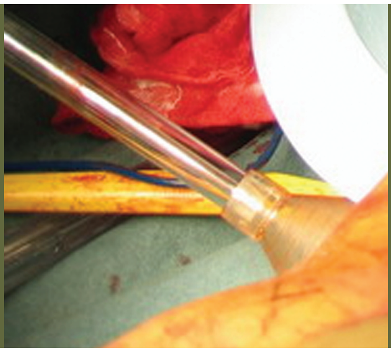
Chapter VI
SOFT-TISSUE TRAUMA AND BURNS



VI.1 Lower Extremity Compartment Syndrome

CASE PRESENTATION

This male patient sustained a blast injury that resulted in multiple fragment wounds to his left leg. He presented shortly after wounding and complained of severe, unrelenting pain in his left leg. The wounds were not considered severe (Fig. 1). Plain radiographs revealed no fractures, but did reveal multiple fragments (Fig. 2). The extremity was neurologically intact, and there was no evidence of vascular injury. During physical examination, the compartments were tense, with severe pain on palpation. Pain was also noted during passive range of motion of the toes. A clinical diagnosis of compartment syndrome was made. The patient was taken to the operating room for irrigation and debridement of his wounds and a four-compartment fasciotomy (Figs. 3 and 4). Intraoperatively, all compartments were tense, and the muscles of all four compartments were very swollen when released. No necrotic muscle was noted. Dressings soaked with Dakin's solution were placed on the affected areas. Postoperatively, symptoms were relieved completely, and the patient remained neurologically intact with a normal vascular examination.

TEACHING POINTS

1. Compartment syndrome is a common result of wounding. It can occur even in the absence of fractures or impressive soft-tissue wounds. It is important to note that compartment syndrome can be caused by one small fragment that makes a very small entry wound.
2. Do not be misled by a small wound or unimpressive radiograph. The diagnosis is made on clinical grounds and demands an urgent fasciotomy to avoid severe disability.
3. If no Stryker pressure monitors are available in theater and a pressure measurement is required, an arterial line setup can be used in the intensive care unit or operating room to measure the pressure of involved compartments. Compartment pressure measurements, however, are fraught with confounders. Pressures vary with the patient's hydration, blood pressure, nature and age of injury, and altitude, among other factors. Pressures higher than 25 to 30 mm Hg are cause for concern, but no specific value, per se, mandates surgical release. If the diagnosis of compartment syndrome is suspected on clinical grounds, obtaining a measurement should not delay surgical treatment or postpone compartment release (see Chapter VII Commentary by Ficke).

FIGURE 1. *Wound prior to surgery.*

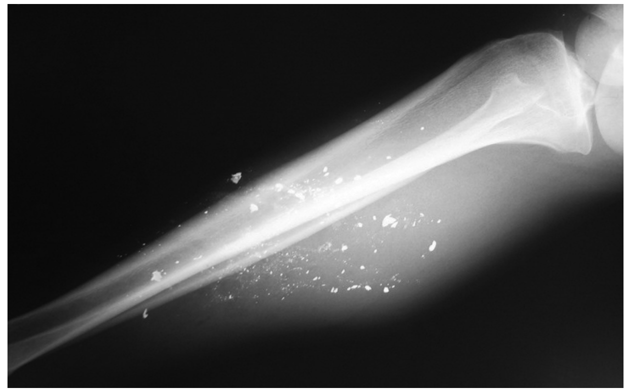


FIGURE 2. *Radiograph of multiple fragments in soft tissue, but no fracture.*

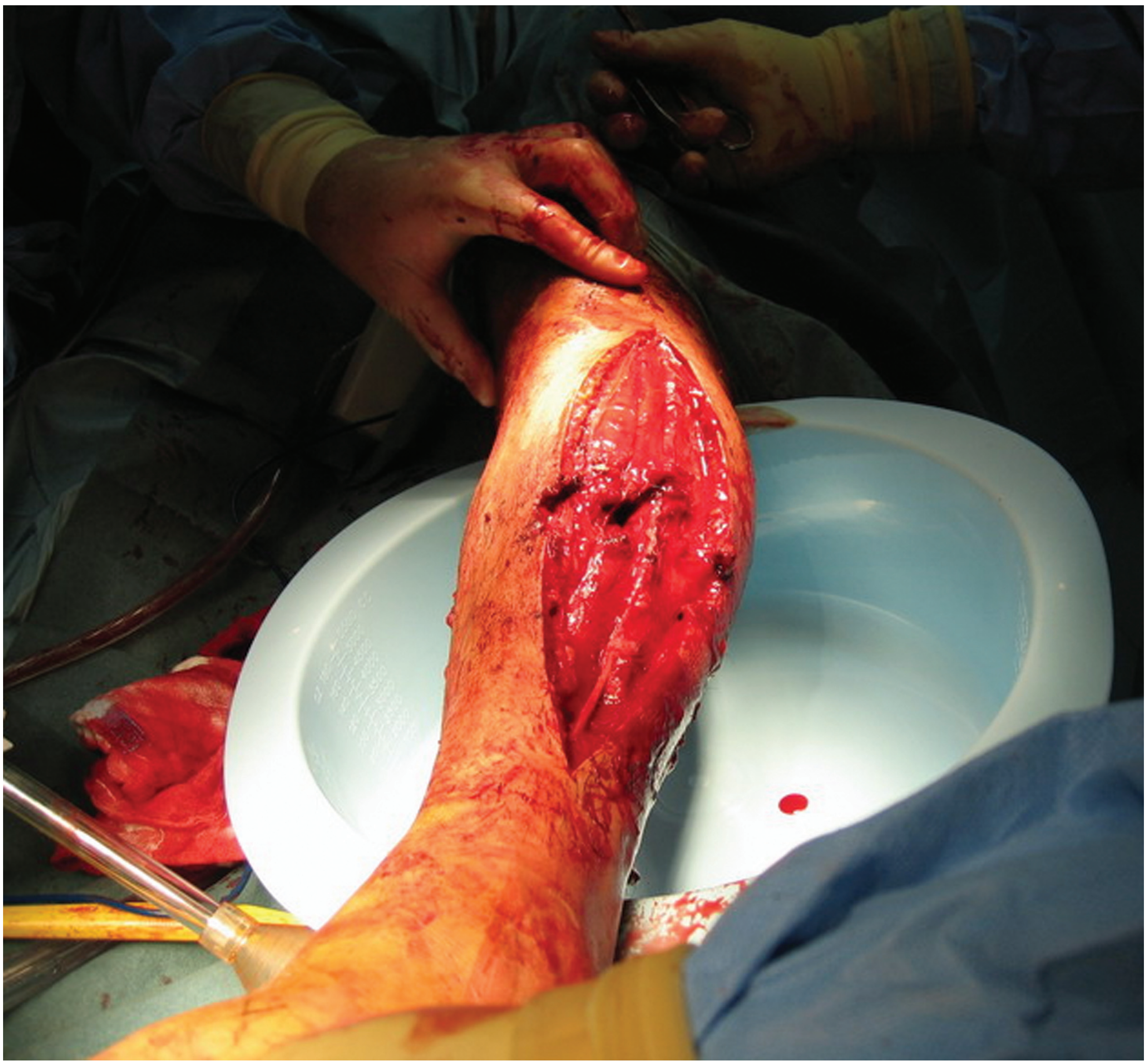


FIGURE 3. *Lateral wound after debridement and fasciotomy.*

FIGURE 4. *Medial wound after debridement and fasciotomy.*

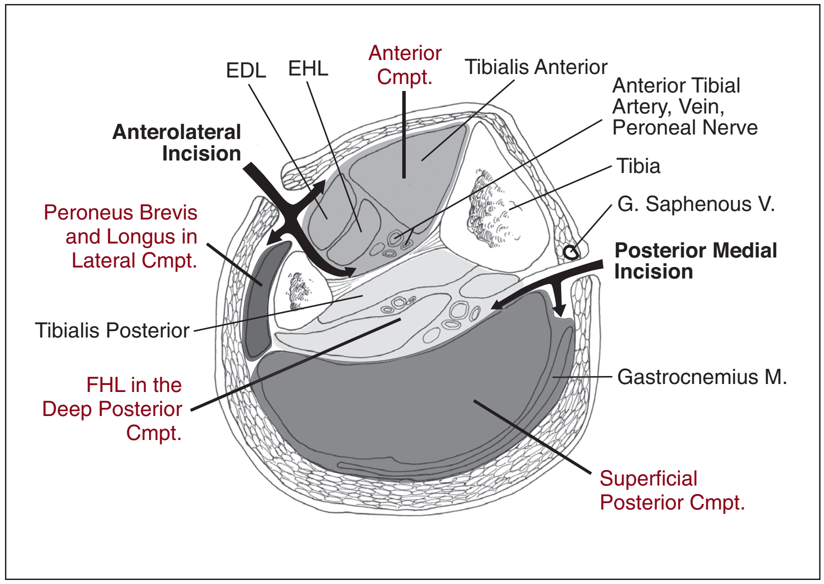


FIGURE 5. *Calf compartments. Cmpt.: compartment; EDL: extensor digitorum longus; EHL: extensor hallucis longus; FHL: flexor hallucis longus; G.: greater; M.: muscle; V.: vein.*

4. Postoperative care: Consider low-dose heparin for deep vein thrombosis prophylaxis. Postoperative deep vein thrombosis in trauma is common. Use caution if patient is multiply injured or has head/eye injuries.
5. Slight elevation of the injured extremity improves postoperative edema.
6. If available, a wound VAC may be used in lieu of Dakin's soaked dressings.

CLINICAL IMPLICATIONS

1. Any wounded soldier can present with compartment syndrome at any point along the evacuation chain. To avoid long-term patient disability, the possibility of this condition appearing in any medical treatment facility must be anticipated and looked for. Head-injured patients and patients with a depressed level of consciousness obviously will require closer monitoring for compartment syndrome.
2. Early clinical signs: pain out of proportion with physical findings, pain with passive stretching, and a tense swollen compartment. Loss of pulses is a late finding.
3. Late clinical signs: paresthesia, pulselessness, pallor, and paralysis.
4. Recheck for compartment syndrome all along the evacuation route.

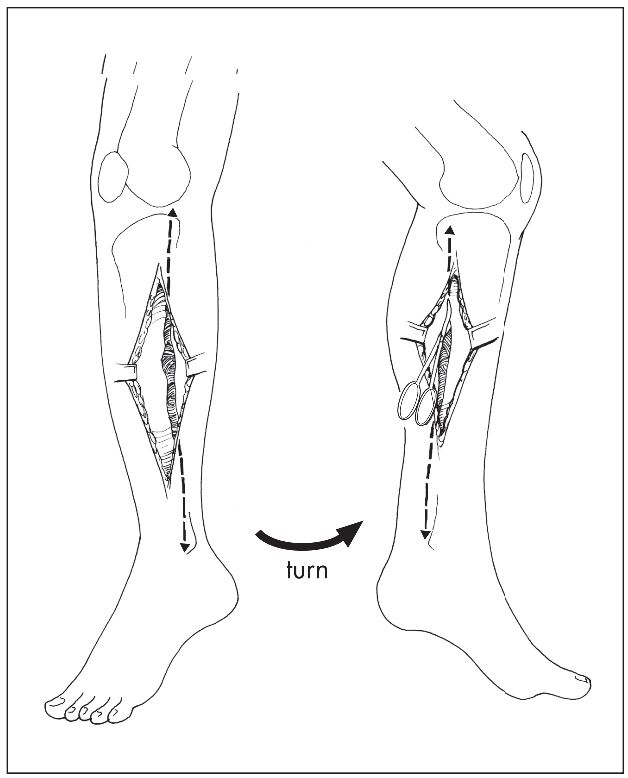


FIGURE 6. *Anteromedial incision of the calf.*

DAKIN'S SOLUTION

Developed during World War I, this solution was the result of a collaboration between Americans Henry Drysdale Dakin (1880–1952) and Alexis Carrel (1873–1944). It is also known as Carrel-Dakin solution, Carrel-Dakin fluid, and Dakin's fluid. It is a highly diluted, neutral antiseptic solution for cleaning wounds. The solution is made of sodium hypochlorite (0.45%–0.5%) and boric acid (4%). However, it is unstable and cannot be stored for more than a few days. It must be prepared fresh as needed.

Note: Century Pharmaceuticals, Inc (Indianapolis, Indiana), modified Dr Dakin's original formula and made it stable for more than 12 months. **Full strength** contains the highest concentration of sodium hypochlorite (0.50%) tolerable to the skin. **Half strength** contains 0.25% sodium hypochlorite. **Quarter strength** contains 0.125% sodium hypochlorite. Diluted Dakin's solution (or Di-Dak-Sol) contains 0.0125% sodium hypochlorite.

5. Early fasciotomy is recommended in the combat zone. Incisions should be long; in this case from 5 cm below the knee joint distally to the musculotendinous junction, with assurance of release of all four compartments.
6. Consider liberal use of fasciotomies in patients facing long-distance aeromedical evacuation.

DAMAGE CONTROL

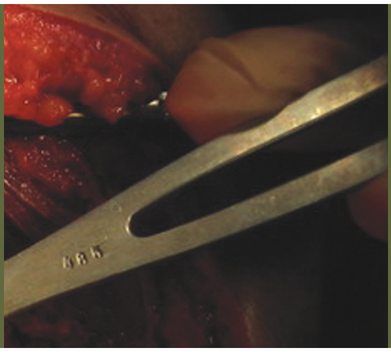
Four-compartment fasciotomy is a primary damage control technique. All general and orthopaedic surgeons working at level II and level III medical treatment facilities should be able to perform this procedure (Figs. 5 and 6; also see Commentary on Case VII.8 by Ficke on page 312).

SUMMARY

Compartment syndrome is commonly encountered in the combat zone. Combat surgeons must be extremely watchful for this condition. Surgeons must consider this diagnosis and treat patients prophylactically, especially if patients are to be evacuated during which frequent examination or surgical intervention is not possible. In this case, diagnosis was made on clinical grounds. The patient's symptoms were relieved completely by performing a four-compartment fasciotomy.

SUGGESTED READING

Chapter 22: Soft-tissue injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.



VI.2 Sciatic Nerve Laceration

CASE PRESENTATION

This 22-year-old host nation male sustained a fragment wound to the left buttock from an improvised explosive device (IED; Fig. 1). The entrance wound measured 4 cm. Communication with the patient was limited due to a language barrier. However, the patient complained of numbness to the lateral side of his left foot. Physical examination revealed an intact motor examination, but decreased pin-prick sensation at the left L5, S1, and S2 levels. Plain radiographs revealed a retained fragment at the level of the left femoral neck (Fig. 2). No fractures were identified. The patient was taken to the operating room and placed in the right lateral decubitus position. A posterolateral approach to the hip was used to explore the sciatic nerve (Fig. 3). The sciatic nerve was partially lacerated in the posteromedial portion. A 3-cm fragment was removed from the superficial surface of the quadratus femoris muscle (Fig. 4), and the wound was irrigated with pulse lavage. The surgical wound was closed, and the traumatic wound was packed with wet-to-dry dressings soaked with Dakin's solution. The patient was discharged from the hospital on postoperative day 1. Follow-up was not possible.

TEACHING POINTS

1. Gunshot and fragment wounds to the buttock frequently result in injury to underlying structures, including muscle, bone, and nerves. In this case, no fracture was noted, but a potentially more severe and less treatable injury to the sciatic nerve was noted on physical examination.
2. The language barrier limited patient interaction, even with the help of an interpreter. For this reason, it is often difficult to obtain a good, reliable, or reproducible preoperative examination and patient history.
3. Never underestimate the damage from blast injury. Usually, muscles are shredded and bones severely comminuted. The zone of injury is always larger than the obvious wound tract, and can be accompanied by thermal injury to the skin and subcutaneous tissues.

CLINICAL IMPLICATIONS

Suspected peripheral nerve injury of the extremities can be difficult to diagnose and is associated with significant morbidity. The following principles apply:

FIGURE 1. *A 4-cm fragment entrance wound from an IED.*

FIGURE 2. *Radiograph of fragment that injured the left sciatic nerve.*

1. When the proximal upper and lower extremities are involved, abdominal and thoracic injuries must be ruled out, because fragments can easily track into these body cavities.
2. Soft-tissue injuries with neurological deficits must be explored to decompress the nerve and document injury.
3. When appropriate, consider compartment syndrome-in-evolution as a possible explanation for patient symptoms.
4. If nerve grafting is to occur at a later date, tag severed nerves. Tagging of the ends of severed nerves is often the only option available during the initial phases of surgical care. This action may seem trivial in the face of massive tissue injury. However, it often proves valuable to our colleagues down the line as patients' wounds heal, and they are able to undergo reconstructive and restorative operations. The prognosis following peripheral nerve injury is highly variable. Nerve injury needs to be recognized immediately and the extent of impairment carefully documented. Resolution may not occur with the passage of time. Neurosurgical consultation should be requested early, because many patients will require operative intervention. Recent advances in the treatment of peripheral nerve injuries include the use of the operating microscope and intraoperative nerve action potential recordings.

DAMAGE CONTROL

Primary repair of peripheral nerves is often *not* performed and is contraindicated when damage control surgery is necessary. To prevent dessication, use soft tissue or moist dressings for coverage.

SUMMARY

This patient sustained a peripheral nerve injury accompanying the soft-tissue wound. The major concern was compression of the nerve by a fragment—a problem potentially resolved by excision of the fragment. Another possible concern was gluteal compartment syndrome (see Case VIII.10), which could adversely affect hip abductor function. Whenever an individual sustains a blast injury to exposed limbs, completed primary and secondary surveys of Advanced Trauma Life Support (ATLS)—with appropriate radiographs, CT, and general surgical consultation—are required to avoid missing potentially serious life-threatening injuries to the trunk.

SUGGESTED READING

Chapter 22: Soft-tissue injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

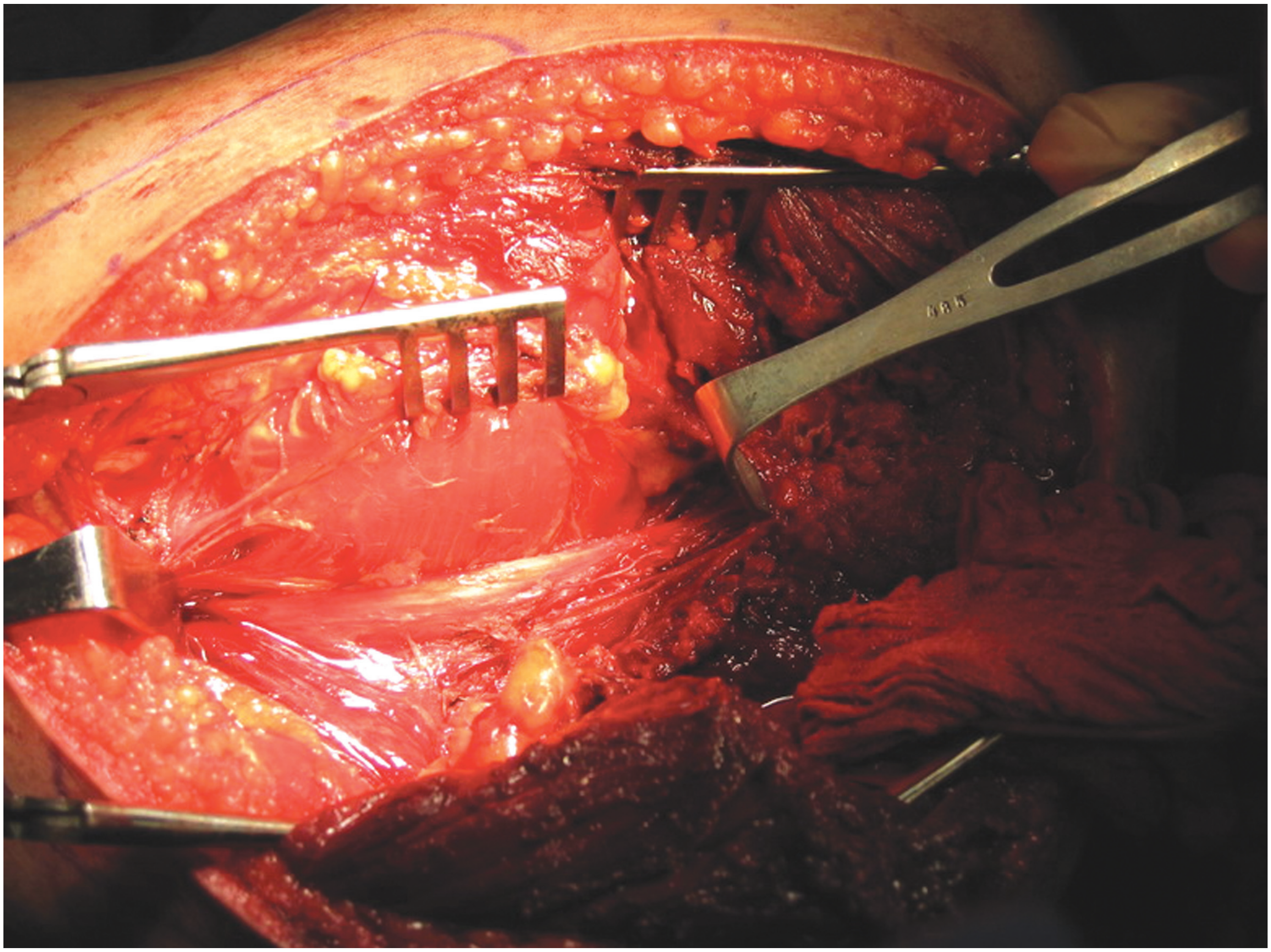
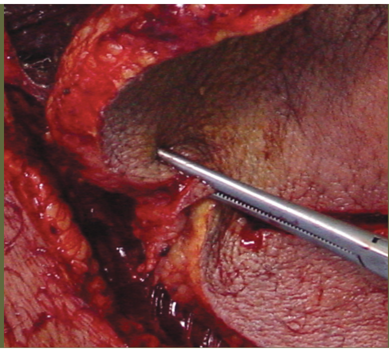


FIGURE 3. (Top) *Partial injury to the sciatic nerve and surrounding tissue.*

FIGURE 4. (Bottom) *A 3-cm fragment from the quadratus femoris muscle.*



VI.3 Posttraumatic Necrotizing Fasciitis

CASE PRESENTATION

This middle-aged male presented with two high-velocity (see sidebar on page 23) gunshot wounds. The first bullet penetrated the left lateral abdomen, injuring the descending colon and spleen. It traveled superior toward the left hemidiaphragm. The second bullet penetrated the left lateral thigh and also traveled superiorly, passing the posterior pelvis, the rectum, and the posterior sacrum. The patient presented in extremis and was taken immediately to the operating room for exploratory laparotomy. He required left hemicolectomy with transverse colostomy and a splenectomy. There was no intraperitoneal injury of the rectum; the rectum was left in situ, with the proximal stump stapled off at the pelvic brim. The extraperitoneal rectum sustained substantial injury, which was managed with distal washout and posterior drainage. By postoperative day 5, he developed persistent high fever and a spreading erythema on his back and right lateral abdominal wall, both suspicious for invasive infection. Open biopsy of the right lateral abdominal wall revealed viable fascia, but abundant gram-negative rods consistent with coliforms were present in the subcutaneous fat (Fig. 1). The patient was returned to the operating room. The bullet had transected the pelvis and rectum, lodged deep in his back (Fig. 2), contaminated the soft-tissue planes, and produced an aggressive necrotizing fasciitis. All dead and threatened muscle and fascia were excised. An initial incision revealed the dead (gray/black) fascia on his back (Fig. 3). This was resected back to viable tissue. Eventually, most of the fascia of the posterior thorax, the left gluteus, and the left lateral thigh were excised (Figs. 4 and 5). The patient's hospital treatment was long and complicated by bacteremic sepsis and multiple organ system failure. He eventually recovered. The large, open wound was treated as a full-thickness burn, with aggressive daily debridement, washing with chlorhexidene gluconate solution, and coverage with burn creams (silver sulfadiazine or mafenide). Once the wound no longer had a septic appearance and had begun to granulate, a large wound VAC was used to manage the open surface area (Figs. 6 and 7). This area was covered with split-thickness skin grafts in multiple stages. The patient was eventually discharged (Fig. 8).

TEACHING POINTS

1. This case demonstrates the devastating soft-tissue injury that typically accompanies high-velocity gunshot wounds. The penetrating missile is not sterile. In colon or rectal transit of the fragment(s), contamination

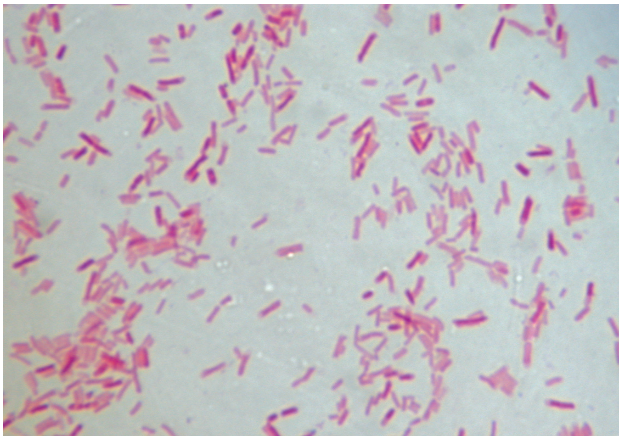


FIGURE 1. *Photomicrograph of Gram stain revealing abundant gram-negative bacilli in the subcutaneous and perifascial fat.*

FIGURE 2. *Axial CT of a bullet that traversed the pelvis and lodged in the back. Note subcutaneous emphysema.*

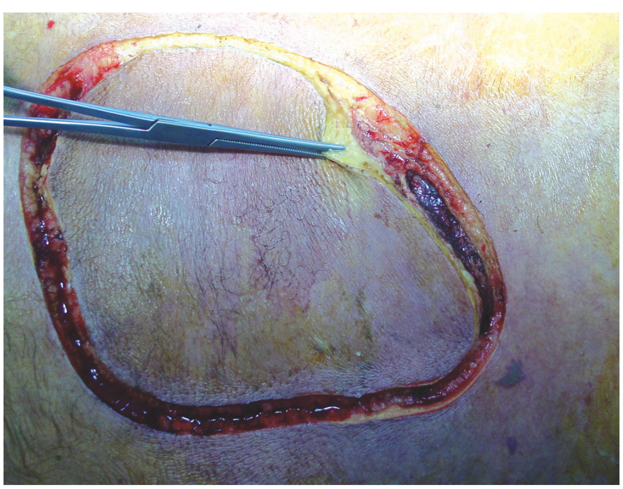


FIGURE 3. *Initial incision of the necrotic-appearing fascia of the back.*

with fecal flora potentiates infection. Aggressive debridement of the penetrating wound and blast cavity, as well as washout of the wound, can help prevent or mitigate subsequent local sepsis.

2. During the initial operation, retained bullets or fragments are generally not removed unless the missile is easily accessible, the patient is stable, and retrieval carries no risk of additional injury. Necrotizing soft-tissue infection might have been prevented or lessened in its severity and extent if planned reoperation by hospital day 2 or 3 had included washout and debridement of the cavity wound.
3. Necrotizing fasciitis is a rapidly spreading, morbid, and often fatal infection. Clinical suspicion and early detection are essential to prevent a fatal outcome. In theater, resources might not be available to support soft-tissue biopsy, Gram stain, and microscopic verification of invading organisms. Simple visual inspection of the soft tissues, fascia, and underlying musculature is all that is necessary to support the diagnosis and aggressive debridement of viable tissue. Typical findings can include the following:

    a. Hemodynamic deterioration.
    b. Tense, shiny skin, bullae, or crepitus in the region.
    c. Soft-tissue gas might be present on plain radiographs.
    d. A foul, gray, dishwater-like fluid emanating from the infected tissues (on operation).
    e. Pale-appearing necrotic fascia that is easily separated from its investing tissues.
    f. Discolored, noncontractile, nonbleeding muscle (if involved).

4. Care of a patient with necrotizing fasciitis is likely to be prolonged, and places great demands on available personnel and resources. Even in the best circumstances, survival is limited. In the case of numerous injured patients or a high critical care census, limited resources, or ongoing operations in theater, expectant management (or watchful waiting) might be the more suitable response. Obviously, this will be a difficult decision to make, and should involve the treating physicians and medical team, an ethics committee (if available), and the hospital command.

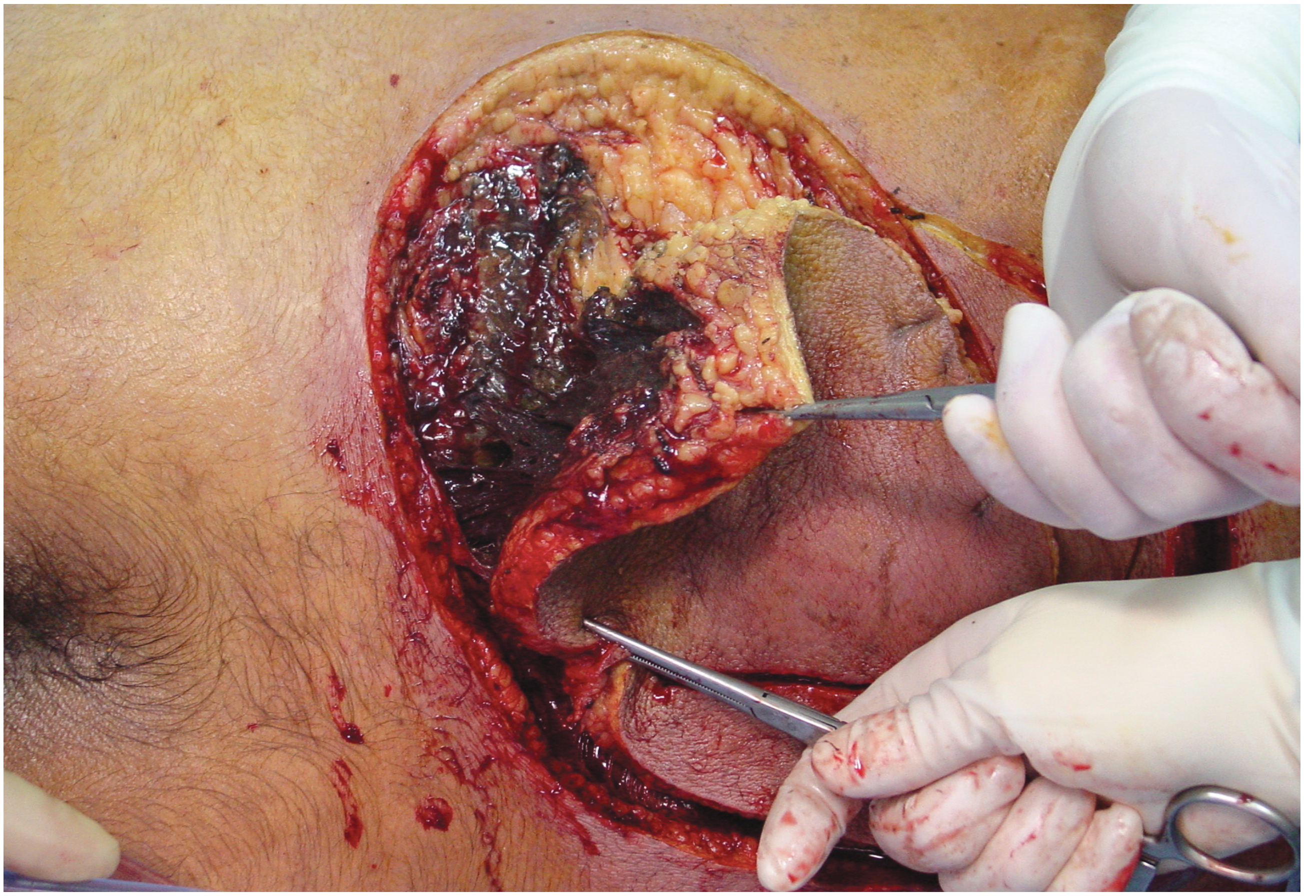


FIGURE 4. *Further debridement of the back.*

CLINICAL IMPLICATIONS

1. Necrotizing soft-tissue infection is a potentially devastating outcome of battlefield wounding.
2. Treatment is primarily surgical and involves aggressive resuscitation, broad-spectrum intravenous antibiotic coverage of all probable organisms, and emergent radical excision of all involved, nonviable tissues—including a low threshold for amputation.
3. The infection is usually caused by mixed aerobic and anaerobic bacteria and can be the result of clostridial myonecrosis or polymicrobial infection, most commonly secondary to *Streptococcus, Staphylococcus, Enterococcus, Enterobacteriaceae, Bacteroides*, or *Clostridia*. Penicillin G should be used if infection is due to streptococci or clostridia, imipenem-cilastin if polymicrobial; add vancomycin if MRSA is suspected.

DAMAGE CONTROL

Stop major hemorrhage, and stop or control major sources of contamination by performing stapled resection of the bowel and temporary colostomy formation. Drain the extraperitoneal rectal injury. Definitive reconstruction or resection may be delayed. Retrieve the fragment only if it is easy. The retrieval process should be delayed or omitted altogether if clinical circumstances do not permit this action.

SUMMARY

This case demonstrates several principles of high-velocity ballistic injury: colonic and rectal injuries predispose to septic complications; a strong clinical awareness of the patient's condition is necessary to detect complications; and early, aggressive treatment of necrotizing soft-tissue infection can lead to ultimate patient survival if appropriate resources are available.

SUGGESTED READING

Chapter 10: Infections. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

FIGURE 5. *Continued debridement involving the back and thigh.*

WOUND VAC

The Vacuum-Assisted Closure (VAC) Therapy System is used to facilitate wound healing by converting an open wound to a closed wound. VAC consists of an evacuation tube embedded in a polyurethane foam dressing (or sponge). After the dressing is placed in the wound bed and sealed by an occlusive dressing, the tube is attached to a vacuum unit. Application of this negative pressure causes the following:

- The foam to collapse—resulting in removal of excess fluids.
- Increased blood flow.
- Decreased bacterial colonization.
- Granulation formation.
- Wound closure.

Procedure

- Debride all devitalized tissue and contaminated material.
- Cut sterile polyurethane sponge to conform with the wound surface.
- Be sure that the deepest portions of the wound are in contact with the sponge.
- Ensure that the sponge makes contact with the entire wound surface.
- Place end of tube on surface of the sponge.
- Apply adhesive plastic sheet over the skin sponge and around the tubing (this seals the vacuum).
- Run tube from the sponge to the VAC pump device.
- Use a continuous setting of 125 mm Hg, which is most common (range: –50 mm Hg to –200 mm Hg).
- Change sponge every 48 to 96 hours (except for skin grafts—in which case the sponge is removed on day 4).

Figure 6. *Eventual extent of the wound now showing healthy-appearing muscle.*

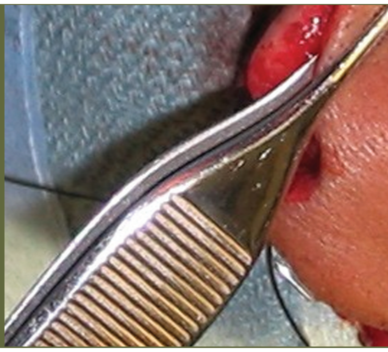
Figure 7. *The large wound was managed with a wound VAC device.*

Figure 8. *Wound in various stages of healing. Approximately 60% of the wound surface is covered with skin grafts.*

Chapter 17: Abdominal injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

Chapter 22: Soft-tissue injuries. In: *Emergency War Surgery, Third United States Revision*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 2004.

McGrath V, Fabian TC, et al. Rectal trauma: Management based on anatomic distinctions. *Am Surg*. 1998;64:1136–1141.



VI.4 Median Forehead Flap

CASE PRESENTATION

After a firefight, this 30-year-old host nation male presented to the combat support hospital (CSH) with a gunshot wound to the face that resulted in loss of his anterior nose (Fig. 1). After wound debridement, a median forehead flap was fashioned based on forehead vessels that were preoperatively localized using a handheld Doppler ultrasound (Fig. 2). The flap was then rotated into the defect (Fig. 3), and the flap bed was closed and the forehead flap sutured into place (Fig. 4). A stent for the right nostril was fashioned and left in place. The flap healed well and remained 100% viable with acceptable cosmetic and functional results (Fig. 5). After 6 weeks, the median forehead flap was revised to eliminate the proximal fold of skin from the original rotation (Fig. 6).

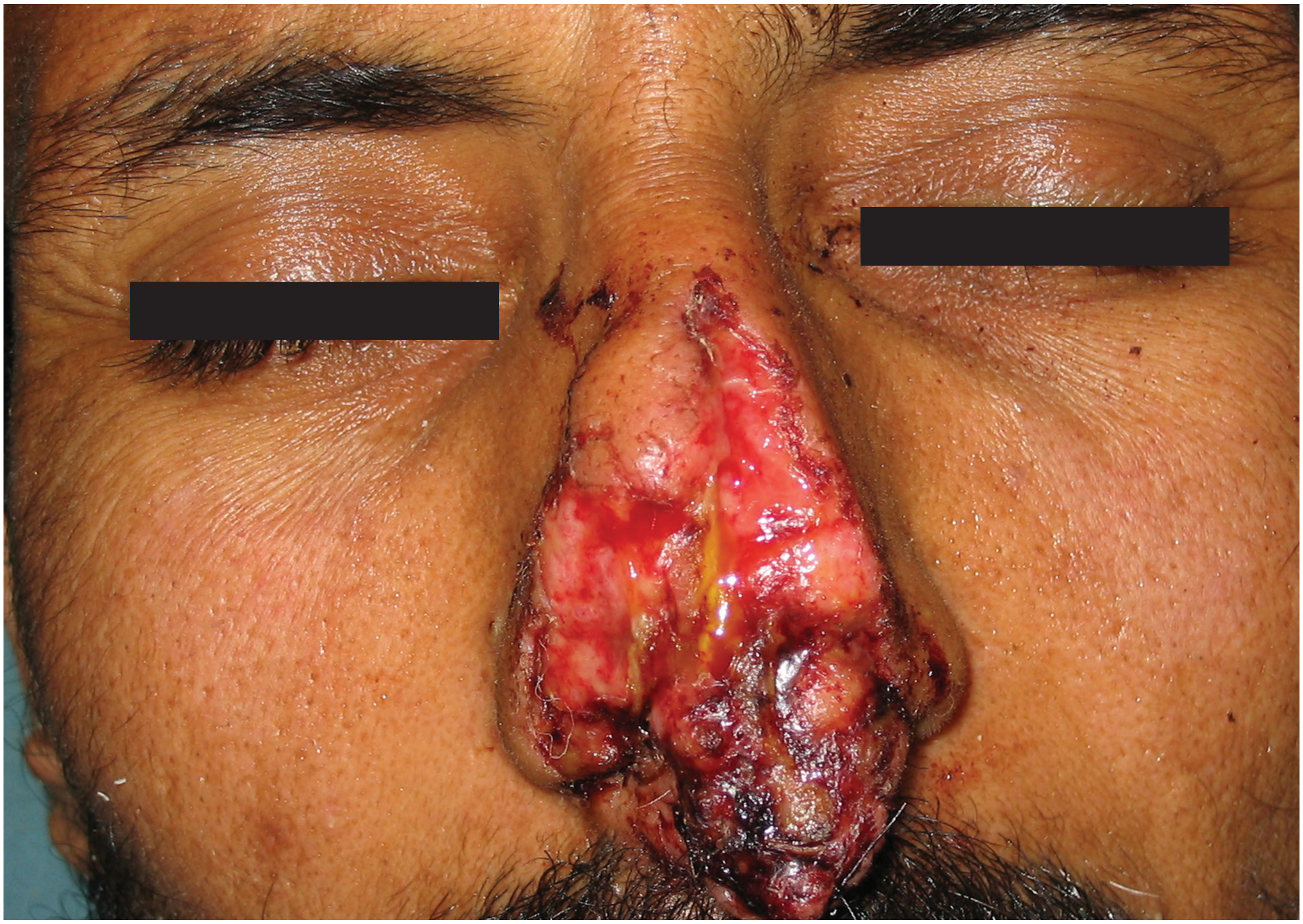
TEACHING POINTS

1. Generally, injured soldiers can be treated with wound debridement and irrigation, followed by dressing changes and evacuation. However, this approach often cannot be used for patients who cannot be evacuated.
2. Complex soft-tissue injuries are common in combat zones. Surgeons deploying to combat zones need to understand how to manage these wounds to include local and rotational flaps.
3. Closure of war wounds or coverage of complex or large wounds should be delayed until necrotic tissue is clearly demarcated and debrided, and the wound appears healthy. This can be accomplished through serial operative debridements and washout, along with either wet-to-dry dressing changes or a wound VAC, if available.

CLINICAL IMPLICATIONS

All war wounds are considered contaminated and should not be closed primarily. The goal of wound management is to preserve function, minimize morbidity, and prevent infections. The following principles apply:

1. Appropriate antibiotics should be administered for all war wounds (see *Emergency War Surgery, Third United States Revision*, page 10.5).
2. Risk of infection is decreased if debridement and washout occur within 6 hours.
3. Debridement of facial injuries should be as conservative as possible because the blood supply to the face is extensive. Allow questionably viable tissue the opportunity to demarcate. Often, tenuous-appearing tissue on second look will recover.



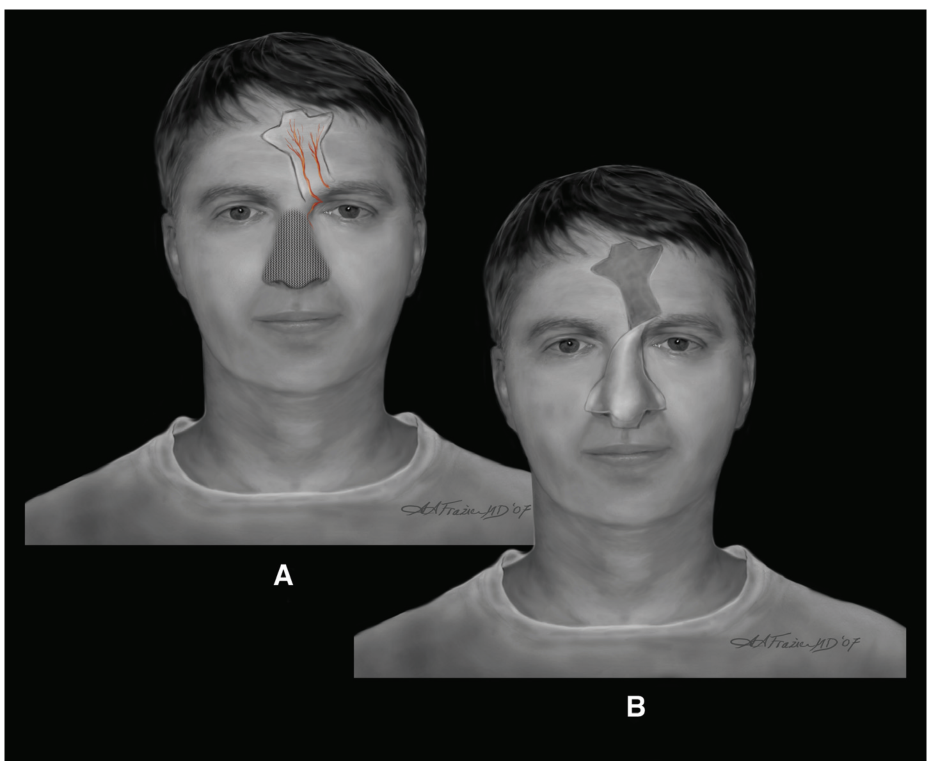


Figure 1. (Top) *Patient's nasal injury.*

Figure 2. (Bottom) (A) *Illustration of median forehead flap blood supply.* (B) *Illustration of rotated flap.*

FIGURE 3. (Left) *Forehead flap prior to rotation*. (Right) *Actual flap rotated into position*.

FIGURE 4. *Flap sutured into position with flap bed closed.*

Figure 5. *Post-op day 7.*

Figure 6. *Revision of forehead flap.*

4. Foreign material and necrotic tissue should be excised and aggressively irrigated.
5. Debridement and washout should be repeated at 24 to 72 hours.
6. Early soft-tissue coverage is desirable within 3 to 5 days—when the wound is clean—to prevent secondary infection.
7. When total or subtotal reconstruction of a nose is required, the nasal lining is required. An option for nasal lining reconstruction includes using a skin graft braced with cartilage to prevent graft contraction, resulting in a closed nostril.

SUMMARY

This case illustrates the importance of basic, soft-tissue repair skills for deployed surgeons, including local and rotational flaps.

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

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VI.5 Soft-Tissue Coverage of Combat Wounds: A Series of Cases

CASE PRESENTATIONS

Following is a collection of eight cases that presented to a combat support hospital (CSH) during a 7-month period in Iraq. All had sustained, in addition to other injuries, gunshot or penetrating blast injuries that resulted in large wounds with bone and significant skin and soft-tissue loss. These latter injuries demanded special attention because wound coverage was problematic. Either due to the size of the open wound and/or because the debrided surface included exposed bone or muscle, or synthetic material, none of these wounds would accept direct skin grafting. Alternative means of soft-tissue coverage had to be accomplished in an austere environment if amputation was to be avoided. Amputation of the involved limbs was, by far, the most likely outcome for civilians at their depleted, overstretched local hospitals. Indeed, operative decisions in deployed American facilities must necessarily factor in considerations of available resources, limited bed space (which may be occupied for weeks by the patients described in the cases included here), limited manpower, unforeseen casualty flow, and patient status before opting to undertake complex and time-consuming reparative surgery.

Courtesy David Leeson, *The Dallas Morning News*

CASE 1 (Fig. 1)

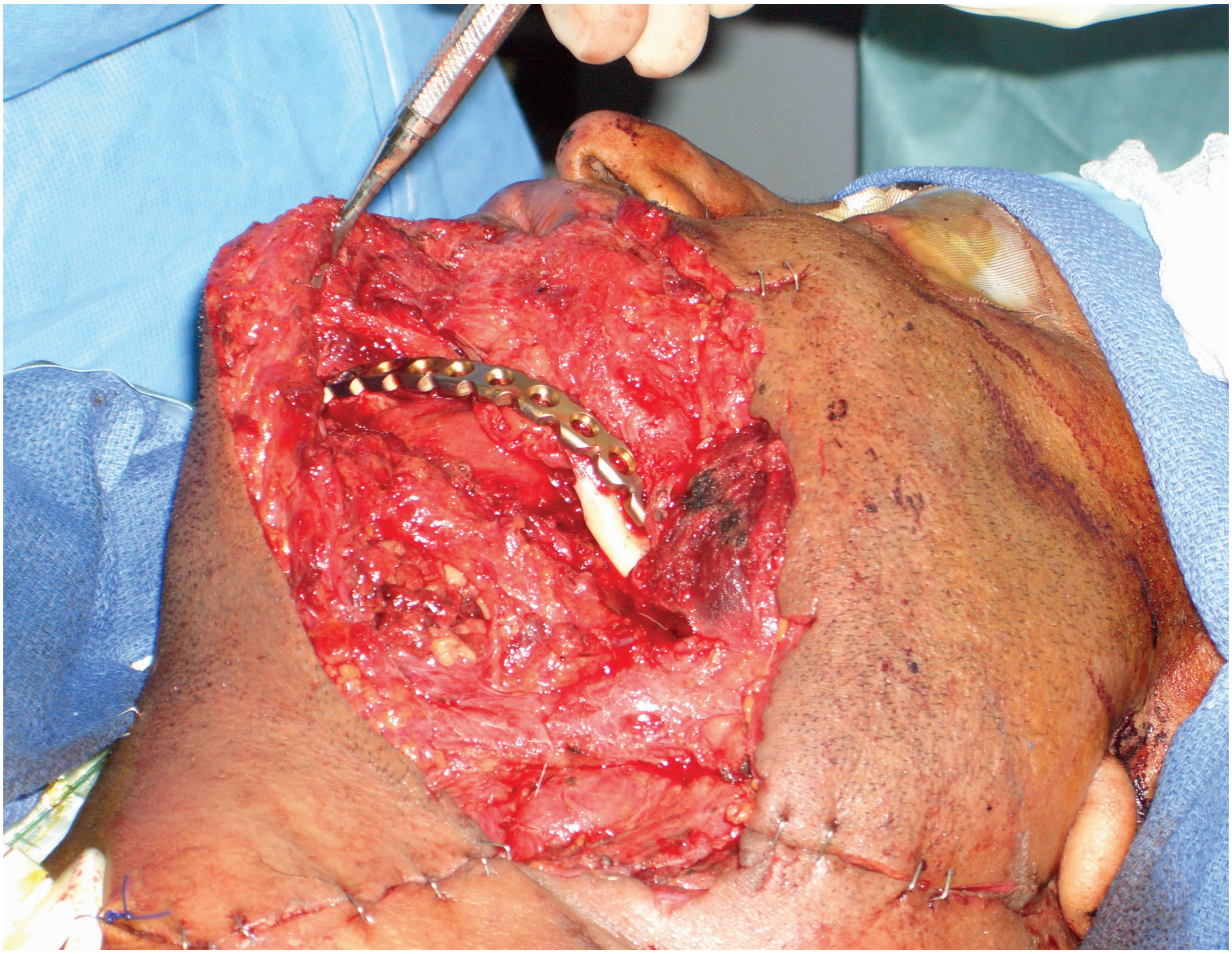
A host nation male civilian presented to a CSH with exposed anterior tibial bone in the middle to distal third of the leg due to soft-tissue loss. The wound was debrided, and the wound VAC was applied in an attempt to obtain granulation tissue over the bone in preparation for a later skin graft. This plan of action was not successful, and the wound was finally closed with a saphenous vein fasciocutaneous flap. A skin graft was applied over the donor site defect. The patient left the hospital ambulating and without further complications.

CASE 2 (Fig. 2)

This male patient's injury, an abdominal wall defect, was repaired with synthetic mesh. The rectus abdominis muscle was not available because of the initial wound through the rectus muscle. In this case, the wound was covered over the mesh with a tensor fascia lata fasciocutaneous flap. The excess tissue (or "dog-ear" tissue) created by the 180-degree rotation of the flap will be removed in a second intervention for flap revision.

Figure 1. **Case 1.** (Left) *Patient immediately post-op.* (Right) *Patient on post-op day 5.*

Figure 2. **Case 2.** (Top Left) *Exposed VICRYL mesh.* (Top Right) *Flap design.* (Bottom Left) *The tensor fascia lata fasciocutaneous flap is in place.* (Bottom Right) *Donor site with skin grafted.*



CASE 3 (Fig. 3)

This male patient had a severe blast injury to the face and neck that resulted in loss of a significant portion of the skin and a comminuted mandibular fracture with overt bone loss. The oral and maxillofacial surgeon repaired the mandibular fracture with plating (see Fig. 3, top). Closure of the skin deficiency was provided by a pedicled pectoralis major myocutaneous flap. In this case, the surgeons were forced to proceed with coverage at the initial surgery because of the nature and location of the wound.

FIGURE 3. **Case 3.** (Top) *Mandibular fracture, plating will approximate mandibular fragments.* (Bottom) *Pectoralis muscle flap is in place.*

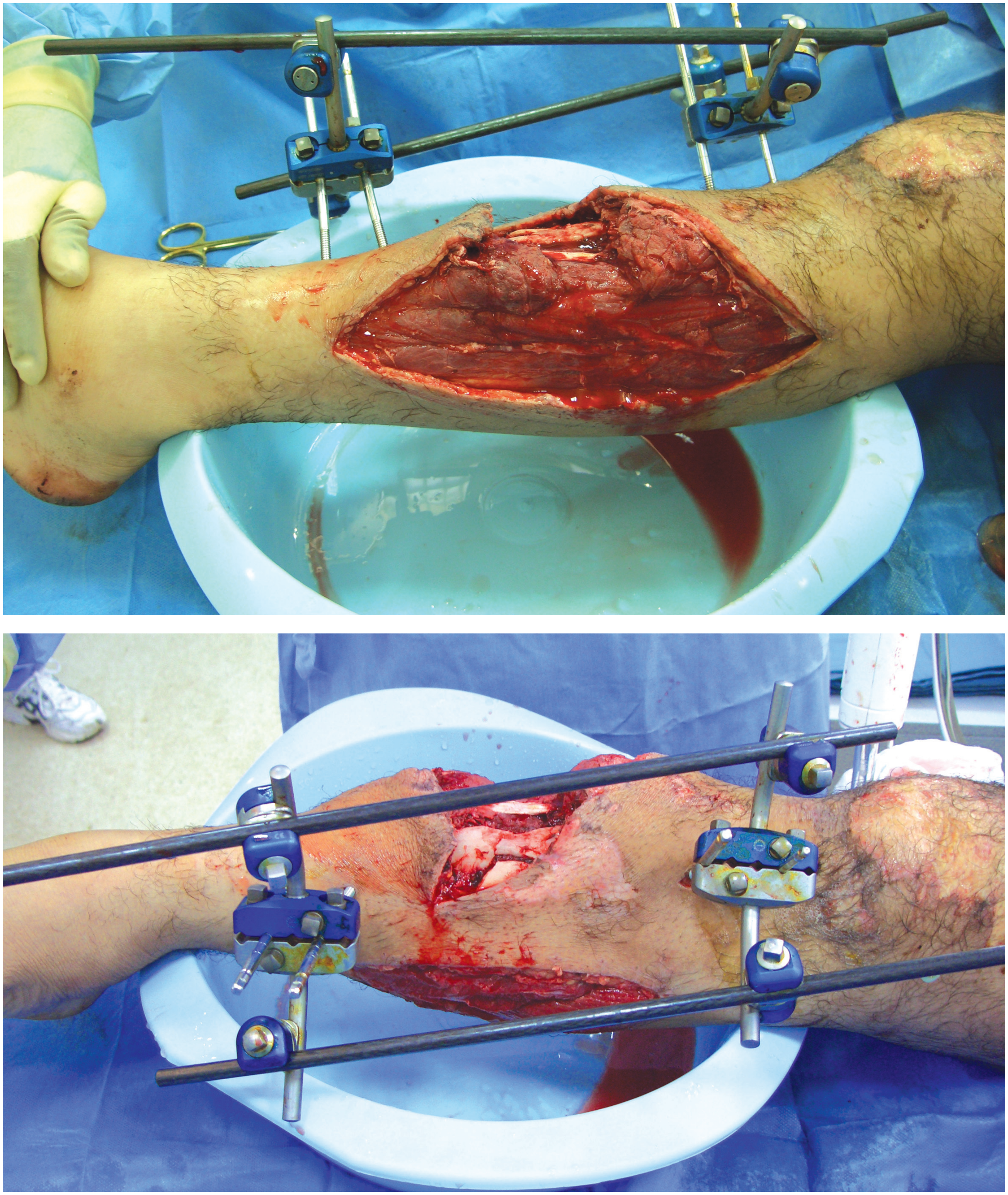


FIGURE 4. **Case 4.** (Top) *Lateral view of the exposed tibial fracture.* (Bottom) *Medial view of the exposed tibial fracture.*

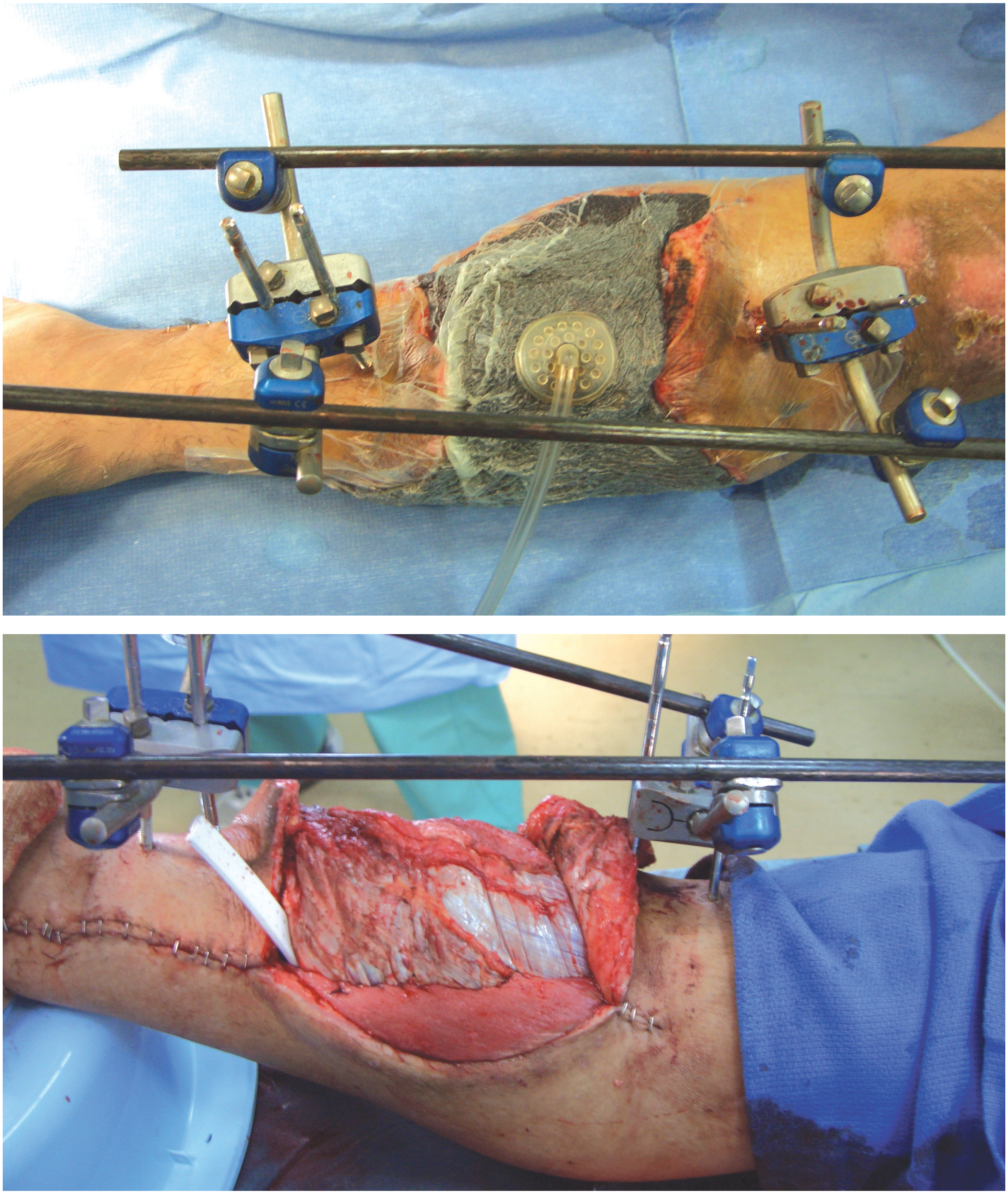
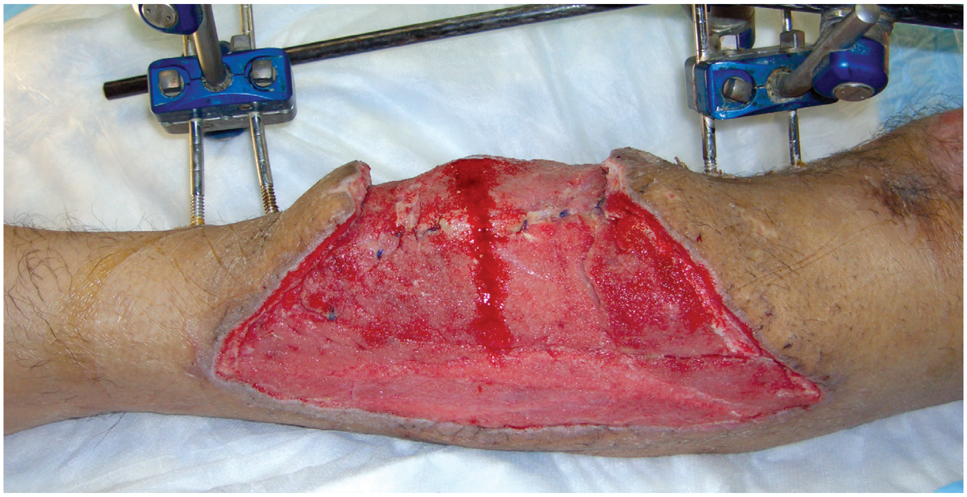
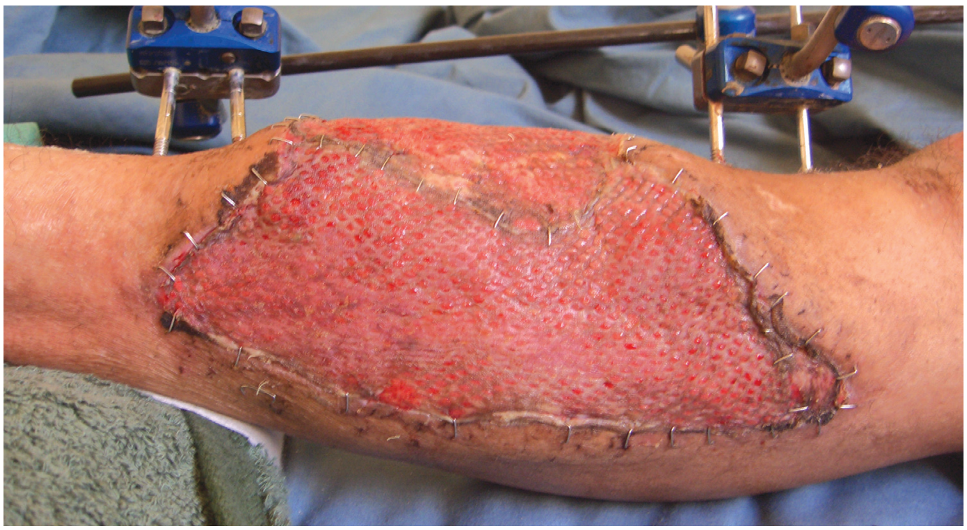


FIGURE 4. **Case 4 (cont'd).** (Top) *Wound VAC positioned over the soleus flap.* (Bottom) *Soleus flap is in place.*

FIGURE 4. **Case 4 (cont'd).** (Top) *Post-op day 7—the result of the wound VAC.* (Bottom) *Completed result after split thickness skin graft over the soleus muscle.*





CASE 4 (Fig. 4)

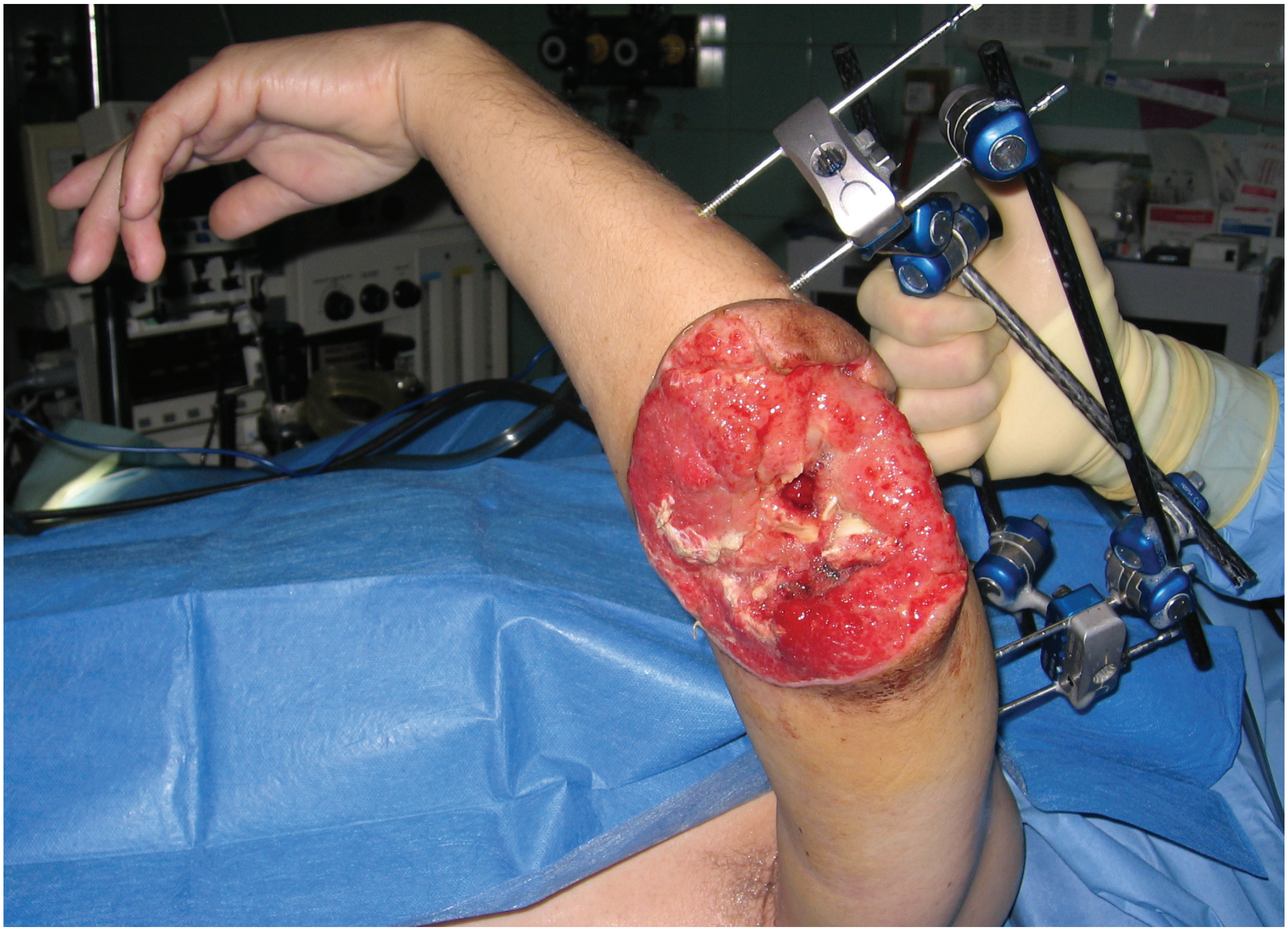
This male patient sustained a complex open fracture of the left tibia from penetrating explosive injury. He underwent debridement and external fixation on the day of the injury (Fig. 4, page 226). Fasciotomies were also performed. The skin defect had exposed tibial bone in the middle third of the leg. Because of swelling and edema, and possible further muscle damage, a muscle flap was not attempted at this time. A wound VAC was applied (Fig. 4, top, page 227) and changed every other day. About 7 days later, muscle swelling had resolved, and a soleus muscle flap was applied (Fig. 4, bottom, page 227). During the procedure, the muscle was found to be bruised and contused. Therefore, the skin graft over the soleus muscle was delayed for another 6 days. Meanwhile, the wound VAC was applied to the muscle flap. The patient recovered well from his injury and subsequent surgeries (Fig. 4, page 228). Follow-up was scheduled later for the final orthopaedic repair.

CASE 5 (Figs. 5–7)

These three cases (patients A–C) were related to orthopaedic injuries resulting in loss of soft-tissue coverage over the exposed bones and/or hardware in the elbow area. Three patients required random abdominal skin flaps of the Tagliacozzi method (see accompanying box, page 232). These male patients had severe injuries to the elbow area, all received by either gunshot wound or penetrating blast. The flaps covered the bone and hardware after the orthopaedic surgeons had performed a limb salvage procedure. In the local host nation medical system, these injuries would have necessarily resulted in amputations of the involved limbs. Separation of the pedicle and insetting the flap were performed 2 to 3 weeks after the flap covered the wound, depending on development of vascularity within the flap.

CASE 5

Patient A: Exposed Elbow Joint



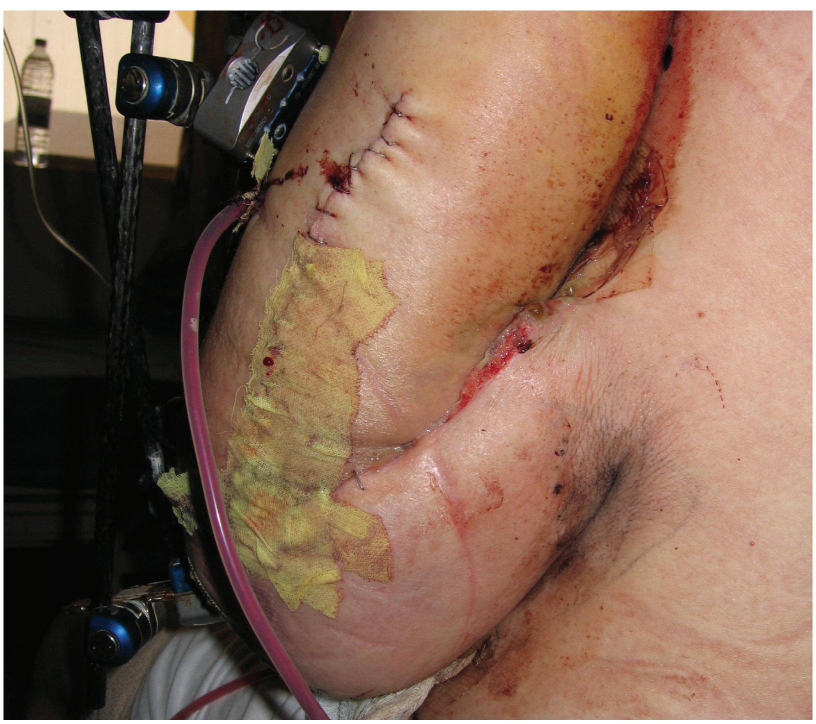


FIGURE 5. **Case 5.** (Top) *Preflap view of elbow wound.* (Bottom) *Random skin flap.*

CASE 5
Patient B: Elbow Injuries

FIGURE 6. **Case 5.** (Top Left) *Initial injury of the elbow.* (Top Right) *Elbow injury after reduction of dislocation.* (Bottom Left) *Flap is in place.* (Bottom Right) *Two weeks after flap separation.*

CASE 5
Patient C: Elbow Injuries

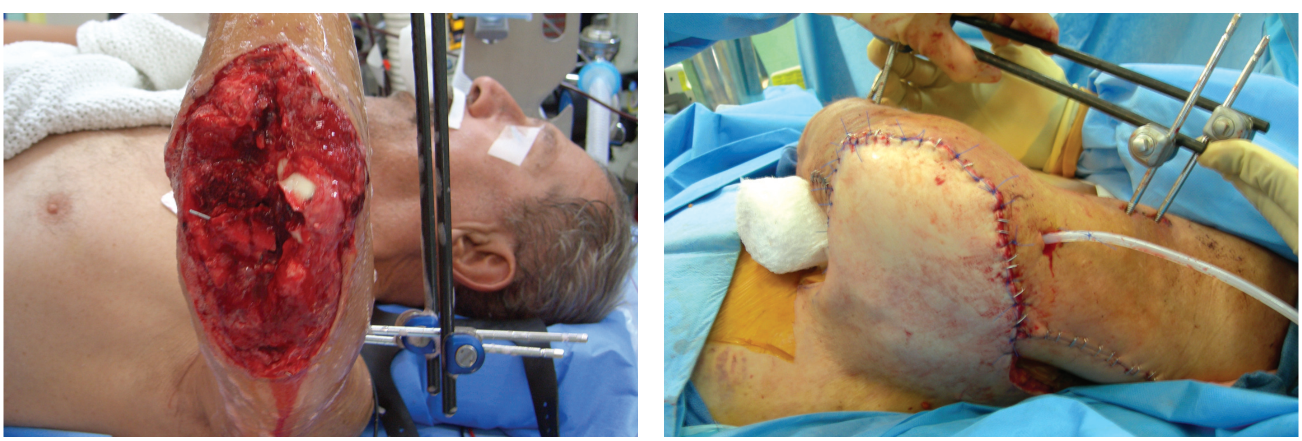


FIGURE 7. **Case 5.** (Left) *Elbow is missing a significant amount of soft tissue.* (Right) *Post-op flap.*

FIGURE 8. **Case 6.** (Top Left) *Exposed bone graft (note pin).* (Top Right) *Random skin flap from the groin area.* (Bottom Left) *After separation of the pedicle.* (Bottom Right) *Secondary closure of the donor site.*

CASE 6 (Fig. 8)

This host nation male 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. A random abdominal skin flap over the dorsum of his right hand was required because of missing tissue to cover the exposed bone graft (Fig. 8). 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 (see Fig. 4, Case VII.4). 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 returned for separation and closure.

CASE 7 (Fig. 9)

A host nation male suffered a fragment injury to the posterior aspect of his foot with exposed bone (Fig. 9, page 232). Once the wound was managed with serial debridement and washouts, soft-tissue coverage was required. The lower third of the leg is a difficult area to cover with a local flap. One option is the sural nerve flap. This flap is based on the sural nerve blood supply and the small perforating artery that is 5 cm proximal to the lateral malleolus. This retrograde blood flow is sufficient to perfuse the distally placed flap. A paddle of skin, subcutaneous fat, and fascia are fashioned at midcalf and the sural nerve identified (Fig. 9, top and bottom, page 233). The skin between the perforator and the paddle is divided, and a strip of subcutaneous fat and fascia 2 cm wide (1 cm on each side of the nerve) is elevated—along with the paddle and the sural nerve—to the perforator (Fig. 9, top, page 234). The flap is then rotated over the defect and sutured in place (Fig. 9, bottom left, page 234). The skin defects are primarily closed or skin grafted (Fig. 9, bottom right, page 234). Some skin loss in the distal paddle is common.[1]

CASE 8 (Fig. 10)

An enemy prisoner of war suffered a fragment injury to the lower leg just below the knee. The skin defect on this

TAGLIACOZZI METHOD

Plastic surgery is believed to have begun during the Renaissance with Gasparo Tagliacozzi (1545–1599), an Italian surgeon who did pioneering work in the field of plastic surgery. He is credited as being the first practitioner of the art of plastic surgery. Tagliacozzi often repaired noses lost in duels or noses that were damaged by syphilis. He created a method of nasal reconstruction (the Tagliacozzi flap or the Italian flap) in which a flap from the upper part of the arm is gradually transferred to the nose.

Additional Information

- For many centuries, nose reconstruction using distant pedicle flaps was done.
- The Tagliacozzi flap was a popular technique in Europe in the 1600s.
- In the early 19th century, the Indian flap method was popular (using the mid-forehead for nose reconstruction).
- In the United States, V. H. Kanzanjian popularized the modern forehead flap.
- Note: The forehead flap can result in excellent cosmetic outcomes for particular kinds of nasal wounds (see Case VI.4). Optimal outcomes depend on patient selection criteria, wound selection, surgical technique, and postoperative management.

FIGURE 9. **Case 7.** *Sural nerve flap. Fragment injury to the posterior aspect of foot with exposed bone.*

FIGURE 9. **Case 7 (cont'd).** (Top) *Sural nerve is identified.* (Bottom) *A paddle of skin, subcutaneous fat, and fascia are fashioned at midcalf.*

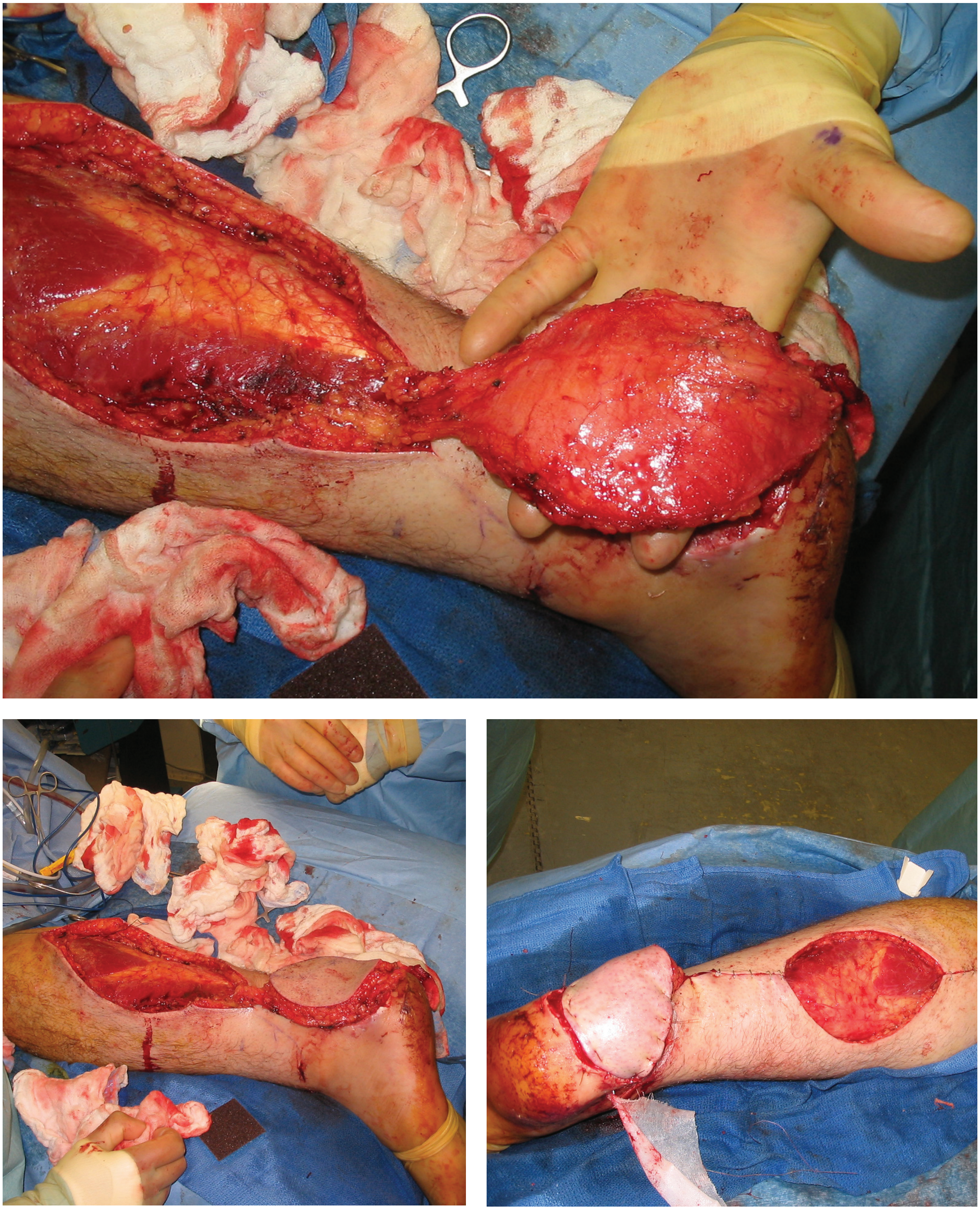
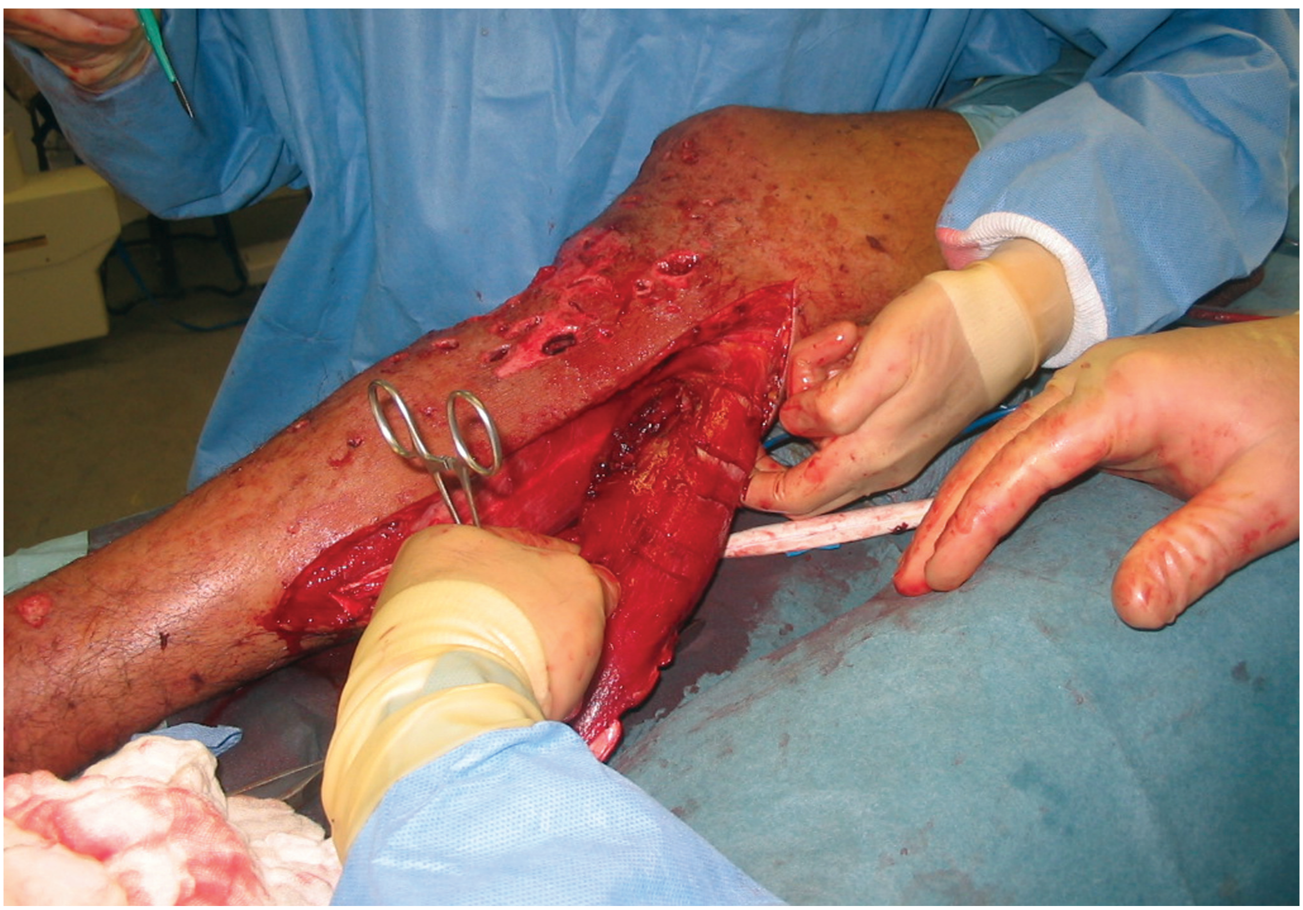


FIGURE 9. **Case 7 (cont'd).** (Top) *A strip of subcutaneous fat and fascia is elevated.* (Bottom Left) *Flap is rotated over the defect and sutured in place.* (Bottom Right) *Skin grafted.*

FIGURE 10. **Case 8.** *Gastrocnemius muscle flap.* (Top) *The skin defect on this anterior wound with tibia exposed.* (Bottom) *The gastrocnemius is exposed and one half divided just above the Achilles tendon. The muscle is split between the two heads and elevated superiorly.*



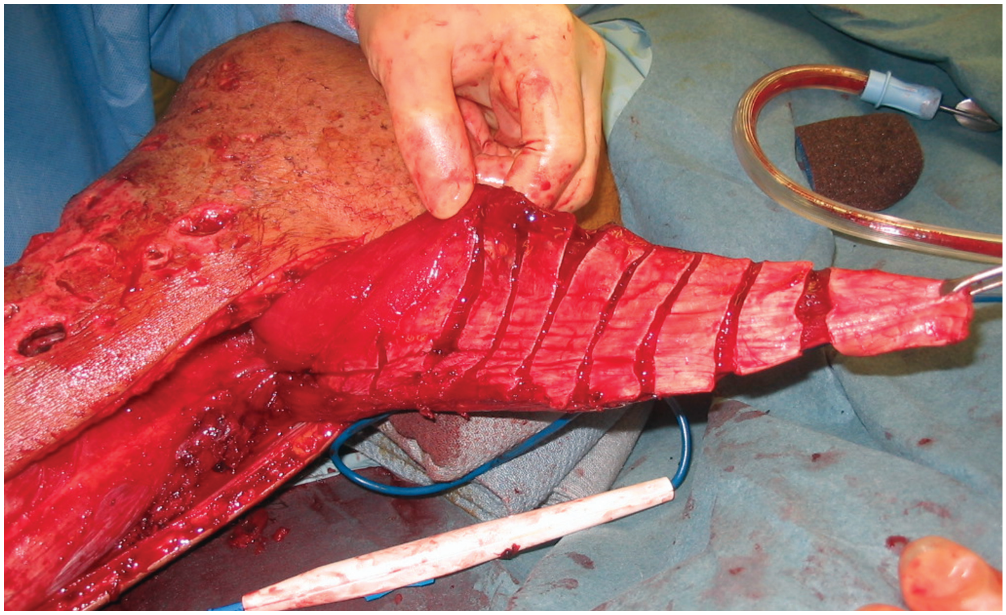


Figure 10. **Case 8 (cont'd).** (Top) *Scoring the fascia in a "step-ladder" fashion.* (Bottom) *The muscle is brought through the tunnel to the defect.*

anterior wound was large, and the tibia was exposed (Fig. 10, top, page 235). Coverage for the upper part of the lower leg can be generally accomplished with a gastrocnemius muscle flap. The gastrocnemius is exposed and one half divided just above the Achilles tendon. The muscle is split between the two heads and elevated superiorly (Fig. 10, bottom, page 235). A subcutaneous tunnel is made that accommodates the muscle. Additional length may be achieved (if needed) by scoring the fascia in a "step-ladder" fashion (Fig. 10, top, page 236). The muscle is brought through the tunnel to the defect (Fig. 10, bottom, page 236). The flap is sutured in place and covered with a split-thickness skin graft.

TEACHING POINTS

1. Battlefield trauma produces difficult injuries in all areas of the body. These injuries are complex because of the high-energy damage to the tissues. The first step in managing these wounds is to perform adequate debridement. It is not appropriate to close these wounds primarily because tissue damage is extensive and often not evident initially. It is important to perform early and repeated debridement until the wound is clean and ready for closure. This may take 5 to 7 days or even longer.
2. It is best to perform delayed primary closure within 5 to 7 days after all devitalized tissue has been identified and debrided. Tissue damage is not always evident at initial surgery. Resist the temptation to close high-velocity injuries early.
3. The “Ladder of Reconstruction” principle calls for proceeding from the simplest method to obtain closure toward more complicated methods of coverage. The simplest method is to obtain primary closure if there is enough tissue/skin available.
4. If the defect is missing skin, then the next step is to proceed with skin grafting. Often, this is not possible because exposed bone or exposure of synthetic materials does not accept skin grafting. Use the wound VAC liberally to protect and prepare the wound for skin grafting, as well as to replace the tie-down bolster over the skin graft.
5. In the abdominal area, try to spare the rectus muscle whenever possible. In these cases, it was evident that the rectus could have been used more frequently for reconstruction of a variety of wounds had it been available. The most common reason for its unavailability was colostomies.
6. The soleus muscle is the best choice for reconstruction of injuries of the middle third of the leg.

DAMAGE CONTROL

Delayed primary closure (3–5 days) requires a clean wound that can be closed without undue tension. This state may be difficult to achieve in war wounds. Definitive closure with skin grafts and muscle and pedicle flaps should not be done in theater when evacuation is possible. These techniques may be required, however, for injured civilians, allied wounded, and enemy prisoners of war. In the austere environment of combat medicine, and under circumstance beyond the surgeon’s control (finite resources, patient instability, “op tempo,” limited expertise), amputation is a necessary consideration.

SUMMARY

When confronted with a difficult wound in theater, the plan for closure should proceed from the simplest method possible to more sophisticated methods. Most important is to remove all nonviable tissue, which may take several days and several surgical debridements. After the wound is clean, begin with delayed primary closure, if possible. Next, proceed with skin grafting. The wound VAC should be used liberally to prepare wounds for skin grafting and to use over skin grafts in lieu of the usual tie-down bolster to secure the graft. Alternative choices involve muscle flaps (with skin grafting) or fasciocutaneous flaps. The combat zone does not provide the resources for more sophisticated methods of reconstruction (eg, free flaps). For this reason, surgeons will be faced with these limitations and will be challenged to use their knowledge and imagination to obtain closure of difficult wounds.

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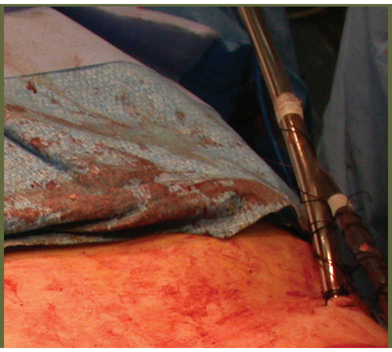

VI.6
80% Body Burn

Courtesy David Leeson, *The Dallas Morning News*

CASE PRESENTATION

A 23-year-old male suffered severe burns during munitions disposal activities. He was found on fire after extricating himself from his burning vehicle. The fire was extinguished, and the patient was transported rapidly by helicopter MEDEVAC to the nearest level III medical treatment facility. On arrival in the Emergency Medical Treatment (EMT) area (Figs. 1 and 2), he was intubated immediately and taken to the operating room (OR) for resuscitation and initial burn wound therapy. The initial estimate of surface area burned was 80%, with extensive burns to the head, face, upper extremities, trunk (front and back), and lower extremities (Figs. 3 and 4). Escharotomies were performed on both upper extremities (Figs. 5–7), with some bleeding evident in the escharotomy sites. The burns were washed vigorously and irrigated using gauze and normal saline, with minimal sharp debridement. Once cleaned, the burns were covered with Silvadene cream, and the wounds were dressed with Kerlex rolls and burn packs (Figs. 8–10). The patient was transported to the intensive care unit (ICU; Figs. 11 and 12). Initial urine output was less than 10 cc for the first hour, with evidence of severe hemolysis (Fig. 13). After intensive volume repletion and resuscitation, his vital signs improved and his urine output exceeded 30 cc per hour. He was then transported to a level IV medical treatment facility within 12 hours of admission. The patient was met by Army burn team members from the Institute of Surgical Research (ISR; Brooke Army Medical Center, San Antonio, Texas). At the level IV medical treatment facility, he underwent bilateral upper extremity amputations above the elbows to remove his completely burned arms. After further resuscitation, he was transported to the ISR in San Antonio. The patient died there several days later.

TEACHING POINTS

1. Although large surface area burns are complex and difficult to manage long term, the initial management and resuscitation are usually straightforward:

   a. Secure the airway: In severe facial burns, intubation is mandatory at the time of presentation since, within hours, airway edema may make it impossible to establish the airway.
   b. An estimate of the burn surface area (Fig. 14) and time of the burn will initially guide the fluid resuscitation. For the first 24

FIGURE 1. *Patient on arrival at CSH, EMT area.*

FIGURE 2. *Patient in EMT. Note extent of chest burns.*

FIGURE 3. *Treatment of lower extremity burns, OR. Note protected area that was covered by boots.*

FIGURE 4. *Extent of back burns.*

FIGURE 5. *Escharotomy performed on right forearm.*

FIGURE 6. (Top Left) *Forearm escharotomy, OR.*

FIGURE 7. (Bottom Left) *Forearm escharotomy, OR.*

FIGURE 8. (Top Right) *Burns covered with Silvadene and Kerlex, OR.*

FIGURE 9. (Bottom Right) *Wound dressing, OR.*

FIGURE 10. *Burns dressed, OR.*

FIGURE 11. *Improvised patient-warming device, ICU.*

FIGURE 12. *ICU care. Note patient's ventilator at bottom of photo.*

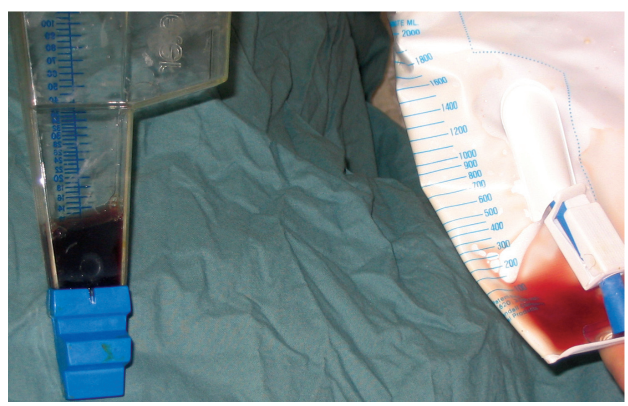

FIGURE 13. *Hemoglobinuria in urometer.*

hours, lactated Ringer's solution at 2 mL × % body burn (second- and third-degree) × the patient's weight in kilograms should be given, with one-half of the estimated fluid given within 8 hours of the burn and the remaining half of the fluid given in the next 16 hours. (This is only an estimate.) The patient's urine output and response to resuscitation must be monitored, and resuscitation must be adjusted accordingly.

c. The OR is the best location for initial debridement and cleaning of burn wounds. With the patient under general anesthesia, scrubbing and sharp debridement—if necessary—and wound dressing are easily performed without patient discomfort.

2. For large burns, once the patient is stable enough for transport, rapid evacuation (within 48 hours) to a dedicated burn facility is imperative. It is important to deliver the patient to a burn center with appropriate staffing and logistical support to begin the complex and difficult process of minimizing burn wound sepsis (rare before 72 hours) and the arduous process of closing the open burn wounds.

CLINICAL IMPLICATIONS

Burns constitute 5% to 20% of combat casualties during conventional warfare and are particularly common on sea vessels and in closed, armored fighting vehicles. Relatively small burn wounds require aggressive and sustained care and can severely strain the logistical and manpower resources of deployed military medical units. Patients with greater than 80% surface area burns have extremely high mortality rates and if the situation warrants may be triaged expectant.

Note: See Appendix D, Clinical Practice Guidelines on Burn Care.

1. Priorities in the care of burn patient casualties is the same as for all other trauma patients. In the burn patient, special attention to exposure, removal of clothing that continues to burn the patient, and prevention of hypothermia are important. Often the depth of burn injury cannot be ascertained immediately. Burn patients may have concurrent penetrating and blunt injuries as a result of explosion or combat.

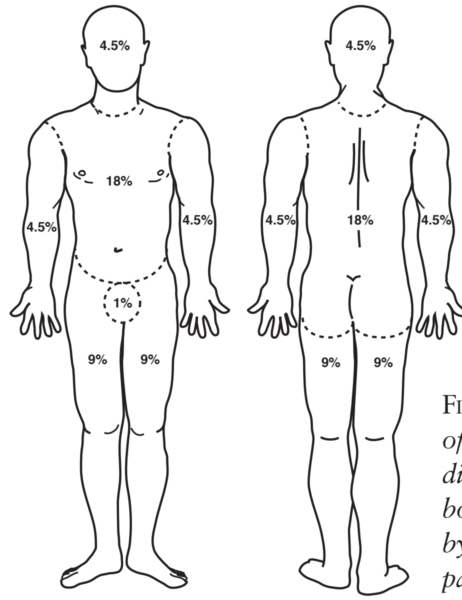

FIGURE 14. *Rule of Nines showing distribution of body surface area by anatomical part in the adult.*

2. Inhalation injury is more common with extensive cutaneous burns, a history of injury in a closed space, facial burns, and at the extremes of age. These patients require supplemental oxygen, pulse oximetry, chest X-ray, and arterial blood gas measurement.
3. Carbon monoxide poisoning results in cardiac and neurological symptoms. Patients with suspected carbon monoxide poisoning require 100% oxygen for at least 3 hours or until symptoms resolve.
4. After calculating initial fluid requirements, titrate fluid resuscitation to maintain urine output at 30 to 50 ml per hour or 1 mL/kg/h in children.
5. Children weighing less than 30 kg have a greater surface-to-weight ratio, and their fluid requirements are greater. Use lactated Ringer's solution at 3 cc/kg/% burn. Children should also receive a standard maintenance infusion of D5 1/2 normal saline concurrently.
6. After 24 hours, discontinue lactated Ringer's solution, and use 5% albumin and normal saline if available unless the wound is less than 30% body surface area.
7. Initial burn wound care includes adequate intravenous pain management, removal of foreign bodies, debridement, cleansing with surgical soap (use only saline around the face), unroofing of blisters, and application of a topical antimicrobial.
8. Burn victims must be adequately immunized against tetanus. If transport to higher level care will take more than 24 hours, they should be treated with a 5-day course of penicillin or similar antibiotics.

9. Progressive diminution of audible arterial flow by Doppler study is an indication for escharotomy. Doppler pulses must be sought in the palmar arch.
10. High-voltage electric injury requires consideration of deep muscle injury, with resultant rhabdomyolysis, hyperkalemia, acute renal failure, and compartment syndrome. Cardiac monitoring, aggressive fluid and electrolyte management, fasciotomy, and debridement are often required.
11. Chemical burns require the removal of the offending agent. Brush dry material off the skin surface before copious water lavage. If the burn is alkali, lavage may be required for several hours. Otherwise, chemical burns are managed the same as other burns.

DAMAGE CONTROL

Inhalation injury may be manifested by stridor, hoarseness, cough, carbonaceous sputum, or dyspnea. It may cause airway obstruction at any time during the first two postburn days. Prior to transport, prophylactically intubate patients with any evidence or suspicion of inhalation injury. Circumferential burns of the chest prevent effective chest motion. If this occurs, perform immediate thoracic escharotomy as a lifesaving procedure to permit adequate chest excursion.

SUMMARY

Burn injuries continue to be a common war injury that can tax the resources of field hospitals. In its 2003 deployment, injuries in 4.6% (86/1,867) of inpatients admitted to the 28th Combat Support Hospital (CSH) included burns. The mortality rate was 8%.[1] Initial treatment should focus on stabilizing the patient by appropriate airway management, fluid resuscitation, wound care, and pain control, with early evacuation to a designated burn center. Burn patients should be anticipated, and protocols should be in place to facilitate these evacuations. Infection control in the deployed setting was described by the 28th CSH as "a Herculean task" and directly impacted the care of host nationals who could not be evacuated.

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COMMENTARY

Soft-Tissue Trauma and Burns

by LTC Evan M. Renz, MD, FACS

EXTREMITY COMPARTMENT SYNDROME

Few topics in war surgery have elicited as much discussion among combat surgeons serving in the current war as that of extremity compartment syndrome. Timely diagnosis and treatment of this problem can pose a challenge to even the most experienced field surgeon. Despite our best training and intentions, there may be great difficulty in performing an adequate fasciotomy, even by experienced surgeons. Ritenour et al[1] carefully examined the morbity and mortality associated with delayed diagnosis and treatment of combat casualties at risk for extremity compartment syndrome. Their detailed review of more than 300 combat casualties who underwent fasciotomies opens our eyes to the unmistakable importance of this pathologic process, the absolute necessity for surgeons to be skilled in the art of the fasciotomy, and the potentially devastating costs associated with failure to anticipate and treat the problem. Ritenour et al noted that 17% of patients who underwent fasciotomies in the operational theaters of Iraq and Afghanistan (2005–2006) later underwent revision of one or more fasciotomy sites on arrival at the level IV medical treatment facility in Landstuhl, Germany. Most revisions involved the lower leg and required extension of the fascial incisions. In those patients with compartments found unopened, the anterior and deep posterior compartments were most often untreated. General guidance regarding fasciotomies performed in the combat environment, or in a situation in which a prolonged transfer time is expected, remains the complete release of skin and fascia of all compartments in the extremity to be decompressed. Surgeons must maintain a high index of suspicion for delayed compartment syndrome in casualties with severe diffuse injuries, large burns, and extensive volume resuscitation.

OPEN WOUNDS AND VAC DRESSING

Negative pressure wound dressings—such as the VAC dressing—offer many benefits to the surgeon caring for the patient with extensive combat wounds, including the ability to provide a sterile wound dressing in a closed environment that protects against further contamination, while at the same time providing stability in the form of a soft splint to the affected region. Many surgeons appreciate the ability to place the conforming sponge into the cavernous spaces of a wound, which "pulls" residual irrigation fluid and potential wound contaminants from the wound. Conversely, no therapy is without its risks, and caution must be exercised when placing a negative pressure dressing over any surface that has the potential for significant bleeding, desiccation, or damage from continuous negative pressure. Placing a VAC dressing directly over muscle, fascia, or subcutaneous tissue for up to several days generally works extremely well in preparing the wound for delayed closure or skin grafting. Leaving a VAC dressing on a wound in need of further debridement can result in a foul-smelling environment, best avoided by earlier dressing change. All in all, the VAC dressing system has endeared itself with most surgeons who continue to find new and innovative ways to use it.[2]

One of the advantages of the VAC is the ability of the patient to move with the dressing in place. When using the VAC device on patients who are awake and functional, it is beneficial to route the suction line toward the torso, thereby avoiding interference from the lines during range-of-motion activities and ambulation.

BURNS

After 4 years of war in Iraq, more than 500 US soldiers and Marines sustained thermal injuries serious enough to warrant specialized care at burn centers. The range of thermal injuries is broad, involving less than 1% of the person's total body surface area to as high as 95% in survivors to date. Although the severity of injury, and mortality, generally parallels that of the size of the cutaneous burn, even a relatively small burn—such as the all-too-common isolated hand burn—can yield devastating, long-term consequences for the casualty. There are a number of key points worthy of emphasis in the case described by the authors.

Many war-related burns are a result of an explosion. The energy from an explosion is seldom limited to the thermal component. To date, more than 50% of all burn patients admitted to the US Army Institute of Surgical Research Burn Center (San Antonio, Texas) had at least one other significant injury, most commonly fractures of an extremity. It is very easy for a provider to become focused on the burned skin and overlook the underlying injury, whether it is a fracture or other penetrating injury. The key here is to treat the burn patient like any other trauma patient requiring a thorough head-to-toe assessment.

Airway protection and support of breathing are early and important steps in treatment of the burn patient, particularly if there is evidence of inhalation injury. Preemptive intubation can be lifesaving. Securing the airway cannot be stressed enough, especially when the patient is going to be evacuated by air. Standard techniques of securing the tube using tape or prefabricated adhesive devices are generally ineffective in the presence of facial burns. Securing the tube with umbilical tape, which can be adjusted as facial edema increases, is recommended.

One of the most critical aspects of care for the burn patient is that of fluid resuscitation. Both under- and overresuscitation can result in severe, unintended consequences. Overresuscitation can worsen edema in the extremities and the abdomen, leading to compartment syndromes in either or both. Monitoring urine output as an indicator of adequate resuscitation remains perhaps the single most useful tool we have, especially in a deployed environment. This process requires close attention and action when targets are not met. Guidelines and tools designed to assist the deployed military provider are available in CENTCOM's Clinical Practice Guidelines for Burn Care on the Joint Patient Tracking Application Web site. (See Appendix D.) Also included on the site is a printable Burn Resuscitation Flow Sheet designed to assist in the process of fluid resuscitation, document the process, and facilitate continuity of care for the burn casualty.[3]

Placement of an indwelling urinary catheter is essential to the process of fluid resuscitation of the burn patient. Occasionally, burn patients are transferred to level III medical treatment facilities without a catheter in place, or with a suprapubic catheter in place for the stated reason that the genitalia were burned. Even in cases of full-thickness burns involving the penis, it is extremely rare that the urethral orifice cannot be intubated. Debridement of the glans may be required, followed by careful dilation of the orifice by the physician to place the catheter. This process is associated with far less risk than placement of a suprapubic catheter.

Initial cleansing and debridement of burns should be postponed until they can be accomplished in a clean environment (eg, the operating room). Until then, the burn casualty should be covered in clean, dry material. There is no advantage to using commercially available cooling gel blankets, especially in the burn patient with large surface area involvement who is already at risk of hypothermia. Once in a proper environment, the wounds can be cleaned and dressed using a number of commonly available products (eg, Silvadene cream or 5% Sulfamyalon [mafenide] solution). Another effective option for burn care is the use of silver nylon dressings. Silver nylon materials, such as Silverlon and Silverseal, provide antimicrobial action through the release of silver ions from the fabric.

The burn patient is prone to edema formation, especially as fluid resuscitation continues. Patients sustaining full-thickness burns, especially circumferential burns involving one or more extremities, often require escharotomies to combat the effects of edema. Escharotomies, and subsequent fasciotomies, should be performed through burned skin, sparing uninjured skin for future harvesting of donor autografts. Escharotomies may be performed using either scalpel or—as depicted here—utilizing electrocautery, which offers the advantages of coagulation along the skin edge if bleeding is present. Elevating the burned extremities above the level of the heart also reduces the adverse effects of edema.

Lastly, consultation with a surgeon at the US Army Institute of Surgical Research Burn Center is available by phone 24 hours a day. Consultation using e-mail is also available. Early physician-to-physician communication regarding casualties is encouraged because it facilitates continuity of care if rapid evacuation is planned. The number of severe burn casualties will help determine whether to deploy a Burn Flight Team to transport the patients.

Our experience from this war has confirmed that even the most severely burned casualties may be safely evacuated back to the continental United States.[4] When air evacuation to a definitive care facility is available, the decision to place a burn patient in an expectant status, based on his or her clinical condition, should be carefully considered.

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