Chapter VII
ORTHOPAEDIC TRAUMA

VII.1 Gunshot Wound With Loss of the Elbow

CASE PRESENTATION

This male patient, an interpreter for Special Operations Forces, sustained a gunshot wound to the left elbow. He was transported to the local host nation hospital where he was offered an above-elbow amputation, which he declined. Forty-eight hours later, he presented to the combat support hospital (CSH) with a large, dorsal elbow wound (Fig. 1). The proximal ulna was missing, but the hand appeared neurologically intact, except for decreased light-touch sensation in ulnar nerve distribution (Fig. 2). All motor function was intact. Plain radiographs revealed a distal humerus fracture and a missing proximal ulna (Figs. 3 and 4). The patient underwent irrigation, debridement, and external fixation from the humerus to the ulna (Figs. 5 and 6). The ulnar nerve was severed. All loose bone was removed, and a dressing soaked with Dakin's solution was placed in anticipation of wet-to-dry dressing changes. The wound required multiple irrigations and debridements. Intravenous antibiotics, including cefazolin and gentamicin, were administered. When the wound was surgically clean, open reduction and internal fixation of the distal humerus were performed, as well as radial head excision and elbow arthrodesis. Wound coverage was obtained with an abdominal pedicle flap. The patient was discharged on postoperative day 5 to a hospital in Jordan for continued care (Figs. 7 and 8).

TEACHING POINTS

1. This patient was provided with full reconstructive care in a level III medical treatment facility. This specialized care posed difficult problems because instrumentation options are limited in theater. Large bone defects are also a particular problem because no bone bank is available in theater. This situation sometimes makes decisions regarding treatment options difficult for the deployed surgeon.
2. This patient presented with intact motor function and decreased light-touch sensation in the ulnar nerve distribution. This condition is most likely caused by the presence of a Martin-Gruber anastomosis that connects the median and ulnar nerves distally.
3. At the host nation hospital, he was offered an above-elbow amputation, despite the fact that his hand still worked. If the patient could obtain a prosthesis, this level of amputation could be very functional. In the host nation, however, prostheses are hard to come by. Advanced

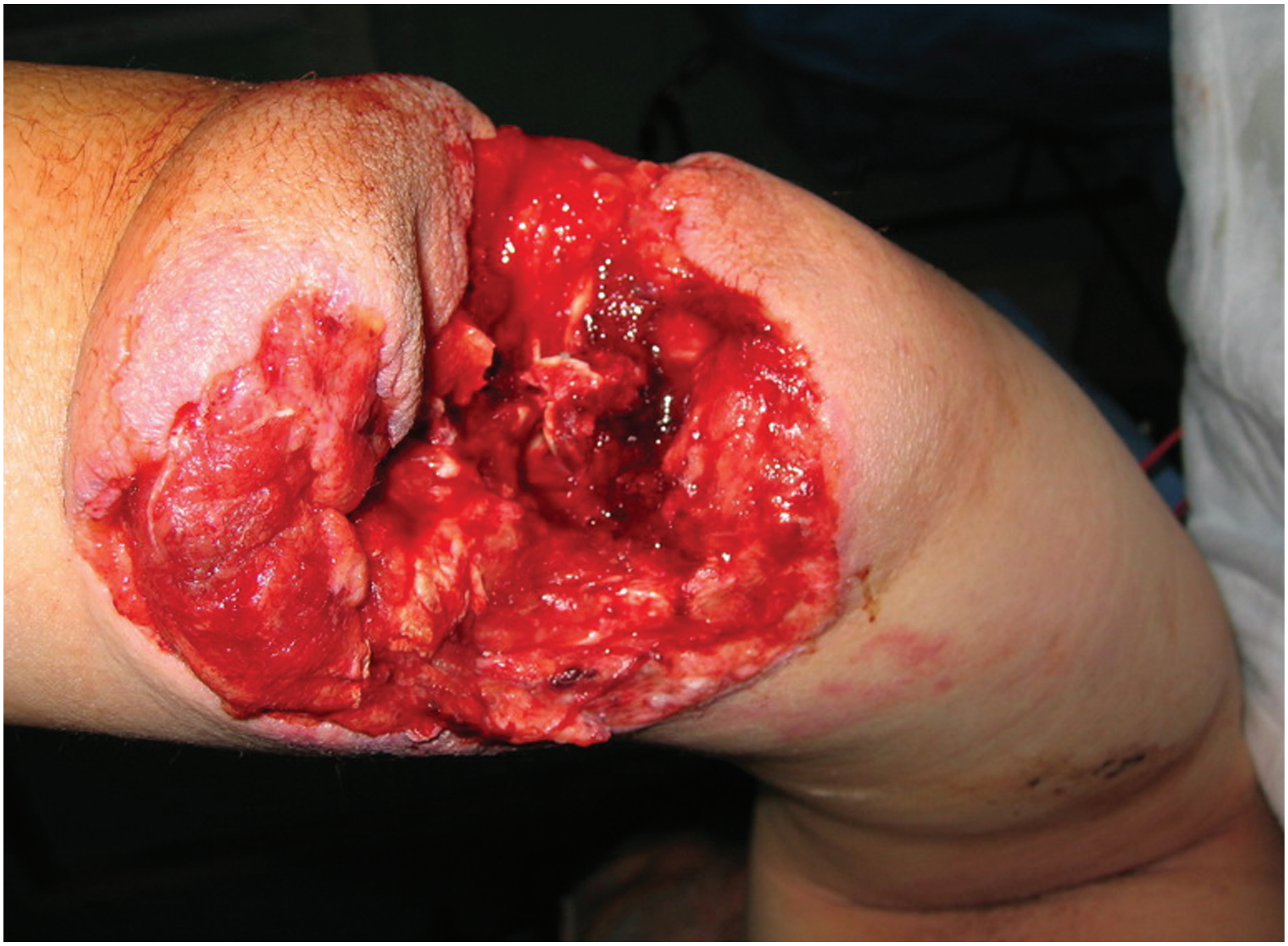


FIGURE 1. *Extensive soft-tissue and bone injuries of the elbow.*

prosthetics and expensive surgical implants (eg, an elbow arthroplasty or osteoarticular allograft) are not available. For this reason, an elbow arthrodesis was performed.

CLINICAL IMPLICATIONS

1. Wounds to soft-tissue and osseous structures around the elbow are common because the elbow is not protected by body armor. These wounds can involve fractures and arterial and nerve injuries, with the ulnar nerve frequently injured.
2. If a nerve laceration is noted and the patient has no function distally, nerve repair with an end-to-end technique or with a NeuraGen tube technique versus cable grafting can be done. These techniques are difficult to perform without a microscope and microvascular instruments. Therefore, every surgeon should bring surgical loupes to theater.
3. Wound coverage is always a problem with the elbow. Free flaps in theater are rarely performed and are fraught with significant complications. Therefore, in this patient—with the help of a plastic surgeon—an older technique of pedicle flap grafting was used.
4. Severe bone defects are difficult to address in theater. The solution to these defects is generally an amputation. In this case, reconstruction of the bone was attempted using an autograft from the iliac crest or fibula.
5. Another treatment alternative is to shorten the bone instead of reconstructing it. If bone reconstruction is successful, the procedure negates the need for a lifetime use of prosthetics in a location where they are difficult to obtain and maintain.

DAMAGE CONTROL

External fixation across the injured joint allows safe

MARTIN-GRUBER ANASTOMOSIS

Originally described by Martin in 1763 and later by Gruber in 1870, this is an anomalous innervation pattern occurring between the median and ulnar nerves in the forearm. Specifically, fibers from the median nerve cross over to the ulnar nerve in the forearm. Martin-Gruber anastomosis is the most common anomalous innervation of the hand, with an incidence of 15% to 28%.

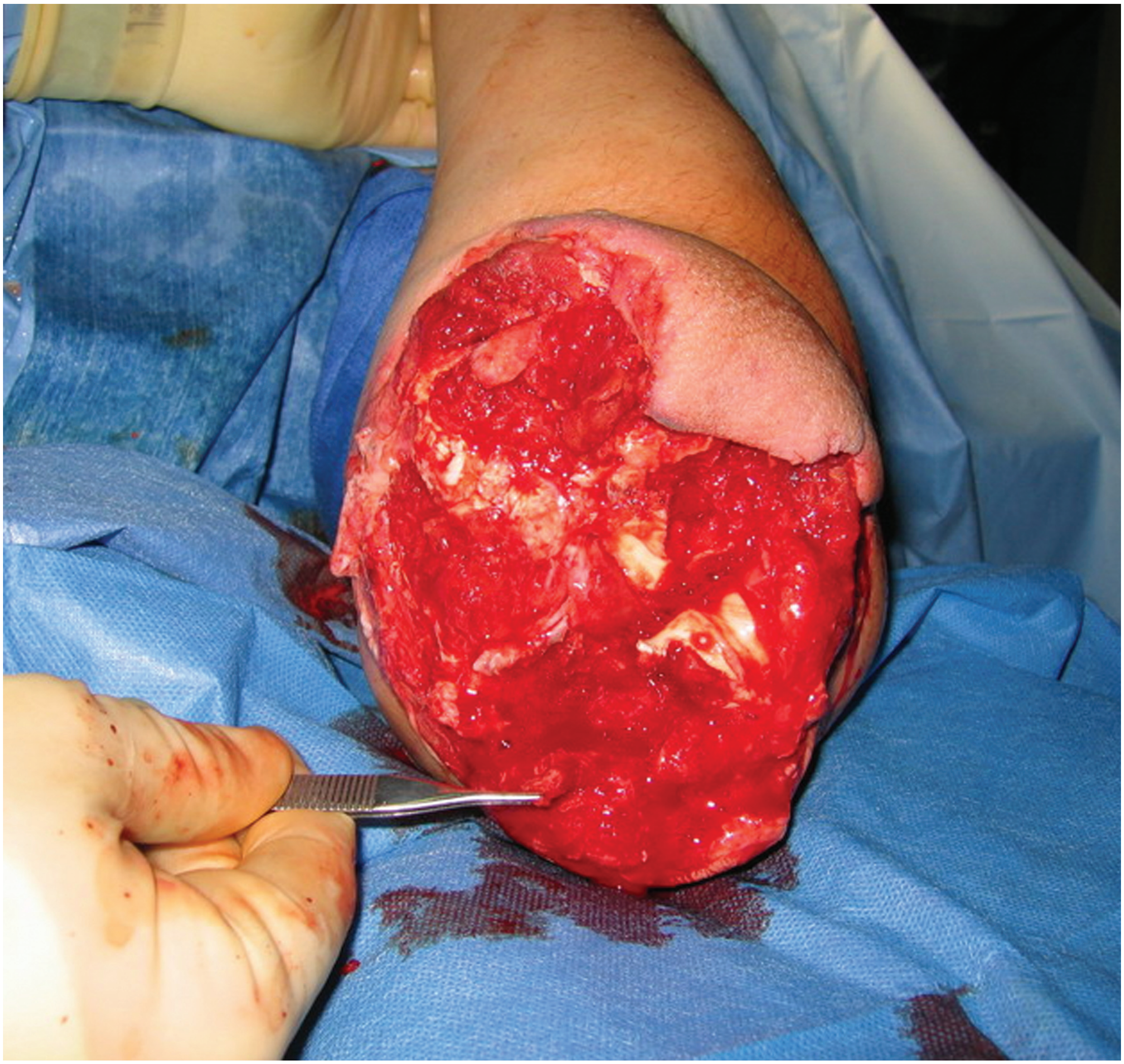


FIGURE 2. *Surgical instrument indicates the severed ulnar nerve.* (*Surgical draping gives the false impression of an amputation.*)

Figure 3. (Top Left) *Radiograph of left elbow wound. There is a fracture of the distal humerus.*

Figure 4. (Top Right) *Radiograph of elbow. Note loss of proximal ulna.*

Figure 5. (Bottom) *External fixation spanning the elbow joint. Wound care can be easily performed. If appropriate, the patient can be evacuated from the CSH.*

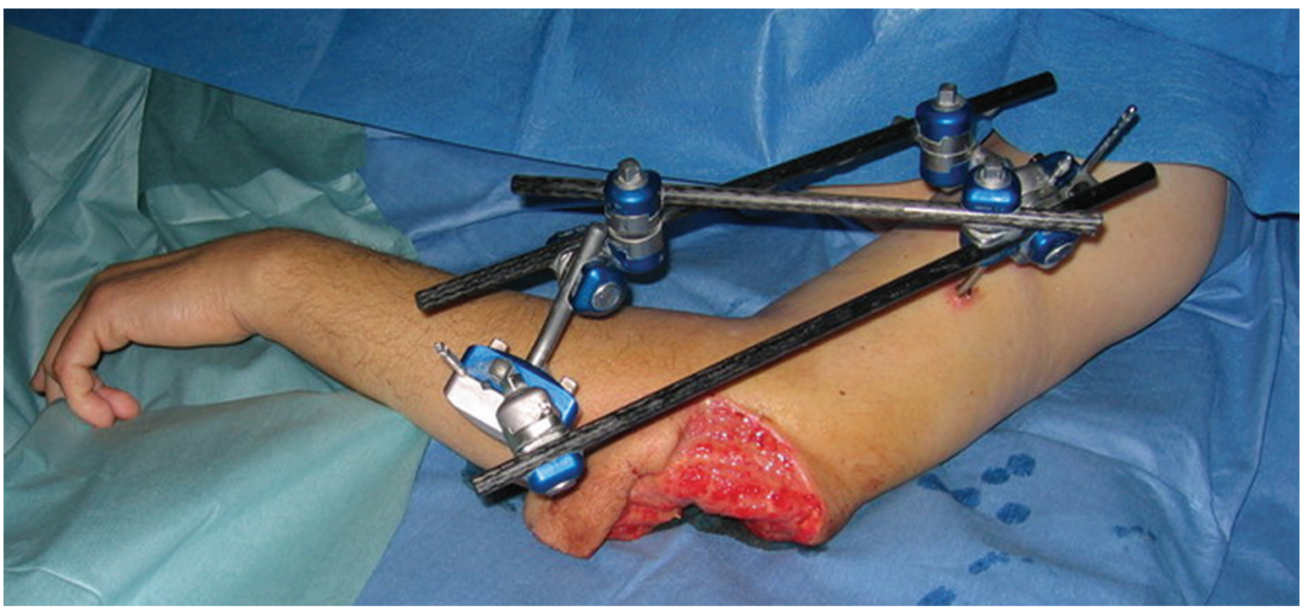


FIGURE 6. *Patient after arthrodesis, external fixation, and abdominal pedicle flap.*

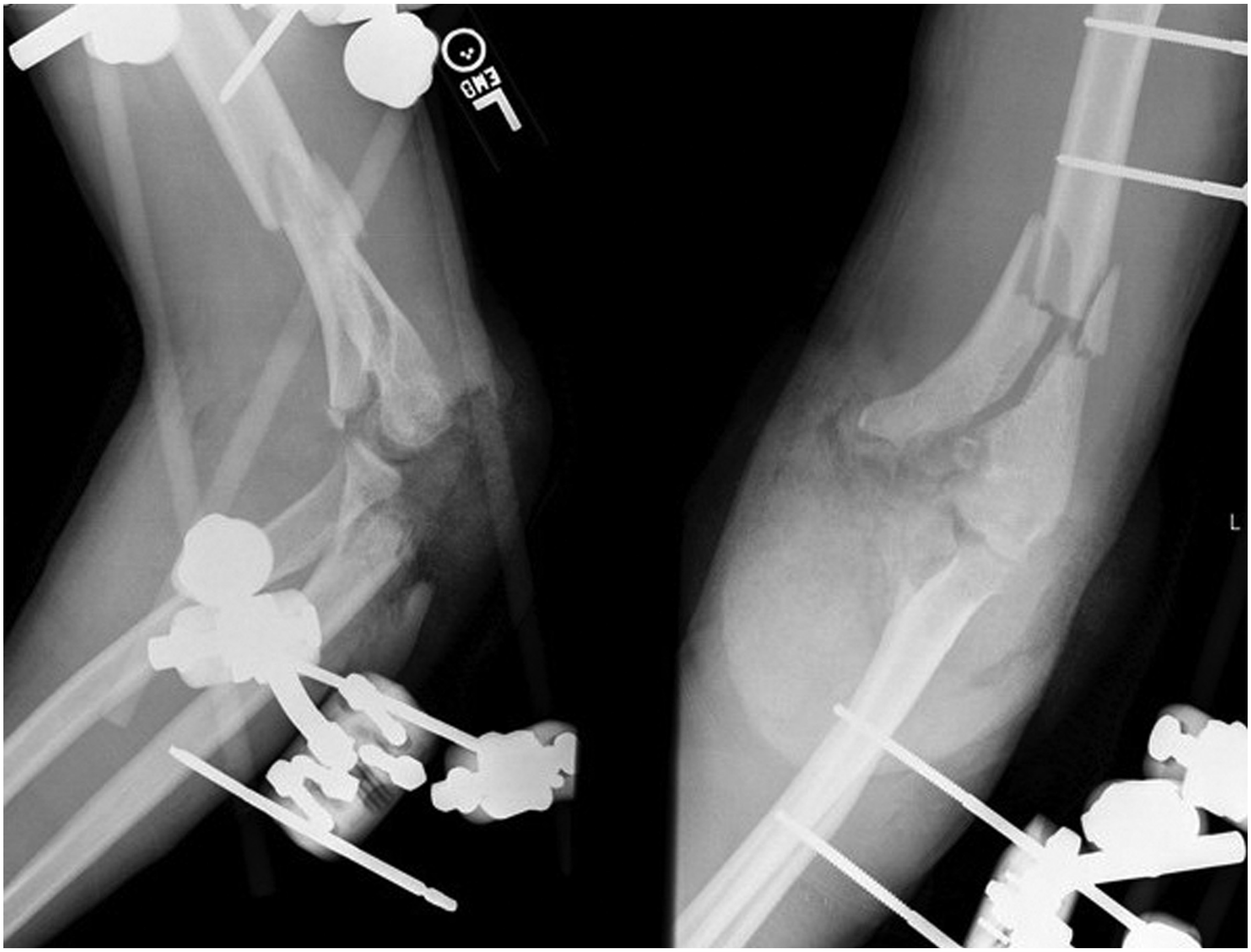


FIGURE 7. *Radiograph of external fixation.*

FIGURE 8. *Radiograph after arthrodesis, external fixation, and abdominal pedicle flap.*

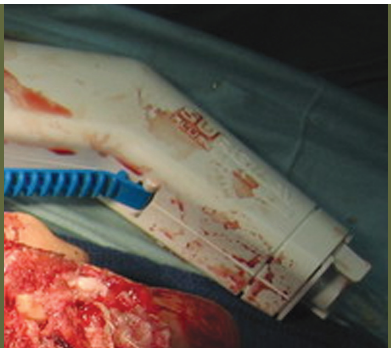
transfer out of theater. The wound should be adequately debrided and washed out before evacuation. If possible, evacuation should be coordinated with the receiving hospital to allow timely, additional wound washouts. Nerve endings should be tagged to allow grafting at a later date.

SUMMARY

This case demonstrates a need for highly sophisticated, technically adequate, surgical capabilities in theater. CSHs are not intended to provide this type of surgery because of the rapid evacuation of American wounded. However, at times, complex surgeries are still necessary and are appropriate in the combat zone.

SUGGESTED READING

Chapter 24: Open-joint injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.



VII.2
Hand and Face Blast Injuries; Polytrauma Management

CASE PRESENTATION

This male patient was the driver of a high-mobility multipurpose wheeled vehicle (HMMWV or “Humvee”) in a convoy that was hit by a blast from an improvised explosive device (IED). The patient sustained severe facial injuries (Fig. 1), as well as right forearm and hand injuries (Fig. 2). He presented to the combat support hospital (CSH) awake and attempting to talk. After resuscitation, he was taken to the operating room. His first surgery lasted 8 hours, and involved general, ophthalmic, oral and maxillofacial, plastic, and orthopaedic surgeries. Priority was given to the patient’s eye and facial wounds, which were irrigated and reapproximated. A tracheostomy was performed. After his facial injuries were treated, the severe hand injuries were addressed. During intraoperative evaluation, an obvious volar forearm wound and a severe dorsal hand wound, with full-thickness tissue loss from the dorsal skin to the volar aspect of the metacarpals, were found. His fingers were blue, and his hand was folded over through the fractured metacarpals. Apropos of this injury, the question was whether or not to amputate any fingers. The surgery team elected to save the fingers. A volar forearm fasciotomy was performed (Fig. 3). The hand wound was irrigated and debrided. All dead tissue and loose bone were removed. Kirschner wire spacers were placed to recreate the anatomical cascade of the hand (Fig. 4). After placing the wire spacers and extending the hand out to length, finger perfusion improved, with good capillary refill and improved temperature. Wet-to-dry dressings soaked with Dakin’s solution were placed on the affected areas. The forearm and hand were splinted. The patient was started on intravenous antibiotics and was evacuated the day of injury. The hand was reconstructed by the Hand Surgery Service at Walter Reed Army Medical Center (WRAMC). The index finger, which was completely missing the metacarpal, was used to reconstruct the other missing metacarpals and extensor mechanism. The skin of the volar index finger was rotated through the first web space to cover the skin defect of the dorsum of the hand.

TEACHING POINTS

1. Blast injuries cause severe injuries to multiple body parts. In this case, severe facial injuries, ocular injuries, and hand injuries occurred. It is crucial that a surgeon not become fixated on any one injury. Advanced Trauma Life Support (ATLS) principles must be followed. In this patient, the airway had to be controlled.

2. The goal of the combat surgeon at the forward CSH is to give the reconstructive surgeon at the level V medical treatment facility in the United States something to work with for reconstruction. The oral and maxillofacial, plastic, and ophthalmic surgeons addressed facial injuries (Fig. 5). From an orthopaedic perspective, the goal was to retain tissue and get as many viable fingers back to WRAMC alive as possible. It appeared that the middle finger and the ring finger could be reconstructed. However, it was not clear that the index finger could be salvaged. Therefore, an attempt was made to save the index finger for reconstructive purposes.

CLINICAL IMPLICATIONS

1. Nearly every surgical service in the CSH was required to manage this multiply injured patient.
2. The most life-threatening injuries should be addressed first, followed by threats to eyesight and limbs.
3. It is vital to salvage as much tissue as possible for later reconstruction.

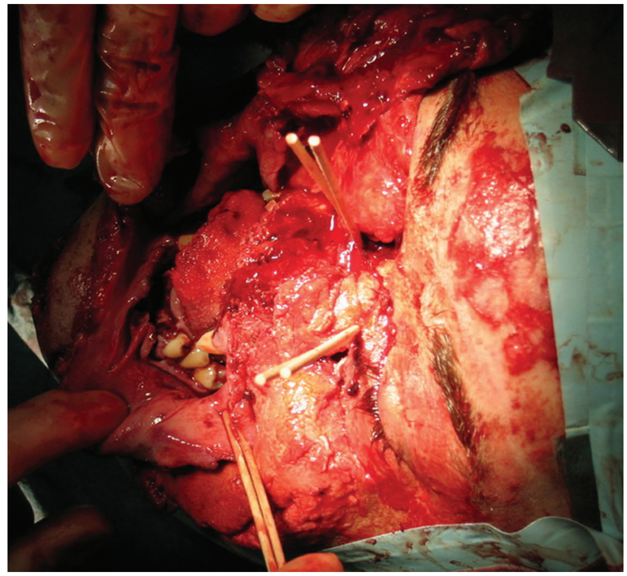
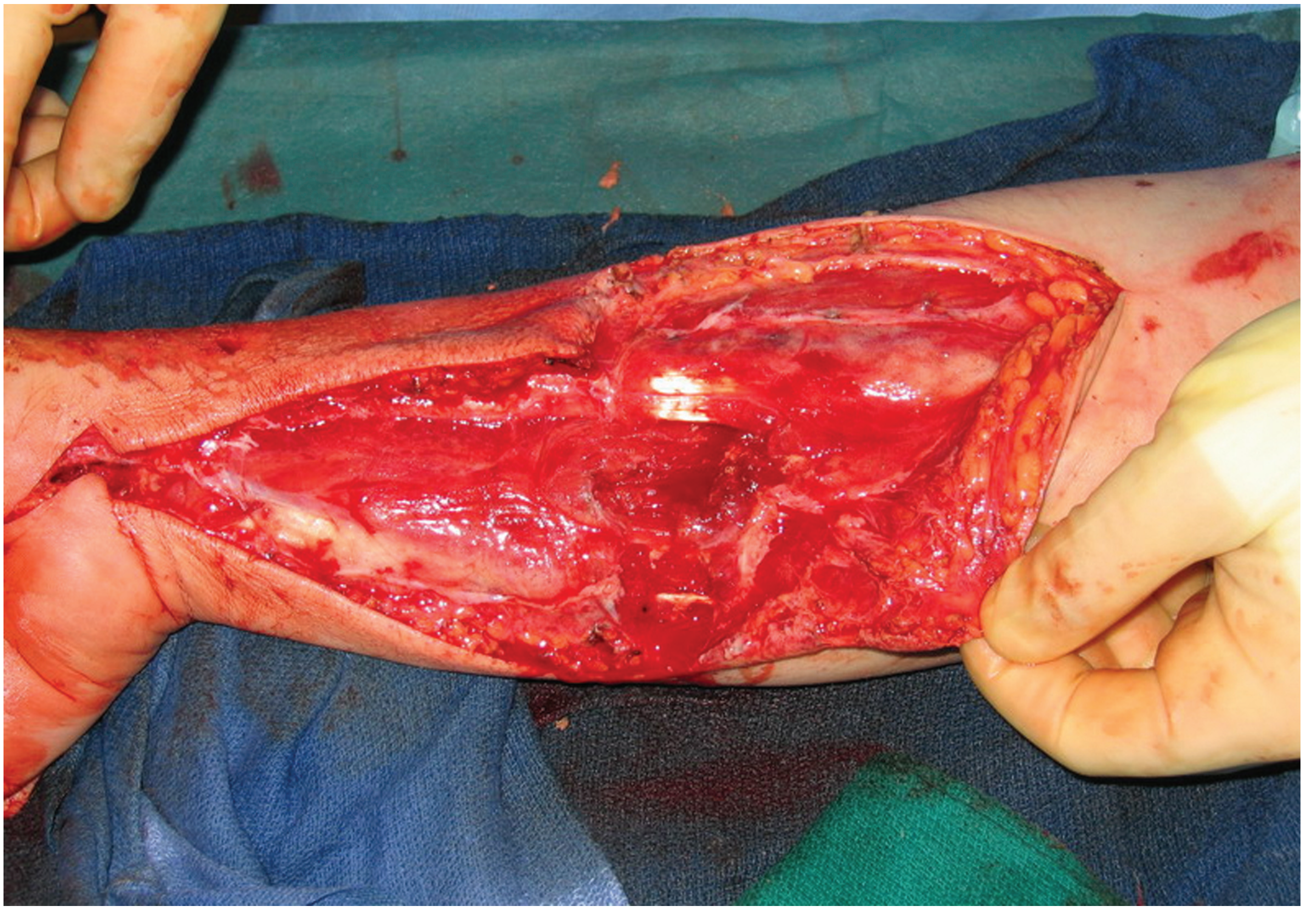


FIGURE 1. (Top) *Extensive face wounds.*

FIGURE 2. (Bottom) *Hand and forearm at presentation.*



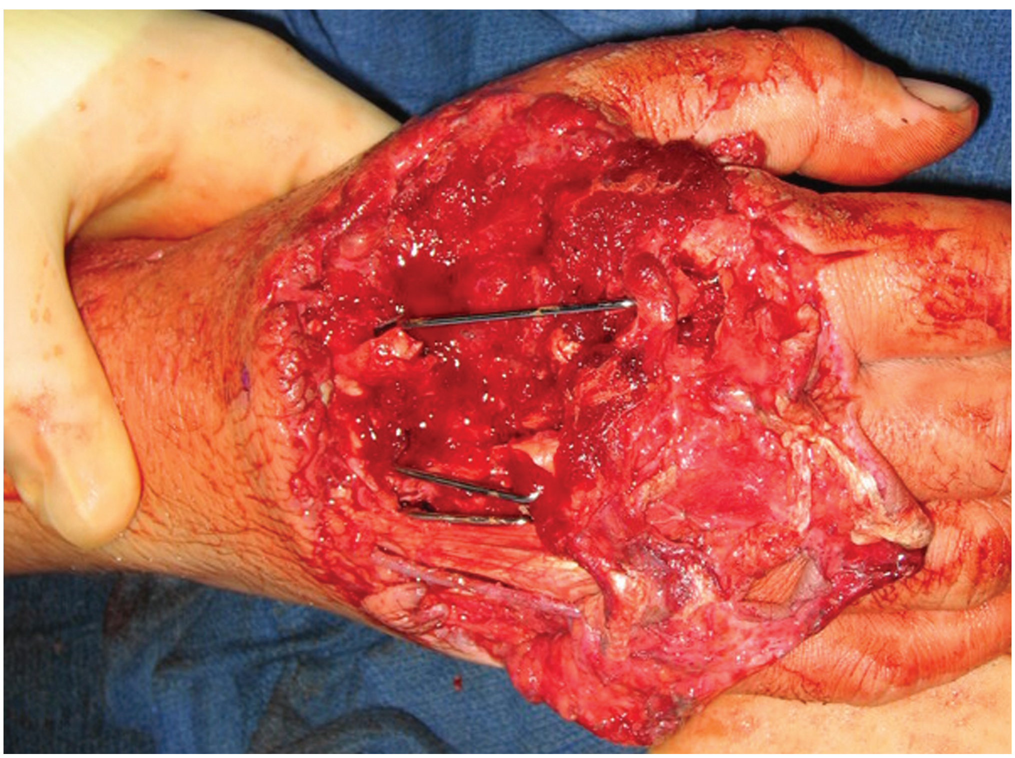


FIGURE 3. (Top) *Volar forearm debridement and fasciotomy.*

FIGURE 4. (Bottom) *Debridement and placement of Kirschner wires.*

Figure 5. *Facial reconstruction and tracheostomy (post-op).*

Figure 6. *Reconstruction performed by the Hand Surgery Service at Walter Reed Army Medical Center.*

Figure 7. *Reconstruction after a rotational flap and skin graft have been performed.*

KIRSCHNER WIRES

Kirschner wires (or K-wires) are thin, rigid wires used to stabilize bone fragments. These wires are drilled into bone to hold the fragments in place. Kirschner wires were introduced in 1909 by Martin Kirschner (1879–1942).

DAMAGE CONTROL

The first priority is to attend to life-threatening injuries. Debride necrotic tissue and perform appropriate fasciotomies while preserving as much tissue as possible for later reconstruction. Amputation may be required for a patient in shock who is not responding to resuscitation or who needs other lifesaving procedures.

SUMMARY

There is a frequent need in the combat environment for a multispecialty team approach to the management of polytrauma. Treatment priorities must be set, and ATLS protocols must be followed. In this case, after the airway was properly secured and the admission Glasgow Coma Scale (GCS) score was > 8, facial and right arm wound management were undertaken with the intent to preserve as much tissue as possible for future reconstruction (Figs. 6 and 7).

SUGGESTED READING

Chapter 13: Face and neck injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 25: Amputations. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 26: Injuries to the hands and feet. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

VII.3
Open Femur Fracture

CASE PRESENTATION

This male patient sustained a penetrating blast injury to his left thigh from an improvised explosive device (IED). Physical examination revealed an isolated injury to the left thigh, with a 3-cm wound at the distal third of the anterolateral thigh. Neurological and vascular examinations were normal. The thigh was moderately swollen, and a retained fragment noted radiographically was not palpable. Plain radiographs showed a long, spiral oblique fracture of the femur, with a fragment proximal to the fracture site (Fig. 1). In the operating room, he underwent irrigation and debridement of the fracture and placement of an external fixator spanning the knee joint (Figs. 2 and 3). The traumatic wound was extended to improve exposure. This extension was closed at the end of the procedure, leaving the traumatic wound open. The open wound was packed with wet-to-dry dressings soaked with Dakin's solution. Intravenous antibiotics were administered, and the patient was evacuated on the day of injury.

TEACHING POINTS

1. Fractures to long bones are very common injuries that result from either penetrating blast injuries or gunshot wounds. They must be irrigated, debrided, and stabilized before evacuation from theater.
2. Complete primary and secondary surveys must be performed because long bone fractures are sometimes accompanied by other major life-threatening injuries.
3. Significant blood loss frequently accompanies a femur fracture. This condition might necessitate transfusion before the patient is accepted into the medical evacuation system.
4. In this patient, the external fixator was placed spanning the knee joint out of concern that placing pins in the distal femur would risk intraarticular pin positioning in the suprapatellar pouch, increasing the risk of joint sepsis.
5. Retained fragments are often seen in theater. There is always a question of whether or not to remove these fragments. In general, there is no urgency to remove them. If the fragments are easily accessible in the traumatic wound, they are removed routinely. If the fragments are remote from the surgical site, they can be left in place. If fragments later become symptomatic, they can be removed electively.

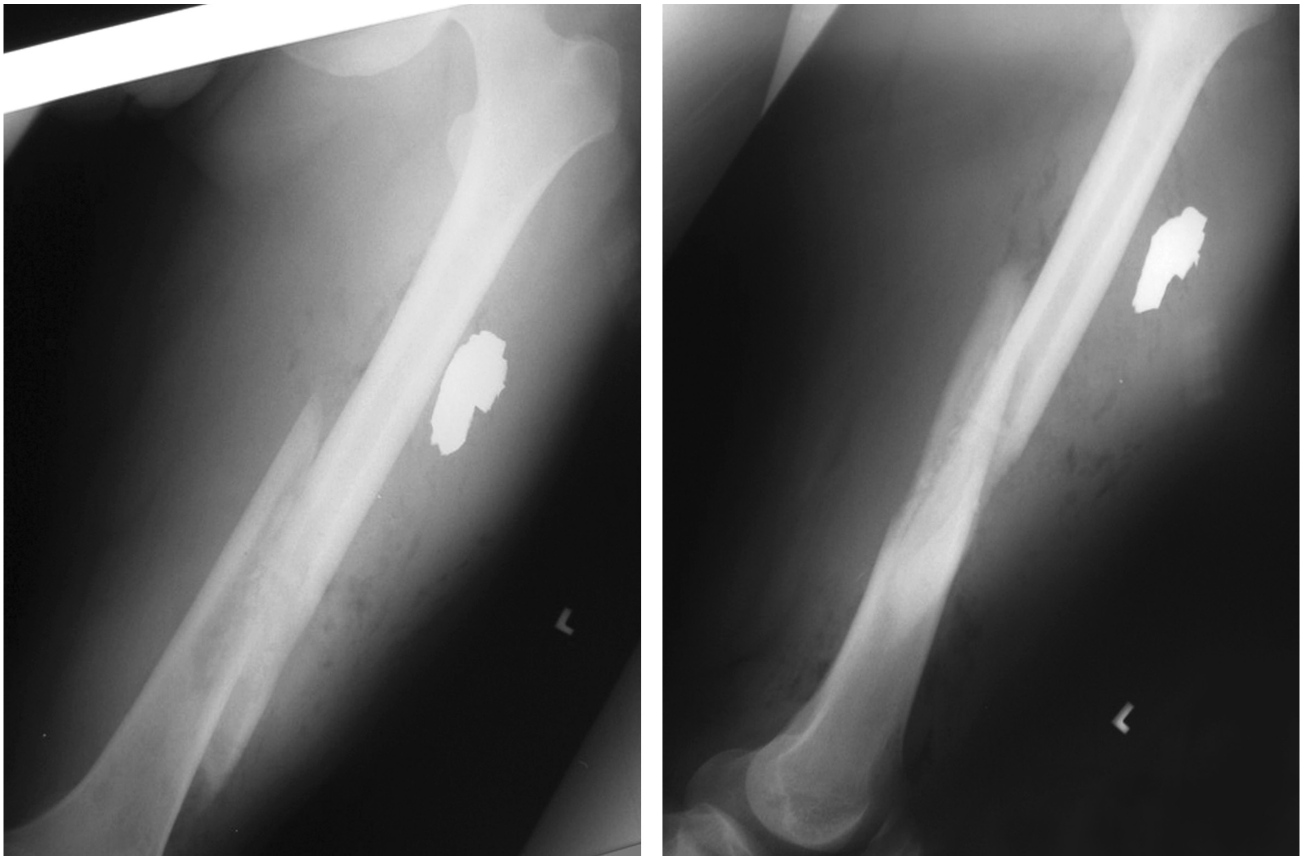


Figure 1. *PA* (Left) *and lateral* (Right) *radiographs show midfemoral fracture and metallic fragment that caused the injury. There is extensive soft-tissue air.*

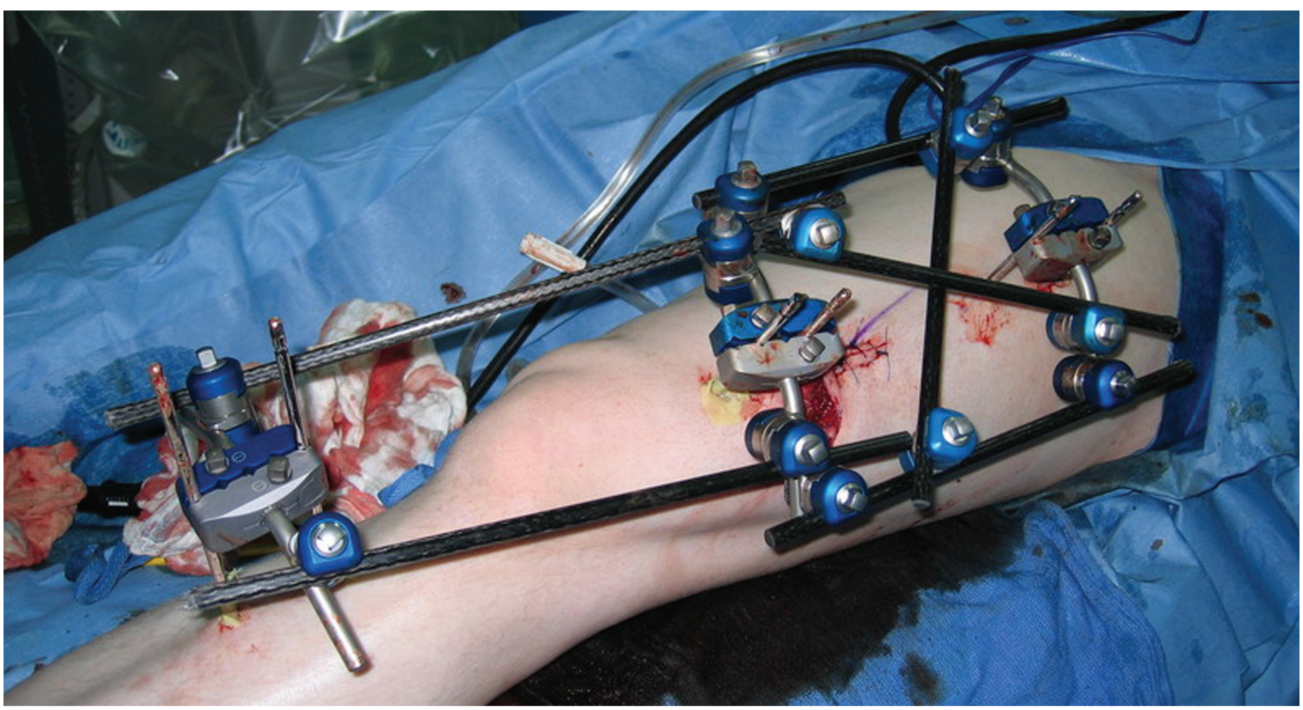


Figure 2. *External fixation spanning the knee and stabilizing open femur fracture in a combat environment.*

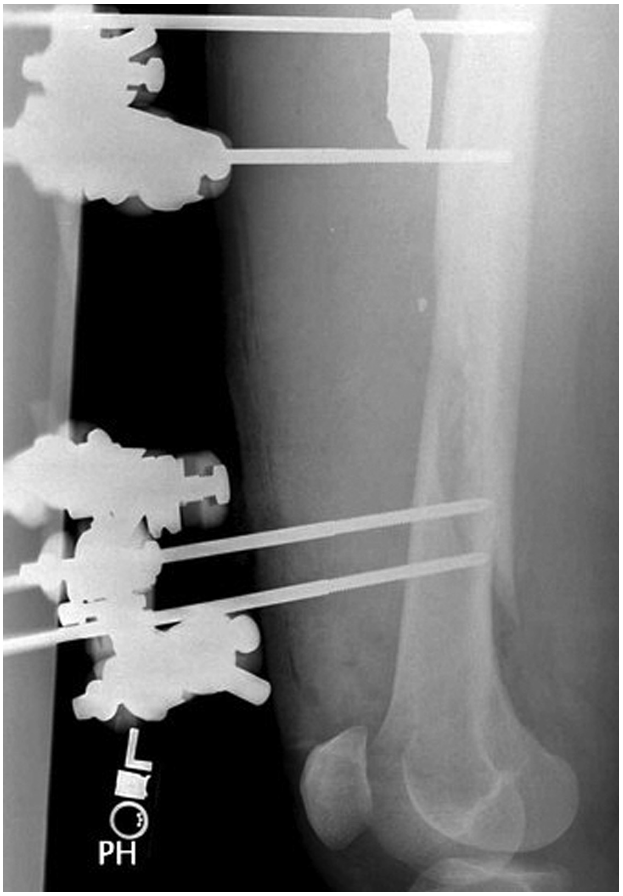


FIGURE 3. (Left and Right) *Radiographs of femoral pin placements. Fixator extension across the joint to the tibia is not shown in these films.*

CLINICAL IMPLICATIONS

Deployed surgeons will see many long bone fractures in general and many femur fractures in particular. They need to be confident stabilizing these fractures with either splints or external fixators. The following principles are important to consider:

1. In a patient with a femur fracture, blood loss might be substantial and must be addressed before entry into the medical evacuation system.
2. Open femur fractures have a historical infection rate of approximately 40%, and these fractures should be irrigated and debrided as soon as possible to minimize infection risk.
3. Initial neurovascular findings should be documented, and the examination should be repeated frequently.
4. Intravenous antibiotics should be started as soon as possible.
5. If wound debridement is performed, bone fragments attached to viable soft tissue and large bone fragments should be retained.
6. Indications for spanning the knee with external fixation include distal femur fractures, proximal tibial fractures, extensive knee injuries, and vascular repairs in the popliteal fossa.

DAMAGE CONTROL

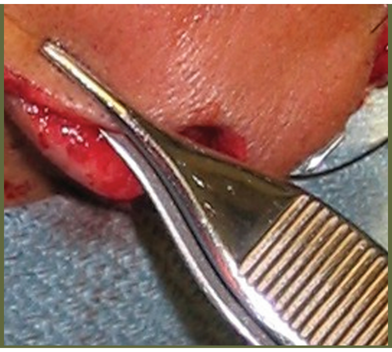
Transportation casts are an acceptable alternative to external fixation.

SUMMARY

Open femur fractures are some of the most commonly encountered injuries in the current combat environment. All general and orthopaedic surgeons should have a thorough understanding of extremity anatomy and treatment options for these injuries. Surgeons should be familiar with the standard constructs of external fixation.

SUGGESTED READING

Chapter 23: Extremity fractures. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.



VII.4
Blast Injury of the Hand

CASE PRESENTATION

This male patient sustained blast injuries to all four extremities. His hand injuries included a right thumb metacarpal fracture with bone loss and large, dorsal soft-tissue loss. In addition, he sustained multiple fragment wounds of both lower extremities, a traumatic ankle arthrotomy with retained fragments, and a left-hand small finger fracture. He underwent irrigation and debridement of all wounds. The right thumb metacarpal head articular surface was stabilized with a longitudinal pin (Figs. 1 and 2). The left finger fracture was also pinned. Wet-to-dry dressings soaked with Dakin's solution were placed on all open wounds. Both upper extremities were splinted. Intravenous antibiotics were administered. The patient underwent multiple irrigation and debridement procedures of his right hand. The wound was then treated with Dakin's solution until it was granulating well (Fig. 3). When the wound was deemed surgically clean, an iliac crest bone graft was pinned in place at the thumb metacarpal bone defect site. An abdominal pedicle flap was placed on the dorsal hand soft-tissue defect. Three weeks after placement of the flap, the patient (a host national) returned for separation and closure.

TEACHING POINTS

1. Wounds to the hand frequently involve bone, muscle, tendon, nerve, and skin loss. It is important to obtain soft-tissue control before performing definitive treatment of a fracture. This patient required multiple procedures and formal dressing changes for weeks before the definitive procedure was performed.
2. Two major options were available for treatment of the thumb injury: amputation and reconstruction. At initial surgery, the thumb metacarpal head was stabilized with pins. This allowed for the possibility, if needed, of metacarpal bone loss reconstruction and later arthrodesis of the metacarpophalangeal joint.
3. Another major problem was dorsal hand soft-tissue loss. Ordinarily, this would be treated with a free flap. In theater, no free flaps are used. The solution to this issue was abdominal pedicle flap coverage of the dorsum of the hand (Figs. 4–6), performed with the help of a plastic surgeon.

FIGURE 1. *Right thumb after stabilization.*

FIGURE 2. *AP* (Left) *and lateral* (Right) *radiographs of hand fracture stabilization with Kirschner wires.*

FIGURE 3. (Top) *Excellent granulation of wound.*

FIGURE 4. (Bottom) *Effective use of a pedicle flap to obtain adequate soft-tissue coverage.*

FIGURE 5. (Left) *Hand after the pedicle flap has healed.*

FIGURE 6. (Right) *Close-up of hand after the pedicle flap has healed.*

CLINICAL IMPLICATIONS

Complex reconstructive surgery is performed in theater, generally on host nationals, with the following cautions:

1. It is important to obtain wound control before proceeding with bone or soft-tissue reconstruction.
2. It is vital that attempts be made to keep things simple. Remember that the instrumentation available in the combat environment is necessarily limited. Kirschner wires are an excellent option for hand stabilization.
3. It is essential to obtain soft-tissue coverage at the time of reconstruction. The pedicle flap has been used successfully in combat support hospitals (CSHs) without requiring highly specialized instruments or a microscope necessary for free flap placement.

DAMAGE CONTROL

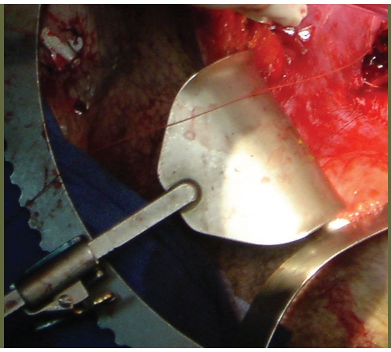
For patients evacuated to level V medical treatment facilities, initial debridement and irrigation—followed by wet-to-dry dressing changes—are adequate. Amputation of limbs with large wounds complicated by bone and soft-tissue loss may become a necessary consideration.

SUMMARY

This case is an example of using available resources to obtain an acceptable outcome. The surgeons were successful in an austere environment by using basic wound care management and relatively simple medical techniques.

SUGGESTED READING

Chapter 26: Injuries to the hand and feet. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.



VII.5
Blast Injury of the Humerus

CASE PRESENTATION

This male patient sustained a blast injury from an improvised explosive device (IED), resulting in a large, lateral arm wound (Figs. 1 and 2) and an open humerus fracture. No loss of consciousness or other injuries were noted. Physical examination revealed a normal vascular examination of the upper extremity. Sensory and motor functions of the median and anterior interosseous nerves were preserved. The radial, posterior interosseous, and ulnar nerves were nonfunctional, with no evident light-touch sensation or motor function in their distribution. A large metallic fragment was palpable in the axilla. Plain radiographs revealed a severely comminuted humerus fracture (Fig. 3). In the operating room, the wound was irrigated and debrided. All necrotic tissue and loose bone were removed. The palpable fragment was excised through an incision in the axilla. Intraoperatively, the brachial plexus and brachial artery were palpable through the lateral arm wound. An external fixator was placed spanning the severely comminuted humerus fracture (Fig. 4). The wounds were packed with wet-to-dry dressings soaked with Dakin's solution. Intravenous antibiotics were administered. The patient was evacuated to a level IV medical treatment facility on postoperative day 1.

TEACHING POINTS

1. Fractures, nerve palsies, and vascular injuries often accompany seemingly minor soft-tissue injuries to the arm making a thorough evaluation critical. It is important to adequately assess the vascular status of the extremity after a humerus fracture with associated nerve palsies. The nerves of the brachial plexus lie immediately adjacent to the brachial artery at the medial side of the humerus. The artery can be injured by the same mechanism causing the fracture, or it can become injured during medical evacuation if initial splinting of the extremity was inadequate.
2. Nerve injuries require only documentation in theater. The extent of nerve injury can be evaluated and addressed more fully at a higher level treatment facility.

CLINICAL IMPLICATIONS

1. Initial neurovascular findings should be documented, and the examination should be frequently repeated, especially after any manipulation of the fractured extremity.

FIGURE 1. (Top) *Large, lateral arm wound on admission.*

FIGURE 2. (Bottom) *Close-up of arm wound in Fig. 1.*

Figure 3. *Comminuted humeral fracture, large metal fragment, and limb shortening are evident.*

Figure 4. *Radiograph status post external fixation.*

2. Intravenous antibiotics should be started as soon as possible. Tetanus immunization should be considered based on the patient's immunization status and the nature of the wound.
3. If wound debridement is performed, bone fragments that are attached to viable soft tissue and large bone fragments should be retained.

DAMAGE CONTROL

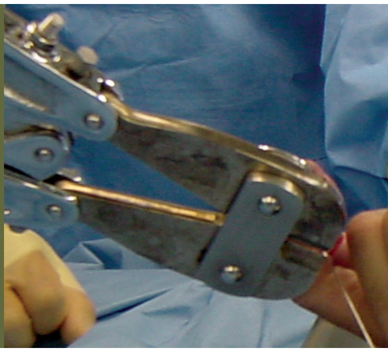
Injuries to the upper extremity range from isolated bone, muscle, nerve, or vascular injuries to any combination of these. External fixation of the humerus poses a significant risk to vascular and neural structures. Transportation casts are an acceptable alternative to external fixation and are described in the *Emergency War Surgery* handbook. Complex vascular repairs are not appropriate in settings requiring damage control. An alternative (shunting, ligation) should be considered. Although the damage associated with the extremity alone (ie, any combination of vascular, nerve, bone, or muscle injuries) may necessitate amputation, a lesser combination of these injuries in an otherwise severely wounded patient may warrant consideration of amputation as well.

SUMMARY

Open humerus fractures resulting from gunshot wounds or blast injuries are very common. It is highly likely that every orthopaedic surgeon deployed to a combat support hospital (CSH) will use an external fixator for this injury. It is also probable that every general surgeon deployed to a CSH will encounter a vascular injury to the brachial artery associated with a humerus fracture. A thorough understanding of these injuries and the range of options to treat them are important.

SUGGESTED READING

Chapter 23: Extremity fractures. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.



VII.6
Open Ulna Fracture

CASE PRESENTATION

This male patient, a host national, sustained multiple gunshot wounds to the chest, abdomen, right upper extremity, and left proximal forearm. He was admitted to the general surgery service of a combat support hospital (CSH) where he underwent laparotomy and multiple surgical procedures. A tube thoracostomy was inserted for management of hemopneumothorax. A right radial nerve palsy was noted. The orthopaedic surgery service was consulted intraoperatively for care of the soft-tissue wounds of his right arm and the open ulna fracture of his left arm (Fig. 1). Both were irrigated and debrided the day of injury. The ulna fracture was stabilized with an external fixator spanning the distal humerus to the ulna (Figs. 2 and 3). Treatment was prolonged and complicated. The arm wound and open ulna fracture were treated with wet-to-dry dressings soaked with Dakin's solution until the soft tissues were healed. Six weeks after injury, the patient returned to the operating room (OR) for definitive fracture care. Soft-tissue wounds were healed, the external fixator was removed, and an open reduction and internal fixation were performed. An iliac crest bone graft was harvested and placed at the fracture site (Fig. 4). The status of the patient's radial nerve palsy was followed on an outpatient basis. The patient performed range-of-motion exercises at home to keep his right elbow, wrist, and hand mobile. An orthoplast splint was fabricated to hold the wrist and fingers in extension. At last follow-up, the patient had a tingling sensation in the distribution of the superficial branch of the radial nerve.

TEACHING POINTS

1. This patient had multiple injuries requiring urgent surgery. Principles of Advanced Trauma Life Support (ATLS) were performed. He was then taken directly to the OR.
2. In this case of polytrauma, orthopaedic injuries are secondary. If the patient is considered stable enough to undergo further surgery, the orthopaedic surgeon is frequently called to address any orthopaedic injuries after the patient is already under anesthesia.
3. Wound control must be obtained before definitive fracture fixation is performed. The ability to cover orthopaedic implants is key to limiting wound contamination and infection of instrumentation.
4. The decision to operate on the extremity affected by radial nerve palsy injuries is difficult. There is no occupational therapy

FIGURE 1. *Penetrating wounds are apparent proximal and distal to the elbow.*

provided by the host nation. Complex orthoses are not available. Considering these two factors, the decision to proceed with observation rather than perform an internal splinting procedure was made. The patient was informed that the nerve may recover, but it would take many months.

CLINICAL IMPLICATIONS

In the war zone, internal fixation of combat injuries is contraindicated. In this case, however, because the patient was a host national and was not evacuated, eventual definitive repair, which required internal fixation, became necessary. The following principles apply:

1. Wound control must be obtained before definitive fixation of fractures is performed.
2. The ability to cover the orthopaedic implants is key to limiting wound contamination and infection.

SUMMARY

This patient required prolonged inpatient and outpatient care. His treatment necessitated operative and postoperative management different from the typical patient treated at a CSH. Fractures that are the result of combat injuries are often complex and invariably open, making them difficult to treat in any circumstance. CSHs are not typically equipped

FIGURE 2. *Completion of external fixation spanning the elbow and joint. Entry and exit wounds are evident.*

FIGURE 3. *Radiographs showing two views* (Left) *lateral;* (Right) *PA of distal humerus and forearm. Reduction accomplished by spanning the elbow with an external fixator.*

FIGURE 4. *Radiograph of fracture after internal fixation.*

with the resources, beds, and manpower necessary to render definitive repairs and comprehensive follow-up therapy. The surgeon must implement management in accordance with the given circumstances, with the understanding that his or her improvisation may differ considerably from stateside practice.

SUGGESTED READING

Chapter 23: Extremity fractures. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

VII.7 Gunshot Wound of the Hand

CASE PRESENTATION

This male patient was cleaning a 9-mm handgun when the weapon discharged, resulting in a through-and-through injury to his left hand (Figs. 1 and 2). At the combat support hospital (CSH), the hand was neurologically intact, and no vascular injury was noted. There was an entrance wound in the palm and an exit wound on the dorsal side of the hand. Plain radiographs revealed a 2-cm bone loss of the fourth metacarpal (ring finger) (Fig. 3). The wound was irrigated and debrided. All loose bone fragments were removed. The ring finger metacarpal shaft was missing, as was the extensor mechanism. A Kirschner wire spacer was placed for stabilization (Fig. 4), and the wound was packed with wet-to-dry dressings soaked with Dakin's solution. A splint was applied, and intravenous antibiotics (cefazolin and gentamicin) were administered. On the hospital ward, the patient's hand was elevated in a stockinette. He was evacuated on postoperative day 1.

TEACHING POINTS

1. A hand wound must be thoroughly debrided and irrigated. All dead tissue and bone must be removed. Tissue, including skin, with marginal or questionable viability is left for subsequent evaluation to improve chances for an optimal outcome. A thorough physical examination is crucial to determine neurological and vascular status. At the time of surgery, it is important to document the damaged anatomical structures.
2. Bone defects in the hand are common injuries resulting from gunshot wounds or blast injuries. When attempting to stabilize fractures in the hand, a simple splint or Kirschner wire is usually sufficient. If multiple fingers are injured or if adjacent metacarpal bone defects are present, the fingers should be stabilized to help protect the soft tissue and vascular structures of the hand. If there is a substantial bone defect in the hand, the palm can fold over and compromise the blood supply to the fingers. This action could cause later injury, thereby limiting reconstructive options or necessitating amputation.

CLINICAL IMPLICATIONS

Even apparently minor wounds distal to the wrist crease may violate tendon sheaths and joints, resulting in serious deep space infection.

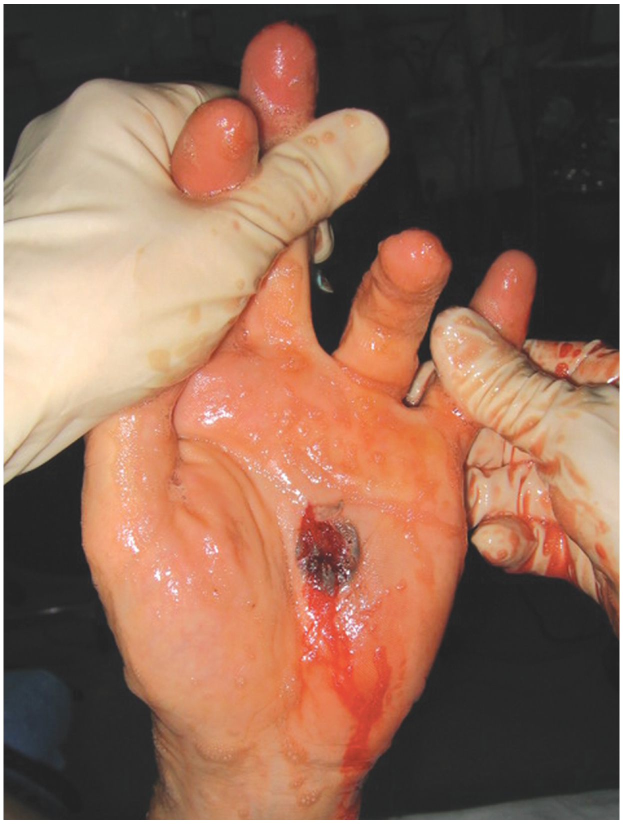


FIGURE 1. *Entrance wound on the palmar surface of the hand.*

FIGURE 2. *Dorsal exit wound.*

FIGURE 3. *Radiograph of ring finger metacarpal bone loss.*

FIGURE 4. *Radiograph after placement of a Kirschner wire.*

IRRIGATION OF WAR WOUNDS

Irrigation of wounds is a common requirement of war surgery, and it prevents wound problems by removing debris, blood, and bacteria. Recent evidence challenges the current practice of routinely using high-pressure pulsatile lavage (HPPL) devices, and questions of fluids, additives, and volumes have been clarified.

Simple bulb irrigation or gravity irrigation is preferred. Although HPPL is fast, available, and easy to use in washing wounds, it also traumatizes tissue such that, at 2 days after HPPL, bacterial load rebounds more than gentler methods (eg, bulb syringe use). Gentler methods lead to the least rebound and are the least expensive and widely available. Large-bore, gravity-run tubing should be used, which is as gentle as bulb syringe, but is faster and accepts two bags at once. Traditional debridement should be performed in addition to irrigation. (See Chapter 22 of *Emergency War Surgery, Third United States Revision*.)

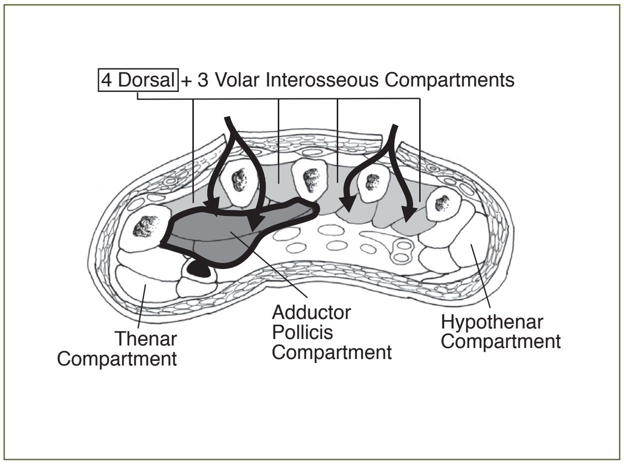
Research demonstrates that normal saline, sterile water, and potable tap water have similar usefulness and safety. The sterile isotonic solutions are readily available and remain the fluid of choice for irrigation. If unavailable, sterile water or potable tap water can be used.

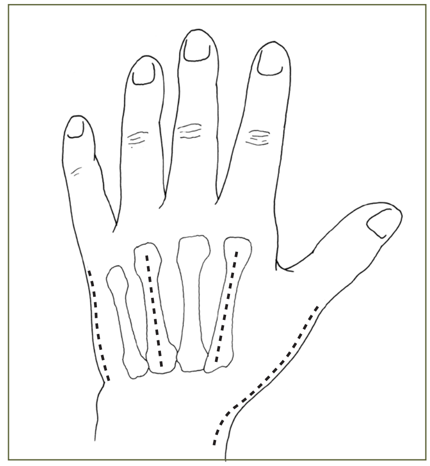
No additive is recommended for routine irrigation of war wounds. Recommended, however, is warm saline in 3-L bags gravity-run as follows:

- 1 to 3 L for small-volume wounds,
- 4 to 8 L for moderate wounds, and
- 9 or more liters for large wounds with heavy contamination.

FIGURE 5. (Left) *Compartments of the hand.*

FIGURE 6. (Right) *Hand fasciotomy incisions.*





Infection involving the flexor synovial sheath of one finger can easily spread via the common synovial sheath to other fingers, the palm, and the thumb. The following principles are important in managing hand wounds:

1. Consider hand fasciotomies (Figs. 5 and 6) before evacuation.
2. Perform a thorough exploration of the area to define the extent of injury.
3. Preserve as much tissue as possible for future reconstruction.
4. Minimize debridement of tendons and preserve nerve tissue.
5. Do not amputate fingers, if possible.
6. Perform stabilization with Kirschner wires to preserve function, ensure patient comfort, and—if multiple fingers are involved—prevent injury during evacuation.
7. Cover exposed tendon, bone, and joints, if possible.

DAMAGE CONTROL

In patients who require urgent evacuation, careful splinting in a functional position is appropriate.

SUMMARY

Hand wounds are very common in the combat theater. Hands are unprotected by armor and are therefore exposed to wounding by gunshots, blasts, and thermal mechanisms. Early evaluation and appropriate treatment of these wounds can help preserve function and limit disability. Gloves can offer some protection against thermal injury.

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VII.8
Tibia Fracture With Compartment Syndrome

CASE PRESENTATION

This 20-year-old male sustained an open left tibia fracture as a result of a blast injury from a vehicle-borne, improvised explosive device (IED). He was taken to a combat support hospital (CSH), where a complete evaluation was performed. The only injuries identified were medial and lateral 3-cm wounds of the left leg (Figs. 1 and 2) with an underlying open tibia fracture (Fig. 3). No vascular or neurological injuries were noted on examination. The knee and ankle were nontender and without effusion. Leg compartments were soft, and there was no pain with passive range of motion of the toes. In the operating room, irrigation and debridement were performed using pulse lavage. Bone ends were curetted, and all loose bone was removed. An anteriorly positioned external fixator was placed using C-arm fluoroscopy guidance (Fig. 4). The leg compartments were tense. Subsequently, through two incisions, a four-compartment fasciotomy was performed. The medial and lateral incisions were connected to the traumatic wounds on both sides. Clinically, the diagnosis of compartment syndrome was confirmed, because the muscles bulged out when the compartments were released (Figs. 5 and 6). The wounds were dressed with wet-to-dry dressings soaked with Dakin's solution. Once on the hospital ward, the patient's leg was elevated. Intravenous antibiotics, including cefazolin and gentamicin, were administered. The operative dressing was not removed before the patient was evacuated on postoperative day 1. He underwent repeated irrigation and debridement at follow-on levels of care. Eventually, a wound infection was diagnosed at a stateside army medical center. Cultures were positive for *Acinetobacter baumannii* (most likely a battlefield contaminant obtained at the time of injury). This organism has been cultured repeatedly from wounds received in Iraq (see sidebar on page 284). Continued care was provided at the medical center.

TEACHING POINTS

1. The injury this patient sustained is a very common one in the combat environment because the lower extremities are exposed and cannot be protected by body armor.
2. Compartment syndrome is a potentially catastrophic complication from a tibia fracture. If it is not diagnosed in a timely fashion, long-term disability will result. It is important to remember that physical examination of a trauma patient should be repeated frequently. The hallmarks of compartment syndrome are pain that is out of proportion

Figure 1. (Top Left) *Lower extremity wounds.*

Figure 2. (Bottom Left) *Close-up of lower extremity wounds on admission.*

Figure 3. (Top Right) *Radiographs of comminuted tibia fracture. Note soft-tissue free air.*

Figure 4. (Bottom Right) *Radiographs of fracture reduced with external fixation.*

ACINETOBACTER AND WOUND INFECTIONS

Infection is a complication of battlefield injuries that can lead to significant morbidity and mortality. During the Vietnam War conflict, a 4% incidence of wound infection was reported despite 80% of wounds undergoing debridement/irrigation and 70% receiving antibiotics. Although the incidence of wound infection has not been determined for Operation Iraqi Freedom/Operation Enduring Freedom (OIF/OEF), it is unclear if it is higher than the 4% incidence noted during the Vietnam conflict.

First noted in April 2003, nosocomial, multidrug-resistant *Acinetobacter baumannii* infections have spread along the evacuation chain from medical facilities in Iraq, through hospitals in Europe, to the United States. After the onset of ground operations in Iraq, *A baumannii-calcoaceticus* complex (ABC) was recognized as an important bacterial pathogen infecting the wounds of casualties.

The initial report described 102 patients with ABC recovered from their blood cultures; 83% of these patients were from OIF/OEF. These numbers were in excess of historical norms.

Among patients admitted to Brooke Army Medical Center (San Antonio, Texas) from Iraq and Afghanistan, there were approximately 10 wound infections for every one patient with ABC bacteremia. Infections frequently involve burn casualties, as well as bone and soft-tissue infections. Although ABC is often considered a low virulent pathogen, its ability to develop broad-spectrum antimicrobial resistance to all modern antibiotics can lead to poor outcomes, especially in immunosuppressed patients. ABC is also of concern because it is often associated with nosocomial transmission of infection. Although the etiology of ABC has not been clearly elucidated, there is supporting evidence that nosocomial transmission was leading to the spread of the infection.

Although ABC's role as a pathogen was being determined among casualties of OIF/OEF, more virulent pathogens that had classically been associated with battlefield trauma—such as *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, and *Staphylococcus aureus*—were also being seen. These pathogens are notable for their more destructive properties and greater propensity to result in poor outcomes. Even more troubling, however, is the multidrug-resistant patterns of these pathogens, including methicillin-resistant *S aureus* (MRSA), extended-spectrum b-lactamase-producing *K pneumoniae*, and multidrug-resistant *P aeruginosa*.

—Clinton K. Murray, MD, MAJ, MC, US Army

to the injury and pain with passive range of motion of the toes. In a combat environment, this is entirely a clinical diagnosis.

3. If at any time the examination results are consistent with compartment syndrome, an urgent fasciotomy must be performed. If all operating rooms are in use, this procedure can be done in the intensive care unit using local anesthesia and sedation. A person with impending compartment syndrome must never be moved via the medical evacuation system. If compartment syndrome is even a slight possibility, perform fasciotomies.

CLINICAL IMPLICATIONS

1. The possibility of compartment syndrome must be constantly reassessed at each stage of the evacuation process.
2. The need for repeated irrigation and debridement of wounds throughout the evacuation process is critical to keeping wounds clean.
3. Battlefield contaminants—such as *Acinetobacter*—may become apparent at any time and produce infection. These contaminants affect hospital treatment, timing of reconstructive procedures, and wound coverage.

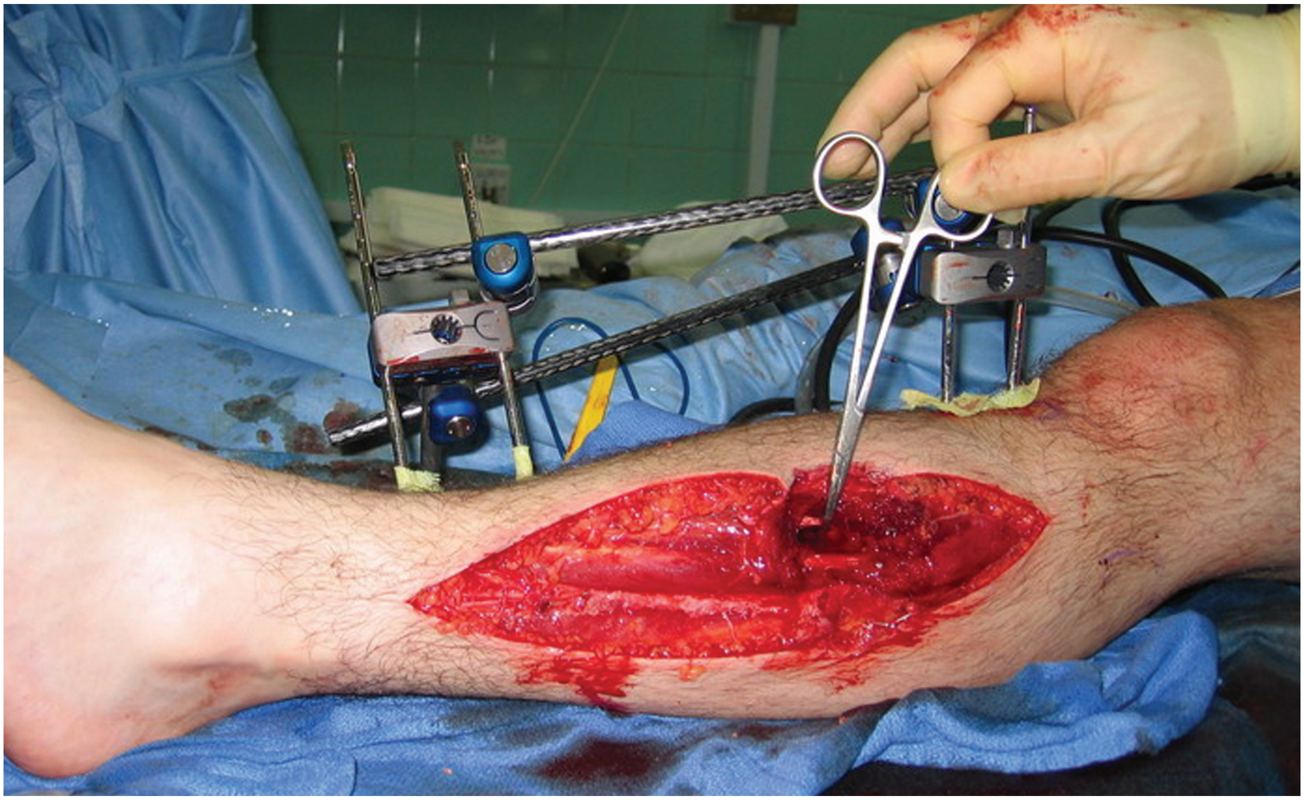

FIGURE 5. *Lateral view of extremity after a four-compartment fasciotomy.*

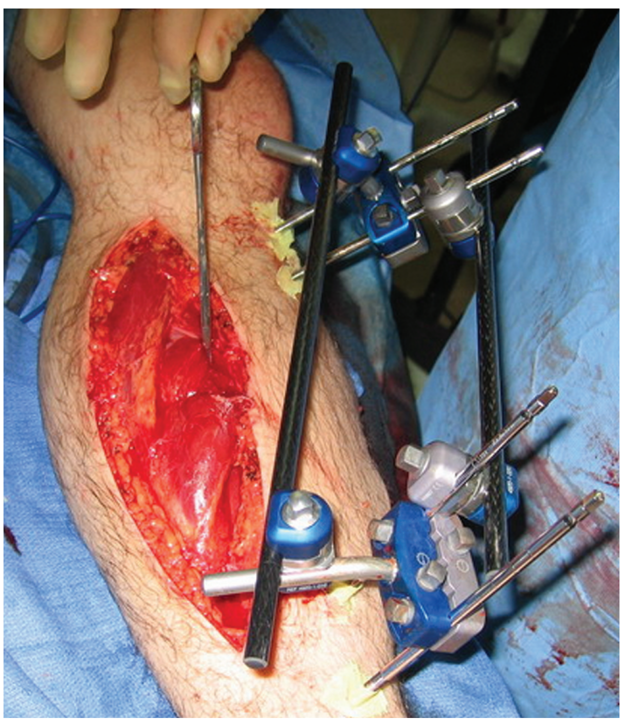

FIGURE 6. *Medial view of lower extremity after a four-compartment fasciotomy.*

DAMAGE CONTROL

Four-compartment fasciotomy is a primary damage control technique. All general and orthopaedic surgeons working at level II and level III medical treatment facilities should be able to perform this procedure.

SUMMARY

This case represents the standard approach to war wounds that results in an open tibia fracture, including irrigation and debridement, external fixation, and medial and lateral fasciotomies.

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VII.9 Traumatic Below-Knee Amputation

CASE PRESENTATION

This 28-year-old male sustained an injury to his right leg from a high-energy blast. A field tourniquet (Combat Application Tourniquet System [CATS]; see sidebar on page 288) was placed above the injury. His clothing was saturated with blood. Removal of his combat boots revealed a significant, grossly contaminated, soft-tissue injury and a poorly perfused foot. Physical examination revealed a cool, paralyzed, insensate foot with no palpable or Doppler pulses (Figs. 1 and 2). An initial survey revealed no other injuries. Plain radiographs revealed fractures of the tibia and fibula, with extensive comminution and bone loss. The patient underwent surgery 1 hour and 40 minutes after the tourniquet had been placed. A pneumatic thigh tourniquet was then applied, and the field tourniquet was removed. Further exploration revealed that all major nerves and vessels supplying the foot had been severed. The decision was then made to proceed with a formal, below-knee amputation (Fig. 3). An open, length-preserving amputation was performed at the most distal level of viable soft tissue. After appropriate muscle debulking and hemostasis, skin traction was achieved by using three loosely applied 0-Prolene trauma sutures (Fig. 4). The limb was then covered with a soft dressing, and the knee was held in full extension with a long leg splint that supported the distal end and secured the knee anteriorly and posteriorly. The patient was evacuated to a level IV medical treatment facility within 12 hours of initial presentation.

TEACHING POINTS

1. High-energy blast and gunshot wounds commonly result in severe soft-tissue loss. These wounds are often dramatic, so much so as to distract medical personnel from other life-threatening wounds. Adequate patient exposure and careful attention are necessary to determine the full extent of all injuries.
2. In this case, an exploration that reveals transection of major arteries and nerves is an absolute indication for amputation. Often, surgeons will undertake heroic measures to salvage a limb that will ultimately cause the patient more severe problems or result in death. Vascular grafts should not be performed on a paralyzed, insensate extremity with extensive soft-tissue loss.
3. Amputation is a common battlefield operation. All general and orthopaedic surgeons should be familiar with upper and lower extremity anatomy and amputation techniques.

FIGURE 1. *Presentation of a seriously injured extremity.*

CLINICAL IMPLICATIONS

Surgeons in combat operations will see high-energy blast injuries that result in traumatic amputation. In treating these kinds of injuries, combat surgeons should be cognizant of the following principles:

1. High-energy blast or gunshot wounds commonly result in severe, soft-tissue loss.
2. Adequate patient exposure is necessary to determine the full extent of injury.
3. Field tourniquets applied correctly can save a patient's life.
4. Noting the timing when applying a field tourniquet is an important consideration in patient management, because it can have an effect on limb salvage.
5. An examination that shows irreparable transection of major arteries is an indication for amputation.
6. Severe soft-tissue and bony injuries to the extremity precluding functional recovery are indications for amputation.
7. All dead or necrotic tissue must be removed.
8. Hemostasis is achieved by double-tying the major vessels.
9. Some form of skin traction should be used to preserve skin length.
10. The knee should be immobilized in extension.
11. Debridement should be performed at the lowest viable level of soft tissue, leaving determination of the definitive or revised level of amputation to staff at a higher level facility.

DAMAGE CONTROL

In these types of cases, appropriately applied field tourniquets are lifesaving (see sidebar on page 288).

SUMMARY

Unfortunately, traumatic amputations are common and are the most severe limb injuries seen. This case illustrates the basic techniques of caring for a patient with a traumatic below-knee amputation.

COMBAT APPLICATION TOURNIQUET SYSTEM (CATS)

CATS is a one-handed tourniquet that completely occludes arterial and venous blood flow of an extremity in the event of a traumatic wound with significant hemorrhage. The CATS uses a windlass system with a free-moving internal band to provide circumferential pressure to the extremity. Once tightened and bleeding has stopped, the windlass is locked in place. A Velcro strap is then applied to secure the windlass during casualty evacuation. The combat application tourniquet (CAT)—also known as the one-hand tourniquet—differs from traditional tourniquets because it can be put on by the soldier with one hand and does not require the use of sticks for tightening.

Courtesy of Phil Durango, LLC (Golden, Colorado).

This patient survived.

Tourniquet use in Operation Iraqi Freedom has been lifesaving for combat casualties. The CAT has been the most effective field tourniquet, both in laboratory testing and clinical experience. Improvised tourniquets are less effective and are only recommended when no scientifically designed tourniquets are available, as evidenced in the casualty data. Prehospital tourniquet use has improved survival 23%, relative to emergency department use, and use before shock onset has improved survival 90% relative to use after shock onset. The rates of complications (eg, compartment syndrome) have been low. Despite the policy of encouragement of tourniquet use for limb bleeding, in 1 year 10 patients arrived dead at a Baghdad combat support hospital (CSH) with isolated limb exsanguinations. Use before extrication and transportation is recommended. For limbs of greater girth and tourniquets of lesser width, side-by-side use of additional tourniquets improved effectiveness if one tourniquet was not effective. Historically, there was only one first-aid device, the Thomas splint, that improved survival for limb-injured patients. Now there are data from Operation Iraqi Freedom that show that tourniquets also save lives.

—John F. Kragh, MD, COL, MC, US Army

FIGURE 2. *Tissue damage is apparent. Note that the tourniquet is still in place before surgery.*

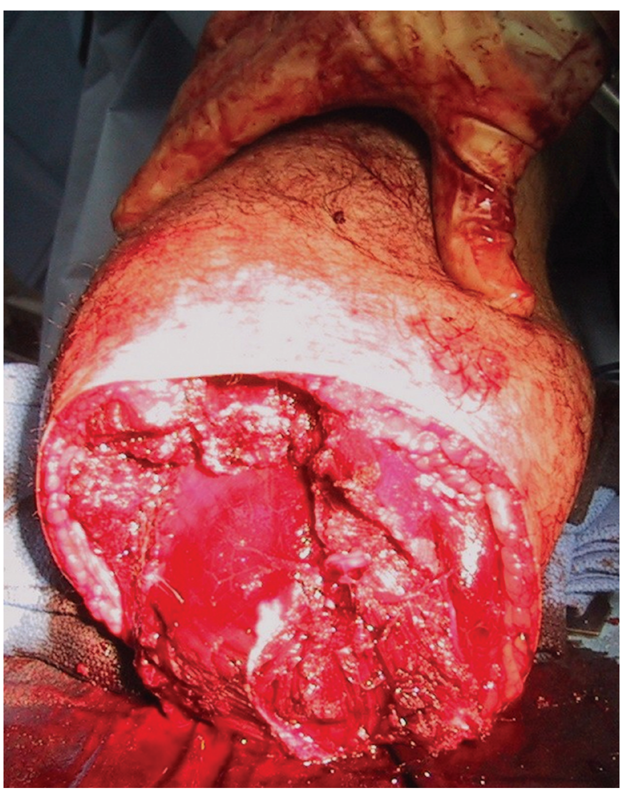

FIGURE 3. (Left) *End-on view of leg at the lowest level of viable soft tissue.*

FIGURE 4. (Right) *Skin traction obtained by using three interrupted sutures.*

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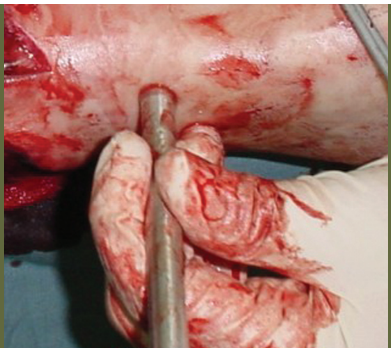

VII.10
Umbrella Effect of a Landmine Blast

CASE PRESENTATION

A 23-year-old male arrived at the Forward Surgical Team (FST) facility after a landmine blast to his right upper extremity. Exact details surrounding this blast were unknown, but the injury was most likely caused by manipulation of the device. On initial evaluation, the patient's airway was patent, and breath sounds were equal bilaterally. His pulse was 118 beats per minute, and his blood pressure was 110/98 mm Hg. With the exception of the right upper extremity, he was fully intact neurologically. Complete exposure revealed a mangled right upper extremity with profuse arterial and venous bleeding (Figs. 1 and 2). Direct pressure failed to control the bleeding, and a brachial artery pressure point was applied. Following this action, a standard blood pressure cuff was placed on the upper arm and inflated to 150 mm Hg. With bleeding temporarily controlled, attention was focused on the secondary examination, which revealed no other injuries. While the patient was being resuscitated with isotonic crystalloid, the arm was examined carefully. Given that this was a high-velocity injury—with significant involvement of soft tissue (skin and muscle), bone, nerves, and blood vessels—the surgeon proceeded with primary amputation, using an approach that preserved as much soft tissue as possible. This procedure was followed with daily operative debridements for 4 days. Once the wound had fully demarcated and was completely clean, the amputation was closed just proximal to the elbow joint.

TEACHING POINTS

1. Typically, landmines are associated with an umbrella effect, in which the blast tears the muscle and soft tissue off the bone. This results in the injury extending more proximally than clinically apparent. This is illustrated in Fig. 3 with a lower extremity injury.
2. Decreased pulse pressure indicated the presence of class II hemorrhagic shock. A common mistake is to consider only the systolic blood pressure, which does not typically decrease until class III or class IV shock (see Table 1). Early initiation of aggressive resuscitation prevented the development of a more complex state of shock and is associated with a less intense systemic inflammatory response and improved outcome.
3. Historically, direct pressure over a wound is the first step in obtaining control of hemorrhage in all types of extremity trauma. The

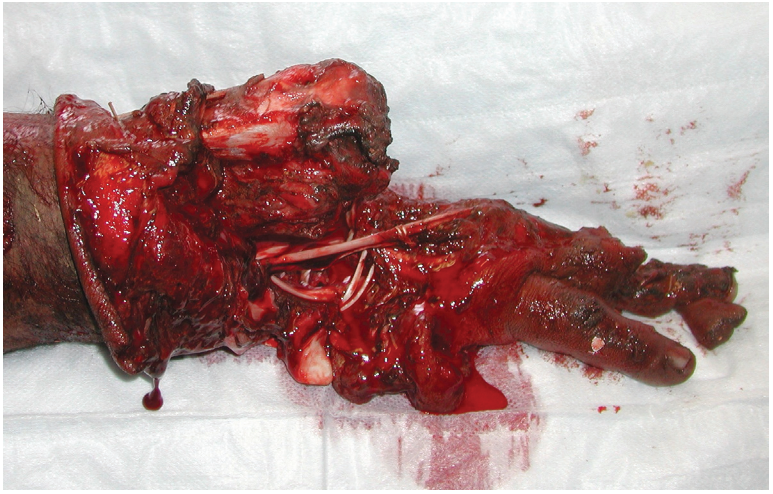

FIGURE 1. *Condition of right forearm on admission.*

FIGURE 2. *Severely mangled forearm with profuse arterial and venous bleeding.*

umbrella effect from a landmine blast frequently renders this action ineffective. The use of a blood pressure cuff proximal to the injury inflated to a pressure above the patient's systolic pressure is an effective means of control. In the forward setting, a simple tourniquet is also effective.

4. Although every reasonable attempt should be made to salvage an arm and hand, a primary amputation should be considered, when there is extensive involvement of three of the following components:

    a. Skin and soft tissue.
    b. Bone.
    c. Nerve.
    d. Blood vessel.

    The presence of significant shock and the inability to provide complex rehabilitative care should also be considered.

5. Because the injury is typically more proximal, a radiograph should be obtained early in order to ensure that the level of amputation does not leave a proximal bony injury.

CLINICAL IMPLICATIONS

1. Historically, these types of injuries have been treated with guillotine amputation in a circular fashion, leaving a flat-ended stump that can be revised at a later date by using standard amputation closure techniques. In the setting of blast injuries, this technique results in a significantly shorter residual limb and more limited function. The current technique of amputation is the open-length preserving amputation, in which all viable soft tissue is preserved. To save length, any shape or form of a viable muscle or skin flap should be preserved. Therefore, the surgeon should save all potentially viable tissue. Further debridement can be performed during subsequent operations. Once the wound is clean, the amputation is closed using an approach that makes use of all residual tissue.
2. A common mistake is premature closure of the amputation site. The wound should never be closed during the first operation. Frequently, it requires serial operative debridements over a period of several days to a week.

DAMAGE CONTROL

In the unstable patient, immediate primary amputation may be lifesaving. If it appears that the extremity can be salvaged, blood supply to the extremity can be reestablished rapidly using a vascular shunt. This technique allows time for harvest of a vein graft and bony fixation without incurring a greater ischemic insult.

SUMMARY

A landmine blast leads to an umbrella effect in which the soft tissues, vessels, and nerves are stripped from the bone. This shredding results in a more proximal injury than may be clinically apparent and requires a reasoned approach to amputation.

HETEROTOPIC OSSIFICATION IN COMBAT-RELATED AMPUTATIONS

Heterotopic ossification (HO) refers to the formation of mature, lamellar bone in nonosseous tissue. It has proven to be a common specter in combat-injured soldiers from Operation Enduring Freedom (Afghanistan) and Operation Iraqi Freedom. Although occasionally noted following open fractures and complex soft-tissue injuries, HO most frequently occurs and becomes clinically problematic in traumatic and combat-related amputations because of the often compromised soft-tissue envelope and the forces transmitted to affected regions of the residual limb (Fig. 1). Previous mentions of HO in combat-related amputations are limited to anecdotal reports from historical conflicts, and it appears to have been conspicuously absent in American casualties of the Vietnam War.

FIGURE 1. *Lateral radiograph of a traumatic transtibial amputation secondary to an improvised explosive device (IED) demonstrating severe HO throughout the residual limb.*

More than one-half of all combat-related amputees from the current conflicts in Southwest Asia have developed HO in their terminal residual limbs. The prevalence of HO is 63% in amputations with adequate radiographic follow-up.[1] The critical risk factors for HO formation in this population are a blast mechanism of injury and a final amputation level within the initial zone of injury. Amputation level within the zone of injury is also predictive of HO magnitude and severity (Fig. 2). However, frequent concomitant injury proximal to amputations, coupled with a desire to maintain functional residual limb length and joint levels, make proximal revision above the zone of injury impractical. For these reasons, we do not advocate it as a routine practice. Prolonged exposure to subatmospheric pressure dressings (wound VACs), serial pulsatile lavage, occult traumatic brain injury, and gross bacterial contamination of wounds have all been theorized as potential inciting factors to HO formation in amputees.

Given this high prevalence of HO, utilization of both clinically proven modalities (eg, nonsteroidal antiinflammatory drugs [NSAIDs] and radiotherapy) and theoretical prophylactic modalities (eg, etidronate, vitamin K antagonists, and corticosteroids) is appealing in the treatment of combat-related amputees. However, at present, medical contraindications (eg, concomitant multisystem trauma or long bone fractures, bleeding risks, and compromised immune system) and logistical barriers preclude their routine utilization early in the postinjury process of care when they would be most efficacious.

Once HO is present in a residual limb, no treatment is required for asymptomatic lesions. When present, symptoms usually consist of focal residual limb pain with activity, with or without associated skin breakdown. Symptomatic HO is virtually always palpable within the residual limb. Nonoperative management of symptomatic ectopic bone consists of medication adjustments, activity modification, and serial liner and socket modifications in an effort to off-load affected regions. Lesions remain asymptomatic, and conservative measures are successful in approximately 85% of amputees with HO.

FIGURE 2. *Three-dimensional CT reconstruction of a transfemoral amputation, within the zone of injury, secondary to blunt trauma. Severe HO is present in the terminal residual limb.*

When nonoperative management fails, surgical candidates should be counseled on the frequent need for myodesis takedown and formal amputation revision in conjunction with surgical excision of lesions, as well as an approximately 25% incidence of postoperative wound complications. Nonetheless, relatively early (median: 6 months) operative excision of symptomatic lesions has been successful, with good clinical results and no symptomatic recurrences to date in more than 40 excisions. Although our low overall recurrence rate precludes a statistical demonstration of efficacy, we advocate perioperative recurrence prophylaxis with NSAIDs and/or external beam radiation. Ongoing and future research may further elucidate causative factors, the specific cells and chemokine signals responsible, and a practicable primary prophylactic regimen for the prevention of HO in amputations.

—MAJ BENJAMIN KYLE POTTER, MD

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TABLE 1. *Classes of Shock*

CLINICAL SIGNS	CLASS I	CLASS II	CLASS III	CLASS IV
Heart rate	< 100	> 100	> 120	> 140
Systolic blood pressure	Normal	Normal	Decreased	Decreased
Pulse pressure	Normal/increased	Decreased	Decreased	Decreased
Respiratory rate	14–20	20–30	30–40	> 35
Urine output (mL/hr)	> 30	20–30	5–15	Negligible
Mental status	Slightly anxious	Mildly anxious	Anxious, confused	Confused lethargic
% Blood volume loss	Up to 15%	15%–30%	30%–40%	> 40%
Blood loss (mL, 70-kg adult)	Up to 750 mL	750–1,000 mL	1,500–2,000 mL	> 2,000 mL

Adapted with permission from the American College of Surgeons, Committee on Trauma. Advanced Trauma Life Support for Doctors—Student Course Manual. *6th ed. Chicago, Ill: ACS; 1997: 98.*

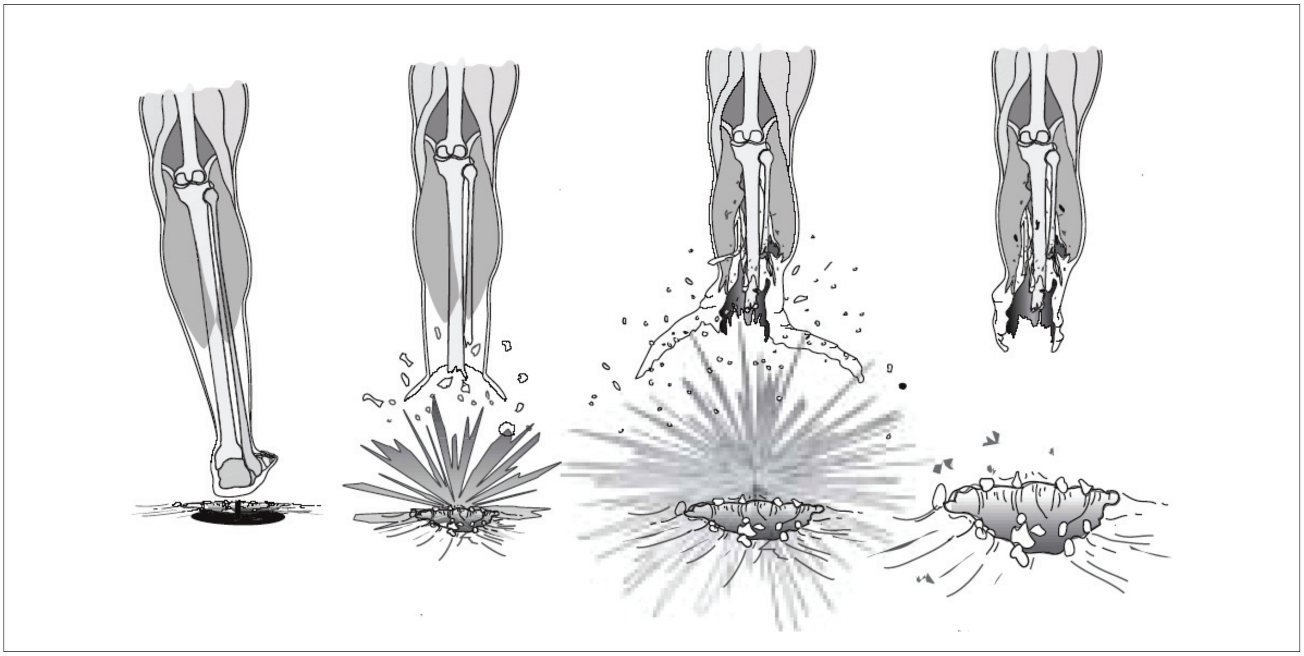

Figure 3. *"Umbrella" mechanisms of injuries caused by antipersonnel landmines.*

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VII.11 Penetrating Injury of the Left Foot

CASE PRESENTATION

An 11-year-old host nation male presented 36 hours after sustaining a blast injury to his left foot during combat operations in a remote area of the country. On evaluation, there was significant gross contamination and soft-tissue damage with a medial longitudinal laceration deep to the first metatarsal. There was also a plantar soft-tissue avulsion through the plantar fascia and a lateral transverse laceration deep to the base of the fifth metatarsal (Figs. 1 and 2). Vascular and neurological integrity were demonstrated on physical examination with the assistance of a translator. Radiographs revealed no bony injury. The patient was taken to the operating room where he underwent meticulous debridement and irrigation, as well as undermining of soft tissues to adequately cover bony and fascial structures. Initially, a wound VAC device was placed medially. He was given intravenous antibiotics with broad-spectrum aerobic and anaerobe coverage for 72 hours. After 3 days, more debridement and irrigation were performed, and wet-to-dry dressing changes were initiated. The patient was then placed on oral antibiotics for 14 days. At 3 months, the foot showed excellent healing, was sensate, and was well perfused (Figs. 3 and 4).

TEACHING POINTS

1. Soft-tissue injuries are very common either as the result of blast injuries or gunshot wounds. All contaminating debris and devascularized tissue must be removed and the wound irrigated liberally. Exposed fibrous and collagenous tissues must be covered ultimately to prevent chronic infection. Wound VACs are excellent devices to promote healing and granulation tissue. However, in the case of small irregular wounds, wound VACs may cause maceration if improperly placed. Wet-to-dry dressings can promote excellent healing. Epithelialization will ultimately result in minimal scarring.
2. In this patient, the initial concern was the prolonged exposure to gross contamination, the extent of soft-tissue injury, and the exposed structures. Strict adherence to accepted principles produced excellent clinical results.

CLINICAL IMPLICATIONS

1. Combat surgeons frequently see soft-tissue injuries with varying degrees of contamination, sometimes many days following the acute injury.

Figure 1. (Top)
The foot on presentation had significant soft-tissue injury.

Figure 2. (Middle)
Another view of the foot on presentation.

Figure 3. (Bottom)
Foot is healing.

2. Generally, host nation patients require definitive treatment. Therefore, soft-tissue stabilization and healing are entirely managed at a level III medical treatment facility.
3. Surgeons need to perform meticulous debridement of the wounds, as well as manage the healing processes.

DAMAGE CONTROL

Often patients with life-threatening injuries concurrently present with these types of soft-tissue injuries. Washout with debridement and wet-to-dry dressing changes remains a safe, effective treatment for these injuries.

SUMMARY

This case demonstrates the effectiveness of secondary intention healing in soft-tissue injuries. In this case, a patient with a serious foot injury made a good, functional recovery with adequate washout, debridement, and dressing changes.

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Figure 4. (Top and Bottom) *Later stages of healing.*

WET-TO-DRY DRESSINGS AND WOUND HEALING

Wet-to-dry dressings are used if the wound is infected or if it is not stitched closed. Wet dressings (gauze that is usually saline soaked) are put inside the wound, and dry dressings are put on top of the wound to prevent drying and contamination. When the wet dressing dries, it sticks to the debris in the wound. When the dressing is pulled off, it cleans out the wound. In this way, wet-to-dry dressings can be used to help promote wound healing because they:

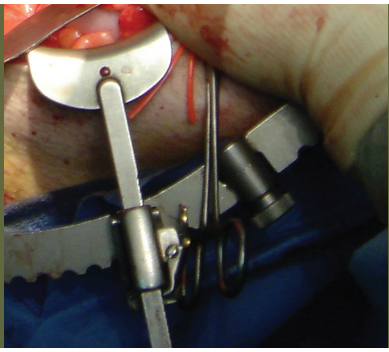
- support autolytic debridement (the body's own capacity to lyse and dissolve necrotic tissue),
- absorb exudate, and
- trap bacteria in the gauze.

Moist environments have been proven to aid in:

- reepithelialization,
- wound healing, and
- shortened healing time.

Wet-to-dry dressings:

- require more intense wound care,
- can adhere to healthy granulation tissue if dries,
- can injure healthy epithelial cells and slow down the healing process, and
- may leave lint or fiber residue in the wound.



VII.12 High-Energy Gunshot Wound to the Forearm

CASE PRESENTATION

An Iraqi Army male sustained a high-velocity (see sidebar on page 23) gunshot wound to the right forearm. On presentation, he reported pain in the right forearm and denied any numbness or paresthesias. Examination revealed an 8 x 6 cm oval wound on the dorsoradial right forearm, with a thin skin bridge in the middle (Fig. 1), as well as a subcentimeter wound over the proximal-ulnar border of the forearm. There were numerous bone fragments visible in the wound, and he was unable to radially deviate his wrist. The radial, ulnar, median, and anterior interosseous nerves had intact motor function. Sensation was grossly intact, except for a small area on the dorsoradial aspect of the hand. There was a 2+ radial pulse, and the hand was well perfused. Radiographs of the right forearm showed a severely comminuted mid-to-distal one third radial shaft fracture with approximately 8 to 10 cm of segmental bone loss. In addition, there was an oblique midshaft ulna fracture with some shortening and displacement (Fig. 2). In the emergency department, the patient was given intravenous antibiotics and tetanus. He was taken to the operating room where he underwent debridement and irrigation of the open fractures. The small skin bridge was excised, and the wound was extended to enhance exposure in the zone of injury. Numerous bone fragments were removed from the wound bed because they were not attached to any soft tissue. The extensor carpi radialis longus and brevis tendons were transected and primarily repaired. The radial artery was patent, and the dorsal sensory branch of the radial nerve was also intact. A wrist spanning external fixator was placed with two pins in the index finger metacarpal and two pins in the radial shaft (Fig. 3). The surgically created wound was loosely closed over a drain, and the remaining soft tissue defect was covered with a soft dressing. Postoperative radiographs showed that the radius had a 10-cm segmental defect. The patient returned to the operating room on hospital day 3 for definitive treatment of the forearm fractures. The ulna fracture was approached along the subcutaneous border of the ulna, and open reduction internal fixation was performed with a nine-hole Synthes, 3.5-mm locking limited contact dynamic compression plate. Following stable osteosynthesis of the ulna fracture, a volar Henry approach was performed to address the distal radius fracture. The distal radius was examined, and there was intraarticular extension of the fracture into the scaphoid fossa. A single 3.5-mm cortical screw was placed in lag fashion to stabilize the radial styloid fragment prior to additional internal fixation. The distal portion of the ulna was exposed, and a distal ulna osteotomy was performed proximal to the distal radioulnar joint. The osteotomized portion of the distal ulna was tapered to enhance fixation of the ulna to the radius. The forearm was placed in neutral position, and bony continuity, radial height, and volar tilt were reestablished. A seven-hole Synthes, low-profile distal radius locking plate was used to secure the residual distal radius to the ulnar shaft, thereby creating a one-bone forearm (Figs. 4 and 5). The external fixator was removed, and the dorsal soft-tissue wound was closed with interrupted sutures. The remaining volar soft-tissue defect was covered with a split-thickness skin graft (STSG) taken from the ipsilateral thigh. A wound VAC was placed over the STSG and was set to 75 mm Hg in continuous mode. Dressings were removed 5 days after surgery, and there was 100% take of the STSG. The patient was discharged from the hospital, and he elected to follow-up with a physician in the Iraqi healthcare system.

TEACHING POINTS

1. A thorough physical examination must include detailed evaluation of wrist and hand function. In addition, a complete neurovascular examination must be performed to evaluate for any potential deficits, because they can potentially alter treatment decisions.
2. Radiographs of the injured extremity should be obtained in orthogonal planes, and the proximal and distal joints should be completely visualized.
3. Complex reconstruction of segmental bone defects in the forearm is challenging in the best conditions, let alone in an austere environment. Use of vascularized free bone transfers is technically demanding and prolonged operative times and extensive exposures increase the risk of complications, as well as donor site morbidity. Vascularized transfer is indicated in segmental bone defects larger than 6 to 8 cm.
4. Although bone stabilization with rigid internal fixation is relatively easy to obtain, the decision to proceed with a vascularized fibula graft or one-bone forearm should be made with great caution. It is important to talk with the patient about the risks and benefits of both treatment options. Furthermore, the surgeon must understand his/her own capabilities, as well as the resources available at his/her disposal.

FIGURE 1. *Gunshot wound to the distal right forearm. Bone fragments are visible in the wound.*

CLINICAL IMPLICATIONS

High-energy open fractures of the forearm should be treated with staged procedures to facilitate management of bone and soft-tissue defects. The following treatment principles should be applied:

1. Administration of intravenous antibiotics and tetanus in the emergency department.
2. Emergent debridement and irrigation in the operating room, with removal of any loose bone fragments or devitalized soft tissue.
3. Extension of the wound proximally and distally to completely expose and evaluate the zone of injury.
4. Placement of a wrist spanning external fixator for bone defects involving the distal one third of the forearm.
5. Primary repair of transected tendons or nerves, if possible.

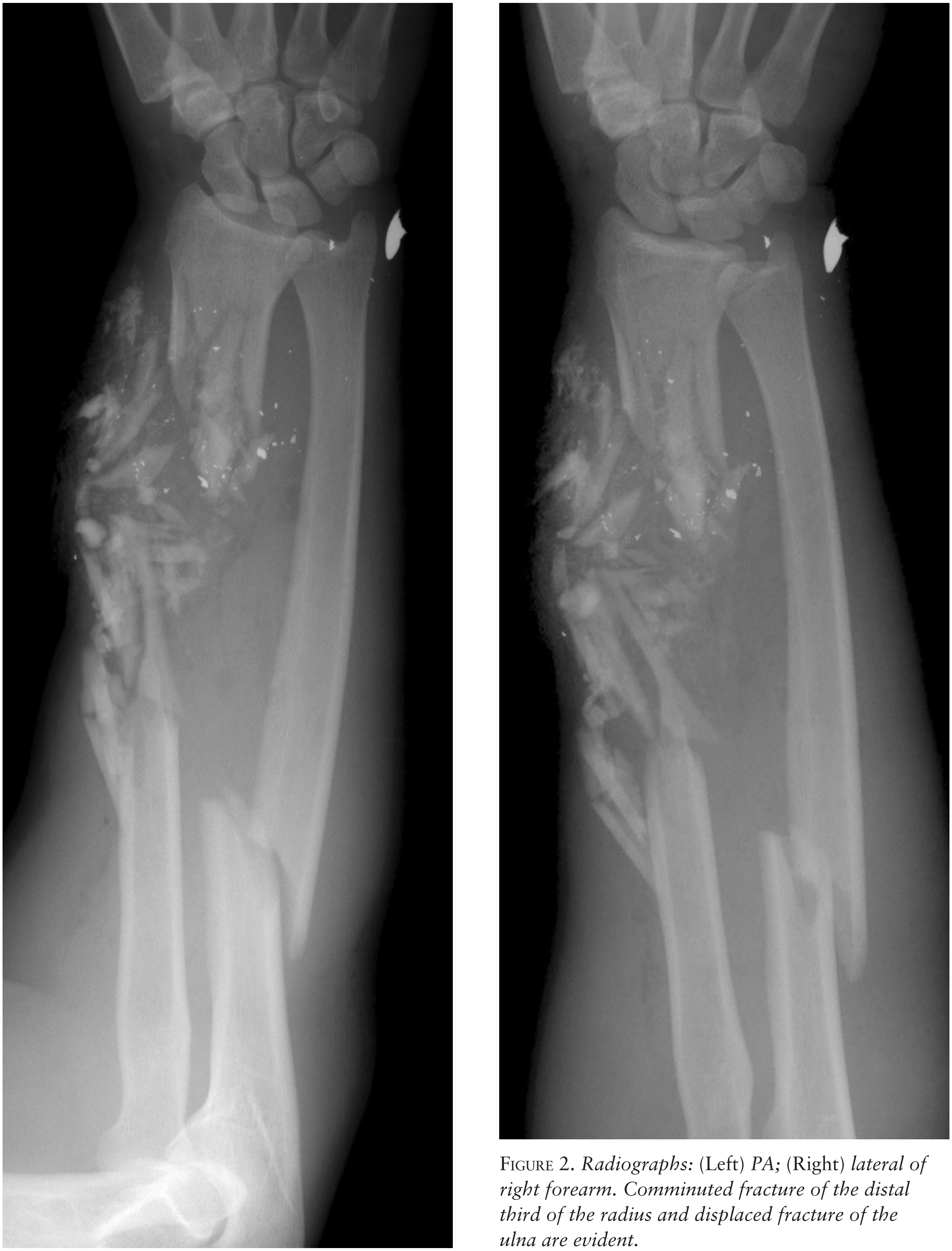


Figure 2. *Radiographs:* (Left) *PA;* (Right) *lateral of right forearm. Comminuted fracture of the distal third of the radius and displaced fracture of the ulna are evident.*

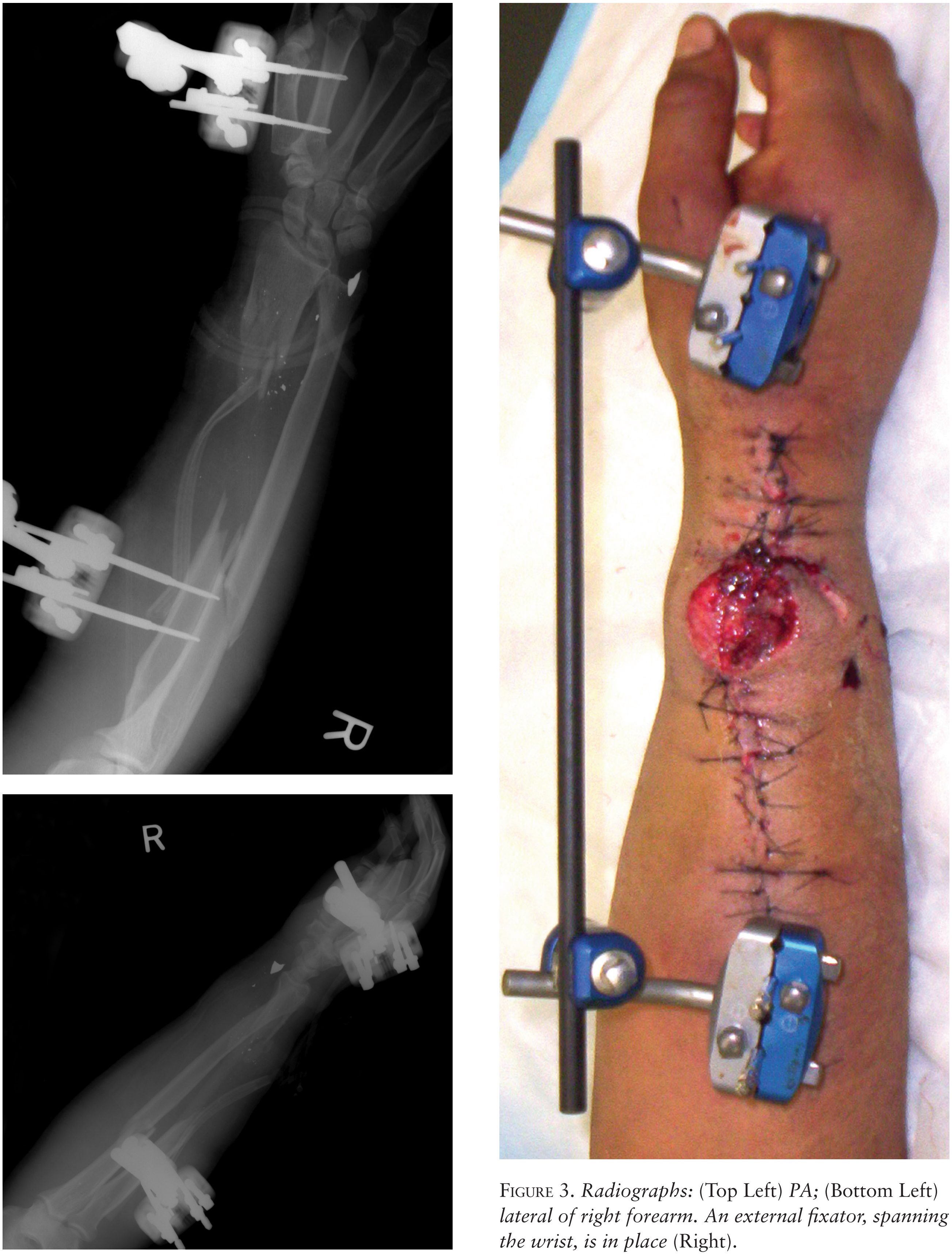


FIGURE 3. *Radiographs:* (Top Left) *PA;* (Bottom Left) *lateral of right forearm. An external fixator, spanning the wrist, is in place* (Right).

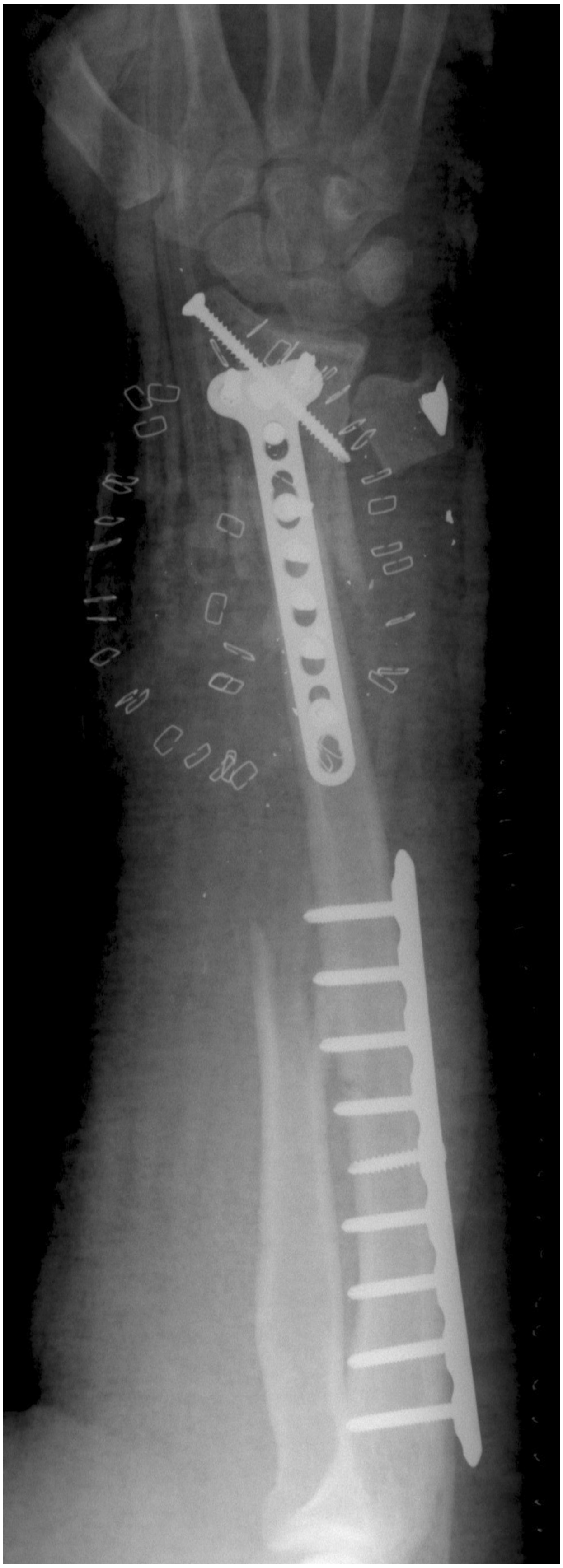
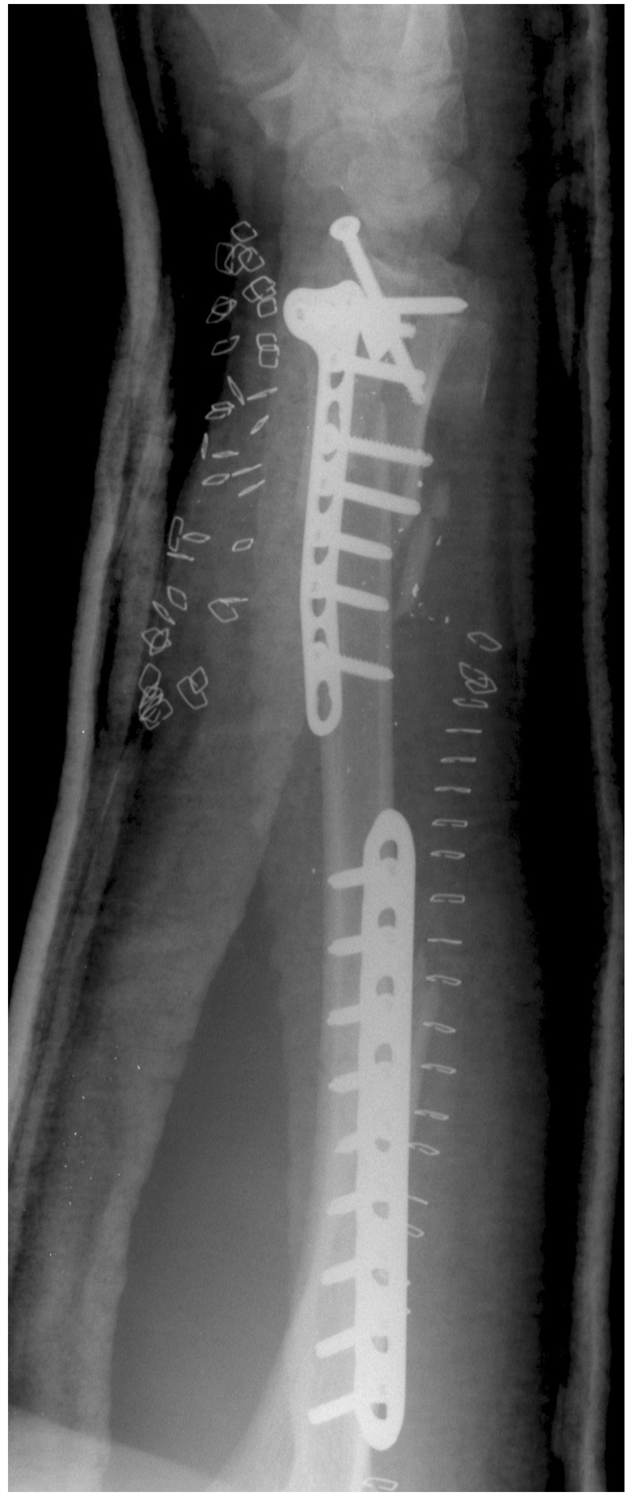


FIGURE 4. (Left) *Radiograph* (lateral view), *hospital day 3, s/p open reduction and internal fixation. See text for more details.*

FIGURE 5. (Right) *Radiograph* (AP view) *of one-bone forearm.*



6. The use of an ulna-to-radius osteotomy to bridge bone defects greater than 6 to 8 cm.
7. Definitive osteosynthesis with rigid internal fixation.
8. Soft-tissue coverage within 3 to 7 days to minimize infection and provide a stable envelope for bone healing.

DAMAGE CONTROL

Open forearm fractures with extensive segmental bone loss can be temporarily managed with intravenous antibiotics, tetanus toxin, and a well-padded sugar-tong splint (so named because it resembles the sugar tong used for handling cubes of sugar). Rapid transport to a facility with an orthopaedic surgeon and the appropriate equipment should be arranged.

SUMMARY

This case demonstrates that open forearm fractures with extensive segmental bone and soft-tissue loss are challenging clinical problems. It is important to obtain initial skeletal stabilization with an external fixator to restore the anatomy and prevent further damage to the soft-tissue envelope. In addition, placement of an external fixator facilitates staging the procedures and allows for further evaluation of the evolving injury. Definitive fixation of forearm fractures with segmental bone loss should take into account the patient's desires, technical skill of the surgeon, environmental factors, and facility resources.

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VII.13 High-Energy Orthopaedic Polytrauma

CASE PRESENTATION

A 21-year-old US Marine Corps male was involved in a rollover motor vehicle collision after driving over an improvised explosive device (IED). He was intubated and hypotensive on arrival. Blood pressure responded appropriately following the administration of 2 L of crystalloid and 2 units of packed red blood cells. CT scan of the abdomen and pelvis revealed grade III liver and spleen lacerations with extravasation, as well as a pelvic hematoma. Head CT scan showed subcentimeter bilateral frontal and left temporal tip petechial hemorrhages, as well as a small right lateral ventricular hemorrhage. Pelvic CT scan and plain films demonstrated a right anterior column acetabular fracture (Fig. 1), a right sacral fracture (Fig. 2), a right hip subcutaneous hematoma (Fig. 3), a right displaced basicervical femoral neck fracture (Figs. 4 and 5), right tibia and fibula fractures (Fig. 6), and a right lateral condyle fracture of the humerus (Fig. 7). His physical examination revealed a stable pelvis with a large area of right hip ecchymosis and edema consistent with a Morel-Lavallée lesion (a closed, degloving injury presenting as posttraumatic hematoma over the thigh; Fig. 8). The right leg had a 4-cm open wound on the anteromedial border of the tibia, consistent with a grade II open tibia fracture. The leg compartments were edematous and tense, consistent with a compartment syndrome. There was also a 6-cm wound over the right lateral knee, which communicated with the knee joint. The right elbow had a 4-cm medial wound; however, this did not communicate with the lateral condyle fracture. The right forearm and hand were edematous, and the compartments were tense, which was also consistent with a compartment syndrome. He was taken to the operating room emergently and underwent an exploratory laparotomy, which revealed 1.5 L of blood in the abdomen. Two small cracks were noted in the liver, as well as a large zone III nonexpanding pelvic hematoma. The liver and pelvis were packed, and the spleen was removed. Further inspection showed no intraperitoneal bladder injury, and the abdomen was temporarily closed over suction drainage. Neurosurgery performed a ventriculostomy to monitor the closed-head injury. Following the lifesaving procedures, Orthopaedics performed four compartment fasciotomies of the right leg and a volar fasciotomy of the right forearm. A carpal tunnel release was also performed to decompress the median nerve. The right tibia was stabilized with a uniplanar external fixator, and the open wound was irrigated and debrided (Figs. 9 and 10). The right open knee joint and right medial elbow wound were irrigated and debrided. Fifteen

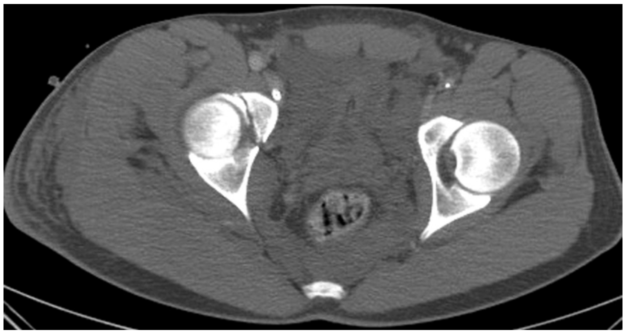

Figure 1. *Pelvis CT. Note right acetabular fracture.*

Figure 2. *Pelvis CT. There is a displaced fracture of the right sacrum.*

Figure 3. *Pelvis CT. There is marked edema and hematoma adjacent to the right hip. Note fracture of left pelvic ramus.*

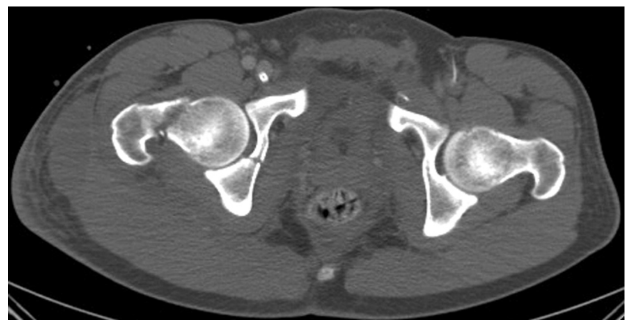

Figure 4. *Pelvis CT. Displaced right femoral neck fracture and acetabular fracture are evident.*

pounds of traction were applied to the external fixator frame, and the right basicervical femoral neck fracture was treated with a closed reduction and percutaneous screw fixation using three 7.0 mm cannulated screws (Fig. 11). All of the patient's wounds were placed in soft dressings, and the right upper extremity was placed into a posterior splint. He was taken to the intensive care unit for further monitoring and then transferred to a higher echelon of care the following day.

TEACHING POINTS

1. A complete examination of the spine, chest, pelvis, and extremities is an essential part of the secondary survey in patients sustaining blunt trauma. All body surfaces should be exposed and thoroughly palpated. In addition, all major joints should be put through a full range of motion and assessed for potential ligamentous injury.
2. Radiographs should be obtained of any painful extremity or if there is any deformity, ecchymosis, or crepitus. It is important to make sure that good quality radiographs are obtained in two orthogonal planes and that the entire bone, to include the proximal and distal joints, is visualized.
3. Compartment syndrome is a clinical diagnosis and usually manifests with pain out of proportion on physical examination and pain that is not controlled with pain medication. In addition, patients can note paresthesias and will have pain on passive stretch of the affected extremity.
4. In patients without a reliable clinical examination (eg, an intubated or head injured patient), compartment pressure measurements can be obtained. Diagnosis of a compartment syndrome is made when either the absolute pressure is greater than 30 mm Hg or the pressure is within 30 mm Hg of the diastolic blood pressure (delta P < 30 mm Hg). Once the diagnosis is made, emergent fasciotomy is indicated.
5. In cases in which the diagnosis of an open joint is not clinically obvious, a saline load test can be performed. Following sterile preparation of the skin, a large bolus of normal saline (ie, 60 cc for the knee and 30 cc for the elbow/ankle) can be injected into the joint. If fluid leaks from the open wound, then

the joint has been violated, and surgery is indicated. To further enhance visualization, methylene blue can be added to normal saline.

CLINICAL IMPLICATIONS

In patients with multiple extremity injuries (orthopaedic polytrauma), it is important to prioritize which injuries should be treated first. This patient has multiple orthopaedic emergencies to include upper and lower extremity compartment syndromes, open tibia fracture, open knee joint, and femoral neck fracture. The following treatment principles should be applied:

1. Administration of intravenous antibiotics and tetanus in the emergency department.
2. **Compartment syndromes should be released first** to minimize ischemia and preserve muscle and nerve function. Large incisions should be used to completely visualize and release the muscular fascia. In the leg, the anterior and lateral compartments are released through a lateral incision, and the superficial and deep posterior compartments are released through a medial incision. The volar forearm compartment can be released through a number of different incisions, and a carpal tunnel release can also be performed by extending the incision across the wrist flexion crease at an oblique angle. If necessary, the mobile wad can be released through the volar forearm incision, and the dorsal forearm compartment can be released through a separate dorsal incision.

FIGURE 5. *AP pelvis plain film. Note displaced fracture of the right femoral neck and right acetabulum fracture and right sacrum.*

FIGURE 6. *Radiographs of right tibia and fibula fractures.*

Figure 7. *Radiograph of right humerus. Note fracture of lateral epicondyle.*

Figure 8. *Note edema and ecchymosis of right hip.*

3. Open fractures should be addressed next, and traumatic wounds should be extended proximally and distally to expose the fracture and zone of injury. All devitalized soft tissue and loose bone fragments should be removed first, and this is followed by copious irrigation using pulse lavage (typically 9 L of normal saline for high-energy fractures).
4. Long bone fractures should be initially stabilized with external fixators. The fracture should be reduced and the external fixator frame tightened. Intraoperative fluoroscopy is a useful adjunct to ensure proper pin placement and to confirm fracture reduction. In addition to stabilizing fractures, external fixators help decrease pain, prevent further soft-tissue damage, and allow for access to complex soft-tissue wounds. Definitive management of fractures with internal fixation devices is carried out after soldiers return to higher echelon facilities in the continental United States.
5. An open joint is also a surgical emergency and requires prompt treatment with debridement and copious irrigation. Once the joint has been adequately lavaged, the arthrotomy should be closed to prevent further contamination of the joint space.
6. Displaced femoral neck fractures in young adults are surgical emergencies because of the potential for blood flow compromise to the femoral head and the development of osteonecrosis. Prompt anatomical reduction and internal fixation with three large cannulated screws were performed on this patient and is the preferred method of treatment.

FIGURE 9. *Right lower extremity. External fixators stabilize a tibial fracture. Lateral compartment fasciotomy and lateral knee wound are evident.*

7. Many upper extremity fractures are amenable to stabilization with well-padded splints. In this instance, the lateral condyle fracture of the distal humerus was treated in a posterior splint, rather than subjecting the patient to the additional surgical time and morbidity of an external fixator.
8. Treatment of Morel-Lavallée lesions is controversial and consists of either observation or percutaneous drainage. The main concern with these injuries is an increased risk for infection related to surgical approaches through the zone of injury. This patient was treated by leaving the skin envelope intact, except for the small incision that was made to fix the femoral neck fracture.

DAMAGE CONTROL

If an orthopaedic surgeon is not available when a patient presents with complex extremity injuries, a general surgeon can perform limb-saving fasciotomies. Orthopaedic damage control involves early intravenous antibiotics, irrigation of open fractures at the bedside, and placement of well-padded splints for transport to a facility with the necessary personnel and equipment. General surgeons deploying to a combat theater should familiarize themselves with the use and application of external fixators.

SUMMARY

This case demonstrates the severity of musculoskeletal injuries from high-energy blunt trauma (see *Emergency War Surgery, Third United States Revision*, Fig. 1-9, page 1.12). In this instance, priority was given to his potentially life-threatening intraabdominal injuries, followed by attention to multiple complex extremity injuries. A systematic treatment plan was used to address, respectively, the compartment syndromes, open fracture, open knee joint, displaced femoral neck fracture, and lateral condyle fracture of the distal humerus. All of the patient's injuries were promptly treated, and he was stabilized for transport to a higher echelon of care.

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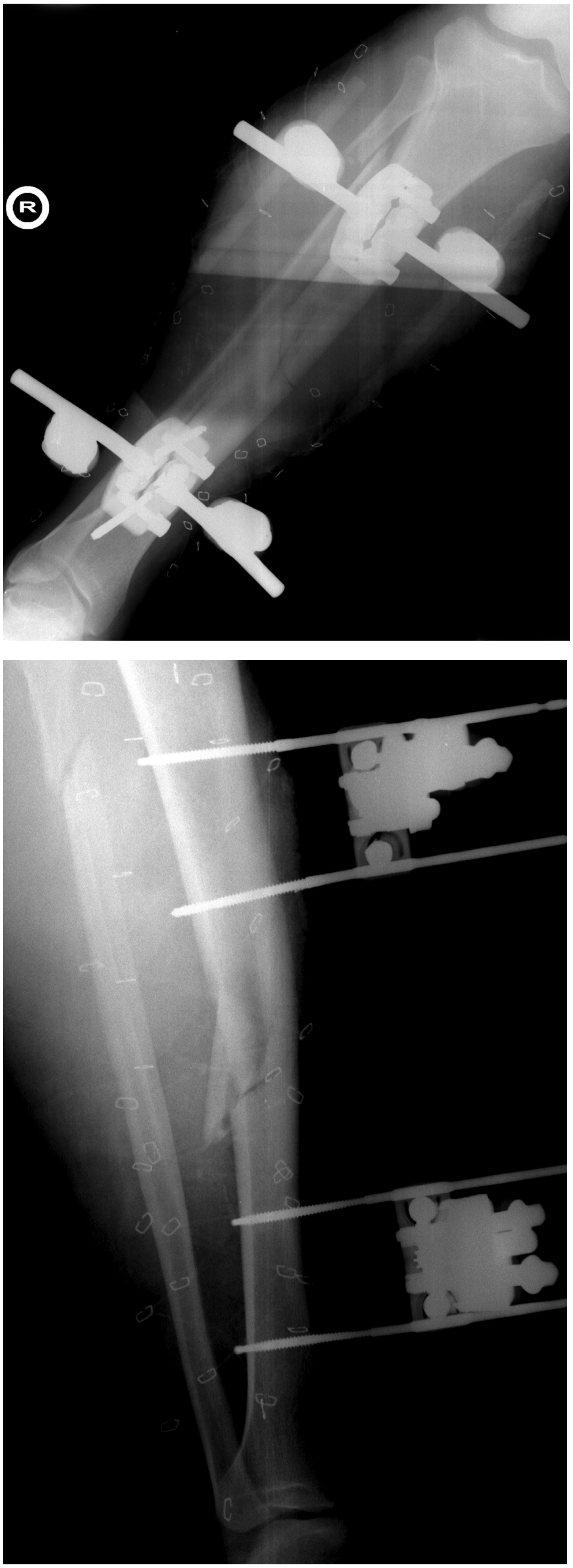
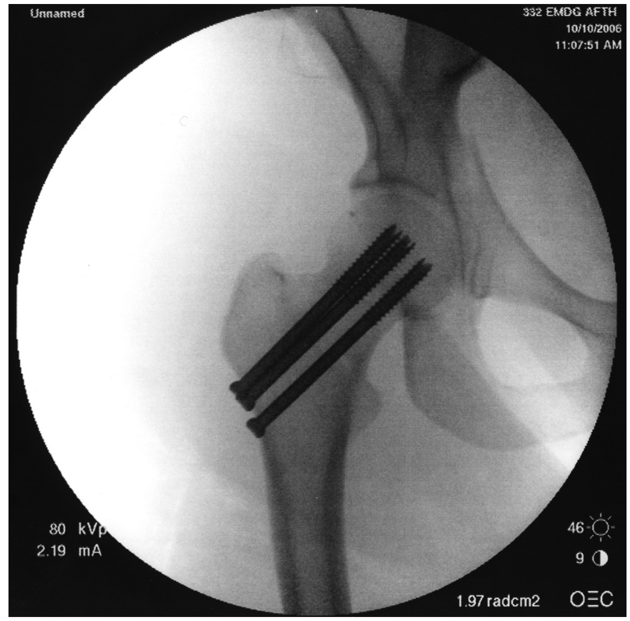


FIGURE 10. *AP* (Top Left) *and lateral* (Bottom Left) *radiographs of right leg with external fixator in place.*

FIGURE 11. (Right) *Radiograph of right hip. Three cannulated screws are in place to reduce femoral neck fracture.*



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COMMENTARY

Orthopaedic Trauma

by COL James Ficke, MD

Since September 11, 2001, US and coalition troops have been actively engaged in the largest conflict since Vietnam. As of January 2008, more than 4,300 US soldiers have died in this conflict, and more than 30,000 have been injured.[1] Of these casualties, approximately 54% sustained open wounds to the extremities and 26% sustained fractures. Of even greater impact, 82% of all of these fractures were open[2] and required urgent, in-theater debridement, often necessitating stabilization. The cases presented in this chapter encompass a thorough survey of typical injuries currently seen in contemporary combat. Leading civilian and military orthopaedic surgeons have collaborated on two annual Extremity War Injury Symposia[3] to identify management principles and challenges faced by surgeons who treat combat injuries. These principles include:

- improvement of prehospital care for extremity injuries,
- initial debridement and stabilization,
- management of massive bone and soft-tissue defects,
- treatment and prevention of wound infections, and
- prevention of heterotopic ossification.[3]

The following additional comments are warranted.

CIVILIAN (HOST NATIONAL) CARE

Often, the only potential for definitive reconstruction rests on the capabilities of the CSH. Definitive care for a host national patient can be accomplished safely without sophisticated techniques. With minimal additional technology, successful wound management and staged reconstruction may be possible. Early fixation and bone grafting in this situation may be deleterious, however, in the face of inadequate soft-tissue coverage. Although microvascular free tissue transfer is not commonly practiced in theater, alternatives such as pedicle flaps and negative pressure wound therapy (wound VAC) can significantly reduce in-hospital stay, while still permitting appropriate definitive fixation.

EXTERNAL FIXATION AND TRANSPORT

The field external fixator has largely replaced a transportation cast. The disadvantage of casting is primarily related to wound access, weight, and time to apply. In nearly all lower extremity injuries, an external fixator can be safely applied, allowing wound access, comfort, and minimal additional soft-tissue trauma. When periarticular fractures are stabilized with joint-spanning external fixators, these should be placed anteriorly whenever possible in order to facilitate transport.

EXTREMITY COMPARTMENT SYNDROME

Tibia fractures as a result of blast injury are fairly common, and this chapter demonstrates essential principles in their management. Open tibia fractures lack the abundant soft-tissue envelope of the femur, and complications (eg, infection or compartment syndrome) tend to occur with higher frequency. This necessitates serial examinations and low threshold for performing four-compartment fasciotomy through two incisions. Recent evidence for incomplete release demonstrates the imperative for long incisions, release from 5 cm below the knee joint distally to the musculotendinous junction, and assurance of release of all four compartments. This is best accomplished for the deep posterior compartment by the ability to directly touch the posteromedial fibula from the medial incision, and performing an "H" between the separate longitudinal releases of the anterior and lateral compartments directly visualizing the intermuscular septum with the horizontal incision. Some surgeons would disagree that simple bulging of muscle confirms the diagnosis of compartment syndrome. More importantly,

Figure 1. (Top) *Distal leg wound at presentation.* (Bottom) *Postoperative view of wound. The irregular soft-tissue margins are intentional.*

DEPARTMENT OF THE ARMY

CONSENSUS STATEMENT ON LENGTH PRESERVING AMPUTATIONS

Goal: Provide standardization of care for the performance of life saving amputations which provide maximum limb length preservation for optimal rehabilitative function.

Background: The notion of the "zone of injury" is dependent upon the mechanism of injury, i.e. blast, gunshot, and crush injuries, as well as comorbidities such as severe blood loss with massive resuscitation, burns, compartment syndrome, and tourniquet use which may extend the amount of tissue damage. The wounds will evolve over time and merit frequent wound inspection and evaluation. Indications for amputation include traumatic amputations, vascular injury not amenable to repair, and limb infection with uncontrolled sepsis. Current consensus on battle injured nonsalvageable limbs is to preserve limb length, and conserve viable tissue for reconstruction in a definitive level V facility. The former open circular technique eliminates many potential options and should be avoided when possible.

Initial Surgical Management: Thorough inspection of the wounds with liberal use of surgical wound extension to inspect all levels of tissue including examination of fascial planes.

A meticulous debridement of all nonviable tissue including skin, fat, fascia, muscle, and bone should be performed. All gross contamination must be debrided.

The amputation level should be performed at the most distal level which provides viable bone and soft tissues for later closure. If an amputation is completed, but a fracture exists proximally, stabilize this segment with pins or external fixation, and preserve length.

Vascular structures should be ligated proximal to the bone resection and separated from nerves.

Be prepared to accept atypical skin and tissue flaps so long as the tissue is viable.

If the limb distal to the wound is viable, but there is a fracture, this should be preserved and the bone stabilized. This is most often accomplished with an external fixator. Amputation can and should be made at the definite treatment facility.

Avoid open circular, or guillotine amputations if possible. If needed then perform the amputation at the most distal level. All wounds must be left open.

Post Operative Management: Soft dry dressing should be applied. Circumferential wraps with gauze rolls and ace wraps must be applied in a figure of 8 fashion without excessive compression.

The limb may be placed in a splint or bivalved cast to prevent joint contractures and provide soft tissue support. There should be simple access for wound inspection.

In the event of the short skin flaps, be prepared to place the limb with skin traction to prevent soft tissue retraction. Alternatively, consider negative pressure dressing when conditions permit.

Avoid placement of pillows under the knee to prevent contractures in the below knee level to prevent hip contractures in the above knee level. Plan on repeat debridement generally within 48-72 hours; however these wounds must be watched closely.

Coordinate dressing changes/repeat debridement with evacuation schedule to avoid extended periods without wound care or inspection. *Closure is not recommended until arrival at the definitive care facility*, and then myodesis should be accomplished whenever possible.

muscle viability and contractility must be assessed, and complete release ensured. Additionally, a fasciotomy with normal muscle should not be criticized; rather, the dire consequences of missed compartment syndrome far outweigh an occasional fasciotomy without compartment syndrome. In the face of evolving compartment status, ongoing resuscitation, or significant coagulopathy, delaying evacuation to ensure limb viability is justified and preferable to delaying fasciotomy.

AMPUTATION

The overall amputation rate in the present conflicts in Southwest Asia appears to remain fairly constant and is more related to immediate nonreconstructible trauma than to any other cause. The principles of open-length preserving amputation include removing clearly devitalized tissue (skin, fat, muscle, and bone) and leaving the wound open (Fig. 1; also see Consensus Statement on facing page). Wound debridement is more important than formal flaps. The ideal incision follows the lines of injury, thus providing greater latitude in the definitive care decision process. Loose approximation to prevent skin retraction may have the same effect without increasing the infection rates. At present, formal skin traction is rarely used. An open circular amputation does not preserve length, and leads to unnecessary challenges in healing and rehabilitation of the residual limb. For these reasons, open circular amputation is no longer recommended.

PELVIC STABILIZATION

Pelvic ring injuries need to be assessed early for stability, and stabilized as part of the damage control and resuscitation process. This is one of the critical roles an orthopaedic surgeon plays in lifesaving hemostasis. A contained retroperitoneal hematoma can be controlled with external fixation. Use of a pelvic binder, although often effective in short term, is not advisable for prolonged transport. Packing can result in hemodynamic stability (as in the case presented). Early or prophylactic fasciotomies should be considered in the face of massive resuscitation and unclear clinical picture. Recent evidence suggests that delayed fasciotomy is associated with increased mortality and amputation rates.[4] However, more rigid analysis of clinical outcomes data is required. Present practice of lower extremity, four-compartment fasciotomy through two separate wide incisions (including release of the entire extent of the muscle) appears to be most preventive of additional muscular injury. It should be emphasized that the vast majority of fractures should not be definitively internally fixed in theater. Femoral neck fractures, however, are one of the very few strong indications for definitive internal fixation in the combat zone. The risk of osteonecrosis of the femoral head outweighs the infection risk in this injury, and pinning with reduction can be safely performed if fluoroscopy is available. Intraarticular foreign bodies constitute a contaminated joint and mandate open debridement.

These 13 cases catalog a wide diversity of extremity trauma, as well as their spectrum of severity. Principles of surgery are learned with practice and study; and a comprehensive review is not in the scope of this book. However, wound debridement, soft-tissue coverage, and consideration of the necessary differences between care of host national patients who often require prolonged and definitive management versus damage control stabilization and transport of US patients are well described. A deployed surgeon of any discipline must know the technique for fasciotomy and the indications for the procedure, as well as be able to anticipate and prevent the drastic consequences of compartment syndrome.

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