason, shrapnel is often left latent in situ, without being removed. Fluoroscopic guidance during these surgeries is crucial, it guides the surgeon through the procedure, locating the shrapnel and properly positioning the surgical tool. The difficulty lies in the fact that fluoroscopy images are uni-planar thus requiring multiple images. Computer assisted surgery has revolutionized these surgical procedures. Using this new technology, the surgeon requires only two fluoroscopic images and navigates the surgical tool to the shrapnel based on real time feedback of virtual 3D information, thus reducing the amount of radiation needed.
The scope of extremity injuries we see in Operation Iraqi Freedom (OIF) is little different from that seen in previous conflicts. The wounds range from traumatic amputation of a limb or limbs to complicated mixed injuries involving all manner of bone and soft tissue to minor injuries such as simple fractures or simple soft tissue wounds. What does appear unique to this war is the situation where we see ever increasing numbers of multiple and severely injured extremities in patients who are otherwise free from serious injury. Typically, these are patients whose individual body armor (IBA) has performed beautifully – beautifully in the sense that the head, eyes, chest and abdomen have been kept free of life-threatening injury. These patients present with extremity injuries familiar in scope but certainly of a volume, degree and complexity the average practitioner, indeed the experienced practitioner, finds very challenging. In other words, the injured soldiers and civilians of OIF present us with a new type of patient.

This new patient would have certainly died in previous conflicts. Instead, in OIF, especially with the success and widespread use of the IBA, we see a novel group of patients with devastating and complicated extremity injuries who are often otherwise uninjured. Certainly this sort of patient existed in previous wars but I am increasingly convinced we are seeing more of this type of patient and are experiencing new challenges in terms of volume, complexity and ultimately the true measures of success – limb salvage and limb rehabilitation.

The sources of injury, like the scope of extremity injuries, are also similar to conflicts past. The sources include direct and indirect fire, improvised explosive devices (IEDs), burns, crush injuries, mines, electrical injuries noncombat violence, infection and even congenital defects and old traumatic sequelae. Of note, military physicians are increasingly called upon to provide care for the civilian populace. If anything is unique to OIF in terms of sources of extremity injury it may be the heretofore unseen volume of patients with multiple sources of extremity injury. It is not unusual to care for a patient with a GSW, multiple shrapnel wounds, burned and crushed tissue all in a single extremity. Again, limb salvage and limb rehabilitation are mightily challenged in this setting.

This presentation will catalogue my experience with a range of OIF extremity injuries and survey the scope of injuries I attended from May – November 2005. I trust the attendee will better appreciate the fact driven home to me by this experience that the surgeon who tackles modern combat injuries, especially extremity injuries, needs to be familiar with a wide range of injuries, facile with a multitude of operative and non-operative techniques and reasoned and philosophical when faced with the need to amputate. Combat situations accelerate our learning as surgeons. The scope of extremity wounds OIF patients and physicians experience presents us with new lessons to master.
Modern medical advances in resuscitation, anesthesia, antibiotics and fracture stabilization have improved survival and outcome from highly contaminated, high energy wounds. However, new insights and technology germane to the physics and physiology of debridement of wounded tissue in this setting have been woefully inadequate. Critical in the determination of the outcome in these injuries are the quality of the initial debridement and the resuscitation of the tissue which appears viable at the end of the initial debridement procedure. The physiology and physics which provide the basis for the utilization of two new modalities applied in the management of these injuries is discussed. The first is a vacuum jet debridement tool (Versajet®) whose basis was a principle delineated by the mathematician Daniel Bernoulli in the mid 1700's. Bernoulli's Principle is the same principle which accounts for the lift provided to an airfoil when wind is directed over its surface or the curve of a curveball thrown by a pitcher in baseball. The second is a closed system topical negative pressure device (VAC®) whose basis is the active evacuation of edema fluid from the injured tissue. Utilization of these modalities in a protocol is a logical extension of the measures called for in Joseph Trueta's Treatise on War Wounds published in 1943 calling for: 1) extension of the traumatic wound, 2) excision of all devitalized tissues and contaminants, 3) provision for drainage, and 4) provision of counterdrainage.

Results of a protocol which employed both these modalities in a small series of eight patients with nine highly contaminated, high energy injuries are presented. All patients were followed through the time of wound coverage and fracture healing. All wounds healed without complications and without the need for muscle flaps. All fractures healed without the need for bone grafting excepting one patient with bone loss. Bone grafting of the defect in that patient resulted in a consolidated fracture by nine months following the injury. Based on these preliminary results, the author has adopted this protocol in his practice for application in managing all patients with highly contaminated high energy wounds.
The use of flaps as a reconstructive technique, dates back over a century, but advances in the last 35 years have made their application in reconstructive surgery and been made an everyday tool. The impact of muscle and myocutaneous flaps both, as island pedicle transfers and as microvascular free tissue transfers popularized over the last quarter century, have directly had a positive impact in salvaging extremities affected by trauma, tumor, and infection. The extremity war symposium is a perfect opportunity to highlight the principles and benefits of so called “flap surgery” in the care of the injured extremity and brings to light new developments and a new philosophy in both island flaps and free tissue transfer.

FLAPS

A flap is tissue transferred from one anatomic site to another. Vascularity of the transferred tissue is maintained by nutrient vessels within the flap pedicle. The pedicle may either remain attached at its origin or be divided during the transfer and reanastomosed to recipient vessels using microsurgical techniques. Microsurgical transfer of tissue is also known as a free flap (autologous tissue transplantation). Flaps are useful to close defects too large for primary closure and when skin grafts are inadequate. Flaps can contain more than one type of tissue and are named based upon the tissues they contain. Examples of compound flaps are fasciocutaneous flaps that contain skin and underlying fascia, and musculocutaneous flaps that contain skin, fascia, and muscle. Rotation flaps, such as muscle, skin, and fascia, or a combination, add much needed vascularized tissue, obliterate dead space, and help to close the wound without tension. When even these options are limited because of wound location or regional donor site deficiencies, free flaps must be considered. The most complex reconstruction employs free tissue transfer.

Muscle can be transferred into adjacent defects if their native vascular supply is preserved. The utility of any given muscle flap is limited by the size of the muscle and the length of its vascular pedicle and hence the distance it can be transferred. The defect, both functional and cosmetic, created by the muscle transfer must also be considered. Muscle flaps transfer richly vascularized and very immunologically active tissue into wounds that are ischemic or infected. The bulk of muscle flaps allow contour defects to be resurfaced. Skin can be transferred with the underlying muscle.

Bone can be also used for reconstruction as a free graft or a vascularized graft, alone or together with other tissues such as skin or muscle. Since the development of microvascular techniques, bone grafts from various sites can be transferred with their intact blood supply. Vascularized bone grafts have proved to be advantageous in clinical setting in which nonvascularized bone grafts have been unsatisfactory.

ADVANCES IN FLAP TECHNOLOGY

Include the popularization of the sural flap, which is a reverse flow flap, based on the perforators of the peroneal artery and the neurocutaneous territory of the sural nerve. The other areas of advances in flaps are the use of the so called perforator flaps, which instead of containing a major artery that goes through muscle into skin flaps it is based on a single perforator. The harvest technique associated with the perforator is much more difficult. However it has expanded reconstructive options for wound closure.
Blast injuries have become common in military conflicts and represent more than 50% of total penetrating war injuries in the recent wars. These injuries were caused not by bullets, but by bombs, missiles, hand grenades, land mines, mortar/artillery shells and many different types of explosives. Explosives are categorized as either high-order explosives (HE) or low-order explosives (LE) based on their damaging effects and on “manufactured” (military) or “improvised” based on their source. The musculoskeletal trauma, however, is the most common blast injury. On the pathophysiological basis blast injuries are divided in four general types:

1. Primary blast or blast wave injury caused solely by direct effect of blast overpressure on the tissue;
2. Secondary blast injury caused by flying objects that strike people making penetrating injuries from primary fragments (fragments that are part of the weapon, shrapnel) or secondary fragments (those that result from the explosion);
3. Tertiary blast injury caused by displacement of the body as whole or the limbs caused by shock wave. Usually the people are physically thrown from the blast wind striking other objects;
4. Quaternary blast injuries refer to explosion-related injuries, illnesses, and diseases not due to primary, secondary, or tertiary injuries.

Extremity blast injury can be graded as light, moderate or severe. Usually, the initial classification of the injuries as light is a result of underestimation of the severity of the injury. The musculoskeletal blast trauma is a consequence of one or more types of blast injuries, and the most serious are the ones developed from primary blast phenomena. The large scope of injuries such as fractures, amputations, crush injury, burns, cuts, lacerations, acute occlusion of an artery, air embolism induced injury, are faced by orthopedic and trauma surgeons. Sometimes the diagnosis of blast injury is difficult because there are no specific signs to enable early and accurate diagnosis. Most commonly used biochemical parameters in the blood are of little value for a diagnosis of blast injury. Only the elevation of arachidonic acid metabolites – eicosanoides has a diagnostic value. Recent data showed statistically significant elevations in blood thromboxane A2 (TxA2), prostacyclin (PGI2) and sulfidopeptide leukotrienes in the patient with lower extremity blast injury. The severity of extremity damage can be graded using many classifications as Gustilo–Anderson, Injury Severity Score (ISS), Mangled Extremity Severity Score (MESS), Red Cross wound classification (RCWC).

Complications of the primary blast injuries of the extremities are very serious with highest MESS or incomplete or complete traumatic amputation. Primary blast limb complete amputation are unreparable (no data of successful replantation) and in high percentage has a lethal outcome. The direct effect of shock waves create a powerful destruction force in coaxial direction relative to the bone, producing severe comminution of the bone and soft tissue damage with extremely large zone of injury.

Complications of the secondary blast injuries are the most frequent, but significantly less severe than the complications of the primary blast injuries. Flying object (part of the weapon or secondary fragments) can also make a severe damage to the extremity, but with the significantly lower rate of amputation. Large secondary flying object resulting from destruction of buildings are sometimes producing crush injuries with all well known subsequent systemic and local complications.

Complications of the tertiary blast injuries are consequence of sudden acceleration of the victims. They are thrown to the walls or ground sustaining vast variety of injuries from mild to the most severe ones such as amputations.

Complications of the quaternary or miscellaneous extremity blast injuries are rare comparing to the secondary blast injuries and most often producing burns as a consequence of thermal effects.

Although some complications are unavoidable, the well organized treatment is the best prevention for many of them. The first step of the contemporary treatment is based on history and physical examination, radiographic evaluation, classification and patterns of the wounding. The treatment can be nonoperative, but it is rare and of controversial success. Hence, the treatment of choice is operative, with many options. The well established protocol of treatment of open fractures made by Gustilo and Anderson can be successfully applied in the treatment of blast injuries. This protocol is based on AT prophylaxis, antimicrobial prevention, wound irrigation, meticulous debridement, and bone stabilization if any fractures are present and definitive wound cover. There are many suggestions that the cover should be early, before bacterial colonization. When the blast injury occurs, the prevention of complications is difficult, especially when one have in mind tremendous destruction capabilities of modern weapons. But, with the well organized team approach to this problem, sometimes encouraging results can be obtained, even in the most severe cases.
The treatment of blast induced injuries presents challenging problems in skin coverage due to extensive degloving, wound contamination, associated burns, and surgical fasciotomies. Theoretically, substitutes to autograft split thickness skin grafting would be useful in a trauma setting, especially for injuries that involve vast skin loss and/or involve a limitation in viable donor sites. The idea alternative to autograft skin coverage would minimize pain and healing time without increasing infection. Three major alternatives exist to autograft split thickness skin grafting: xenografts, allografts and synthetics. The purpose of this lecture is to discuss the pros and cons of the various skin replacement products available for the management of burns and wounds.

Cadaver skin is used by most burn centers for temporary wound closure following burn wound excision. Allograft skin applied to burns promotes the development of a vascularized wound; increasing the chance that subsequent autografting will be successful. Immunosuppression that typically occurs in large burns allows an allograft to remain in place for several weeks without rejection. Allograft skin can also be used in preparing chronic wounds for skin grafting. There are disadvantages, however, associated with the use of cadaver allograft skin in the treatment of chronic wounds. Chronic wounds may be colonized with microorganisms that delay or inhibit autograft adherence. Cadaver allograft availability is also limited due to high demand. The quality of the allograft tissue varies, depending on donor age and harvest location. Prolonged ultralow temperature storage may diminish allograft viability. Epidermal slough can occur following placement of frozen allograft on the wound bed. In spite of Food and Drug Administration and American Association of Tissue Banks have guidelines; one of the most serious drawbacks of allograft skin is the potential for disease transmission.

Biobrane (Bertex Pharmaceuticals, Morgantown, WV) is a biosynthetic wound dressing constructed of a silicon film with a nylon fabric partially imbedded into the film. The fabric is a complex structure of trifilament thread to which collagen is chemically bound. Blood/sera clot in the matrix firmly adhere the dressing to the wound until epithelialization occurs. It has been successfully used as a temporary skin replacement for clean burn wounds that do not require surgical excision, such as partial-thickness burns. It may be used as a protective covering over meshed autografts. Biobrane has not been used for the treatment of chronic wounds because it has no antimicrobial properties.

TransCyte (Advanced Tissue Sciences, La Jolla, CA), is a human fibroblast-derived temporary skin substitute consisting of a polymer membrane and cultured newborn human fibroblast. TransCyte is frozen so no cellular metabolic activity remains. The human dermal matrix contains essential structural proteins (collagen types I, III, and V), provisional matrix proteins (fibronectin, tenascin, and SPARC), glycosaminoglycans (versican, decorin), and growth factors (transforming growth factor-beta1, keratinocyte growth factor, vascular endothelial growth factor, and insulin-like growth factor-1). TransCyte is indicated as a temporary skin replacement for mid-dermal to indeterminate depth partial-thickness burns or for surgically excised full-thickness and deep partial-thickness burns prior to autografting.

The major indication of all these products is for temporary stabilization of primarily clean healthy wound beds prior to definitive skin autografting. Each product has inherent limitations when used in wound beds with bacterial colonization. Rather than burns, the vast majority of extremity injuries seen in the current conflict are blast induced with massive zones of deep injury and gross contamination with foreign bodies and multiply resistant environmental bacteria. The use of these alternative skin coverage products for the stabilization of high-energy penetrating wounds does not appear to be indicated.
BACKGROUND CONTEXT: Retained missile is a perplexing problem frequently faced in military surgery. It creates a lot of medical and medico-legal issues, on the short and the long term. It may lead to many complications in form of persistent pain, discharging sinuses, anteriovenous complications, delayed nerve palsy, stiff joints and other complications. Therefore, it is vital for the Orthopaedic Surgeon to understand all the complications that may arise from a retained missile and how to behave accordingly.

PURPOSE: To review a 24 years experience with handling a retained missile of the spine and the extremities and to provide a rationale to guide clinical decision making.

STUDY DESIGN/SETTING: Clinical experience and literature review.

RESULTS: Missiles are either solid or frequentation, and either primary or secondary. The secondary can be reclassified into intrinsic and extrinsic missiles. In this article, all vital points related to retained missiles will be clearly discussed, consisting of: the indication for removal, the local and systemic effect of retention, the chemical natures of same retained missiles, and the relation between retained missile and malignancy. Also the practical technical points required for the safe removal and the proper timing for the extraction will be discussed. Late complications (after 25 years) and the interesting phenomena of migration of a missile need special consideration.

CONCLUSIONS: Handling a retained missile should be based on a solid experience, Military Surgeons should be aware of both the early and late complications, in addition to his awareness about the phenomena of migration. Complications may arise even after several years.
The three most important factors in the use of antibiotic prophylaxis prevent infection are the choice of agent, the timing of dosage, and the duration of treatment. In the war on terror, we have been presented with different injury patterns, different bacteria, and a different environment. Thus, the three factors of choice, timing, and direction need to be reanalyzed in this new situation.

Prevention of orthopaedic infection has been a high priority in the planning and execution of medical care given to combat casualties in Iraq and Afghanistan. Strategies to prevent infection include aggressive wound care, early administration of antibiotics, and fracture stabilization. However, 40 percent to 60 percent of the combat wounds treated at Brooke Army Medical Center (BAMC), an echelon V treatment facility, and Walter Reed Army Medical Center are deep-culture positive.

New resistant strains, in addition to methicillin-resistant Staphylococcus aureus (MRSA) and vancomycin-resistant enterococci (VRE) have been detected in the infected wounds treated at military hospitals. Cultured organisms include resistant gram-negative bacteria such as Acinetobacter baumannii, Pseudomonas aeruginosa, Klebsiella pneumoniae and Enterobacter cloacae.

The study of wound contamination and bacterial resistance in the Iraq theater of combat presents a challenge. Treatment is delivered on a multi-tiered basis at a variety of locations by a relatively small number of surgeons. While troop numbers have ranged from 130,000 to 150,000 at any time, 120 general surgeons are on active duty, and 10 to 15 of them are orthopaedic surgeons. Forward Surgical Teams move swiftly behind the lines of combat and establish mobile hospitals quickly. The larger Combat Support Hospitals are shipped by truck, air, or sea and are fully functionally within 48 hours of arrival. Patients needing further hospitalization are transferred to Level IV hospitals, in Kuwait, Germany, or Spain. Patients needing more than 30 days' treatment are transferred to the final level of care, stateside at Walter Reed or BAMC.

Our knowledge of wound contamination, antibiotic usage, and bacterial resistance is the result largely of careful study over years of often controlled, prospective trial. The knowledge that can be gained from military war wounds in Iraq is doubtless of tremendous value, both for military medicine and for civilian applications, but it will have to be attained in a very different environment with different challenges. The variety of locations and levels of treatment – from mobile field hospitals near conflict areas to sophisticated U.S. military medical centers – create inherent difficulties in collection of accurate data.
In April of 2003, a large number of soldiers from OEF and OIF were noted to be colonized or infected with a highly resistant strain of Acinetobacter baumannii. The nature of this resistance led to a marked increase in utilization of imipenem and amikacin, as most isolates were only sensitive to one or both agents. In addition, some isolates were resistant to both agents necessitating a search for alternative antimicrobial agents.

The microbiology laboratory standardized the development of a process that would automatically conduct testing against a wide variety of other agents, including older agents rarely used any more (such as the polymyxins).

Since 2003, we have seen a wide variation in the number and percentage of soldiers colonized and/or infected with A. baumannii, however the challenges continue. Over the past year, there may have been an increase in other, relatively more virulent pathogens, with almost identical resistance patterns to A. baumannii. These organisms include E. coli, Pseudomonas aeruginosa, and Klebsiella pneumoniae. This has led to a greater concern for the long term1 outcome in soldiers with open fractures and exposed bone injuries because of the well known probability of chronic osteomyelitis from these particular organisms.

We continue to be presented with challenges in treatment decisions and selection of appropriate agents as we gain more experience with soldiers returning with wound infections and osteomyelitis from many of these highly resistant pathogens. Many of the older agents and most of the new agents have little data regarding chronic bone infections and for some, the toxicity profiles make these patients a real challenge. The limited historical data makes monitoring and reporting these patients and their outcomes even more critical.
A variety of acute infections can arise after musculoskeletal injury, particularly after substantial open wounds. The acute infections that will be reviewed include anaerobic myonecrosis (clostridial gas gangrene), anaerobic cellulitis/fasciitis, tetanus, streptococcal myonecrosis, and acute osteomyelitis.

The clinical course of an anaerobic infection depends on the spread of cytotoxins produced by clostridial organisms in a local area of necrotic tissue. Under favorable anaerobic conditions, they multiply and produce toxins that cause necrosis of the surrounding tissues, allowing further proliferation of the organisms and more toxin production. Anaerobic cellulitis/fasciitis and myonecrosis have distinct clinical manifestations. Anaerobic cellulitis or necrotizing fasciitis usually occurs several days after injury with a gradual onset, in an inadequately debrided wound, with rapidly spreading infection along fascial planes with robust gas formation, but no muscle invasion. Toxemia and pain are minimal. Clostridial myonecrosis develops quickly after injury with an acute onset, severe toxemia, severe pain and swelling, thin dark exudate, and slight gas production. Progression of clostridial myonecrosis is rapid, so diagnosis must be prompt. Treatment consists of radial wound debridement, which should be repeated daily to remove necrotic tissue promptly. Amputation may be necessary, and all wounds are left open. Aggressive antimicrobial administration should be utilized. Penicillin in large doses should be administered. Concomitant infections should also be treated. Adjunctive treatment can include gas gangrene antitoxin, whose effectiveness unclear and hyperbaric oxygen therapy, if readily available.

Tetanus is an infection preventable by immunization, but can occur after traumatic wounds. Clostridium tetani grows in wounds containing necrotic tissue, foreign bodies or associated infections where low oxygen tension exists. Toxins disturb the function of inhibitory synapses along motor neurons, blocking spinal inhibition, so peripheral motor neurons receive a relatively constant efferent signal. Treatment involves aggressive wound care similar to the treatment of other clostridial infections. The toxin can be neutralized with human tetanus immune globulin, but precise dosage not been established. Parenteral antimicrobial therapy should be started with agents active against anaerobes, such as penicillin. Supportive care should be provided for systemic symptoms, and immunization should be completed or updated.

Streptococcal myonecrosis can occur after a severe or a seemingly innocuous injury. The incubation period is 3-4 days, with a subacute onset. Swelling and erythema is severe, and the exudate is seropurulent with bullae formation. Toxemia is severe and late. Treatment is similar to other necrotizing infections, with wide, thorough, repeated debridements, wounds left open, systemic support, and targeted antimicrobial therapy.

The development of acute osteomyelitis after an open fracture depends on the severity and prior treatment of the associated wound, the location of the open fracture, and immune competence of the host. The critical level of bacterial inoculum is unknown, but decreases with any coexisting foreign material. There are often few signs or symptoms except local edema or erythema, and purulent drainage. Systemic toxicity is uncommon, and laboratory values are inconsistent. Imaging may demonstrate osteolysis on plain films, or sequestrum on computerized tomography. Magnetic resonance imaging is the most sensitive tool, but often is unavailable, or cannot be utilized due to the presence of metallic implants. Treatment starts with a systematic, thorough debridement, removing all nonviable tissue, and obtaining several specimens of different tissues for microbiological analysis. Debridement of necrotic or infected bone may result in a skeletal defect, which can be reconstructed once the infection is controlled. Implants that provide rigid stability to infected fractures should not be removed, with the exception of nails in the femur and tibia which can be exchanged. Once the fracture has healed, the implant can be removed. If the infection has resulted in poor fracture stability, the implant should be removed, and may be replaced by external fixation. Antimicrobial therapy consists of parenteral agents directed against organisms grown in culture from biologic specimens. Consultation with Infectious Disease specialists is helpful in selecting the proper antibiotic, duration of antibiotic, surveillance for toxic side effects during therapy. Antibiotics can also be delivered locally in the area of infection, when mixed with a carrier. Elution of high concentrations of antibiotics into the local tissues that surpass the minimal inhibitory concentration for most pathogens can be achieved with minimal systemic levels or complications. Adequate soft tissue coverage over the infected bone should be achieved, either with local tissue or rotational or free tissue transfers. Reconstruction of bone defects caused by the infection and the debridement can be performed with iliac crest graft or structural grafts.
INTRODUCTION: Failure of an acute inflammatory response to resolve a wound infection heralds a cascade of events affecting the host and pathogens. Chronic infection culminates in a refractory condition. The factors that contribute to this end-point include immune compromise of the host, ineffective and resistive antimicrobial therapy, wound healing deficiencies and the adherence of pathogens to exposed wound surfaces by an impenetrable and resistant biofilm.

To eradicate such a condition, the pathogens, their biofilm, surfaces available for adherence and all tissues compromising treatment must be removed. The treating team must 1) discover factors contributing to pathogen persistence; 2) analyze the various treatment options; 3) orchestrate treatment.

DISCOVERY: Imagery techniques are used to define the zone of injury. The host is quantitatively evaluated for wound healing deficiencies through laboratory profiles. Pathogens are characterized with wound cultures and tissue samplings.

SOLUTION: In preoperative planning sessions, the anatomic extent of the anticipated debridement is mapped with regard to coverage, revitalization and reconstruction. Probable outcomes are compared for the various treatment options with the ultimate goal of an infection-free, limb and salvage within the capabilities of the host. If reconstruction is neither safe nor reasonable, amputation or palliation are considered.

EXECUTION: Once a treatment protocol has been selected, the surgical approach to debridement is expansile, atraumatic and choreographed to coincide with procedures necessary for the future reconstruction. All non-vital tissue, foreign bodies and hardware are removed. Deadspace and instability are eliminated. The host and wound are resuscitated and the antibiotic protocol adjusted to cover new isolates. The reconstruction takes place as a clean-contaminated procedure. The methods used in the reconstruction are tailored to the needs of the patient and matched to the resources of the treatment team.

RESULTS:


84% 1ST treatment success
95% overall success (2yrs)

417 Recent Case Studies (1999-2004 analysis)

92% limb-salvage protocols
2% palliative treatments
6% primary amputations
97% Success Rate (2yrs)
Extremity injuries are among the most common injuries seen in modern warfare. High-energy ballistic injuries, including those resulting from improvised explosive devices (IEDs), commonly result in unstable open fractures. Bone loss resulting in gross instability can often be associated with both nerve and/or vascular injuries. Due to the high-energy nature of these battlefield wounds, soft tissue envelopes are routinely severely damaged. Pain from unstable fractures during evacuation from the theatre of operations can be significant. Wounds frequently require second and third look debridements to remove marginal tissue and to further decontaminate the limb. However, in addition to a complete and aggressive debridement, a critical component in the successful management of these patients and their limbs is to provide early restoration of bony rigidity.

The benefits of early fracture stabilization have been well documented in civilian trauma centers. Mechanical stability of fracture fragments is critical for wound healing and for minimizing the risks of infection. However, in a combat zone, resources limit the ability of the orthopaedic surgeon to provide definitive bony fixation. Issues ranging from injury complexity to marginal sterility make this routine practice inadvisable.

As a result, temporary stabilization techniques are employed. Several options are available for temporary stabilization in the far forward setting. These include splintage, traction and external fixation. Traction has limited applicability in a combat zone due to the complexity of its setup and difficult maintenance during transport. Splints are reserved for closed, low energy injuries of the ankle and upper extremity not associated with a significant soft tissue injury. External fixation (EF) has become the stabilization method of choice for the high-energy open fractures seen in the combat zone.

External fixation not only provides stability for fractures but it may diminish the systemic effects of the injury – including minimizing ongoing hemorrhage and resultant coagulopathy, decreasing transfusion requirements and blunting the release of inflammatory mediators. This can be a critical component in the resuscitation and survival of a multiply injured patient undergoing medevac out of theatre. It improves pain control, minimized narcotic requirements during transport, enhances pulmonary toilet and allows simpler, more comfortable mobilization for the injured patient. Finally, it allows a surgeon to easily access injured soft tissues during repeat debridements by simply disassembling and then reassembling the fixator.

Application of the external fixator in the field must be performed quickly and without radiographic assistance. It requires some baseline understanding of the anatomy and safe zones for pin insertion, as well as some familiarity with pin placement, insertion techniques and frame assembly to confer the benefits of a stable construct. Indirect reduction methods are executed to grossly restore length, alignment and rotation. Periarticular fractures are spanned across the joint avoiding intraarticular pin placement. Schantz pins are placed outside of the zone of injury with consideration of future fixation options. Modular external fixation systems have made frame adjustability simpler, but they can be more difficult to apply and may result in somewhat less stable constructs. The orthopaedic surgeon must use his judgement when deciding how to best stabilize a complex extremity injury.

Indications for application external fixation in the far forward setting include open fractures of the lower extremity, instability associated with vascular injury, soft tissues in jeopardy (impending open fractures), fractures with significant bone loss and certain closed fractures that are difficult to splint during a prolonged transport. This could include a relatively simple and stable fracture that is associated with a badly injured soft tissue envelope that requires frequent re-evaluation. Finally, external fixation may be to restore length and alignment to closed periarticular injuries by spanning the joints involved.

Complications of external fixation applied in the austere environment are not uncommon. Without radiographic assistance, pins can be placed into fracture sites and within joint capsules. Pins may be placed too shallow or too deep, causing secondary bony or neurovascular injury. Heterotopic ossification and joint stiffness have been reported as problems even when external fixation is used in a temporizing manner. Pin tract infections are the most feared complication, as they may preclude definitive stabilization with another fixation method in the future. Most of these complications can be avoided with careful planning and frame application technique.

Splints are still used for select low energy injuries of the foot and ankle and upper extremity. In fact, they are still the most frequent method of immobilization used for routine injuries seen in the field. Due to the risks of compartmental syndrome, circumferential casts are avoided.
A concept of temporary external fixation was developed by civilian trauma centers in the 1980's and 1990's as a means to stabilize a limb with a severe injury or a polytrauma patient who is not able to physiologically withstand a more extensive procedure. At a later time, when the patient became more stable, more definitive fixation could be provided until fracture healing. Investigators found that external fixator pins did not increase the risk of sepsis when fracture stabilization was converted to an intramedullary nail within two weeks.

Temporary external fixation was applied to the care of those wounded in combat during the first Gulf War. In Combat Zone hospitals, the wounded would have an external fixator applied to stabilize the limb before medical evacuation to a site of definitive care. Limitations with the devices that were available at the time did not allow for modular use nor were they biomechanically sound.

There are several requirements of a fixator system for military use. The fixators potentially could be applied by general surgeons in addition to orthopaedic surgeons who care for the majority of patients with fractures. Because of this, any system used must be readily applied by a surgeon who has been trained in its use. The ready application of external fixation requires the system to be “user friendly” for the average surgeon. Additionally, because of the exigencies of combat surgery, there are demands placed on the military system that are not commonly encountered at civilian trauma centers. Logistics and supply are potentially a problem; therefore a system that uses a minimal number of components (four pins, two clamps, and single bar) for a standard construct is useful. Because power availability is not reliable for all settings, the half pins should have the capability to be inserted without the use of power or predrilling. Surgery in Combat Zone Hospitals may be done without ready x-ray capability. Alignment of fractures is sometimes not possible at the initial surgery and may be deferred to a later time when the patient is in a more stable environment. Because of this, the capability of reducing the fracture after application of the frame is an important requirement. Once at a site of definitive care, the patient may have another method of treatment used or continue the use of the fixator. If the fixator is used, then the capability to build up or build down the construct as a patient’s healing progresses is an important consideration. To allow for changing the fixator, modular capability for military use is an important consideration.

The Department of Defense adopted the Hoffmann II external fixator in 1998 to meet the above requirements. Its widespread use has demonstrated a good clinical record in the present conflict. Questions about the optimal use of external fixation remain. A limitation using a sterile peel pack is that one main connecting bar is provided. Use of one main bar has shown to provide limited stability. Surgeons found that they must open a second pack to improve stability, thereby increasing the cost.

Lessons from the present conflict include the placement of a label on each fixator containing the findings from and date of the last surgical procedure. Because multiple surgeons may operate on the same patient in Combat Zone Hospitals and separate medical records for the patient may become unreadable or not available, the use of a brief medical record taped to the frame provides the best means to communicate for a surgical team; particularly during a period of high casualty load.

Relatively little is known about the behavior of present external fixators in vivo and their optimal use. Future research should consist of evaluation of the fixators in vivo, comparison of those results to biomechanical laboratory studies, and use this information to develop standard constructs for the femur, tibia, humerus and spanning of the ankle and knee to cover the most common applications of wartime use. Future research should also develop indications for use of external fixation in comparison to casting. Specific endpoints should be the risk of infection, cost analysis, amount of bulk for supplies with each method. Training of both general surgeons and orthopaedic surgeons in the application of standardized external fixator constructs that may be safely applied is of paramount importance to ensure quality care of patients in combat zone hospitals. Finally, parameters for safe conversion to another method of fracture stabilization should be studied with the present group of wounded soldiers.
Current Problem/Situation: Peri-articular Injuries (fractures, bone loss, soft tissue loss, and neurovascular associated injuries) pose a specific challenge to the military orthopaedic surgeon today. War injuries (blunt trauma, penetrating trauma, and blast type injuries) have been and are the wounding mechanisms of current warfare in Operation Iraqi Freedom and Operation Enduring Freedom. What previously would have been unsalvageable limbs from these injuries, are now routinely being saved. Because of the U.S. Military’s far forward deployed surgical assets, wounded U.S. servicemen are in the hands of an attending level orthopaedic surgeon and general surgeon very rapidly. In previous military conflicts, these war injuries would have rapidly evolved into amputations, due to the lack of advanced surgical capabilities that now exist in the far forward deployed positions (orthopaedic and general surgery assets).

Injured limbs are rapidly stabilized with external fixation, debrided and receive fasciotomies if needed in forward deployed positions. Our injured U.S. servicemen are then medically evacuated, usually to Landstuhl U.S. Military Hospital in Germany. Additional debridements, external fixation modifications, select conversions to internal fixation are accomplished at Landstuhl, and then the patient is then medically evacuated to CONUS and U.S. military medical centers. The medical evacuation chain has been very effective, delivering our wounded warriors back to CONUS within 48 hours from time of injury, if the need arises.

One of the current clinical dilemmas is the timing of when to provide definitive fixation to those peri-articular injuries that have been temporarily stabilized by external fixation. Factors that weight into this decision are: The condition of the soft tissue; the nature of initial injury (open/closed); possible need for further surgical debridements; possible associated open fasciotomy wounds; location of previously placed external fixator pins; condition of existing external fixator pins; mechanical stability of present external fixator configuration; bone loss; soft tissue loss; associated neurovascular injuries; pPresence or absence of infection. These concepts pertain to any peri-articular injury, but specific anatomic areas continue to be problematic with regard to complication rates. These are the tibial pilon region, the tibial plateau region, the elbow region, and the wrist region. Very commonly, it is the injury and condition of the soft tissue that contributes most significantly to poor outcomes. More specifically, it is the lack of an abundant soft tissue envelope around these areas that make them specifically challenging to treat.

Surgical Goals: The definitive surgical goal of these injuries is to restore the articular surface to its anatomic position (decreasing chances of disabling arthrosis developing), providing stabilization of the articular surface to the diaphysis, and restoring full motion of the joint. Additionally, the surgical goal is to accomplish this without the presence of infection. Acute and chronic osteomyelitis can be devastating, and is extremely challenging to treat in the peri-articular regions.

Current Literature: Multiple recent articles1-8 demonstrate the effectiveness of staging peri-articular fracture management. Initially, spanning external fixation is applied to provide skeletal stabilization, and to facilitate soft tissue injury recovery. After a period of time (10-14 days), definitive formal open reduction and internal fixation is accomplished, and most commonly the external fixator is removed as well. Lower infection rates are reported with the staged fracture management protocols1-8. Levels of evidence of these studies varies (Levels 1, 2, and 3), with a majority being retrospective.

Future Direction of Research: Ideally, the surgical goal of obtaining an anatomic reduction, free of infection, with full range of motion in these complex peri-articular war injuries will require a multi-armed approach. Primarily, early orthopaedic intervention with skeletal stabilization and appropriate soft tissue management in the deployed situation will be the cornerstone to superior outcomes in these injuries. Uniform application of external fixation in a “spanning” fashion, keeping external fixator pins out of the “zone of injury” or future potential “surgical corridors” (if possible), will greatly contribute to more surgical options at the time of definitive fixation. This may be obtainable with a standardized “pre-deployment” military orthopaedic surgical techniques “briefing”. Future “research” efforts may include developing an agreed upon “best practice plans” for the deployed orthopaedic surgeon. A standardized treatment protocol would then be instated for all war extremity injuries managed in the deployed theater of operations.

Currently, the United States Military has the necessary infrastructure to develop and implement such a plan (“briefing”). Each branch of our military has specific military trauma training centers in place and is currently training teams of military medical personnel, in order to maintain readiness in trauma surgery capabilities.

- U.S. Army: Ryder Memorial Trauma Center, Miami, FL
- U.S. Air Force: R Adams Cowley Shock Trauma Center, Baltimore, MD
- U.S. Navy: L.A. County Medical Center, Los Angeles, CA

Additionally, there are other research efforts which would greatly facilitate making clinical decisions on the timing of definitive fixation in these peri-articular injuries. A standardized staged protocol has repeatedly demonstrated to facilitate care in this patient population, and decrease complications.
Multiple modes of fixation exist for operative treatment of closed diaphyseal femur and tibia fractures. These include intramedullary nailing, plate and screw constructs, and external fixation. The method of treatment is often dictated by the expertise of the treating surgeon, as well as availability of implants and the condition of the patient. Rapid stabilization of closed diaphyseal tibia and femur fractures in the setting of major vascular injury or in the polytraumatized patient is often performed through expeditious external fixation which allows for subsequent vascular repair/reconstruction or resuscitation of the critically-injured patient. During armed conflict, forward surgical teams perform external fixation quickly before the injured soldier is evacuated to a center where definitive care can be accomplished. Some of these soldiers are treated with early conversion to intramedullary nails or plate and screw constructs.

External fixation for definitive therapy of closed diaphyseal femur and tibia fractures is considered by many to be an acceptable, and even preferred, method of treatment in the pediatric population. However, a paucity of current literature exists regarding definitive treatment of these injuries with external fixation in the skeletally-mature population. Also, little is currently published regarding conversion of external fixation to intramedullary nailing in these fractures, despite it being a common practice in many trauma centers nationally, and all but one study in the literature is retrospective in nature.

Conversion of an external fixator to an intramedullary nail is determined by the condition of the soft tissues and the stability of the patient. In the tibia, conversion to an intramedullary nail is accomplished as expeditiously as possible. Early conversion (less than two weeks) to an intramedullary implant may be accomplished safely. Authors have documented increased infection rates when conversion is done after two weeks of external fixation. Prolonged external fixation may warrant conversion in a staged fashion. Recommendations have been made to remove the external fixator and allow the pin sites to heal prior to placement of the nail. Infection risk has been minimized by aggressive debridement of pin tracts and utilization of antibiotic-impregnated beads prior to nailing in a staged fashion. Staged external fixator removal and placement of an intramedullary nail in a delayed fashion carries the risk of fracture instability leading to increased pain and infection risk, and requires prolonged limb immobilization. Finally, some patients are perhaps better served without conversion to an intramedullary nail. These patients include those with very proximal or distal metadiaphyseal fractures with or without intra-articular extension, those with pre-existing diaphyseal deformity, those with exceptionally small medullary canals who would require extensive reaming before insertion of an implant, and those with an ipsilateral knee arthroplasty.

In the femur, conversion of external fixator device to nail is done as the patient’s overall physical condition and soft tissues allow. Acute conversion to an intramedullary device in a single procedure is favored in patients without evidence of pin tract infections. Staged conversion to an intramedullary nail often requires a prolonged period of bed rest with skeletal traction to maintain fracture stability and patient comfort, with the attendant risks of pneumonia, decubiti, and thromboembolic events. Infection rates appear acceptably low and union rates high in the few retrospective studies available. These studies, however, have confounding results as they include patients with open femoral shaft fractures. Further prospective studies are necessary to define the efficacy and safety of treatment of closed femoral shaft fractures either with external fixation and staged nailing or with external fixation alone. Patients perhaps best served without conversion to intramedullary implants may include those with significant pre-existing femoral shaft deformity (post-traumatic or otherwise), ipsilateral knee and/or hip arthroplasty, extremely small medullary canal diameter, and distal metadiaphyseal fractures with or without intra-articular extension.
Most extremity injuries in modern warfare and terrorism acted upon civilians are related to blast injuries caused by the detonation of explosives. Its harmful effect upon human tissues is traditionally classified as follows: the primary blast effect is caused by the acceleration / deceleration of supra-sonic airwaves generating tissue damage mainly in air-fluid interface such as within the lungs, ears and bowel. The secondary blast effect is primarily related to shrapnel or fragments originating from either the explosive’s shell or having been deliberately implanted in it, causing high energy penetrating injuries. The tertiary blast effects are the blunt trauma effects caused by the blast wind due to the victim’s falling or objects hitting them. The quaternary blast effect is the thermal or chemical injury caused by the heat and fumes of the explosive.

Orthopedic trauma caused by a blast is predominantly of a secondary effect i.e. penetrating fragment injury. In the Middle East this has been the main cause of injury both in warfare and in most of the terrorist attacks. Although primary blast effect to limbs can cause fractures and soft tissue avulsions, this effect may be a sign of a very high energy blast wave which is generally fatal. Some primary amputations in blast injury fatalities have been described, but survivors with such injuries are the exception. In a biomechanical study by Hull and Cooper, almost all blast amputations are through a fracture rather than through a joint. This was explained by the coaxial forces created by dynamic forces (blast wind) during fracture and avulsion of the limb. The secondary effect of fragments and penetrating foreign bodies depends on the distance from the detonation center, shape and size of the fragments, and the number of foreign bodies implanted or created by the explosive.

For didactic purposes these injuries may be compared to high velocity gunshot injuries but with several important differences. The velocity of a fragment leaving the detonation may start at 1800m/sec, but decreases rapidly due to its irregular shape and lack of streamlining. Most limb injury survivors are struck by fragments with a lesser velocity. Both very high energy and low energy bone and soft tissue trauma may occur depending on the distance of the victim from the detonation. The course of the fragment within the tissues is usually irregular due to tumbling or the so called shimmy effect that can increase soft tissue damage. Furthermore, blast fragments can carry debris into wounds. Additionally, the number of fragments has a crucial impact on associated injuries as well as on the injury severity score, morbidity, and mortality. Our experience in Israel indicates that these latter parameters are significantly increased in blast injured patients as compared with gunshot injured patients. The size and shape of fragments may affect soft tissue damage, e.g. a large serrated piece of metal may cause severe muscle and skin loss due to the high contact area as compared with the relatively narrow path of a handgun bullet. However, neurovascular complications, compartment syndrome and fasciotomy rates seem to be somewhat lower in blast injuries when compared to high velocity gunshot injury.

The risk of infection in particular HBV, HCV, and HIV, through body fluids and/or tissues propelled from suicide bombers and penetrating victims should also be considered. Screening of the victim’s and/or suicide bomber’s remains should be performed.

Tertiary blast effects to the musculoskeletal system, although rare, also occur. Some unique injury mechanisms have been described such as spinal burst fracture in victims sitting in a vehicle inflicted by landmine explosions. The treatment of these devastating injuries is based on aggressive and meticulous debridement and prevention of contamination. Blast and penetrating injuries have roughly the same infection rate as high velocity gunshot injuries and therefore thorough tissue care should take place. In contrast to large published series in military medicine, civilian victims of terror can be treated in level 1 trauma centers where modern early fracture care can take place i.e. immediate internal fixation. However, late bone and soft tissue reconstruction may be staged due to soft tissue and bone loss, deformation, non-union and deep infection.

Modern terrorism and warfare present new challenges for orthopedic traumatologists in treating severe blast related extremity injuries. It requires prompt recognition of life threatening injuries, aggressive and meticulous fracture and soft tissue care, and reconstructive challenges.
The skeleton has an intrinsic capacity to repair itself. This is best observed in the healing of fractured bones. The healing process has been well studied in the past and much is known about the cellular and molecular events. Essentially, the process can be divided into three stages. The first stage is a disruption of skeletal integrity by trauma or injury leading to inflammation and a hematoma, the second stage occurs in a low oxygen tension and is characterized by chondrogenesis and the process of endochondral ossification and the third stage involves the formation of a mineralized callus that stabilizes the ends of the broken bone until remodeling can re-unite the fragments. Unfortunately, these stages can take variable amounts of time to occur and depending on the age and health of the individual and the site of fracture may incapacitate the person for prolonged periods. Moreover, other mitigating factors can affect the healing to the point were a permanent non-union of the bone occurs.

It would be of paramount importance, especially in military situations, to accelerate the healing process and eliminate the possibility of non-unions. Pharmacologic agents (currently approved by the FDA for other uses) appear to have this effect.

New drugs developed for the treatment of osteoporosis in elderly individuals seem to have the ability to stimulate the formation of new cartilage and bone at sites of fracture. These drugs work on progenitor stem cells in the bone to accelerate progression through the three stages described above.

In anecdotal observations, it has been shown that the use of these drugs in an “off-label” fashion induced a more rapid healing (in professional athletes) and accelerated callus formation and prevented non-unions (in older persons). However, there have been no controlled human studies to document this effect. This is due, in part, to the difficulty in quantifying the healing process and measuring a return to high function. Recent developments in the field of musculoskeletal imaging and motion analysis now make such a trial feasible.

The benefits of accelerating normal fracture healing in a battlefield setting could be great. If it were possible to decrease by 50% the time it took for a fracture to heal and thus return the soldier to full function, substantial manpower and resources could be saved.
The purpose of this presentation is to provide a summary of the principles associated with tissue engineering approaches to the repair, replacement or augmentation of musculoskeletal tissue function that has been lost due to trauma. The presentation is also focused on providing a synopsis of some of the current research and technologies being explored with an emphasis on identifying their successes as well as potential limitations. This will then be followed by a glimpse or perhaps prediction for future developments in tissue engineering.

The repair or regeneration of musculoskeletal tissues can be characterized as a symphony of cellular activities, beginning with an acute inflammatory response followed by granulation tissue infiltration; recruitment, proliferation and differentiation of progenitor cells; and eventual matrix formation, and remodeling. These processes occur within the context of both biologic and mechanical signals. The success of the repair or regeneration of the tissue will depend on the induction of critical biochemical signaling cascades, the availability and viability of the progenitor cells, nutritional support and, for connective tissues, mechanical stability. The challenge of tissue engineering, therefore, is to recapitulate these highly organized events in a predictable and reproducible way.

Tremendous advances in tissue engineering have occurred over the past decade and it is clear that any therapeutic strategy must involve some combination of cells, bioregulatory factors and structural matrices. The source of the cells or their manipulation (endogenous or exogenous), is the specific bioregulatory factor or factors, and the chemical, mechanical and architectural features of the matrix may vary tremendously as a function of both the specific tissue function being replaced or the therapeutic strategy being employed. Issues regarding vascularity or nutritional support, mechanical competence, and cell behavior will be reviewed by providing examples of tissue engineering approaches for the repair or replacement of bone, cartilage, tendon and skin. Finally, the presentation will also briefly consider factors that may be associated with the handling, storage and implementation of tissue engineering therapeutics.
Autogenous bone cancellous grafting is considered the referenced standard by which all other osteobiologics are compared to for healing rates with regard to nonunion or delayed union care. The advantage of autogenous cancellous bone is that it provides living cells (osteogenic), its structure provides an osteoconductive environment as well as being osteoinductive. Depending on how fast the graft is taken and transferred to a site, the amount of living cells are variable but are always present. As well as its osteogenic/osteconductive qualities, using it with cortical bone in either a bicortical or tricortical form will also provide structural support.

There are many sites in the body to take a useful size graft. The most common sites are the anterior iliac crest followed by the posterior iliac crest which may supply the most osteogenic bone. Other areas are the proximal and distal femoral metaphyses along with proximal tibial metaphysis. Smaller autogenous grafts maybe harvested from the distal metaphyses of the radius and tibia

The disadvantage of autogenous cancellous grafts is the fact that it must be taken form somewhere in the human body. In the pelvis, this may lead to pain and discomfort, potential stress induced pelvic ring injuries secondary to weakening of the bone or damage to the sacroiliac joint, infection, blood loss, and the cosmetic consequences of the incision. Also there is a limit the to amount of autogenous cancellous bone available for multiple grafting procedures These complications can range up to ten percent of cases but generally speaking are minor. As with all surgery the complications are related the skill, care and knowledge of the surgeon procuring the graft The cost of procuring a graft has been estimated up to $4,154.

As with any other osteobiologic bone substitute, the graft must be placed into a viable bed which will provide a blood supply to the graft. The effective amount of graft is unknown. All grafts require revascularization and this occurs at a very limited rate and to a very limited distance. A massive amount of graft may not be suitable or of any benefit. The clinical results using autogenous graft generally have healing rates up 90% and may cover defects up to 8 to 10 cm. especially if coupled with profibula type procedures or in a viable muscular bed such as femoral shaft defect

At the present time, autogenous graft still remains the standard. The desire for an off-the-shelf stimulus or substitute for autogenous bone will continue although it will never replace this form of bone substitute material. It is agreed that in certain circumstances autogenous graft will not be available or indicated hence the need for a substitute but these conditions are rare. Generally the reason for not using autogenous grafts has to be the surgeon’s failure to plan for this eventuality, reticence of the patient for a second incision, or laziness on the surgeon to perform another operation knowing full well that this could be the best bone.
As noted by Ilizarov, all tissues will respond to a slow application of prolonged tension with metaplasia and the differentiation into the corresponding tissue type. Bone responds best followed by muscle, ligament, and tendons in that order. Neurovascular structures will respond with gradual new vessels and some degree of nerve lengthening.

The treatment of bone loss occurring as the result of acute trauma or segmental resection for reconstructive procedures in the skeleton has traditionally been a complex surgical problem. Numerous procedures have been devised to reconstitute bone stock, obtain fracture union, and provide a stable functional limb.

In an attempt to avoid the problems associated with deficient graft materials and free tissue transfers, internal bone transport is a technique that has been a successful methodology for bony reconstruction for both acute and reconstructive bone loss. Under the influence of the tension stress effect, fibroblast like cells of the corticotomy site (interzone) form collagen fibers that align parallel to the vector of tension stress. Osteoblasts lay down osteoid tissue upon these collagen fibers. Osteoid tissue gradually blends into the newly formed bone trabeculae in the regions furthest away from the central interzone. Thus, the newly formed bone grows both proximally and distally toward the middle of distraction zone during elongation. A high level of osteogenic activity occurs throughout the entire period of distraction resulting in the formation of bone with similar morphologic and functional organization along the lines of tension stress. The fibroblast, like cells found in the middle of the growth zone, have an elongated shape and are oriented along the tension stress vector during distraction. These are concentrated around the sinusoidal capillaries. Osteoid producing osteoblasts are located in chains along the collagen fibers forming a framework for the production of trabeculae. The distraction regenerate demonstrates significant neovascularity and is filled with long vascular sinusoidal regions. All tissues undergo a response to gradual tension stress as does this dense network of newly formed blood vessels. This neovascularity has longitudinal orientation connecting to the intact soft tissues by numerous arteries that perforate the regenerate bone. This intense formation of new blood vessels under the influence of tension stress occurs not only in bone, but also in the soft tissues. As such, this phenomenon of neovascularization can occur indirectly via traction on living tissue, as well as with tension stress simulated by nonviable implants, i.e. the implantation of soft tissue expandable prosthetics.

The ability to induce this neovascular response allows not only the ability to transport bone, but also facilitates the ability to transport soft tissues as well. If soft tissue loss is not sufficient enough to expose bone at the site of skeletal defect then soft tissue transport in conjunction with the bone transport is possible. Tissue loss that exposes bone is not amenable to combined soft tissue / bone transport without first addressing the exposed bone. This is accomplished thru rotational or free tissue transfer to cover the bone. Alternatively, the bone should be resected back until healthy soft tissue covers the bony segment.

Distraction across a well vascularized corticotomy accomplished through the use of a ring fixator, a stable monotube device, intramedullary device, or a combination of each can initiate the histogenesis of bone, muscle, nerves, and skin all of which can be incorporated in to the treatment of complex orthopaedic conditions. Bone transport methodologies can replace large skeletal defects with normal healthy bone structure, which is well vascularized and is relatively impervious to stress fractures. The ability to correct significant angular, translational and axial deformities simultaneously through relative percutaneous techniques, as well as perform these corrections in an ambulatory outpatient setting adds to the attractiveness of this methodology.

Acute or gradual shortening offers advantages over transport in the patient that presents with vascular insufficiency, i.e. a one vessel leg where free vascularized tissue transfer is contraindicated. Shortening acutely can be accomplished safely for defects up to 3-4 cm in the tibia and 5-7 cm in the femur. Shortening aids in soft tissue coverage by decreasing tension and gaps in the open wound; this approach may allow wounds to be closed by delayed primary closure or healed by secondary intention or simple skin grafting. With this technique, one may avoid extensive free flap coverage. Delayed lengthening thru a remote corticotomy may be accomplished once the soft tissues have healed.

Ideally, the ability to rapidly distract a transport segment, with a simplistic fixator construct, followed by percutaneous application of docking and regenerate site enhancements to allow rapid consolidation and frame removal is the ultimate goal for the treatment of massive skeletal defects.
Our knowledge about, and availability of, orthobiologic materials has increased exponentially in the last decade. While previously confined to the experimental or animal-model realm, there are a variety of orthobiologies that have been shown to be useful in a variety of clinical situations. As our surgical techniques in vascular anastomosis, soft-tissue coverage, limb salvage and fracture stabilization have improved, the size and frequency of bony defects (commensurate with the severity of the initial injury) has also increased. While there are a variety of ways of dealing with segmental bony defects, they all have drawbacks, be it the time required for distraction osteogenesis, the limited availability of autograft, the cost of recombinant growth factors or the donor site morbidity and surgical complexity of vascularized fibular grafting. There remains a need in such situations for a readily available, void-filling, inexpensive bone substitute that, at least if not actually producing new bone per se, fulfills a permissive role in allowing new bone to grow into a given defect. Such osteoconductive materials include ceramics, calcium sulphate or phosphate compounds, hydroxyapatite, de-proteinized bone, corals and newer polymers. Some materials that have osteoinductive properties, such as demineralized bone matrix or DBM, also display predominant osteoconductive properties.

Osteoconductive materials essentially provide a substrate or matrix that supports the migration, attachment and proliferation of mesenchymal stem cells that then differentiate into osteoprogenitor cells that form bone. To do so these substances typically have a microscopic structure similar to cancellous bone and attractive surface kinetics. The various biologic properties are not mutually exclusive: it is possible, even common, for a substance to display osteoinductive, osteoconductive and even osteogenic properties. Also, these substance need not be used in isolation only. Although most of the initial experimental and clinical work has been done with products used in isolation as a “single variable” (per proper experimental technique), they may have qualities that are mutually beneficial when used in combination. In addition, several promising areas of research include additives (such as antibiotics or growth factors) that can be applied to simple osteoconductive substrates to enhance their clinical utility.

This article will discuss the indications, contra-indications, techniques, reported outcomes and complications of commonly-used osteoconductive substances such as calcium sulphate, calcium phosphate, DBM, hydroxyapatites, ceramics, and coral-derived products.
What are BMPs? In 1965 Marshall Urist demonstrated that demineralized bone matrix could induce bone formation at extra-skeletal sites in a rat model. He subsequently was able to identify a series of soluble, low molecular weight glycoproteins that he named Bone Morphogenetic Proteins or BMPs. The osteoinductive properties of BMPs are affected by induction of differentiation of mesenchymal progenitor cells into osteoblasts, chondrocytes leading to bone formation. Bone formed under the influence of BMPs is structurally and biologically identical to normal bone. Genes responsible for several of the BMPs have been isolated (chromosome 20) which has allowed recombinant manufacture. Two recombinant proteins are currently commercially available: rhBMP-7 with the brand name OP-1™, and rhBMP-2 sold as INFUSE™.

Pre-Clinical Studies Numerous animal studies have found the BMPs effective in induction of bone healing in a segmental defect model, long bone osteotomy and fracture models. Other studies have demonstrated efficacy in a spinal fusion model. More recent non-human primate models have demonstrated acceleration of fracture healing in a fibular osteotomy.

Clinical Studies in Humans The use of BMPs in human fracture care has so far been focused on its use in fractures of the tibia, as a adjunct to fracture healing in severe, open fractures, and as an alternative to autogenous bone grafting in nonunion and bone defects. In 2002, Govender et al (BESTT Study Group) published a prospective, randomized, controlled, multi-center study in 450 Patients with open fractures of the tibia. This group found, that the application of rhBMP-2 at the time of wound closure decreased the need for secondary procedures to achieve fracture healing, accelerated the rate of fracture union, and decreased the incidence of infection in the more severe fractures. Friedlaender et al prospectively compared the use of rhBMP-7 (OP-1) to autogenous bone graft in the treatment of 124 recalcitrant tibial nonunion. They found that the use of OP-1 resulted in comparable rates of healing of these challenging problems, while avoiding the morbidity and limited supply associated with autogenous bone graft harvest. More recently, Jones et al presented a series of tibia fractures with associated bone defect, randomized to either autogenous bone graft or rhBMP-2 in combination with cancellous allograft. He reported similar rates of healing between groups while avoiding the morbidity of bone graft harvest in the rhBMP-2 group. Ongoing research will explore the use of recombinant proteins in other fracture scenarios as well as the possible role of BMP2 in the acceleration of fracture healing.

Current Role in Fracture Care Currently recombinant proteins are use in the most challenging orthopaedic cases. Severe open fractures, fractures with bone loss, and long bone nonunion are the most common diagnoses when the use of a recombinant protein is considered. While clinical experience is growing, recombinant proteins are an important adjunct to extremity fracture care in some our most difficult situations.

Cost Considerations The use of recombinant proteins in extremity injury care is currently limited by relatively high cost (~$5000) and inadequate reimbursement by third party payers. Jones et al evaluated the potential for cost offset when rhBMP-2 was used in the care of open tibial fracture using a cost model. This model predicted that without third party payment, the hospital would realize only a small offset in the cost of acute fracture treatment when rhBMP-2 was used. In this model the use of rhBMP-2 did result in a sizeable offset for the payer. This model would suggest that at least partial payment by payers for recombinant proteins would be offset by a decrease in secondary procedures and complications while achieving better outcomes for patients.

Summary The use of recombinant Bone Morphogenetic Proteins or BMPs has an evolving role in the treatment of severe extremity injuries. While cost considerations remain a limiting factor in our society, recombinant BMPs are an important means to improve outcomes in patients with open fractures, bone defects and long bone nonunion. Alternative delivery vehicles, including an injectable system along with our growing clinical experience, will undoubtedly expand their future role in extremity injury treatment.
Session | Session V: Management of Segmental Bone Defects: Presentation 26
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Title | Vascularized Fibula Transplantation for Orthopaedic Reconstruction
Author(s) | Scott Levin, MD

**History** The vascularized fibula graft is first described by Ian Taylor in 1978. Recent authors such as Fu Chan Wei, Beppu and Yoshumira from Japan have performed anatomic studies indicating that a cutaneous skin panel can be taken and is reliable, based on consistent anatomy of peroneal artery. The anatomy details of the osteoseptocutaneous fibula lie in the fact that the perforators traverse the posterior crural septum or the posterior investing layer of the peroneal longus and brevus muscles. An island pedicle flap can be harvested on the peroneal artery with a small buccal monitor, or a large skin component can be taken. The gastrocnemius or soleus muscles can be harvested as well, if one wanted to transplant an osteomyocutaneous flap.

**Pre-Operative Planning** Pre-operative planning for vascularized fibula transfer involves coordination of recipient vessels, bone length, and internal fixation. Preferences for venous anastomosis: Venous recipient vessels must be large enough in diameter to accept the peroneal artery which can be quite large in adults.

**Biomechanics** The biomechanics of the limb in terms of its axis must be considered as well as the planning for any osteotomy of the fibula transplant that increases the cross sectional area of vascularized bone delivered such as in the femoral position.

**Transplant Pre-op Planning** The transplant planning includes determination of bone length, whether or not an intermedulary component will need to be fabricated. The pedicle length can be augmented by subperiostal dissection along the long axis of the fibula. The use of the paddle, whether for soft tissue augmentation or monitoring or both, in the location of the skin paddle on the fibula as it relates to the soft tissue deficiency in the recipient site.

**Fixation Options** These include plates, screws, external fixation, and intermedulary devices or a combination in there of. Our preference in lower extremity is the Ilizarov device as a fibular positioning device which can be slowly disassembled to increase stress to the fibula. Characteristically large plates create unnecessary stress shielding and retard the hypertrophy of the fibula.

**Vascular Access Strategies** Using the radial artery as an inflow system particularly around the humerus. If there is an end artery from previous trauma or tumor resection in the upper extremity, this should be used as an end to end anastomosis. AV loops in the lower extremity are particularly helpful for the femur and help the peroneal artery in the vein can be lengthened with venous interposition grafts to provide access to the peri-articular areas around the knee.

**Versatility** The fibula can be used in the cervical spine, clavical, humerus, radius, ulna, lumbar spine and femur (including knee arthrodesis) tibia and ankle. Patients who are candidates for the osteoseptocutaneous fibula are those that have failed conventional bone grafting or are in beds that are characteristically notorious for poor healing such as radiation patients or patients with severe peripheral vascular disease.

**Regional Specific Applications** Shoulder (the free fibula can be used to augment shoulder arthrodesis or can be used in cases where there is has been prosthetic failure and massive bone loss); Humerus (Non union infection, Tumor, Epiphysseal transfer); Forearm (Radius, Ulna, One Bone Forearm, Emergency Free Flap); Femur (Single, Double Barrel, with Allograft); Knee (Knee arthrodesis following tumor, Knee arthrodiosis following failure of total knee arthroplasty, Island pedicle transfer to fibula for juxta articular nonunions); Reconstruction of the tibia (Post traumatic reconstruction of the tibia, septic reconstruction of the tibia, and tumor); Ankle-Arthropdesis; Application clavical; Application spine; Donor Site Morbidity (Includes an occasional need for skin grafting over the peroneal tendons. Every attempt should be made to avoid dorsi, and plantar flexion for several weeks until the skin graft matures.); Osteoseptocutaneous (Summary: excellent bony union, the soft tissue component is essential for not only coverage but as a bony monitor essential tool in complex cases).
Musculoskeletal cells are attachment dependent and function in vivo via specific interactions with their substrate that are mediated by their extracellular matrix. The underlying substrate, particularly in bone, also has structural features that can alter the mechanical environment experienced by the cells. At the micron-scale and submicron scale, these structural features modulate the nature of cell attachment and resulting cell shape, affecting cell proliferation and differentiation. Understanding how musculoskeletal cells respond to biomaterials is critical in designing biologically inspired implants. Even in the absence of a biomaterial, mesenchymal cells migrate on biological substrates including a fibrin clot, calcified cartilage, or osteoclast-conditioned bone. Autograft and allograft provide substrates for osteoconduction. Similarly, ceramic and bioresorbable bone graft substitutes, as well as metal implants, provide surfaces with specific characteristics that influence the rate and extent of tissue formation, in vivo and in vitro.

There is an increasing body of information examining the mechanisms by which osteoblasts and chondrocytes interact with their substrate. The chemistry, surface energy, and microarchitecture of a material influence the kinds of proteins that adsorb onto the surface, which in turn affects integrin mediated attachment. Signaling via integrins initiates the transfer of information to the cell about the microenvironment. Studies examining osteoblast response to model substrates demonstrate that the cells can differentiate between crystallinities of the same chemistry as well as complex differences in surface structure. Cells grown on smooth surfaces tend to attach, spread and proliferate, whereas cells grown on micro-rough surfaces tend to assume a more differentiated phenotype and exhibit marked differences in how they respond to external stimuli and how they produce local paracrine regulators. These differences in the in vitro response correspond to differences in clinical effectiveness.

By designing biomaterials to maximally enhance mesenchymal cell attachment, migration, proliferation and differentiation, their value for tissue repair will be markedly increased. The goal is to provide materials that are capable of supporting tissue regeneration in vivo, often at sites that are compromised by infection and loss of structure. Many of our current therapies are based on information obtained in cell culture using substrates that have little in common with the substrates the cells will encounter in vivo. Moreover, we now know that the genetic sex of a cell also plays a role. To produce materials that are clinically valuable, we must develop a more in depth analysis of how musculoskeletal cells interact with the physical features of their environments.
Since the First World War, the delivery of medical care to combat casualties by the United States’ Armed Forces has been organized into five echelons. Echelon I, the Aide Station, supports a battalion of 500 to 600 soldiers and is capable of ATLS-style resuscitation. Echelon II, the Clearing Station, supports a brigade or regiment of about 2500, can continue resuscitation, has basic diagnostic equipment, and has a holding capability of a few days for soldiers with minor injury or illness that precludes immediate return to duty (RTD). Echelon III, the Combat Support Hospital (Army), Air Transportable Hospital (Air Force), and Fleet Hospital (Navy), supports a division of about 12,000 and traditionally is the first echelon capable of providing basic surgical services. Echelon III hospitals are still located in the Combat Zone, have more complete diagnostic services, intensive care capabilities, and a longer holding capacity than the Clearing Station. Echelon IV facilities, the Evacuation Hospital, General Hospital, and MEDDAC, among others, can be located in or out of the Zone of Communication and support a Corps. They have full specialty support and are capable of definitive care for all but the most complex injuries. Echelon V facilities are Medical Centers, and all, with the exception of Lanstuhl Regional Medical Center, are within the United States. They are tertiary care facilities with full subspecialty support and complete diagnostic, surgical, and rehabilitation capabilities.

This traditional structure of casualty care has undergone several changes over the last 70 years as a result of evolving technologies that have reduced the mortality and morbidity of combat, beginning with the move to push surgical care forward by Norman Bethune during the Spanish Civil War. This concept matured during the Gulf War with the fielding of the first Forward Surgical Teams, bringing damage control surgical capability to Echelon II. This has been especially important in Afghanistan, where dispersed Special Operations and frequent evacuation delays due to flying conditions make forward surgical assets critical. Fixed-wing evacuation of the ventilated patient, however, did not become available until the current conflict. This advance, supported by the Air Force’s Critical Care Air Transport Teams (CCATTs), has enabled the most critically wounded soldiers, sailors, marines, and airmen to arrive at a tertiary care facility within 24 hours of wounding. This rapid evacuation to the most sophisticated treatment facilities available would, intuitively, explain the dramatic decrease in mortality noted in the current conflict—today’s soldier is 50% less likely to die if wounded by enemy action than in the last 4 conflicts—however, there is no scientific support that either far-forward surgery or rapid evacuation to Echelon V is responsible for the decreased mortality. Other factors, such as improved body armor or improved training and equipping of medics, may prove to be the explanation.

Both the far-forward surgical capability and the rapid evacuation have altered our management of severe extremity injury. Debridement and external fixation of long bone injuries has virtually eliminated transport of the soldier with severe extremity trauma in bivalved hip spica or long-leg casts, decreasing the casualty’s pain and lessening the demands on in-flight nursing care. Open circular amputations outside the zone of injury with application of skin traction have also been eliminated, as the evacuation time is so short that skin retraction is no longer a clinical issue. Whether this has allowed preservation of length with its attendant improvement in function is another question that remains to be answered, as it appears that the incidence of revision for heterotopic ossification is greatly increased over previous conflicts.

We, in the academic orthopaedic community, have the responsibility to examine these questions to improve trauma care delivered to military and civilian populations in the developed and developing world. The one benefit derived consistently from conflict is improved surgical care. The sacrifices currently being made by our young men and women need to be utilized for this contribution to humanity.
Heterotopic ossification (H.O.) refers to the formation of mature, lamellar bone in non-osseous tissues. H.O. most commonly occurs following inciting events such as traumatic brain injury, spinal cord injury, total hip arthroplasty, severe burns, and acetabular or elbow fractures, especially those requiring surgical treatment. Although commonly mentioned as a potential cause of pain in residual limbs, there is a paucity of literature and no clinical trials to date on the prevention or treatment of H.O. in amputees. Nonetheless, the recent experience of the Army amputee centers with nearly 350 traumatic and combat-related amputees from Operations Enduring and Iraqi Freedom has demonstrated H.O. to be a surprisingly common and problematic clinical entity in these patients.

H.O. formation is thought to require an inducing event, an osteogenic precursor cell, and an environment conducive to osteogenesis. Animal and in vitro human studies have recently increased our understanding of the molecular basis for this disorder, etiologically implicating the bone morphogenetic proteins and their receptors, and demonstrating the inhibitory potential of noggin to block H.O. formation. Nonetheless, the exact cascade of inciting cellular and molecular events necessary to trigger H.O. development remains elusive.

Numerous level 1 clinical trials have demonstrated the efficacy of both non-steroidal anti-inflammatory drug (NSAID) and low-dose local irradiation (XRT) prophylaxis to prevent H.O. formation following total hip arthroplasty and the operative treatment of acetabular fractures. Limited clinical evidence suggests that there may be an additive or synergistic beneficial effect when these treatment modalities are combined. Two level 1 and numerous less rigorous studies support the utilization of etidronate for prevention and/or treatment of early H.O. in patients with spinal cord or traumatic brain injuries. Although H.O. may “recur” via delayed mineralization after the cessation of treatment, some benefit may be sustained with this modality. Limited human studies have suggested potential benefits from coumadin and calcitonin therapy, and animal studies have demonstrated successful H.O. prophylaxis utilizing corticosteroids and colchicine.

No studies have evaluated the prophylactic potential of any treatment modality in the setting of traumatic or combat-related amputations. Numerous barriers to potential prophylactic therapy exist in a traumatic amputee population. These include the timing of and logistical barriers to therapy initiation, as well as patient factors including residual open wounds with tenuous soft tissues, concomitant local and remote long-bone fractures, multi-system injuries placing patients at risk for renal, gastrointestinal, and bleeding complications of prophylaxis, potential local or systemic immunosuppression, and the need for serial additional surgical procedures. Additionally, the amputee patient groups most at risk for symptomatic H.O. formation require identification in order to allow a risk-benefit analysis and guide therapy. Early analysis of our current amputee population data suggests that a blast, rather than blunt or projectile, mechanism of injury and final amputation level within, rather than above, the zone of initial injury are the greatest risk factors for H.O. development.

The historical approach to the excision of symptomatic H.O. has often involved a prolonged waiting period to allow for radiographic and histologic maturation, normalization of the serum alkaline phosphatase, and quiescence of three-phase bone scans in order to prevent unacceptable rates of post-operative recurrence. However, the basis for these recommendations has often been anecdotal and without solid clinical evidence, and several studies have questioned the reliability and validity of these criteria. Additionally, numerous recent, low-level clinical studies have demonstrated successful early excision of symptomatic H.O., often with peri-operative NSAID and/or XRT recurrence prophylaxis, about the elbow and forearm following fractures and burn injuries.

We have performed 19 H.O. excisions from the residual limbs of 18 amputees at a mean of 8.2 months (range, 3-24; median 6) months after injury. In each case the surgical indications included breakdown of residual limb, repeated difficulties with prosthetic fitting, and localizable pain with prosthetic wear. All patients had amputations within the zone of initial injury, with 16 patients sustaining blast injuries and two amputations occurring due to motor vehicle accidents. Radiographically, the H.O. was graded as mild in five, moderate in seven, and severe in seven limbs, respectively. Ten patients (10 limbs) were treated with adjunctive NSAID therapy, and 14 patients (15 limbs) underwent local XRT postoperatively. At an average of six months of radiographic and nine months of clinical follow-up, 16 patients (17 limbs) demonstrated no radiographic evidence of recurrence, and two patients demonstrated mild juxtacortical, clinically asymptomatic, recurrence of H.O. All 19 limbs have been successfully fit for prostheses and all patients have resumed prosthetic wear. Four patients experienced wound complications requiring return to the operating room. Each of these limbs (4/15) received post-operative XRT; however, with the numbers of available, XRT was not a statistically significant risk factor for wound complications.

H.O. is being increasingly recognized as a sequelae of traumatic amputation, particularly following blast injuries. Although surgical treatment, when necessary, can be technically challenging, we have found it rewarding with ultimately favorable clinical outcomes. Additional research is needed with regard to the etiology, treatment, and prevention of H.O. in this patient population.
The medical legacy of the Iraq war may well be the restoration of function after traumatic limb loss. Many soldiers have returned from Iraq with traumatic amputations, occasionally loss of multiple limbs, and often at proximal levels where restoration of function is difficult. Barriers to successful prosthetic use include (1) Prosthetic sockets are uncomfortable, hot, heavy, and irritating to the skin. Scarring and poor socket fitting can lead to skin ulceration. (2) Inadequate length of residual limbs, particularly in post-traumatic limb loss, can impair prosthesis fitting and cause loss of muscular strength and balance. (3) Loss of neuromuscular function—particularly proprioceptive deficits—and loss of muscle strength, result in fatigue and impaired balance, limiting ambulation in lower extremity prosthetics. (4) Approximately 25%–35% of lower-extremity amputees give up ambulation because of severe chronic pain.

The focus of our program is the restoration of limb function through a biohybrid approach. We consider the limb conceptually as a biohybrid organ consisting of biological tissue, endoprostheses (including neural devices and joint replacements) and exoprostheses. The biohybrid limb maximizes biological function and functional articulations, including endo and exoprosthesis, with optimized human-prosthetic interfaces.

Commercially available lower extremity prosthetic devices remain to this day either passive-spring mechanisms or actively controlled variable-damping devices. Although extensive research has been conducted to advance prosthetic materials and construction techniques, little research effort has focused on the advancement of lower-extremity prosthetic joints where both joint impedance and motive force are actively controlled, capabilities of critical importance if leg prostheses are to truly mimic biological function. Microprocessor-controlled robotic leg prostheses employ distributed sensory systems, muscle-like actuators, and biomimetic control strategies. Electromyographic (EMG) signals measured from the residual limb are combined with mechanical information measured local to the robotic prosthesis. These sensory data guide control actions to an external prosthesis comprising electroactive polymer and artificial muscle in parallel to variable damping and spring stiffness elements. The intent of the amputee is assessed and translated into the physical movements and impedances of the robotic prosthesis, enabling the amputee to have direct neurological control of their active, dynamic, and realistic artificial limb.

Osseointegration is a promising technique for improving human-prosthetic interfaces, especially for transfemoral and transhumeral amputations. Typically, however, transcutaneous implants exhibit inflammation and infection, leading to bone loss and loosening of the implant. This has been associated with movement of the soft tissue envelope around the implant leading to sinus track formation from the exterior environment to the bone. Concerns about infection and loosening, and consequent loss of bone in residual limbs, have focused our attention on the soft tissue—particularly skin—interface with osseointegrated prosthetics. One way to develop an environmental seal, eliminating contact between the bone and the environment and restricting contamination of the prosthesis and bone, would be to promote dermal and epithelial growth into prosthetic surfaces. Tissue engineering and biomaterials approaches are being used to study soft tissue integration (fibroblasts and epithelial cells) with titanium prostheses with modified surface characteristics.

A serious problem for amputees is short residual limbs, which are particularly common after traumatic amputations and which compromise prostethesis use even to the point of requiring a higher functional amputation level. Strategies for lengthening residual limbs are available for immediate clinical translation. We are focusing on limb lengthening and bone regeneration with growth factors and physical agents. More research needs to be done to determine the maximum rate of lengthening as well as the quantity and length of bone that can be produced in residual limbs with bone transport. Techniques that accelerate the rate of bone formation, the consolidation of callus, and the gain of biomechanical strength need to be studied. Such techniques may include demineralized bone matrix, growth factors, gene therapy, and interaction with physical stimuli.

Microelectronics can interact with the nervous system to restore lost function. Mathematical algorithms are currently being studied that translate complex patterns of neural activity into outputs that can be used as control signals for prosthetic devices, such as robotic limbs or semiautonomous assistive robots. The understanding that sensory and motor information is represented in patterns of electrical signals in the nervous system has paved the way for the development of closed-loop brain-machine interfaces (BMIs), which have the promise of enabling bidirectional interaction between machines and the human nervous system. The application of BMI neurotechnology has the potential to restore lost neurological function to disabled humans and to provide novel control of physical devices, including prosthetic limbs or semiautonomous robots. New mathematical models are being developed for representing and decoding human neurospiking to allow two-way communication between prostheses and the nervous system.
The Lower Extremity Assessment Project (LEAP) is an ongoing multi-center study of severe lower extremity trauma in the U.S. civilian population (1-12). At two and seven year follow-ups, the LEAP study found no difference in functional outcome between patients who underwent limb salvage surgery or amputation as measured by the Sickness Impact Profile (SIP) and return to work. Among all patients, regardless of treatment, worse outcome was associated with low educational level, poverty, lack of private health insurance, low self-efficacy and a poor social-support network. Severe lower extremity injury was associated with a 42% incidence of likely psychological disorder as determined by the Brief Symptom Inventory (BSI), compared with a normative value of 2.3% in the general population. Although the study's results may be considered comprehensive for the targeted population, because of essential differences between the civilian and military populations, the findings of the LEAP study may only roughly correlate with combat casualty outcomes.

Although the study’s results may be considered comprehensive for the targeted population, because of essential differences between the civilian and military populations, the findings of the LEAP study may only roughly correlate with combat casualty outcomes. First, in contrast to the LEAP study in which amputation and salvage outcomes were similar, recent small case series suggest that functional outcomes are better for upper extremity limb salvage when compared with amputation. Function of the lower extremities primarily affects stance and ambulation, which current prostheses adequately support. Function of upper extremities, however, requires coordinated function of the digits and is dependent on sensation. While current prostheses can provide gross motor movements such as grasp, in many instances they do not adequately restore fine motor function. Due to the relatively high incidence of major trauma to the upper limb sustained in the current conflicts, the study proposed here will provide a unique opportunity to examine the benefits of reconstruction and amputation following these injuries.

In addition, many of the risk factors for poor outcome in the LEAP study do not exist or are minimized in the military population. Soldiers are employed, have guaranteed health care and have better pre-injury physical conditioning. They also are likely to have higher levels of self efficacy and, at least initially, have a psychosocial support network provided by their military units. It should be noted, however, that there is concern that the extent of social support and self efficacy may not remain as high after discharge from active duty. In addition, the rate of post traumatic stress disorder (PTSD) will be higher in the military versus civilian populations. The high incidence of mental health disorders generally has been recently reported by Hoge et al. The effect of PTSD and other mental health disorders on functional outcomes and quality of life will be of major interest in any follow-up.

A limited amount of information about major limb trauma has begun to trickle in from the current conflicts in Afghanistan and Iraq. Gambel et al reported a cohort of almost 100 active duty service members that underwent major limb amputation for injuries sustained in Afghanistan or Iraq. These casualties were fitted with both advanced myoelectric arm or microprocessor leg prostheses and conventional body-powered and cosmetic arm prostheses or nonmicroprocessor leg prostheses. This is in contrast to civilian care that typically employs either advanced or conventional prostheses. The authors concluded that this approach improves the patient’s overall functional results. In a case series of orthopaedic injuries from the conflict in Afghanistan, Lin et al reported on the current doctrine of early irrigation, debridement and skeletal stabilization of orthopaedic injuries in the forward deployed area and definitive reconstruction after evacuation to their facility in the Continental United States. They stated that early operative treatment in the theatre of operations improved their ability to reconstruct the injured extremities after evacuation to CONUS. This information is useful but considering the significance of severe penetrating upper extremity injuries on the battlefield, a thorough follow-up study of survivors is needed.

A military study has several advantages not present in a civilian population. Prospective data on pre-injury function is collected routinely. Many outcome measures are also routinely collected for soldiers returning from deployment to the Iraq and Afghanistan conflicts. Finally, our ability to track these patients through military and VA treatment facilities will facilitate good follow-up.

In summary, very little is known about the long term consequences of limb threatening injuries and their treatment in a military setting. Of particular interest and concern is the status of soldiers once they are discharged from care at one of the participating facilities and either return home or return to active duty. We are proposing to establish procedures for a uniform, long term follow-up to better define the clinical, functional and quality of life outcomes following major orthopedic trauma. This long term follow-up will serve two objectives. First it will provide a unique opportunity to examine the benefits of reconstruction versus amputation in a military population, especially for those sustaining limb threatening trauma to the upper versus lower limb. The results will have important implications for treatment of future patients with major upper limb trauma. Second, the study will be used to identify ongoing (post-discharge) needs for additional services and provide the basis for targeting interventions and conducting focused research on carefully selected aspects of long-term recovery. Over the long term, the proposed research will assist in assuring that these soldiers are provided with every opportunity for a good long-term outcome.