Chapter 21

Pelvic Injuries

Introduction
● Injuries of the pelvis are an uncommon battlefield injury.
● **Blunt injuries** may be associated with major hemorrhage and early mortality.
● **Penetrating injuries** to the skeletal pelvis are usually associated with abdominopelvic organ injury.

Blunt Injuries
● Patterns and mechanisms are the same as those seen in civilian blunt trauma.
  o Lateral compression injuries are marked by internal rotation or midline displacement of the hemipelvis.
  o Anterior posterior injuries demonstrate external rotation of the hemipelvis.
  o Vertical shear injuries have cephalad displacement of the hemipelvis.
● Increasing degrees of displacement in any direction are associated with greater risk of hemorrhage.
  o Anterior posterior injuries with complete disruption of all sacroiliac ligaments represent an internal hemipelvectomy and have the greatest potential for hemorrhage.

**Early pelvic stabilization can control hemorrhage and reduce mortality.** This is particularly true in an austere environment with limited blood replacement products and other treatment resources.

● Open injuries require early recognition and prompt treatment to prevent high mortality due to early hemorrhage and late sepsis.
Diagnosis.
- Physical examination demonstrates instability of the pelvis when manual pressure is applied to the iliac crests.
- Leg length difference, scrotal or labial swelling/ ecchymosis, or abrasions over the pelvis raise suspicion for pelvic ring injury.
- *Perineum, rectum, and vaginal vault must be evaluated for lacerations to rule out an open injury.*
- Radiograph (AP pelvis, and when possible, inlet and outlet views) confirm the diagnosis. Computed tomography (CT) defines the location of injury more accurately.
- Bladder and urethral injuries are suspected when blood is present at the meatus or in the urine, or when a Foley catheter cannot be passed. Retrograde urethrogram and cystography confirm the diagnosis.

Treatment.
- Hemorrhage control.
  - Mechanical stabilization.
    - Tying a sheet or placing a binder around the pelvis at the level of the greater trochanters.
    - Bean bags or sand bags.
    - Lateral decubitus positioning with the affected side dependent.

*External fixator placement in the iliac crests allows for the most direct control of the pelvis.*

- Angiography is a useful adjunct, but is not usually available in the deployed environment.
- As a last resort, retroperitoneal packing may be attempted, but will expend tremendous resources and is often unsuccessful.
- Open blunt injuries require:
  - Immediate hemorrhage control by packing.
  - Aggressive and thorough debridement.
  - Pelvic stabilization.
  - Diverting colostomy in the presence of wounds at risk for fecal soilage.
Definitive internal pelvic stabilization (plates, screws, among others) is done outside of the combat zone.

Missile and fragmentation wounds can cause fracture of the pelvis.
- The pelvis usually remains stable.
- The colon, small intestine, rectum, and the genitourinary tracts must all be assessed for associated injury.
- Major hemorrhage can result from injury to the iliac vessels.

Penetrating Injuries
- Evaluation.
  - Diagnosis of associated injuries may require exploratory laparotomy.
  - Fractures should be assessed with radiographs and CT scans, when available, to rule out extension into the hip and acetabulum.
- Treatment.
  - Control hemorrhage.
  - Control hollow visceral injury.
  - Debride wounds and fractures.

For combined hollow-viscus and acetabulum /hip joint injuries, the joint is contaminated and must be explored and treated as described in Chapter 24, Open Joint Injuries.

- Technique of pelvic external fixator placement (Fig. 21-1).
  - Prep the iliac crests.
  - Place a 2-cm horizontal incision over the iliac crest, 2 fingerbreadths proximal or medial ventral to the anterior superior iliac crest.
  - Bluntly dissect to the iliac crest.
  - To determine the angle of the pelvis, first slide a guide pin between the muscle and the bone along the inner table of the iliac wing, no deeper than 3–4 cm.
Emergency War Surgery

Failure to properly determine the angle of the iliac wing leads to inadequate fixation and may cause significant complications.

- Locate the junction of the middle and medial thirds of the thickness of the iliac crest with the tip of a 5-mm external fixator pin.
- Paralleling the guide pin, begin drilling the pin into the crest.
- Drill between the inner and outer tables to a depth of about 4 cm, aiming generally towards the greater trochanter. **Only gentle pressure should be applied once the pin threads have engaged, to allow for the pin to guide itself between the tables.**
- A second pin is inserted 1–2 cm more posteriorly on the crest.
- Check the stability of each pin. If unsatisfactory, attempt reinsertion by aiming between the tables.
- Place pins in the contralateral iliac crest in the same manner.
- Reduce the pelvis by applying pressure on the pelvis (**not the pins!**) and connect the external fixator pins with bar(s) across the abdomen and pelvis to maintain reduction.

Fig. 21-1. Pelvic external fixator placement.
The goal in treatment of soft-tissue wounds is to save lives, preserve function, minimize morbidity and prevent infections through early and aggressive surgical wound care far forward on the battlefield.

Presurgical Care

- Prevent infection.
  - Antibiotics:
    - Antibiotics are not a replacement for surgical treatment.
    - Antibiotics are therapeutic, not prophylactic, in war wounds.
    - Give antibiotics for all penetrating wounds as soon as possible.
  - Sterile dressing:
    - Place a sterile field dressing as soon as possible.
    - Leave dressing undisturbed until surgery. A one-look soft-tissue examination may be performed on initial presentation. Infection rate increases with multiple examinations prior to surgery. Initial wound cultures unnecessary.

Surgical Wound Management Priorities

- Life-saving procedures before limb and soft-tissue wound care.
- Save limbs.
  - Vascular repair.
  - Compartment release.
Emergency War Surgery

- Prevent infection.
  - Wound surgery within 6 hours of wounding.
  - Antibiotics.
  - Sterile dressing.
  - Fracture immobilization.
- **Superficial penetrating fragment (single or multiple) injuries usually do not require surgical exploration.** Simply cleanse the wounds with antiseptic and scrub brush. Nonetheless, depending on location and clinical presentation, maintain high suspicion for vascular injury or intraabdominal penetration.
  - Avoid “Swiss cheese” surgery (in an attempt to excise all wounds and retrieve fragments).

Wound Care

<table>
<thead>
<tr>
<th>Primary Surgical Wound Care</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Limited longitudinal incisions.</td>
</tr>
<tr>
<td>- Excision of foreign material and devitalized tissue.</td>
</tr>
<tr>
<td>- Irrigation.</td>
</tr>
<tr>
<td>- <strong>Leave Wound Open—No Primary Closure.</strong></td>
</tr>
<tr>
<td>- Antibiotics and tetanus prophylaxis.</td>
</tr>
<tr>
<td>- <strong>Splint for transport</strong> (improves pain control).</td>
</tr>
</tbody>
</table>

- Longitudinal incisions.
  - Wounds are extended with incisions parallel to the long axis of the extremity, to expose the entire deep zone of injury. At the flexion side of joints, the incisions are made obliquely to the long axis to prevent the development of flexion contractures.
  - The use of longitudinal incisions, rather than transverse ones, allows for proximal and distal extension, as needed, for more thorough visualization and debridement.
- Wound excision (current use of the term **debridement**).
  - Skin.
    - Conservative excision of 1–2 mm of damaged skin edges (Fig. 22-1a).
    - Excessive skin excision is avoided; questionable areas can be assessed at the next debridement.
Fat. Damaged, contaminated fat should be generously excised.

Fascia. Damage to the fascia is often minimal relative to the magnitude of destruction beneath it (Fig 22-1b). Shredded, torn portions of fascia are excised, and the fascia is widely opened through longitudinal incision to expose the entire zone of injury beneath. Complete fasciotomy is often required as discussed below.

Muscle.
Emergency War Surgery

Removal of dead muscle is important to prevent infection. Accurate initial assessment of muscle viability is difficult. Tissue sparing debridement is acceptable if follow-on wound surgery will occur within 24 hours. More aggressive debridement is required if subsequent surgery will be delayed for more than 24 hours.

♦ Sharply excise all nonviable, severely damaged, avascular muscle (Fig. 22-1c).
♦ The “4 Cs” may be unreliable for initial assessment of muscle viability (color, contraction, consistency, circulation).
  ◊ Color is the least reliable sign of muscle injury. Surface muscle may be discolored due to blood under the myomesium, contusion, or local vasoconstriction.
  ◊ Contraction is assessed by observing the retraction of the muscle with the gentle pinch of a forceps.
  ◊ Consistency of the muscle may be the best predictor of viability. In general, viable muscle will rebound to its original shape when grasped by a forceps, while muscle that retains the mark has questionable viability.
  ◊ Circulation is assessed via bleeding tissue from a fresh wound. Transient vasospasm, common with war wounds, may not allow for otherwise healthy tissue to bleed.

• Bone.
  ♦ Fragments of bone with soft-tissue attachments and large free articular fragments are preserved.
  ♦ Remove all devitalized, avascular pieces of bone smaller than thumbnail size that have no soft-tissue attachment.
  ♦ Deliver each of the bone ends of any fracture independently, clean the surface and clean out the ends of the medullary canal.

• Nerves and tendons.
  ♦ Do not require debridement, except for trimming frayed edges and grossly destroyed portions.
  ♦ **Primary repair is not performed.** To prevent desiccation, use soft-tissue or moist dressings for coverage.
o Vessels.
  ♦ Only minimal debridement of vessel is required for a successful repair.

o Irrigation.
  ♦ Following surgical removal of debris and nonviable tissue, irrigation is performed until clean (Fig. 22-1d).
  ♦ While sterile physiologic fluid is preferred, do not deplete resuscitation fluid resources. May use potable water as an alternative. The last liter of irrigant should be a sterile solution with antibiotics.

o Local soft-tissue coverage.
  ♦ The development and rotation of flaps for this purpose should not be done during primary surgical wound care.
  ♦ Local soft-tissue coverage through the gentle mobilization of adjacent healthy tissue to prevent drying, necrosis, and infection is recommended. Saline-soaked gauze is an alternative.

No Primary Closure of War Wounds.

o Dressing.
  ♦ Do not plug the wound with packing as this prevents wound drainage. Leaving the wound open allows the egress of fluids, avoids ischemia, allows for unrestricted edema, and avoids the creation of an anaerobic environment.
  ♦ Place a nonconstricting, nonocclusive dry dressing over the wound.

Wound Management After Initial Surgery
- The wound undergoes a planned second debridement and irrigation in 24–72 hours, and subsequent procedures until a clean wound is achieved.
- Between procedures there may be better demarcation of nonviable tissue or the development of local infection.
- Early soft-tissue coverage is desirable within 3–5 days, when the wound is clean, to prevent secondary infection.
Emergency War Surgery

- 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.
- Soft-tissue war wounds heal well without significant loss of function through secondary intention. This is especially true of simple soft-tissue wounds.
- Definitive closure with skin grafts and muscle flaps should not be done in theater when evacuation is possible. These techniques may be required, however, for injured civilians or prisoners of war.

Crush Syndrome
- When a victim is crushed or trapped with compression on the extremities for a prolonged time, there is the possibility for the crush syndrome (CS), characterized by ischemia and muscle damage or death (rhabdomyolysis).
  - With rhabdomyolysis there is an efflux of potassium, nephrotoxic metabolites, myoglobin, purines, and phosphorous into the circulation, resulting in cardiac and renal dysfunction.
  - Reperfusion injury can cause up to 10 L of third-space fluid loss per limb that can precipitate hypovolemic shock.
  - Acute renal failure (ARF) can result from the combination of nephrotoxic substances from muscle death (myoglobin, uric acid) and hypovolemia resulting in renal low-flow state.
- Recognition.
  - History.
    - Suspect in patients in whom there is a history of being trapped (eg, urban operations, mountain operations, earthquakes, or bombings) for a prolonged period (from hours to days).
    - Clear history is not always available in combat, and the syndrome may appear insidiously in patients who initially appear well.
  - Physical findings.
    - A thorough examination must be done with attention to extremities, trunk, and buttocks. The physical findings depend on the duration of entrapment, treatment rendered, and time since the victim’s release.
Extremities.
◊ May initially appear normal just after extrication.
◊ Edema develops and the extremity becomes swollen, cool, and tense.
◊ May have severe pain out of proportion to examination.
◊ Anesthesia and paralysis of the extremities, which can mimic a spinal cord injury with flaccid paralysis, but there will be normal bowel and bladder function.

Trunk/buttocks: may have severe pain out of proportion to examination in tense compartments.

Laboratory findings.
♦ Creatinine phosphokinase (CK) is elevated with values usually > 100,000 IU/mL.
♦ The urine may initially appear concentrated and later change color to a typical reddish-brown color, so called “port wine” or “iced tea” urine. The urine output decreases in volume over time.
♦ Due to myoglobin, urine dipstick is positive for blood, but microscopy will not demonstrate red blood cells (RBCs). The urine may be sent to check for myoglobin, but results take days and should not delay therapy.
♦ Hematocrit/hemoglobin (H/H) can vary depending on blood loss, but in isolated crush syndrome H/H is elevated due to hemoconcentration from third spacing fluid losses.
♦ With progression, serum potassium and CK increase further with a worsening metabolic acidosis. Creatinine and BUN will rise as renal failure ensues. Hyperkalemia is typically the ultimate cause of death from cardiac arrhythmia.

Therapy.
◊ On scene while still trapped.
♦ The primary goal of therapy is to prevent acute renal failure in crush syndrome. Suspect, recognize, and treat rhabdomyolysis early in victims of entrapment.
♦ Therapy should be initiated as soon as possible, preferably in the field, while the casualty is still trapped. Ideally it is recommended to establish IV access in a free arm or leg vein.
Avoid potassium and lactate containing IV solutions. At least 1 L should be given prior to extrication and up to 1 L/h (for short extrication times) to a maximum of 6–10 L/d in prolonged entrapments. As a last resort, amputation may be necessary for rescue of entrapped casualties (ketamine 2 mg/kg IV for anesthesia and use of proximal tourniquet).

Hospital care.
- Other injuries and electrolyte anomalies must be treated while continuing fluid resuscitation, as given above, to protect renal function.
- Foley catheter for urine output monitoring.
- Establish and maintain urine output > 100 cc/h until pigments have cleared from the urine. If necessary, also:
  - Add sodium bicarbonate to the IV fluid (1 amp/L D5W) to alkalinize the urine above a pH of 6.5.
    - If unable to monitor urine pH, put 1 amp in every other IV liter.
  - Administer mannitol, 20% solution 1–2 g/kg over 4 hours (up to 200 g/d), in addition to the IV fluids.
- Central venous monitoring may be needed with the larger volumes (may exceed 12 L/d to achieve necessary urine output) of fluid given.

Electrolyte abnormalities.
- Hyperkalemia, hyperphosphatemia, hypocalcemia, hyperuricemia must be addressed.

Dialysis.
- ARF requiring dialysis occurs in 50%–100% of those with severe rhabdomyolysis.

Surgical management centers on diagnosis and treatment of compartment syndrome—remember to check torso and buttocks as well.
- Amputation: consider in casualties with irreversible muscle necrosis/necrotic extremity.

Hyperbaric oxygen therapy: may be useful after surgical therapy to improve limb survival.
**Compartment Syndrome (see Chapter 27, Vascular Injuries)**

- Compartment syndrome may occur with an injury to any fascial compartment. The fascial defect caused by the injury may not be adequate to fully decompress the compartment, and compartment syndrome may still occur.

- Mechanisms of injuries associated with compartment syndrome.
  - Open fractures.
  - Closed fractures.
  - Penetrating wounds.
  - Crush injuries.
  - Vascular injuries.
  - Reperfusion following vascular repairs.

- Early clinical diagnosis of compartment syndrome.
  - Pain out of proportion.
  - Pain with passive stretch.
  - Tense, swollen compartment.

- Late clinical diagnosis.
  - Paresthesia.
  - Pulselessness and pallor.
  - Paralysis.

- Measurement of compartment pressures: **Not recommended, just do the fasciotomy**.
  - The diagnosis of a compartment syndrome is made on clinical grounds.
  - Measurement of compartment pressures is not recommended in the combat zone.

- Consider **prophylactic fasciotomy**.
  - High-energy wounds.
  - Intubated, comatose, sedated.
  - Closed-head injuries.
  - Circumferential dressings or casts.
  - Vascular repair.
  - Prolonged transport.
  - High index of suspicion.
Fasciotomy Technique

- Upper extremity.
  - Arm: The arm has two compartments:

    - The **anterior flexors** (biceps, brachialis) and the **posterior extensors** (triceps).
    - Lateral skin incision from the deltoid insertion to the lateral epicondyle.
    - Spare the larger cutaneous nerves.
    - At the fascial level the intermuscular septum between the anterior and posterior compartment is identified, and the fascia overlying each compartment is released with longitudinal incisions.
    - Protect the radial nerve as it passes through the intermuscular septum from the posterior compartment to the anterior compartment just below the fascia.
    - Compartment syndrome in the hand is discussed in Chapter 26, Injuries to the Hands and Feet.
  - Forearm: The forearm has three compartments:

    - The **mobile wad** proximally, the **volar** compartment, and the **dorsal** compartment (Fig 22-2).
    - A palmar incision is made between the thenar and hypothenar musculature in the palm, releasing the carpal tunnel as needed.
    - This incision is extended transversely across the wrist flexion crease to the ulnar side of the wrist, and then arched across the volar forearm back to the ulnar side at the elbow.
    - At the elbow, just radial to the medial epicondyle, the incision is curved across the elbow flexion crease. The deep fascia is then released.
    - At the antecubital fossa, the fibrous band of the lacertus fibrosus overlying the brachial artery and median nerve is carefully released.
    - This incision allows for soft-tissue coverage of the neurovascular structures at the wrist and elbows, and prevents soft-tissue contractures from developing at the flexion creases.
    - A second straight dorsal incision can be made to release the dorsal compartment, reaching proximally to release the mobile wad if necessary.
Soft-Tissue Injuries

- Lower extremity.
  - Thigh: The thigh has three compartments:
    - The **anterior** (quadriceps), the **medial** compartment (adductors), and the **posterior** compartment (hamstrings).
    - A lateral incision is made from greater trochanter to lateral condyle of the femur.
    - Then iliotibial band is incised, and the vastus lateralis is reflected off the intermuscular septum bluntly, releasing the anterior compartment.
    - The intermuscular septum is then incised the length of the incision, releasing the posterior compartment.
    - This release of the intermuscular septum should not be made close to the femur, because there are a series of perforating arteries passing through the septum from posterior to anterior near the bone.
    - The medial adductor compartment is released through...
a separate anteromedial incision.

- Calf: The calf has four compartments:
  - The **lateral** compartment, containing peroneal brevis and longus; the **anterior** compartment, containing extensor hallucis longus, extensor digitorum communis, tibialis anterior, and peroneus tertius; the **superficial posterior** compartment, containing gastrocnemius and soleus; and the **deep posterior** compartment, containing the flexor hallucis longus, flexor digitorum longus, and the tibialis posterior (Fig. 22-3).
  - Two-incision technique.

Fig. 22-3. Calf compartments.

- Incisions must extend the entire length of the calf to release all of the compressing fascia and skin (Fig. 22-4).
- A lateral incision is made centered between the fibula and anterior tibial crest.
- The lateral intermuscular septum and superficial peroneal nerve are identified, and the anterior compartment is released in line with tibialis anterior
muscle, proximally toward the tibial tubercle, and distally toward anterior ankle.

◊ The lateral compartment is then released through this incision in line with the fibular shaft, proximally toward the fibular head, distally toward the lateral malleolus.

◊ A second incision is made medially at least 2 cm medial to the medial-posterior palpable edge of the tibia.

◊ A medial incision over or near the subcutaneous surface of the tibia is avoided, preventing exposure of the tibia when the tissues retract.

◊ The saphenous vein and nerve are retracted anteriorly.

◊ The superficial compartment is released through its length, and then the deep posterior compartment over the FDL is released. Then identify the tibialis posterior and release its fascia.
Emergency War Surgery

- Foot: See Chapter 26, Injuries to Hands and Feet.

- Fasciotomy wound management.
  - Following the fasciotomy, the fasciotomy wound undergoes primary surgical wound management, removing all devitalized tissue.
  - As with all war wounds, the fasciotomy is left open, and covered with sterile dressings.

- Vacuum Wound Closure Systems.
  - Vacuum assisted wound closure is an important adjunct to modern combat wound care.
  - Only one device is currently approved for this application: the Wound Vacuum Assisted Closing (VAC) Therapy System.
  - Field expedient vacuum assisted wound closure is an alternative. Field expedient vacuum dressings are easily created with standard issue items, including the following:
    - Laparotomy sponges.
    - Jackson-Pratt (JP) drains.
    - Ioban.
    - Benzoin.
    - Adaptec (nonadherent gauze, for skin grafts).
    - Sterile perforated IV bags.
      - For wounds of the **soft tissue and extremities**, layer laparotomy sponges with JP drains sandwiched between the sponges and covered with Ioban. Apply benzoin to the skin edges to prevent leaks.
      - Attach the JP drains to the standard vacuum pump, adjusted to 125 mm Hg suction. This dressing eliminates the need for skin traction in amputations.
      - For **skin grafts**, staple the graft to the edges of the wound. Apply nonadhering gauze, and apply to field-expedient vacuum dressing. Do not remove for 3 days. Grafts can be dressed with Silvadene when the field-expedient vacuum dressing is removed.
      - For **open abdominal wounds**, place sterile perforated IV bags on the bowel, and sew the IV bag to the fascia, or underlay the fascia with the IV bag. Place laparotomy sponges on the IV bags and layer
with JP drains. Apply benzoin to the skin edge and cover with Ioban. Attach the drains to suction. This dressing prevents leaking of abdominal fluids during transport.

Many surgeons consider this an important part of wound management because the use of vacuum systems may improve and accelerate wound healing in a variety of conditions to include: pressure ulcers, partial thickness burns, orthopaedic wounds with large soft tissue defects, open abdominal wounds, and assistance with skin graft viability.

The treatment of soft tissue injury is the most common denominator in the management of war wounds. This chapter summarizes some principles of this management.
Emergency War Surgery
Chapter 23

Extremity Fractures

Introduction
This chapter discusses two techniques for safe transportation of a wounded soldier with a long bone fracture: transportation casts and temporary external fixation. Both of these methods are acceptable for initial treatment of a patient who will be evacuated out of theater. Precise indications for external fixator use versus casting have not been established.

In general, good indications for external fixator use include when the soft tissues need to be evaluated while en route, such as with a vascular injury; when other injuries make use of casting impractical, such as with a femur fracture and abdominal injury; or when the patients have extensive burns. Advantages of external fixation are that it allows for soft tissue access, can be used for polytrauma patients, and has a minimal physiologic impact on the patient. Disadvantages are the potential for pin site sepsis or colonization and less soft tissue support than casts.

Advantages of transportation casts are that they preserve the maximum number of options for the receiving surgeon; the soft tissues are well supported, and the casts are relatively low tech. Disadvantages are that casts cover soft tissues, may not be suitable for polytrauma patients, and are more labor-intensive than external fixators.

Both transportation casts and external fixators are equally acceptable methods for the initial management of long bone fractures. In the end, the choice of initial fracture stabilization must be made on a case-by-case basis by the treating surgeon. That decision should be based on the surgeon’s experience, his assessment of the evacuation process, the materials available,
Emergency War Surgery

the nature of the patient’s wounds and the patient’s overall condition.

Though standard in civilian trauma centers, intramedullary nailing of major long bone fractures is **contraindicated** in combat zone hospitals because of a variety of logistical and physiologic constraints. This method may be used once a patient reaches an echelon above corps (EAC) or other site where more definitive care can be provided.

In this chapter, the term **casting material** is used in place of describing either plaster or fiberglass for constructing casts. Both are acceptable materials for application of transportation casts.

**General Considerations of Wound Management**

- **Initial management.**
  - Treat by irrigation and debridement as soon as feasible to prevent infection.
  - Femur fractures are at high risk for infection (about 40%, historically).
  - Biplanar radiographs should be obtained.
  - Neurovascular status of the extremity should be documented and checked repeatedly.
  - Internal fixation is contraindicated.
  - Begin IV antibiotics as soon as possible and maintain throughout the evacuation chain. Use a broad spectrum cephalosporin (cefazolin 1 g q 8 h). An aminoglycoside may be harmful for someone in shock or dehydrated. The two most harmful bacteria—clostridia and streptococci—are covered by a 1st generation cephalosporin.

- **Wound incision/excision.**
  - Guidelines as per soft tissue injury section.
  - Longitudinal incisions to obtain exposure.
  - Fascia incised longitudinally to expose underlying structures and **compartment release.**
  - All foreign material in the operative field must be removed (Fig. 23-1a, b, c).
Bone fragments should be retained if they have a soft tissue attachment.

Fig. 23-1. Wound incision/excision.
Detached bone fragments smaller than a thumbnail are discarded. Larger fragments that contribute to the structural integrity of the long bone should be retained. Irrigation is essential (Fig. 23-1d).

Closure of wounds.
- Primary closure is never indicated. Loose approximation of tissues with one or two retention sutures is appropriate to cover nerves, vessels, and tendons, but there must be a provision for substantial free drainage.
- Skin grafts, local flaps, and relaxing incisions are contraindicated in the initial management.
- Delayed primary closure may be attempted as described in the section on soft tissue wounds. This should be accomplished in a stable environment.

Transportation Casts
- Introduction.
  - A transportation cast is a well-padded cast that is unique to the treatment of combat casualties. It is used to transport patients between hospitals and not intended as a means of definitive care.
  - Definitive reduction is not required with the initial surgical procedure.
  - The goal of transportation casts is to immobilize a fracture along the evacuation chain. The cast must meet the dimensions of the standard NATO litter (FM 8-10-6).
  - Transportation casts are applied prior to evacuation.
  - All casts must be bivalved prior to evacuation. (Hip spica — univalved.)
  - If a patient is expected to have multiple procedures at the same hospital, balanced skeletal traction should be utilized until the last procedure prior to transportation. The traction pin may be incorporated into the transportation cast.
  - Slab splinting may not be adequate for transportation, particularly for severely unstable fractures. Splinting is appropriate for stable fractures, particularly in the hand, wrist, forearm, foot, ankle and lower leg.
Portable skeletal traction should not be used for transportation of a patient.

Tobruk splint (a Thomas splint with circular plaster) should not be used.

- **Hip, femur, and knee, and some proximal tibia fractures.**
  - Low hip spica transportation cast.
  - Disadvantages: Limited soft tissue access. Not suitable in polytrauma.
  - Technique.
    - Adequate anesthesia is given, and patient is placed on fracture table (Fig. 23-2).
    - Irrigation and debridement as indicated above.
    - Precise reduction not necessary, but usually requires two assistants.
    - Stockinette over abdomen, distal thigh of uninvolved side, and foot of the involved side (Fig. 23-3).
Emergency War Surgery

Fig. 23-4. Hip spica transportation cast.

- Felt padding is placed over sacrum and anterior superior iliac spine (ASIS) and other bony prominences.
- Towel is placed over abdomen to allow breathing space.
- Six-inch Webril or similar cotton batting is wrapped, 2-4 layers.
- Six-inch casting material is then rolled over the Webril from ASIS to the foot on the affected side to the distal thigh on the unaffected side (Fig. 23-4). Splints are applied over the posterior, lateral, or groin areas to reinforce the groin (Fig. 23-5). Use a finishing roll after turning down the edges of the stockinette to give a neat appearance.
- An adequate perineal space must be left for hygiene.
- Use a ½" dowel or similar material to make anterior/posterior crossbars.
- Affected knee bent about 20°.
- Space between feet must not exceed standard litter, although this makes perineal access difficult.
- Towel is removed, cast is bivalved, and a circular area over the abdomen is cut out.

Fig. 23-5. Reinforce cast at hip with splints.
Extremity Fractures

- Use an indelible marker to draw the fracture configuration, and note the dates of surgery and wounding on the cast.
- Support the cast with towels, blankets, or pillows to relieve pressure on the cast, especially the back edge.

- Proximal/mid/distal tibia and ankle fractures.
  - Long Leg Cast (Fig. 23-6).

  ![Fig 23-6. Long leg cast.]

  o Technique.
    - The foot, leg, and thigh are placed in a stockinette at the conclusion of the operation for the open wounds.
    - Two people are needed to maintain the reduction and apply the cast. Hold the knee flexed about 20°.
    - Webril applied from the toes to the groin.
    - Six-inch wide casting material is then rolled over this region, with a turn down of the stockinette prior to the final layer, to make a neat edge.
    - Reinforce the knee to strengthen the cast.
    - Make a supracondylar mold to provide support (Fig. 23-7).

  ![Fig. 23-7. Supracondylar mold of long leg cast.]
♦ Bivalve the cast.
♦ Label the cast with the dates of injury and surgery, and draw the fracture on outside of the cast.
♦ Elevate the leg so the tibia is parallel to the litter or bed.

• Shoulder and humeral shaft fractures.
  o Velpeau technique. (External fixator is an acceptable alternative, however without direct visualization there is a high risk of iatrogenic injury to the radial nerve and vascular structures. Review anatomy carefully.)
  ♦ At the conclusion of open wound treatment, the extremity is manipulated on the fracture table to obtain the best alignment.
  ♦ Large cotton pads are placed under the axilla and arm (Fig. 23-8a).
  ♦ The Webril is wrapped around the torso and affected extremity to the wrist (Fig. 23-8b).
  ♦ Six-inch wide casting material is then wrapped over the extremity and the torso. The first wrap should start around the trunk, go over the shoulder posteriorly, down the arm anteriorly, around the elbow, and then up the posterior aspect of the arm (Fig. 23-8c).
  ♦ The trunk and the extremity should be wrapped in plaster to stabilize the cast.
  ♦ Four layers should be sufficient (Fig. 23-8d).
  ♦ Bivalve this cast, and wrap with elastic bandages. There are no cast saws available on the aircraft. If a patient in a Velpeau cast develops any respiratory problems, emergency measures cannot be taken if the cast cannot be removed.

• Elbow/forearm.
  o Long arm cast.
  o Technique.
    ♦ After treatment of open wounds, the extremity is wrapped in stockinette from the fingers to the axilla.
    ♦ Gross alignment of fractures is the goal. Precise reduction is not necessary.
    ♦ Four-inch wide Webril is wrapped from metacarpal heads to axilla.
♦ Four-inch wide casting material is applied from metacarpal heads to axilla.
♦ Fold the stockinette before finishing layer for a neat edge.
♦ Bivalve cast after drying.
♦ Reassess neurovascular status.

Bivalving Casts
When a cast is bivalved, it is completely split longitudinally along opposing sides of the cast. Splitting the cast into anterior and posterior halves is preferred. The purpose of bivalving is to allow room for soft tissue swelling, thus lessening the chance

Fig. 23-8a. Padding Velpeau.
Fig. 23-8b–c. Webril application for Velpeau cast.
Fig. 23-8d. Completed Velpeau cast.
of postcasting compartment syndrome. It is important that the underlying cast padding also be completely split underneath the cast cuts; otherwise, the cast padding can restrict swelling and a compartment syndrome could still develop.

**External Fixation**

- General technique: The surgeon should be familiar with four types of standard constructs of external fixation for use in the initial care of battle casualties: femur, tibia, knee, and ankle. External fixation can also be applied for humerus and ulna fractures as needed.
  - A thorough understanding of the anatomy of the lower extremity is essential for application of the pins in a safe corridor.
  - The external fixator for military purposes should be modular and allow for building up or down as healing progresses.
  - Application of the external fixator may be done without the use of plain films or fluoroscopy.
  - Pins can be inserted by hand using a brace without power instruments.
  - Enough pins should be used to adequately stabilize the fracture for transport. This is usually two per clamp, but three may occasionally be required.
  - The present external fixation system (Hoffmann II) allows for the use of either single pin clamps or multipin clamps. Both clamps are acceptable to use in standard constructs.
  - Multipin clamps provide greater stability and are the current fixators fielded. Dual pin placement (with multipin clamps) is described here. The technique for single pin placement is similar.

- **Femur diaphyseal fracture technique.**
  - The entire limb is prepared for surgery, from the ASIS to the toes.
  - A standard OR table or portable fracture table may be used.
  - An assistant should apply counter pressure while pins are inserted.
  - Precise reduction is not necessary. A padded "bump" under the thigh will help reduce the fracture (Fig. 23-9).
The position of the proximal femur should be identified by palpation. A 1-cm longitudinal stab incision is made over the midaxis, or midlateral axis, of the femur (Fig. 23-10). The pin closest to the fracture should be outside of the fracture hematoma, and at least three fingerbreadths from the fracture (Fig. 23-11).

Bluntly spread with a clamp down to bone. Put the pin down on the bone, and determine the midportion of the bone by moving the pin back and forth across the width of the femur. You do not want to plunge to one or the other side. Your assistant should provide stability and counter

Fig. 23-9. Placing a towel underneath the thigh helps to reproduce the bow of the femur.

Fig. 23-10. A 1-cm or so incision directly over the middle of the bone, cut in a longitudinal direction.

Fig. 23-11. Femur pin placement.
pressure. Two taps on the end of the bit brace should provide an indent in the bone and allow you to start insertion. Apex pins are placed by hand. There is no predrill nor power insertion. 5-mm half-pins should be used. Insert the pin in the midportion of the bone through both the near and far cortex of the bone (Fig. 23-12). The pin will move easier as it enters the intermedullary canal, and then get more difficult to drive as it enters the far cortex.

- Place a multipin clamp over the inserted pin (Fig. 23-13). Ideally, the pin should occupy one of the end positions (eg, position 1, Fig. 23-14).
- Using the clamp as a guide, insert a second pin through the clamp. An assistant should hold the clamp. Ensure that the clamp is aligned to the bone and that bicortical purchase is obtained with the second pin. The second pin must be parallel to the first (Fig. 23-15). Use the pin sites that are the farthest apart on the clamp as possible for biomechanical stability (clamp positions 1 and 2).
5 are best, see Fig. 23-14). A third pin may be inserted if needed for additional clamp stability.

- Apply a second multipin clamp and pins in the same manner to the distal femoral fracture fragment.

- Connect the two clamps with elbows, bar-to-bar clamps, and two longitudinal bars placed parallel to each other (Fig. 23-16).

Fig. 23-14. Multipin clamp showing pin positions 1-5.

Fig. 23-15.

- Reduce the fracture with longitudinal traction. Manipulating the fracture fragments using the clamps may be helpful. Once adequate reduction is achieved, tighten all the connections. Precise reduction is not necessary.

- **Tibia shaft fracture technique.**
  - Palpate the anterior-medial border of the tibia. Place a 1-cm longitudinal incision over the midportion of the surface (Fig. 23-17). The pin closest to the fracture site should be outside the hematoma and at least three fingerbreadths away from the fracture site (Fig. 23-18).
Insert one pin into either the proximal or distal fragment, engaging both cortices. This pin should be placed perpendicular to the subcutaneous border of the tibia, and centered across the width of the tibia (Fig. 23-19).

Fig. 23-17. Palpation of the anterior and posterior margins of the medial face of the tibia where a 1 cm incision has been made midway between these two points.
Using the clamp as a guide, insert a second pin through the clamp. An assistant should hold the clamp. Ensure that the clamp is aligned to the bone and that bicortical purchase is obtained with the second pin. The second pin must be parallel to the first. Use the pin sites as far apart on the clamp as possible for biomechanical stability (Figure 23-20 and positions 1 and 5 in Fig. 23-14). The second pin should be through the clamp farthest away from the fracture site (Fig. 23-20).
Apply a second multipin clamp and two pins in the same manner to the other main fracture fragment (Fig. 23-21). Connect the two clamps via two elbows, bar–bar clamps, and a single bar (Fig. 23-22).

Most battle caused fractures are comminuted; therefore, a second bar should be added to the construct (Fig. 23-23). Use a single bar for stable fractures only.

Check the reduction.

Fig. 23-21. Application of the second multipin clamp and two pins. Repeat those steps with the other major fracture fragment so that you have two sets of multipin clamps as shown here. You will then add the 30 degree elbows as shown here, pointing them in a direction that allows for the best access. At this point you should have gross alignment of the fracture.
Extremity Fractures

**Technique to span knee.**
- Indications are proximal tibia fractures, distal femur fractures, or extensive knee injuries, or vascular repairs in the popliteal fossa.

---

**Fig. 23-22.** Addition of the cross bar and two bar-to-bar clamps. Have your assistant apply longitudinal traction to reduce the frame, and then tighten the frame in alignment.

**Fig. 23-23.** Two-bar apparatus. As the majority of tibia fractures are unstable, it creates a more stable construct by adding a second bar. This requires the use of two of the kits but makes little difference when you are using the tub container at the CSH or equivalent hospitals.
Check the distal vascular status of the limb prior to and after the procedure. If there is a vascular injury, refer to Chapter 27, Vascular Injuries.

An assistant will be required to help apply the frame.

General reduction maneuver should be longitudinal traction with slight (10°–15°) flexion at the knee.

Pins are placed anterior medial on the proximal tibia and antero-lateral on the distal femur. Pin placement should be outside of the zone of injury, at least three fingerbreadths from a fracture site, and outside of the knee joint. At the distal femur, a longitudinal stab incision is made over the antero-lateral aspect of the bone, so that the pin may be inserted into the center of the bone at about a 45° angle from the horizontal. Depending on the fracture configuration, it may also be placed directly anteriorly, though it is generally better to avoid the quadriceps tendon.

Blunt dissection is used to create a corridor to the bone.

A single pin is inserted by hand through both cortices of the bone fragment.

A multipin clamp is used as a guide for a second pin. The second pin must be parallel to the first and also bicortical — care should be taken to maintain pin alignment. The proximal tibia should be palpated on the anterior medial surface and the anterior and posterior border should be identified. Midway anterior/posterior, a 1-cm longitudinal stab incision should be made and a blunt soft tissue dissection made to bone.

A multipin clamp should be used as a guide to insert a second pin in the proximal tibia.

The two pin clusters (femur and tibia) should be connected via two elbows, two bar-bar clamps, and a single bar. The knee should be aligned.

A second bar should be added in the manner described above.

- **Technique to span ankle.**
  - An assistant will be required to help apply the frame and reduce the ankle.
o General indications are for open distal tibia fractures and open ankle wounds.
o Pins should be inserted on the anterior medial surface of the tibia and the medial aspect of the calcaneus.
o Check the distal vascular status prior to and after the procedure. Mark where the posterior tibial and dorsalis pedis artery pulses can be felt.
o Palpate the anterior medial border of the tibia. Make a 1-cm longitudinal incision midway between the anterior and posterior border of the tibia. Insert the most distal pin on the tibia outside the zone of injury, at least three fingerbreadths from the fracture site.
o Using a multipin clamp as a guide, insert a second pin in the tibia more proximal to the first. The pin must be parallel and be aligned in the longitudinal axis to the first.
o Palpate the medial border of the calcaneus. Make a longitudinal incision over the calcaneus away from the posterior neurovascular structures: dissect to the bone with a clamp and insert the pin.
o Using a multipin clamp as a guide, insert a second pin in the calcaneus.
o Connect the two clamps via two elbows, two bar–bar clamps, and a single bar.

• Skeletal traction.
o Skeletal traction provides a quick means to immobilize a large number of fracture cases with a minimum of technical support.
o Indications.
  ♦ Patients who are expected to have more than one procedure in the same forward hospital prior to evacuation.
  ♦ Large casualty load.
o Technique.
  ♦ Large threaded Steinman pins are used to obtain skeletal traction of a femur or tibia.
  ♦ Aseptic preparation of a pin site is necessary prior to placement.
  ♦ Apply local anesthetic to pin site.
Emergency War Surgery

♦ Incise skin and dissect to bone bluntly.
♦ For femur fractures, incision is made 2 cm posterior and lateral to the tibial tuberosity (directly under, as in Fig. 23-24). Place pin from lateral to medial through and through the proximal tibia.
♦ Apply a Thomas splint with Pierson device, with weight applied midthigh (10–20 lb), to the leg (10–20 lb), and to the traction pin (20–40 lb) to obtain balanced skeletal traction as shown in Fig. 23-25.
♦ For tibia fractures, incise medially 2 cm anterior and 2 cm cephalad from the tip of the heel. Place the pin from medial to lateral through and through the calcaneus. Place the leg on a Bohler-Braun frame and apply traction to the calcaneal pin (10–20 lb).
♦ Wait at least 1/2 hour after applying traction to obtain radiographs.

• Care in the evacuation chain.
  o Patients do not improve in the evacuation system.

Fig. 23-24. Thomas splint with Pierson device.  Fig. 23-25. Bohler-Braun frame with traction.

Consider patient safety during evacuation when planning procedures.
  o Medications should be arranged prior to departure. Ensure adequate pain control.
  o Skeletal traction should not be used for transportation.
Extremity Fractures

- Casts should be bivalved. Follow neurovascular status during transport because **casts may act as tourniquets due to tissue swelling**.
- All documentation, including radiographs, should accompany the patient.
Emergency War Surgery
Open-Joint Injuries

Introduction

Open injuries to the joints are rarely immediately life threatening. They are frequently quite dramatic in appearance and draw the inexperienced caregiver’s attention away from the truly life threatening, associated injuries. Neurovascular structures are in close proximity to the major joints, and may require vascular management and repair. Open joints have long-term morbidity and some secondary mortality from infection due to missed injury or inadequate treatment.

All open-joint injuries must be explored and treated within 6 hours to prevent infection and joint destruction.

With rare exceptions, closed-joint injuries should be treated nonoperatively in the combat zone. Definitive intervention and rehabilitation usually require months before complete recovery. Thus, patients with closed injuries to major joints should be evacuated from the theater for definitive surgical intervention and rehabilitation.

The key to treating open-joint injuries is recognition. Once identified, goals are prevention of infection and preservation/restoration of normal joint function.

- Signs of possible open-joint injury are a wound associated with the following:
  - Proximity to a joint.
  - Periarticular fracture.
  - Exposed joint.
  - Effusion.
Emergency War Surgery

- Loss of joint motion.
- Intra-articular air or foreign body on biplanar radiographs.
- Abnormal joint aspiration demonstrating hemarthrosis.
- Extravasation from joint on diagnostic injection.

**Open-joint injuries always require surgery. Joint aspiration/injection may be performed to confirm a suspected open joint. If in doubt, treat as an open-joint injury to prevent missed injury sequelae.**

- The technique for aspiration/injection involves:
  - Sterile prep.
  - 18-gauge needle, 30-cc syringe.
  - Enter suspected joint, avoiding neurovascular structures.
  - Attempt aspiration — if blood is aspirated a hemarthrosis is present.
  - If no hemarthrosis, inject with normal saline (methylene blue if available) until joint is fully distended — the joint is damaged if extravasation is detected.
  - If there is no extravasation, open joint injury may still be present.

- Approaches for aspiration are shown for the shoulder, elbow (Lateral), knee (Medial parapatellar), and ankle (Anterolateral) (Fig. 24-1a,b,c,d).

**Treatment of All Open-Joint Injury**

- IV antibiotics should be started ASAP after wounding, and continued postop for 48 hours.
- Tourniquet control of operative bleeding is essential.
- Standard arthrotomy incisions are utilized (Fig. 24-2a,b,c). (Wound margins are incorporated if possible, provided they do not compromise exposure or create non-viable flaps).
- The extremity must be draped free to allow full range of motion during surgery.
- All intra-articular foreign material, loose cartilage (including flaps), blood clots, and detached bony fragments without major articular surface must be removed.
All recesses must be explored and all damaged tissue must be removed.

The joint must be thoroughly irrigated with normal saline (pulse lavage and 6 to 9 L is recommended).

Internal fixation is contraindicated with the exception of large articular fragments that may be stabilized with Kirschner wire (K-wire) or Steinmann pins.

Fig. 24-1a,b,c,d. Aspiration/injection approaches to the shoulder, elbow, knee, and ankle.
Emergency War Surgery

- Close synovium if possible without tension and without surgical tissue advancement. The remainder of the wound should never be closed at the initial surgical exploration.
- If synovial closure is not possible, the joint should be dressed open with moist fine mesh gauze occlusive dressing.
- The wound should be reexplored in 48–72 hours.
- A bivalved cast or splints can be used to stabilize the joint.

Fig. 24-2a,b,c. Surgical approaches to the ankle, elbow, and knee.
● If there are delays in evacuation or inability to move the patient, the following steps can be taken:
  o Delayed primary closure (DPC) can be undertaken in 4–7 days if there are no signs of infection.
  o If there is extensive soft-tissue loss, split-thickness skin grafts may be applied to granulating synovium.
● After DPC, gentle range-of-motion therapy is begun, based on consideration of any associated fractures or neurovascular injuries.

Any time joint infection is suspected, the joint should be immediately explored/re-explored.

**Signs of Joint Sepsis**
- Persistent swelling.
- Marked pain.
- Local warmth.
- Fever.
- Intense pain with restriction of the range of motion.

**Special Considerations for Hip Wounds**
- Open injuries of the hip joint are problematic for several reasons.
  - Difficulty in diagnosis.
  - Highly virulent organisms leading to mortality or long-term morbidity.
- Violations of the hollow viscus organs associated with fractures that extend into the acetabulum or femoral neck uniformly contaminate the joint.
  - Ruling out joint involvement is difficult in the field environment due to poor radiographic support and difficulty in reliable joint aspiration/injection. Therefore, a high index of suspicion with a low threshold for joint exploration is essential for preventing devastating complications.
- Presacral drainage is highly encouraged in rectal injury with joint extension.
Emergency War Surgery

**Hip Exploration Technique**
- Semilateral or lateral decubitus position, with the abdomen, pelvis, and full lower extremity prepped and draped free.
- A tibial traction pin to suspend the leg from the ceiling is advantageous.
- Anterior iliofemoral (Fig. 24-3a,b,c) approach gives the most extensive exposure to the hip, acetabulum, and ilium. (If the incision was extended superior and posterior, closure of the

![Anterior iliofemoral approach to the hip.](image)

Fig. 24-3a,b,c. Anterior iliofemoral approach to the hip.
superior/posterior aspect of the incision only over the iliac crest is necessary at the initial surgery to prevent muscle retraction and subsequent inability to close the wound.)

- A posterior or Kocher approach (Fig. 24-4a,b) allows for posterior exposure and allows for posterior drainage. It may be used in conjunction with the iliofemoral approach or in select cases alone for debridement. In an echeloned care/delayed evacuation scenario, dependent posterior drainage may be more critical than currently practiced in the civilian environment.

Fig. 24-4a,b. Posterior approach to the hip.
Complete fractures of the femoral neck/head should be resected due to nearly uniform complications of sepsis and avascular necrosis.

Except as described above, the surgical incision is not closed. Dressing of the wound is as previously described. The patient may be placed in a spanning external fixator from the iliac crest to the distal femur, or placed in a one and one-half hip spica cast. (See Chapter 23, Extremity Fractures, for diagram.)

Special Considerations for the Shoulder

- Often associated with life-threatening thoracic or vascular injuries. See Chapter 27, Vascular Injuries, for approaches to the axillary and subclavian arteries.

- Technique for shoulder exploration:
  - Semilateral position will allow both anterior and posterior approaches to the glenohumeral joint.
  - Anterior deltopectoral approach is recommended (Fig. 24-5a,b,c,d). (Detachment of the short biceps, coracobrachialis, and pectoralis minor off the coracoid may be needed for adequate exposure.) The subscapularis is detached and the joint capsule is trimmed of devitalized tissue. All attempts are made to preserve the supraspinatus attachment.
  - Loose fragments or a completely devitalized humeral head are resected to prevent infection. In an echeloned care/delayed evacuation scenario, dependent posterior shoulder drainage may be more critical than currently practiced in the civilian environment.
  - At the time of the DPC, 4–7 days later, the infraspinatus and teres minor are reattached if previously detached.
  - A Velpeau dressing is utilized for the wounds.
  - For transport, the shoulder can be wrapped in plaster, suspending the cast from the opposite shoulder for comfort. If this is not feasible, a sling and swath, immobilizing the arm against the chest wall, may be used. These patients will require litter transport.
Open-Joint Injuries

The key to success in dealing with open joints is a high index of suspicion. If the joint is open, then aggressive surgical management is imperative.

Fig. 24-5a,b,c,d. Anterior deltopectoral approach to the shoulder.
Emergency War Surgery
Chapter 25

Amputations

Introduction
Battle casualties who sustain amputations have the most severe extremity injuries.

- Historically, one in three patients with a major amputation (proximal to the wrist or ankle) will die, usually of exsanguination.
- Though amputations are visually dramatic, attention must be focused on the frequently associated life-threatening injuries.

Goals for initial care are to preserve life, prepare the patient for evacuation, and leave the maximum number of options for definitive treatment.

- The following are indications for amputation.
  - Partial or complete traumatic amputation.
  - Irreparable vascular injury or failed vascular repair with an ischemic limb.
  - Life-threatening sepsis due to severe local infection, including clostridial myonecrosis.
  - Severe soft-tissue and bony injury to the extremity precluding functional recovery.

The surgeon must balance the realistic likelihood of ultimate reconstruction of a functional extremity against the risk of death associated with attempts to preserve a limb. It is always desirable to secure the opinion of a second surgeon before amputating. The tactical situation may require amputation in cases where the limb might otherwise have been preserved.
Emergency War Surgery

- Battlefield amputations are unique.
  - Most commonly due to explosive munitions, with penetration and blast effects (see Chapter 1, Weapons Effects and Parachute Injuries).
  - Involve a large zone of injury with a high degree of contamination, which may affect the level of amputation and/or surgical intervention.
  - Require staged treatment with evacuation out of the combat zone prior to definitive closure.

| Amputations should be performed at the lowest viable level of soft tissues, in contrast to traditional anatomic amputation levels (eg, classic above knee (AK), below knee (BK), and so forth), to preserve as much limb as possible. A longer stump is desirable for final prosthetic fitting. |

- The Open Length Preserving Amputation (formerly Open Circular Amputation) procedure has two stages.
  - Initial. Complete the amputation at lowest possible level of bone and prepare the patient for evacuation to the next level of care.
  - Reconstructive. Involves final healing of the limb to obtain the optimal prosthetic stump.
  - Final level of amputation and definitive treatment of the residual limb should occur in the stable environment of a CONUS hospital, not in the combat zone hospital.

- All viable skin and soft tissues distal to the indicated level of bone amputation should be preserved for use in subsequent closure of the amputation stump. These tissues may be considered “Flaps of Opportunity” and can add length to the stump. This is especially true for amputations below the knee. Short tibial stumps can be saved with posteriorly based flaps because the gastrocnemius and soleus are frequently preserved following landmine injury.
To save length, any shape or form of a viable muscle or skin flap should be preserved. The lowest level may be an oblique or irregular wound, creating an oblique or irregular residual limb.

**Technique of Amputation**

- Surgical preparation of the entire limb, because planes of injury may be much higher than initially evident.
- Tourniquet control is mandatory. If a tourniquet was placed in the prehospital setting for hemorrhage control, it is prepped entirely within the surgical field.
- Excise nonviable tissue.
  - Necrotic skin and subcutaneous tissue or skin without vascular support.
  - Muscle that is friable, shredded, grossly contaminated, or noncontractile. (This muscle is usually at the level of the retracted skin.)
  - Bone that is grossly contaminated or devoid of soft tissue support. Bone is transected at a level at which it has the potential for coverage. (This is usually at the level of the retracted muscle.)
- Identify and securely ligate major arteries and veins to prevent hemorrhage in transport.
- Identify nerves, apply gentle traction, and resect proximally to allow for retraction under soft tissue. Ligate the major nerves.
- Preserved muscle flaps should not be sutured, but should be held in their intended position by the dressing.
- Flaps should not be constructed at the initial surgery, to facilitate later closure.

In blast injuries, particularly landmine injuries, the blast forces drive debris proximally along fascial planes. It may be necessary to extend incisions proximally parallel to the axis of the extremity to ensure adequate surgical decontamination of the wound.

**The stump is never closed primarily.**
Emergency War Surgery

- **Special considerations.**
  - Primary Symes (ankle disarticulation) has a high failure rate due to heel pad necrosis during transport. The wound should simply be debrided, retaining the clean hindfoot (talus and calcaneus).
  - Primary knee disarticulation is problematic due to skin and tendon retraction necessitating reamputation at a higher less functional level. It is preferable to leave even a very short (1–2 cm) clean transtibial stump, even though nonfunctional, to prevent retraction.
  - Fractures, when present proximal to the mangled segment, should not determine amputation level, but must be treated appropriately (cast, external fixator) to preserve maximal length.
  - Plan the initial amputation solely on the qualities of the wound and surrounding tissues, never on the hope of achieving a particular level or flap pattern as a final result. The combat surgeon’s goal is a thorough and complete debridement. Trying to preserve marginal tissue in the hope that a better stump can be constructed may lead to subsequent infection and a higher amputation level.

**Dressings and Prevention of Skin Retraction**

Since amputations must be left open, skin retraction is likely, causing the loss of usable limb length by making definitive closure difficult. This is particularly true of a patient who is the evacuation chain. Because of this, patients who will be evacuated should be placed in skin traction in order to leave the wound open and prevent skin retraction. Surgeons working for the International Committee of the Red Cross (ICRC) in a stable environment have successfully treated refugees by delayed primary closure. However, ICRC surgeons work in a relatively stable environment where evacuation is not a consideration for the refugee population. This situation does not apply to those in the air evacuation system.

**Skin Traction**

Ideally, skin traction should be maintained throughout the course of treatment. If evacuation times are reliably very short
Amputations (1–3 days), skin traction may be omitted. If there is the possibility of any delay, use skin traction to preserve limb length. When tactical conditions or resources are not available for application of casts, skin traction may be applied through weights off the end of the bed before and after transport.

- Dry fine mesh gauze is loosely placed over the open wound. Preserved flaps are not suspended freely, but are held in their intended position by the dressing (Fig. 25-1).
- Absorbent dressing is placed over the stump.
- Tincture of benzoin is applied proximally on the skin up to 2 cm from the wound edge, but not including the preserved flap.
- A stockinette for skin traction is applied.
- Wrap stockinette with a figure-of-8 elastic wrap.
- Two to six pounds of traction is applied through the stockinette/wrap. This may simply involve a weight attached via parachute cord to the stockinette. However, during transport, hanging weights are problematic and may be substituted with a light elastic such as surgical tubing or elastic exercise tubing applied through a transportation cast described below.
- A transportation cast should be applied to prevent contracture and allow for continuous traction (Fig. 25-2).

Postoperative Management
- Prevention of contracture.
  - BK amputations are at risk for knee flexion contractures. These contractures are preventable by using a long leg cast.

Fig. 25-1. Skin Traction
Splinting in extension requires closer monitoring. Pillows should never support the knee, because of the increased risk of flexion contractures.

- AK amputations are at risk for hip-flexion contractures. Prone positioning and active hip extension exercises will avoid this complication. When the casualty is supine, sandbags may be applied to the anterior distal thigh as well.

- Prevention of hemorrhage: A tourniquet should be readily available at the bedside or during transport for the first week following injury.
- Pain control: Patient comfort is paramount following amputation, particularly if dressing changes are required. Adequate analgesia should be available and the patient should be counseled regarding phantom limb pain.

**Transportation Casts**
Prior to evacuation, transportation casts should be applied to maintain traction of the residual limb and support the soft tissues. The transportation cast is a well-padded cast that has integral skin traction maintained by use of an outrigger.

**Cast Application Techniques**
Low Hip Spica cast
- Indications: Transfemoral amputation.
- Technique.
  - Adequate anesthesia is administered and the patient is placed on the fracture table.
Amputations

- Nonviable tissue is excised, as indicated above.
- Stockinette or Webril is applied over lower abdomen and thigh on side of amputation. Stockinette should already be applied for skin traction.
- Felt padding is placed over sacrum and anterior superior iliac spine (ASIS).
- Towel is placed over abdomen to allow breathing space.
- Six-inch Webril or similar cotton batting is wrapped in 1–2 layers (Fig. 25-3).
- Six-inch plaster is then rolled over the Webril from the ASIS to the end of the residual limb on the affected side. Splints are applied over the posterior, lateral, and groin areas. Use a finishing roll after turning down the edges of the stockinette to give it a neat appearance.
- Prior to the last roll, a Cramer wire splint should be attached over the distal end of the cast to provide skin traction via the stockinette.
- An adequate perineal space must be left for hygiene.
- The towel should be removed, the cast bivalved, and a circular area over the abdomen should be cut out.
- Use an indelible marker to label the cast with the date of injury and surgery(ies).

- Indications: Transtibial amputations.
- Technique.
  - Adequate anesthesia is provided. The wound is evaluated, nonviable tissue is excised, and the wound is irrigated.
  - Stockinette is applied to the distal end of the residual limb with tincture of Benzoin to maintain skin traction.
  - Two to three layers of Webril are applied from the amputation to the proximal thigh.
  - A six-inch plaster is then rolled over the thigh and leg.
  - Prior to application of the last layer, a Cramer wire splint should be incorporated over the distal end of the residual limb. Apply skin traction when the cast is dry.

Fig. 25-3. Low hip spica cast.
Bivalve the cast.
Label the cast with dates of injury and surgery(ies).

Shoulder Spica Cast
- Indications: Transhumeral amputation.
- Technique.
  - Administer adequate anesthesia.
  - Irrigate wound and excise nonviable tissue.
  - Apply stockinette to axilla for skin traction applied with tincture of Benzoin.
  - Wrap Webril over chest wall and around to edge of residual limb.
  - Apply 4–6 in. plaster over the Webril.
  - A Cramer wire splint outrigger should be applied with the last roll to allow for connection of the stockinette and application of skin traction.
  - Label the cast with dates of injury and surgery(ies).

Long Arm Cast
- Indications: Transradial amputation.
- Technique.
  - Administer adequate anesthesia.
  - After treatment of open wounds and application of a dressing, apply a stockinette over the distal edge of the residual limb.
  - Apply 4-inch Webril from the residual limb to the axilla.
  - Apply 4-inch plaster from the residual limb to the axilla.
  - Use plaster to incorporate a Cramer wire splint over the distal edge of the residual limb in order to apply skin traction.
  - Bivalve the cast.
  - Label the cast with dates of injury and surgery(ies).
Injuries to the Hands and Feet

Introduction
Combat injuries to the hands and feet differ from those of the arms and legs in terms of mortality and morbidity. Death is rare, but a minor wound, causing no lasting impairment if inflicted, for example, on the thigh, can result in life-long disability when it occurs in a hand or foot. The hands and feet have an important commonality: an intricate combination of many small structures that must function smoothly together.

Types of Injury
- Nonbattle injuries resulting in laceration of the hands and crush injuries involving either the hands or feet are common. Such crush injuries may result in compartment syndrome.
- Missile and blast injuries involving the hands and feet are common in combat and may result in mutilating injuries with a permanent loss of function.

The Hand

Even apparently minor wounds distal to the wrist crease may violate tendon sheaths and joints, resulting in a serious deep space infection. Such wounds require a high index of suspicion for injury and a low threshold for operative exploration.

Evaluation and Initial Management
- The casualty’s upper extremities should be exposed.
- Rings, watches, and other constrictive material must be removed immediately.
Emergency War Surgery

- A preliminary neurologic exam should be performed and documented.
- Vascular status of the hand should include an assessment of radial and ulnar arteries (Allen test, Doppler, among others).

**Treatment of Hand Compartment Syndrome**
- The hand has 10 separate fascial compartments (4 dorsal interossei, 3 volar interossei, the thenar muscles, the hypothenar muscles, and the adductor pollicis [Fig. 26-1]).

**Fig. 26-1.** Compartments of the hand.

- A complete hand fasciotomy consists of four incisions (shown in Fig. 26-2).
- One incision on the radial side of the thumb metacarpal releases the thenar compartment.
- A dorsal incision over the index finger metacarpal is used to release the 1st and 2nd dorsal interosseoi, and to reach ulnar-to-index finger metacarpal and to release the volar interosseoi and adductor pollicis.

**Fig. 26-2.** Hand fasciotomy incisions.
A dorsal incision over the ring finger metacarpal is used to release the 3rd and 4th dorsal interossei, and to reach down along the radial aspect of the ring finger and small finger metatarsal to release the volar interossei.

An incision is placed at the ulnar aspect of the small finger to release the hypothenar muscles.

Although compartments are not well defined in the fingers, grossly edematous fingers may require release of dermal and fascial constriction; care should be taken to place the skin incision away from the neurovascular bundles (Fig. 26-3).

**Surgical Technique**

Do not blindly clamp bleeding tissues because nearby nerves may be injured. If unable to control the bleeding with pressure, isolate the vessel under tourniquet control and tie off or clamp under direct vision.

General or regional (block) anesthetic is required; local infiltration of anesthetic is inadequate. Epinephrine is never injected into the hands or fingers.

Although either the radial or ulnar artery may be ligated, both should not be.

Thorough exploration under tourniquet down to normal tissue is mandatory to define the extent of the injury.

Debridement removes buried foreign matter and deep devitalized tissue.

- Dead tissue is removed.
- Tissue, including skin, with marginal or questionable viability is left for subsequent evaluation to improve chances for optimal outcome.

The fingers are not amputated unless irretrievably mangled.
Viable tissue, even though nonfunctional, is retained and stabilized for later reconstruction.

Provisional stabilization of fractures with Kirschner wires (K-wires) may enhance patient comfort and later management.

**Specific Tissue Management**

- **Bone**: Unless extruding from the body or severely contaminated, fragments should be left in place. At forward hospitals, only small K-wires should be used for internal fixation.
- **Tendon**: Minimal excision of tendons should occur. No attempt at repair should be made in the field.
- **Nerve**: Do not excise nerve tissue. No attempt at repair should be made in the field.
- The ends of lacerated nerves and tendons may be tagged with 4-0 suture so that they may be more easily identified later during definitive reconstruction and repair.

**Closure of wounds is delayed; however, exposed tendon, bone, and joint should be covered with viable skin, if possible, to prevent desiccation.**

**Dressing and Splinting**

**Fig. 26-4. Hand splint position.**

- Fine mesh gauze is first laid on the wounds and covered with a generous layer of fluffed gauze.
- The entire wound should be covered but the fingertips left exposed, if possible, to evaluate perfusion.
A splint is applied, immobilizing all injured parts and extending one bone or joint beyond. A palmar plaster slab is routine, but a dorsal one may be added for additional stability.

The Foot
Penetrating injuries of the foot frequently result in prolonged morbidity and disability. Crush injuries and injuries from blast are more likely to result in an unsatisfactory result than are wounds made by low-velocity bullets or isolated fragments. This is especially true when there is loss of the heel-pad, significant neurovascular injury or when the deep plantar space has been contaminated. The ultimate goal of treatment of these injuries is a relatively pain free, plantigrade foot with intact plantar sensation.

Evaluation and Initial Management
- The zone of injury with both open and closed injuries of the foot is often more extensive than is apparent with the initial inspection.
- The vascular status of the foot should be assessed by palpation of the dorsalis pedis and posterior tibial pulses. An assessment of capillary refill in the toes should also be made as a compartment syndrome of the foot can coexist with intact pulses.
- Anesthesia of the plantar aspect of the foot indicates an injury to the posterior tibial nerve or one of its major branches and portends a poor prognosis for a satisfactory outcome.
- Compartment syndrome of the foot can occur even in the presence of an open foot injury, and when identified, requires emergency treatment.
- At the time of debridement, small, contaminated bone fragments without soft tissue attachment should be removed.
- High-volume irrigation for all open wounds is mandatory.

All wounds should be left open.
Emergency War Surgery

Injuries to the Hindfoot
- Severely comminuted, open fractures of the talus may require talectomy, but this decision should be left to higher levels of care.
- The talus is best debrided through an anterolateral approach to the ankle extended to the base of the 4th metatarsal.
- Penetrating wounds into the plantar aspect of the heel pad can be approached through a heel-splitting incision to avoid excessive undermining of this specialized skin.
- Transverse gunshot wounds of the hindfoot are best managed by medial and lateral incisions with the majority of surgery performed laterally to avoid medial neurovascular structure.

Injuries to the Midfoot
- Tarsal and metatarsals are best approached through dorsal longitudinal incisions. In addition, compartment release can be adequately performed through longitudinal incisions medial to the 2nd metatarsal and lateral to the 4th metatarsal in order to leave a wide skin bridge.
- Contamination of the deep plantar compartments of the foot is best managed through a plantar medial incision that begins 1 inch proximal and 1 inch posterior to the medial malleolus and extends across the medial arch ending on the plantar surface between the 2nd and 3rd metatarsal heads. The medial neurovascular structures must be identified during this approach. A full compartment release can also be performed through this incision.

Injuries to the Toes
- Every effort should be made to preserve the great toe.
- Amputation of the lateral toes is generally well-tolerated.

Foot Compartment Syndrome
- There are 5 compartments in the foot.
  - The interosseous compartment is bounded by the lateral 1st metatarsal medially, metatarsals and dorsal interossous fascia dorsally, and the plantar interosseous fascia plantarly.
The lateral compartment is bounded by the 5th metatarsal shaft dorsally, the plantar aponeurosis laterally, and the intermuscular septum medially.

The central compartment is bounded by the intramuscular septum laterally and medially, the interosseous fascia dorsally, and the plantar aponeurosis plantarly.

The medial compartment is bounded by the inferior surface of the 1st metatarsal dorsally, the plantar aponeurosis extension medially, and the intramuscular septum laterally.

The calcaneal compartment contains the quadratus plantae muscle.

- The foot may be released through a double dorsal incision.
- One incision placed slightly medial to the 2nd metatarsal, reaching between the 1st and 2nd metatarsals into the medial compartment, and between the 2nd and 3rd metatarsals, into the central compartment (Fig. 26-5).
- A second dorsal incision is made just lateral to 4th metatarsal, reaching between 4th and 5th metatarsals into the lateral compartment.
- To spare the dorsal soft tissue, a single incision medial fasciotomy may be used.
A medial approach to the foot is made through the medial compartment, reaching across the central compartment into the interosseous compartment dorsally and lateral compartment releasing all the away across the foot (see description in this chapter’s Injuries to the Midfoot and Fig. 26-6).

Fasciotomy wound management.
- Following the fasciotomy, the fasciotomy wound undergoes primary surgical wound management; all devitalized tissue is removed.
- As with all battle wounds, the fasciotomy is left open and is covered with a sterile dressing.

Fig. 26-6. Central compartment releases through medial approach.

**Stabilization**
- K-wires can be utilized for temporary stabilization.
- A bivalved cast or splint is adequate for transport to a site of more definitive care.
Chapter 27

Vascular Injuries

Introduction

- History.
  - World War II: Popliteal artery injuries were routinely ligated with a 73% amputation rate.
  - Korean War: Formal repair of peripheral arterial injuries instituted.
  - Vietnam War: Further refinements in arterial repair; amputation rate for popliteal artery injuries is reduced to 32%.

- There are various types of wounds seen in combat.
  - Low-velocity missile damages a blood vessel lying directly in its path.
  - High-velocity missile blast effect causes fragmentation of the missile or bone and widespread destruction, including vascular injury at a distance.
  - Blunt trauma, often resulting from sudden deceleration in motor vehicle accidents, falls, rail and air disasters.
  - Popliteal artery injury associated with posterior knee dislocations.

Evaluation and Diagnosis

- Physical examination — detailed examination is paramount.
  - **Hard signs of arterial injury** (pulsatile external bleeding, enlarging hematoma, absent distal pulses, a thrill/bruit, or ischemic limb) should lead to immediate surgical exploration, without further preoperative studies.
  - The 6 Ps of acute ischemia are: pain, pallor, pulselessness, poikilothermia, paresthesia, and paralysis.
  - Degree of injury and adequacy of collateral flow will determine the severity of distal ischemia. **Remember:** Warm ischemia of striated muscle for > 4–6 hours will likely lead to myonecrosis and major amputation.
♦ Falsely attributing loss of pulse, diminished pulse, or asymmetry of pulses to arterial spasm may cause delay in detection/repair of limb-threatening arterial injury.

♦ Distal pulses may be intact in up to 20% of patients with arterial injuries.

- **Soft signs** of arterial injury that require additional diagnostic evaluation include proximity of wound to major vessels, history of hemorrhage/shock, nonexpanding hematoma, diminished pulse, and anatomically related nerve injury.

- Doppler examination.
  - A patient with penetrating or blunt trauma who has a normal distal pulse exam and ankle-brachial index (ABI) \( \geq 1.0 \) does not require arteriography.
  - In the patient without a palpable pulse distal to the injury, perform a Doppler examination and an ABI. ABI < 0.9 or a difference in ABI between extremities of > 0.1 indicate an arterial injury until proven otherwise. Because of extensive collateral flow, injuries to the deep femoral or deep brachial artery are not ruled out by this technique.

- Duplex ultrasound (US).
  - Color flow duplex ultrasonography has demonstrated high sensitivity and specificity for detecting arterial injuries. It is noninvasive, portable, and painless, and repeated exams are easily performed.
  - Duplex is highly operator-dependent and may fail to detect all arterial injuries (eg, deep femoral or tibial injuries).

- Contrast angiography.
  - Precise localization of vascular injury is useful in patients with multiple pellet wounds (eg, shotgun blast), fractures, and penetrating injuries to the neck and thoracic outlet.
  - Consider with high-velocity wounds, where arterial injury may occur outside the path of the missile, or in the presence of soft signs of arterial injury.
  - Consider as routine for knee dislocations where occult arterial injuries may occur, and undetected delayed popliteal artery thrombosis may lead to major amputation.
Management Aspects

- Initial management.
  - **Control external bleeding immediately!** Blind or imprecise placement of vascular clamps in a bloody field is discouraged. Direct pressure to the bleeding wound is preferable; temporary tourniquet (BP cuff) placed proximal to the injury site and inflated above systolic blood pressure may be useful.
  - Administer IV antibiotics, tetanus toxoid, and analgesia.
  - In most long-bone fractures, resuscitation and fracture alignment will restore distal flow.
  - **Indications for operation for a suspected vascular injury:**
    - Hard signs as discussed above.
    - Soft signs confirmed by duplex US and/or angiography.
- Operative management.
  - Preparation and draping of injured extremity as well as contralateral uninjured lower or upper extremity in case repair requires autogenous vein graft.
  - Surgical approaches to the femoral popliteal, and brachial arteries are shown in Figures 27-1–Figure 27-5.

![Inguinal anatomy](image)

**Fig. 27-1.** Inguinal anatomy.
Fig. 27-2. Exposure of distal femoral and popliteal vessels.

Fig. 27-3. Medial approach to popliteal vessels.
Fig. 27-4. Posterior approach to popliteal vessels.

Fig. 27-5. Exposure of brachial and radial arteries.
Longitudinal incisions usually directly over injured vessel followed by **proximal and distal control**. A tourniquet (e.g., blood pressure cuff) may occasionally be useful to obtain proximal control or to improve intraoperative visualization.

**Once control is obtained,** perform the following steps:
- Debride injured vessels to macroscopically normal wall.
- Pass balloon catheters proximal and distal to remove any residual thrombus.
- Flush both directions with heparinized saline.

**Consider temporary intraluminal shunting.**
- Successful shunt placement allows ample time for wound debridement and copious irrigation, identification of nerve injuries, and careful consideration of reconstruction vs primary amputation.

**Shunt placement technique.**
- Proximal and distal vessel control with Silastic vessel loops or Rumel tourniquet.
- Release proximal control to flush clot and place Argyle shunt.
- Distal thrombectomy (Fogarty catheter) until no clot is returned.
- Instill heparinized saline (20 U/mL) into distal vessel.
- Place shunt into distal end and secure.
- Check for distal pulse/perfusion.

In injuries to both artery and vein in which no shunt is used, **repair artery first** to minimize ischemic time, followed by venous repair.

**Suture:** 5-0 or 6-0 Prolene; 7-0 Prolene for small arteries. All completed repairs must be tension free.

Upon completion, forward and back bleed repaired segment until clear of air and debris prior to final closure.

**Type of repair** will depend on the extent of injury.
- **Lateral suture repair:** Required for minimal injuries that, when repaired, will not compromise the lumen > 25%, result in a thrill, nor decrease pulse or Doppler signal.
- **Patch angioplasty:** Needed for larger, tangential wounds; to prevent stenosis.
- **End-to-end anastomosis:** Excise extensively damaged segments and perform anastomosis if able to mobilize ends (generally, < 2 cm gap) without tension. An oblique anastomosis is less likely to stenose.
**Interposition graft:** Required if the vessel cannot be primarily repaired without undue tension.

- **Autogenous vein** grafts preferred, usually the contralateral greater saphenous vein (GSV).
  - Harvest vein from the contralateral limb, if possible. The reason for this is in the injured limb, superficial veins may be an important source of venous outflow if deep veins are injured.
  - Order of preference vein harvest for arterial conduit is contralateral GSV, ipsilateral GSV (if no concomitant deep venous injury), contralateral lesser saphenous vein (LSV), ipsilateral LSV (if no deep venous injury), cephalic vein, and basilic vein.

- **Prosthetic** grafts may be required when autogenous vein is inadequate or unavailable, expeditious repair is indicated, or for large vessels (aortoiliac system) for which there is a large size discrepancy.
  - Polytetrafluoroethylene (PTFE) grafts are more resistant to infection than Dacron and have acceptable patency rates when used in the above-knee position.
  - The use of prosthetic grafts can hasten the completion of a procedure in patients whose physiology requires expeditious surgery.
  - Prosthetics can also be used in areas of extensive soft-tissue debridement as a “prolonged shunt” where planned revision days to weeks later, out of theatre, will be expected.

- **Graft coverage:** Exposed vein grafts will desiccate, leading to graft blow-out and potential exsanguination. They must be covered by soft tissue or muscle; superficial muscles such as sartorius or gracilis in the thigh may be mobilized to cover a graft. If coverage is not possible, an alternate subcutaneous or subfascial route through uncontaminated viable tissue must be chosen.

- **Prolonged shunting:** If the above techniques are unsuccessful or precluded by patient physiology or the tactical environment, shunting (as outlined above) with the following modifications can be used for up to 72 hours.
  - Replace silastic loops with suture, and secure firmly.
Emergency War Surgery

- Systemic heparinization is not required.
- Monitor distal perfusion hourly.
- Re-evaluate/evacuate early for definitive repair.

- **Ligation of artery:** If the above options for repair are unsuccessful or unavailable, vessels can be ligated in light of known rates of morbidity. **Emphasis is Save Life Over Limb.**

- **Intraoperative completion angiogram** or duplex US (if available) should be done to evaluate the technical adequacy of the repair, visualize the runoff, and detect any missed distal clot.
  - Full strength contrast 30–60 cc.
  - 20 gauge Angiocath.
  - Inflow occlusion.

- **Venous repair:** Options are similar to arterial repairs outlined above.
  - **Ligation** of major veins is acceptable in life-threatening situations, although in a stable patient and time permitting, venous repair should be performed and may enhance arterial repair patency.

- **Compartment syndrome:** Muscle compartments of the forearm and palm in the upper extremity and anterior compartments of the lower leg are particularly susceptible.
  - Indications for fasciotomy:
    - ♦ 4–6 hour delay after vessel injury.
    - ♦ Combined vein and artery injury.
    - ♦ Arterial ligation.
    - ♦ Concomitant fracture/crush, severe soft-tissue injury, muscle edema or patchy necrosis.
    - ♦ Tense compartment/compartment pressures exceeding 40 mm Hg.
    - ♦ Prophylactic for patients with prolonged transport times or long periods without observation (no surgical care available enroute).
  - A standard two-incision, four-compartment approach for the calf is simple and effective (see Chapter 22, Soft-Tissue Injury).
  - Arm fasciotomy will consist of a longitudinal centrally placed incision over the extensor compartment and a curvilinear incision on the flexor aspect beginning at the antecubital fossa.
Post-op care.

- Palpable pulses obtained in the operating room (OR) should remain palpable post-op.
  - Pulse changes, even if Doppler signals remain, may indicate graft thrombosis and should be investigated.
- Consider low-dose heparin as deep vein thrombosis (DVT) prophylaxis.
  - Use with caution in multiply injured and head-injured patients.
- Slight elevation of injured extremity improves post-op edema.
Burn Injuries

Introduction
Burns constitute between 5% and 20% of combat casualties during conventional warfare, and are particularly common during war at sea and combat involving armored fighting vehicles. Even relatively small burns can be incapacitating, and can strain the logistical and manpower resources of military medical units. Optimal treatment currently results in salvage of approximately 50% of young adults whose burns involve 80% of the total body surface area (TBSA) or greater. Thus, in a battlefield triage scenario, expectant care should be considered for patients with burns that exceed 80%. Care can be delayed for those patients with burns of 20% or less who are otherwise stable.

Point-of-Injury Care
The following are key steps in the first aid of burn patients:

- **Stop the burning process.** Extinguish and remove burning clothing, and remove the patient from a burning vehicle or building. In an electrical injury, remove the patient from the power source, while avoiding rescuer injury. Wash chemical agents from the skin surface with copious water lavage.
- **Ensure airway patency, control hemorrhage, and splint fractures.**
- **Remove all constricting articles**, such as rings, bracelets, wristwatches, belts, and boots. However, do not undress the patient unless the injury has been caused by a chemical agent, in which case remove all contaminated clothing.
- **Cover the patient** with a clean sheet and a blanket, if appropriate, to maintain body temperature and to prevent gross contamination during transport to a treatment facility; special burn dressings are not required. Hypothermia is a complication of large surface area burns.
- **Establish intravenous access** through unburned skin if possible, and through burned skin if necessary. Intraosseous access is also acceptable.
- **Begin resuscitation** with lactated Ringer’s solution (LR) or similar solution, and continue during evacuation.
- Dress white phosphorus-injured patients with saline-soaked dressings to prevent reignition of the phosphorus by contact with the air.

**Primary Survey**

> Do not be distracted by the burn! The priorities of management for burn casualties are the same as those for other injured patients, with the addition of burn pathophysiology.

- The primary survey includes airway management (with cervical spine control, if appropriate given the mechanism of injury), diagnosis and management of any breathing condition, rapid circulatory assessment, and hemorrhage control. **In the burn patient, special attention to exposure, removal of clothing that continues to burn the victim, and prevention of hypothermia are important.**
- Airway.

- **Inhalation injury may be manifested by stridor, hoarseness, cough, carbonaceous sputum, dyspnea, and so forth.** It may cause airway obstruction at any time during the first 2 days postburn.
- Patients who may have sustained inhalation injury should be closely observed in an intensive care unit, and may be monitored without intubation if minimally symptomatic.
- Prior to transport, prophylactically intubate patients having/or who have symptomatic inhalation injury.
- Tubes, such as the orotracheal tube, should be definitively secured with cloth ties (eg, umbilical tape). Avoid adhesive tape.

- Cervical spine injury is uncommon in burn patients, except in those injured in explosions, high-speed vehicular accidents, and falls, or by contact with high-voltage electricity.
Burns are a “distracting injury,” pain secondary to burns, and the treatment of pain with narcotics, may make the clinical diagnosis of spinal injury difficult.

- Breathing.
  - Inhalation injury is more common in patients with extensive cutaneous burns, a history of injury in a closed space (e.g., building or vehicle), facial burns, and at the extremes of age.
  - Patients with major burns and/or inhalation injury require supplemental oxygen, pulse oximetry, chest radiograph and arterial blood gas measurement.
  - Circumferential burns of the chest may prevent effective chest motion. If this occurs, perform immediate thoracic escharotomy as a life-saving procedure to permit adequate chest excursion (see Fig. 28-1).
  - Definitive diagnosis of lower airway injury requires fiberoptic bronchoscopy.

**Fig. 28-1.** The dashed lines indicate the preferred sites for escharotomy incisions. The bold lines in the figure indicate the importance of extending the incision over involved major joints. Incisions are made through the burned skin into the underlying subcutaneous fat using a scalpel or electrocautery. For a thoracic escharotomy, begin incision in the midclavicular lines. Continue the incision along the anterior axillary lines down to the level of the costal margin. Extend the incision across the epigastrium as needed. For an extremity escharotomy, make the incision through the eschar along the mid-medial or mid-lateral joint line.

- Carbon monoxide (CO) poisoning causes cardiac and neurologic symptoms. Patients with CO poisoning require 100% oxygen for at least 3 hours or until symptoms resolve.

- Circulation.
  - Secure all cannulae (peripheral and central) with suture, because tape will not adhere well.
Cuff blood pressure (BP) measurements may be inaccurate in patients with burned or edematous extremities. Arterial BP is preferred.

**Estimation of Fluid Resuscitation Needs**

Initiate resuscitation with LR based on the patient’s weight and the burn size. Then, use the urine output as the primary index of adequacy of resuscitation (see below). It is equally important to avoid both over-resuscitation and under-resuscitation.

- **Determine the burn size** based on the Rule of Nines (Fig. 28-2). A patient’s hand (palm and fingers) is approximately 1% of the total body surface area (TBSA). Only 2nd and 3rd degree burns are included in burn size calculations.
  - Overestimation is common and may lead to over-resuscitation and over-evacuation.
- **Estimate crystalloid needs for the first 24 hours**, using the following formula:

\[
\text{Total Volume} = (2 \text{ mL}) \cdot (\% \text{ burn}) \cdot (\text{kg weight}).
\]

- Half of this total volume is programmed for the first 8 hours postburn, and half for the second 16 hours postburn:
  - Hourly rate, first 8 hours postburn
    \[
    = \left( \frac{\text{Total Volume}}{2} \right) / (8h - \text{elapsed time in hours since burn}).
    \]

*Fig. 28-2. Rule of nines, showing distribution of body surface area by anatomical part in the adult.*
Assume: 40% burn, 70-kg person, time of injury 1 h ago, (no fluids received yet).

Fluid Requirements for First 24 h = 2 x 40 x 70 = 5600 ml
One half of this to be given over first 8 h = 5600/2 = 2800 ml
But one hour has elapsed, therefore hourly rate =
2800 ml/7 h = 400 ml/h

- These calculations are only an initial estimate. Patients with inhalation injury, predominantly full-thickness burns, and delay in resuscitation will have higher fluid requirements. The rate of infusion of LR must be adjusted every 1–2 hours, based on physiologic response (see below). Despite the formula, no abrupt change is made at the 8-hour mark.
- If LR is not available, use other crystalloids such as normal saline. If crystalloid supplies are severely limited, consider starting colloid at the 12-hour mark, at the rate recommended for the second 24 hours (see below).
- Children (<30 kg) have a greater surface-to-weight ratio, and their fluid requirements are greater. The formula for children is based on 3 cc/kg/% burn.
  - In addition, children must be given a standard maintenance infusion of D5 1/2NS concurrently.

Monitoring the Burn Patient
- Two intravenous catheters (IVs), a Foley catheter, continuous ECG, pulse oximeter, core thermometer, and nasogastric (NG) tube are needed for ICU care of a patient with burns of 20% TBSA or greater.
- Vital signs and fluid input/output are recorded every hour on a flow sheet.
- NG decompression is essential for all patients with burns over 20% TBSA, due to potential gastric ileus.

Secondary Survey
- Perform a thorough head-to-toe secondary survey, looking for nonthermal injuries, to include corneal abrasion, tympanic membrane rupture, fractures, or dislocations.
- If there is a question of intra-abdominal injury, diagnostic peritoneal lavage, through burned skin if necessary, is appropriate.
Resuscitation Management, First 24 Hours

- On an hourly basis, reassess the patient’s urine output, which is the single most important indicator of the adequacy of resuscitation.

- Seek a urine output of 30–50 mL/h in adults or 1 mL/kg/h in children. If the urine output is less than the target for 1–2 consecutive hours, increase the LR infusion rate by about 25%. If it is greater than the target, decrease it by about 25%.
- Avoid over-resuscitation, which may lead to edema-related complications (e.g., compartment syndromes and pulmonary edema).
- Other indices of adequate resuscitation include a decreasing base deficit, a moderate tachycardia (typically a pulse of 100 to 130 is normal in adult burn patients), and an acceptable mental status.
- Diuretics are never indicated in the treatment of burn shock, except when gross pigmenturia is present (see below).
- Glycosuria is common following severe thermal injury and may cause hypovolemia secondary to osmotic diuresis. Check the urine for glucose and treat hyperglycemia with IV insulin as needed.

Resuscitation Management, Second 24 Hours

- At the end of the first 24 hours postburn, discontinue the LR. For the second 24 hours, use 5% albumin in normal saline.

- The 24-hour albumin volume is as follows:

  \[
  \text{5\% albumin volume} = (\text{\# mL}) \times (\% \text{TBSA burned}) \times (\text{preburn wt, kg})
  \]

  \[
  \begin{array}{|c|c|c|}
  \hline
  \% \text{TBSA burn} & 30–49 & 50–69 & 70+ \\
  \text{* mL} & 0.3 & 0.4 & 0.5 \\
  \hline
  \end{array}
  \]

  For example, in a burn of approximately 40% in a 70-kg patient:
  \[
  \text{Albumin volume} = (\text{\# mL}) \times (40\%) \times (70\text{kg}) = (0.3) \times (2,800) = 840 \text{ mL/24 h} = 35 \text{ mL/h}
  \]
Burn Injuries

- Burns < 30% TBSA do not require colloid infusion.
- It is rarely necessary to adjust the colloid infusion rate.
- If albumin is not available, fresh frozen plasma or synthetic colloid can be used at the same dose. If none of these is available, continue the LR until the 48th hour postburn, monitoring urine output, and so forth.
- At 24 hours, start D5W at half the last hourly rate of LR.
- Follow serum sodium closely. Resuscitation is usually complete by the 48th hour postburn. Continued evaporative water loss replacement is needed thereafter—beware of hypo- or hypernatremia!

Burn Wound Care
- The burn wound is not an early management priority, but must be attended to by 24 hours postburn.

\[\text{Initial burn wound care includes adequate IV pain management, removal of foreign bodies, debridement, cleansing with surgical soap (use only saline around the face), unroofing of all blisters, and application of a topical antimicrobial.}\]

- Adequate wound care requires adequate pain control. Small, intermittent boluses of IV morphine or fentanyl are effective for background pain control. Ketamine, 1 mg/kg IV, is generally effective for painful wound care.
- Apply a topical antimicrobial cream twice daily after thorough cleansing with a surgical detergent such as chlorhexidine gluconate Hibiclens.
- One-percent silver sulfadiazine (Silvadene), and/or 11.1% mafenide acetate (Sulfamylon), burn creams should be used. They are applied as a thick (1/16- to 1/8-in. thick) layer—not as a lotion.
- Following burn cream application, burns may be treated open or closed (wrapped in gauze).
  - Extremity wounds can be wrapped in a thick layer of roller gauze that is changed twice daily.
During the period of active wound exudation, it is helpful to place bulky dressings beneath the burned parts to absorb the exudate.

Burn cream should be reapplied to open burns as often as needed to keep them covered.

---

Burn victims must be adequately immunized against tetanus and (if arrival at the burn center will take longer than 24 hours) should be treated with a 5-day course of penicillin or similar antibiotic (intravenously for large burns, orally for small ones).

---

- Definitive burn surgery in the combat zone is generally not recommended.
- Prevent thermal (cold) stress by keeping the environment as warm as possible (> 85°F).
- Corneal abrasions in burn patients can lead to full-thickness ulceration and blindness, and require aggressive treatment with antibiotic ointments, preferably gentamicin or a quinolone every 4 hours, alternating with erythromycin every 4 hours.
- It is common for patients to develop a sterile, chemical cellulitis, manifested by an erythematous rim of normal tissue extending 1–2 cm around the wound margin. Erythema extending beyond this margin, with other clinical evidence of infection, likely represents beta-hemolytic streptococcal cellulitis. Consider vancomycin if penicillin has already been given. Treat with appropriate IV antibiotics.
- Invasive gram-negative burn-wound infection is heralded by striking changes in the color of the burn wound and a clinical course consistent with sepsis.
  - Initiate an aminoglycoside and a semi-synthetic antipseudomonal penicillin; apply Sulfamylon cream bid if available; and plan urgent evacuation.
  - Consider subeschar clysis (injection via a spinal needle) with the daily dose of an antipseudomonal penicillin (ticarcillin, piperacillin) in a suitable volume of crystalloid solution (eg, 500 mL). This is done at time of diagnosis, and then immediately prior to excision to fascia.
Burn Injuries

Daily inspection of the burn wound by a surgeon is essential to identify early infection complications.

Extremity Care

- Carefully monitor the extremities throughout the resuscitation period. The management of the burned extremity can be summarized as follows:
  - Elevate;
  - Exercise burned extremities hourly;
  - Evaluate pulses and neurologic status hourly; and
  - Perform escharotomy as indicated.
- In extremities with full thickness, circumferential burns, edema formation beneath the inelastic eschar may gradually constrict the venous outflow and, ultimately, arterial inflow. Adequate perfusion must be assessed hourly during resuscitation.

Progressive diminution of audible arterial flow by Doppler flowmetry is the primary indication for escharotomy. Doppler pulses should be sought in the palmar arch, not the wrist.

- Pulses may be difficult to palpate in edematous, burned extremities. However, in the absence of a Doppler flowmeter, and in the appropriate clinical setting, loss of palpable pulses may indicate a need for escharotomy.
- Patients requiring escharotomy often present with a tight and edematous extremity. They may have progressive neurologic dysfunction such as unrelenting deep tissue pain or paresthesias, and/or distal cyanosis.
- Prior to prolonged transport, strongly consider prophylactic escharotomy.
- Note that loss of the palmar arch Doppler signal, in the presence of adequate radial and ulnar pulses, is an indication for dorsal hand escharotomies. These are performed over the dorsal interossei. Digital escharotomies may be useful in some cases.
- Following escharotomy, document restoration of normal pulses and continue to monitor the patient. If one incision fails to restore pulses, make a second incision on the other side of the limb.
Emergency War Surgery

- After escharotomy, cover wounds, including the escharotomy incisions, in burn cream.
- The patient may still develop a true intramuscular, subfascial compartment syndrome requiring fasciotomy.
- Fractures associated with thermal injury are best treated by skeletal traction or by external fixation to permit exposure of the burns and their treatment with topical antimicrobials. Plaster, if used, should be bivalved immediately to permit access for wound care and to accommodate edema of the burned limb.

Other Considerations
- Burn patients manifest a hypermetabolic state, with hyperthermia, tachycardia, and hypercatabolism, which may be difficult to distinguish from early sepsis.
- Stress ulcer prophylaxis is critical (see Chapter 19, ICU Care).
- Early enteral nutrition—once hemodynamically stable, generally at 24 hours.
- Respiratory care.
  - About one week after injury, patients with subglottic inhalation injury may develop obstructing bloody casts. Inhaled heparin sodium, at a dose of 10,000 units, may be given by nebulization every 4 hours in order to prevent the formation of these casts.
  - Subglottic inhalation injury may persist longer than clinically evident. Extubation must be performed with caution after adequate airway assessment.
- Patients with large burns are at risk for abdominal compartment syndrome.

Electrical Injury
- High-voltage electrical injury (>1,000 volts) causes muscular damage that often is much greater in extent than the overlying cutaneous injury.
- Examine the extremities for compartment syndrome and perform urgent fasciotomy as needed.
- Gross pigmenturia (myoglobinuria) may result, and fluid resuscitation must be modified to protect against renal injury.
Pigmenturia is diagnosed by reddish-brownish urine, with a dipstick test which is positive for blood, but with insignificant numbers of red blood cells on microscopy.

- Increase the hourly LR rate until a urine output of 100 ml/h is achieved.
- If this fails to cause a progressive clearing of the urinary pigmenturia over 3 to 4 hours, add 12.5 g mannitol to each liter of LR infused and consider invasive monitoring.
- Infusion of sodium bicarbonate in water (150 mEq/L) in order to alkalinize the urine may be useful.

- Hyperkalemia may occur as a result of rhabdomyolysis, and must be carefully assessed and treated, with calcium gluconate infusion, insulin, and glucose.
- Surgical debridement of nonviable muscle is the definitive treatment of myoglobinuria.

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.

- Patients with electrical injuries are also at high risk for spinal fractures.

**Chemical Burns**

- Initial treatment requires immediate removal of the offending agent.
  - Brush any dry materials off the skin surface before copious water lavage.
  - In the case of alkali burns, lavage may need to be continued for several hours.
  - Resuscitate and manage just as a thermal burn.

**White Phosphorus Burn**

- Most of the cutaneous injury resulting from phosphorus burns is due to the ignition of clothing, and is treated as a conventional burn.
Fragments of this metal, which ignite upon contact with the air, may be driven into the soft tissues.

First aid treatment of casualties with imbedded phosphorus particles includes copious water irrigation, and placement of a saline-soaked dressing that must be kept continuously wet.

Profound hypocalcemia, and hyperphosphatemia, have been described as effects of white phosphorus injury. Treat with IV calcium.

Rapid surgical removal of the identifiable particles is often required. UV light can be used to help locate them.

A dilute (1%) freshly mixed solution of copper sulfate has been used to help identify white phosphorus particles. However, this is no longer recommended because if the solution is absorbed, it can cause fatal hemolysis. If it is used, immediately wash it off with copious saline irrigation. Never apply it as a wet dressing.

Liberally apply topical antimicrobial burn creams postoperatively.

“How I Do It”: Excision and Grafting

Definitive burn care, including surgery and rehabilitation, is manpower and resource intensive; therefore it is generally inadvisable to perform excision and grafting of burns in a theater of operations. However, under certain circumstances, this may be unavoidable.

Patient Selection

Do not attempt to autograft patients with grossly colonized or infected wounds. Such patients are best treated with deep tangential excision or primary excision to fascia, followed by immediate placement of a biologic dressing such as gamma-irradiated allograft (Gammagraft, Promethean LifeSciences, Inc., Pittsburgh, PA). Many second-degree (partial thickness) wounds are likely to heal in 14–21 days with acceptable cosmetic and functional outcomes. Partial-thickness wounds which take longer to heal, are likely to heal with fragile or hypertrophic scar, and should be considered for grafting. Likewise, full-thickness burns will only heal by contracture and should be considered for grafting.
**Preparation**

When performing burn surgery in a theater of operations, it is preferable to perform several limited procedures (eg, 10% TBSA or less at each operation) in order to limit the physiologic stress of the operation. Plans for the operation must be discussed and rehearsed with all personnel involved, and the availability of OR equipment and postoperative dressings and splints must be ascertained. At least 4 units of PRBCs should be available for a patient undergoing a 10% TBSA excision. A single dose of prophylactic intravenous antibiotic, such as a first-generation cephalosporin, should be administered. (However, antibiotics effective against *Pseudomonas* and other gram-negative wound pathogens should be considered for patients with heavily colonized wounds.) Total IV general anesthesia (TIVA), based on ketamine, is very effective in burn patients. Select the donor sites to be used. Often, the anterior thighs are available and easy to harvest. However, any area of clean unburned skin can be harvested. Hair is removed from the donor site, and both the area to be excised and the donor site are prepped.

**Tangential vs Fascial Excision**

Many surgeons recommend that extensive burn wound excision of the extremities be performed after exsanguination and pneumatic tourniquet application to limit blood loss. Using a Weck knife for small areas, or a Blair knife (or similar) for large areas, the burn is tangentially excised to the level of viable tissue. When an area has been exsanguinated, absence of hemosiderin staining of the dermis or fat is the usual endpoint for tangential excision. When an area has not been exsanguinated, the usual endpoint is diffuse punctuate bleeding (in the dermis) or viable-appearing fat. When the surgeon believes that all nonviable tissue in the surgical field has been excised, gauze soaked in a 1:100,000 solution of epinephrine in lactated Ringer’s can be applied, followed by a tight ace wrap. The tourniquet is released and the wound is reassessed after 5–10 minutes. Hemostasis in the bed is then achieved by electrocautery. If available, topical hemostatic agents such as spray thrombin and fibrin sealant can be applied before letting the tourniquet down.
Alternatively, if the burn extends into fat and/or demonstrates evidence of invasive burn wound infection, the burn wound can be excised to the level of the investing muscle fascia, using electrocautery.

**Donor Site Harvesting**

The subcutaneous space of the selected donor site is clysed with a saline solution containing a 1:1,000,000 dilution of epinephrine. This technique reduces bleeding and can be used to round out irregular contours of the donor site when skin must be harvested from bony or irregularly shaped areas. It is particularly important to do this prior to harvesting the scalp to control bleeding. It is optional for most other locations. A pneumatic or electric dermatome is loaded with a wide blade and the thickness of the skin to be harvested is adjusted to a depth between 8/1,000 and 15/1,000 inch. It would be appropriate to use 10/1,000 for grafting of most sites. Many surgeons use skin harvested at a depth of 12/1,000 to 15/1,000 inch for the hands. If a powered dermatome is not available, skin grafts can be harvested using a manual dermatome or a Weck knife. Hemostasis of the donor site is achieved with the application of warm gauze packs, soaked in a 1:100,000 solution of epinephrine.

At the end of the procedure, the packs are removed and the donor site is dressed with a single sheet of rolled, fine-mesh gauze or xeroform (petrolatum and 3% bismuth tribromophenate) gauze. Donor sites can alternatively be dressed in a biosynthetic membrane material such as Biobrane. When the donor site is small, another alternative is to apply an occlusive transparent film dressing such as a large OpSite (Smith & Nephew, Largo, FL) to the donor wound.

**Application and Securing of the Graft**

The harvested split-thickness skin may be meshed. It would be appropriate in this case to use 1.5:1 or 2:1 for the arms; but unmeshed skin, or skin meshed 1:1 or 1.5:1, is preferred for the hands. If a mesher is not available, the graft can be pie-crusted.
using a scalpel. The graft is applied to the prepared bed and stapled in place. Over the hands, the graft is minimally expanded. Bridal veil (or another product to prevent shear, such as fine-mesh gauze) is applied over the grafted areas, followed by a moist gauze dressing. Dressings should be kept slightly moist, for example, by application of normal saline or aqueous 5% Sulfamylon solution (Bertek Pharmaceuticals Inc., Morgantown, WV) every 6–8 hours. Another option, when the grafted area is surrounded by normal skin, is the use of a vacuum-assisted closure device (V.A.C., Kinetic Concepts, Inc., San Antonio, TX).

Following dressings, the extremities are splinted, with the axilla at 90° horizontal with bedside troughs or in an airplane splint, elbow fully extended. Hands and wrist are splinted in the “beer can” position: wrist slightly extended (10°), metatarsophalangeal joints of the fingers flexed, interphalangeal joints fully extended, and thumb in 40°–50° of abduction with interphalangeal joint extended.

**Postoperative Care**
Donor sites dressed with fine-mesh gauze are treated open, with a heat lamp applied until the gauze is dry. Grafted extremities are immobilized for 4–5 days. Grafted sites are inspected 4–5 days after surgery. They should be inspected sooner in case of fever, malodor, or other evidence of infection. Moist dressings are continued until the interstices of the grafted area have entirely closed.

Physical and occupational therapy are begun as soon as graft take is sufficient to discontinue immobilization, usually 5 days after surgery. Extremities are splinted in the position of function at night. The dried gauze on the donor site is allowed to separate spontaneously, at which time the donor site can be recropped as necessary for further grafting. After all wounds are closed, the patient is fitted for custom compression garments. If garments are not available, compression can be achieved with ace bandages.
Introduction
The successful prevention and control of cold, heat, and altitude injuries depend on vigorous command interest, the provision of adequate clothing, and a number of individual and group measures. The medical officer must ensure that he or she understands how military duties impact the occurrence and severity of environmental conditions and advise the commander on preventive measures.

Cold Injuries
Trench foot and frostbite together have accounted for over 1 million US casualties in WW I, WW II, and the Korean War. Influencing factors include previous cold injury; fatigue; concomitant injury resulting in significant blood loss or shock; geographic origin; nutrition; tobacco use; activity; drugs and medication; alcohol; duration and exposure; dehydration; environment (temperature, humidity, precipitation, and wind); and clothing.

Non–Freezing Cold Injury
- Chilblain.
  - Results from intermittent exposure to temperatures above freezing, usually accompanied by high humidity and moisture; 1 to 6 hours of exposure.
  - Swelling, tingling pain, and numbness with pink-to-red flushing of skin (especially the fingers).
  - Extremities will be pruritic as they warm up.
  - Symptoms usually subside overnight; some superficial scaling may occur.
  - Mild joint stiffness may occur acutely but subsides in a few hours.
  - No permanent damage occurs.
Emergency War Surgery

- Pernio.
  - Continuum of events from chilblain.
  - Exposure for > 12 hours to cold and/or wet conditions.
  - Tight-fitting footwear can shorten exposure time and increase severity of injury.
  - Swelling is more severe; pain is more persistent than with chilblain.
  - Thin, partial-skin thickness, and necrotic patches (from dorsum of the hands or feet).
  - Plaques may slough without scarring but may be particularly painful for months or years.

- Trench foot.
  - Epidemiology / clinical appearance.
    - Occurs from prolonged exposure to cold, wet conditions or prolonged immersion of feet at temperatures as high as 17°C for > 12 hours. Shorter duration at or near 0°C results in the same injury.
    - Occurs in nonfreezing temperatures 0°C–12°C.
    - Can occur at higher temperatures from prolonged water immersion.
    - Blunt trauma of marching can produce more serious injury.
    - First symptom often is the feet becoming cold, mildly painful, and numb.
    - Tight footwear increases risk of trench foot.
    - Common symptoms are “cold and numb” or “walking on wood.”
    - Foot may appear swollen, with the skin mildly blue, red, or black.
    - Limb is hot and often hyperhidrotic.
    - On rewarming, pain is excruciating and does not respond to pain medication, including morphine.
    - As time progresses, liquefaction necrosis occurs distally, but more proximal tissue may also be compromised.
    - No sharp line of demarcation of dead from viable tissue.
    - Nerve, muscle, and endothelial cells are most susceptible to this long-term cooling.
    - Microvascular vasospasm with tissue ischemia is the apparent etiology of trench foot.
Postinjury sequelae include pain, numbness, loss of proprioception, and cold feet. Hyperhidrosis with subsequent paronychial fungal infections are common.

Life-long, life-changing injury.

**Treatment.**

- Prevent further cold exposure.
- Do not massage.
- Dry extremity, warm torso, and allow slow passive rewarming of feet. *Never immerse feet in warm or hot water.*
- Elevate feet.
- Rehydrate.
- If vesicles develop do not debride.
- Pain medication. The only effective approach is amitriptyline 50–150 mg at bedtime. Other analgesics are either completely ineffective, or (as with narcotics) do not actually relieve pain.
- Blisters should be left intact; ruptured blisters require meticulous antisepsis after unroofing.
- Systemic antibiotics and tetanus prophylaxis are indicated when there are nonviable tissues, as with any other contaminated wound, or when there is evidence of infection.
- Debridement of necrotic tissue may be required in trench foot.
- Macerated or damaged skin requires topical antibacterial precautions.
- Avoid trauma.
- Early mobilization is vital to prevent long-term immobility.
- Recovery is protracted and may require evacuation because trench foot may lead to weeks-to-months of pain and disability.
- Long-term sequelae are very common and include sensitivity to the cold (secondary Raynaud’s phenomenon), chronic pain, neurological impairment, and hyperhidrosis.
Emergency War Surgery

- Frostnip.
  - Exposed skin appears red or minimally swollen.
  - Tissue is not actually damaged.
  - Not true frostbite; freezing is limited to skin surface only.
  - Signals imminent likelihood of frostbite developing.
  - Resolves quickly with warming.

- Frostbite.
  - Results from crystallization of water in the skin and adjacent tissues exposed to temperatures below freezing.
  - Depth and severity of injury is a function of temperature and duration—the lower the temperature, the shorter the time required to produce injury.
  - At low temperatures in the presence of wind, exposed skin can freeze within a few seconds—starts distally and progresses up the finger or toe.
  - Freeze-front (line where the ice is formed in the tissues) is where liquefaction and necrosis occur. Tissues immediately proximal to this line may also die, but therapeutic modalities are directed at improving their survival.
  - Clinical appearance.
    - Skin initially becomes numb and feels stiff or woody.
    - Mottled, bluish, yellowish, “waxy,” or “frozen.”
    - Depth of involvement may be difficult to determine until demarcation occurs, which may take an extended period.
  - Frostbite grading.
    - Classification into degrees is primarily a retrospective evaluation and has little treatment value.
    - A more clinically useful grading typically divides injuries into superficial or deep.
    - Superficial frostbite.
      - Involves only the skin with swelling, mild pain, and minor joint stiffness.
      - No blisters form.
      - Nonmedical personnel can manage simply by rewarming.
    - Deep frostbite.
      - Involves deeper tissues to include bone.
      - White-hard, anesthetic, blanched, and inflexible.
◊ Skin will not move over joints.
◊ On rewarming, there is great pain and a blue-gray-to-burgundy color change.
◊ Blisters form and are clear, fluid-filled, or hemorrhagic (the latter indicates a more severe, deeper injury). They should be left in place; will slough in 7–10 days without consequence.
◊ Failure to form vesicles in an obviously deep-frozen extremity is a grave sign.
◊ Postinjury sequelae include Raynaud’s phenomenon; pain; paraesthesias; hyperhidrosis; loss of proprioception; cold, discolored feet; and gait modification.

- Field treatment (first aid).
  - Superficial (blanched cheeks, nose, ears, fingertips).
    - Warm with palm of hand or warm, wet cloth; warm fingers in armpits.
    - Emollients may help prevent skin from drying or cracking.
    - Do not massage, rub with snow, or warm part by an open fire or high-heat source.
    - Meticulous skin care is required.
  - Deep frostbite.
    - Prevent further cooling of body part as well as the patient as a whole.
    - Apply dry, sterile bandage and elevate involved extremity.
    - Protect from refreezing during evacuation.
    - Evacuate promptly to definitive medical care.

**Avoid thawing and refreezing; this leads to the greatest damage to tissue and the poorest outcome.**

- MTF treatment.
  - The outcome of a frozen extremity is not directly related to length of time frozen, but more importantly to the method of rewarming and any subsequent refreezing.
  - If the soldier will again be at risk for refreezing, no attempt at rewarming should be initiated; the soldier
should ambulate on the frozen extremities until he reaches definitive care.

♦ For transport, the patient’s extremity should be splinted, and padded with dry dressings and protected from heat sources that would slowly rewarm the extremity.

♦ Rapid rewarming (without the possibility of refreezing) is the treatment of choice.
  ♦ Immerse in gently circulating water (whirlpool bath) at 40°C (104°F) for at least 30 minutes longer than could be needed to defrost all affected tissues. If deep freezing of the leg or arm has taken place, thorough surgical fasciotomy is mandatory prior to rewarming, to prevent lethal increase in deep tissue pressures as ice melts. Extremities are rewarmed until pliable and erythematous at the most distal areas.
  ♦ Twice daily whirlpool baths at 40°C with topical antibacterial added to the water, together with oral ethanol. The alcohol reduces the need for analgesia and may improve outcome. Other drug regimens remain unproven.
  ♦ After rewarming, edema will appear within a few hours and vesicles form within the next 6–24 hours.
  ♦ Intensive mobilization is essential to avoid long-term immobility.

♦ Vesicles.
  ♦ Frostbite vesicles are typically left intact.
  ♦ Debridement is not recommended. Early surgery is only indicated in severely infected cases. Normally surgery should be delayed for at least 6 months.

♦ General considerations.
  ♦ Ibuprofen or ketorolac should be given as systemic thromboxane/prostaglandin inhibitors.
  ♦ Systemic antibiotics and tetanus prophylaxis are indicated when there are dead tissues, as with any other contaminated wound, or when there is evidence of infection.
  ♦ Dry, loose dressings may be applied.
  ♦ Cigarette smoking and/or nicotine use is contraindicated during treatment due to its effect on the microvasculature.
♦ Daily hydrotherapy is recommended. Pain control with NSAIDs and narcotics will be needed.
♦ Sequelae include contractures, cold sensitivity, chronic ulceration, arthritis, and hyperhidrosis.
♦ Frostbite cases will require prolonged hospital care (9 d on average); therefore, all but those with the most trivial injuries should be evacuated to more definitive care as soon as possible.
♦ Early surgery is indicated only in the most severe freeze-thaw-refreeze cases, where massive tissue destruction has taken place, and in some more severely infected cases. Normally, surgery should be delayed for at least 6 months (“Freeze in January, operate in July”).

Due to the inability to reliably predict the outcome in the postthaw period, there is no role for debridement/amputation of necrotic or potentially necrotic tissue in the initial treatment of frostbite.

Hypothermia
Hypothermia is classically defined as whole-body cooling below 35°C. Degree of hypothermia is further defined according to the body’s core temperature and the clinical effects seen in a given temperature range.

♦ Causative factors and prevention.
  o Water immersion.
  o Rain and wind.
  o Prolonged exposure to severe weather without adequate clothing. The insulation effect of clothing is markedly decreased with wetness, which increases the conductive heat loss.
  o Stay dry and avoid windy exposure.
  o Shivering can provide five times the normal metabolic heat production. Exhaustion and glycogen depletion decrease the time of shivering. Compromise of shivering due to inadequate food intake (skipping meals), exhaustion, heavy exercise, alcohol, and drugs increases threat of hypothermia.
Emergency War Surgery

- Mild hypothermia > 33°C (> 91°F).
  - Shivering, hyperreflexia.
  - Amnesia, dysarthria, poor judgment, ataxia, apathy.
  - Cold diuresis.
- Moderate hypothermia 28°C–33°C (82°F–91°F).
  - Standard hospital thermometers, mercury as well as digital, cannot measure temperatures below 34°C (93°F).
  - Stupor, loss of shivering.
  - Onset of atrial fibrillation and other arrhythmias.
  - Progressive decrease in level of consciousness, respiration, and pupillary reaction, eventual pupil dilation.
- Severe hypothermia < 28°C (< 82°F).
  - Increased incidence of ventricular fibrillation, which often occurs spontaneously.
  - Loss of motion and reflexes, areflexic at approximately 23°C (72°F).
  - Marked hypotension/bradycardia.
- Profound hypothermia < 20°C (< 68°F).
  - Asystole.
  - Lowest known adult survival from accidental hypothermia is 13.7°C (56°F).

Treatment

- Prehospital (field) treatment.
  - Awake patients.
    - Remove wet clothing; dry and insulate the patient.
    - Give oral sugar solutions to hydrate.
    - Walk out or transport to MTF. (This should be attempted if it is the only alternative because it is likely to worsen the condition.)
    - Although walking may deepen hypothermia due to the return of peripheral colder blood to the core, adequate prehydration decreases the postexposure cooling.
  - Comatose patients.
    - Patient should remain horizontal and be handled gently to avoid inducing arrhythmias; do not massage.
    - IV fluids, warmed to 40°C–42°C, if possible.
    - Do not use lactated Ringer’s solution because the cold liver cannot metabolize lactate; warm (40°C–42°C...
Environmental Injuries

[104°F–107.5°F]), D5NS is the fluid of choice.
♦ Remove wet clothes, dry, insulate, and add an outer vapor barrier. Wrap patient in multiple layers of insulation.
♦ Limit active rewarming principally to the body’s center/core only.
◊ Heated (40°C–45°C), humidified air/O₂ is the method of choice.
◊ Norwegian personal heater pack (charcoal heater), with warming tube placed into insulation wrap.
◊ Forced air (Bair Hugger) with rigid chest frame.
◊ Hot water bottles in groin/axilla.
♦ Intubation and heated ventilation may be performed.
♦ If apneic and asystolic, consider CPR, because the brain may survive longer.

Remember: The patient is not dead until he is warm and dead. Continue resuscitation, if possible, until patient has been rewarmed.

• Medical treatment.
  o Ventilate; apply CPR if asystolic or in ventricular fibrillation.
  o As the body cools, the peripheral vasculature constricts, causing pooling of cold acidotic blood.
  o Rewarming the periphery of the body rather than the core causes an inrush of this cold acidotic blood into the core, further dropping the core temperature (afterdrop), and worsening cardiac instability.
  o Core rewarming—peritoneal dialysis, thoracic lavage, heated and humidified oxygen, external warm blankets, and warm-water torso immersion.
  o For ventricular fibrillation.
    ♦ Bretylium tosylate, 10 mg/kg. Bretylium is the only known effective antidefibrillation drug for hypothermia. It remains functional in a cold heart. Other medications have not proven effective.
    ♦ Warmed IV (lactate and potassium-free).
♦ Monitor core temperature via esophageal (preferred) or rectal probes.
♦ Careful correction of acid/base balance.
♦ Rewarm core to 32°C (90°F) and attempt cardioversion (360 J). Continue rewarming and repeat. Defibrillate after every 1°C rise in temperature.
♦ Monitor potassium, glucose, temperature, and pH.
♦ Major causes of failure to resuscitate include elevating central venous pressure too fast or too early; attempting defibrillation when core temperature is below 32°C, or continuing to rewarm past 33°C when potassium levels are high and pH is low. If serum potassium levels are high, consider the use of intravenous glucose and insulin.
♦ Avoid other antiarrhythmics and other medications.
♦ Patients with core temperature (rectal) above 30°C can generally be rewarmed externally in a variety of methods including warm blankets, warm-water torso immersion. Patients below 30°C rectal should be considered more fragile and will often require internal methods of rewarming (ie, warm gastric, colonic, and/or bladder lavage; warm peritoneal lavage dialysis; warm thoracic lavage; and arteriovenous (blood rewarming). Lavage fluids should be warmed to 40°C–42°C (104°F–107.5°F).
♦ Core temperature will continue to drop after the patient is removed from the cold exposure. Continued temperature drop can have grave prognostic implication and increases the likelihood of fibrillation. Post-rewarming collapse of an apparently functional heart often leads to a nonresuscitable heart and death.

- Cardiopulmonary resuscitation.
  o If cardiac monitor shows any electrical complexes, check carefully for apical and carotid pulses before initiating CPR. If any pulse—however thready—is present, do NOT initiate CPR.
Environmental Injuries

Trauma patients should be considered to have hypothermia more profound than the core temperature indicates and be warmed more aggressively.

- Treatment of mild stable hypothermia.
  - Insulation.
  - Heat lamps.
  - Warmed IV fluids.
  - Warmed forced air (Bair Hugger). Hair dryers have been jury-rigged for this purpose.
  - Consider arteriovenous anastomoses (AVA) warming.
    - Immerse hand, forearms, feet, calves in water heated to 44°C–45°C (111°F–113°F).
    - Opens AVAs in the digits causing increased flow of warmed venous blood to the heart and decreases afterdrop.

- Treatment of severe hypothermia with hemodynamic instability.
  - Cardiopulmonary bypass with rewarming, when available, is the ideal technique in this circumstance because it provides core rewarming while ensuring circulatory stability.

Heat Injury
In the military setting, heat illness occurs in otherwise healthy individuals, and ranges from mild (heat cramps) to life threatening (heatstroke). Individuals typically present with exertional heat illness and are hot and sweaty, not hot and dry as seen in classic heatstroke.

Lack of sweating is not a criterion for heatstroke. Some military casualties of heatstroke have profuse sweating, especially with rapid onset of heatstroke.

Minor heat illnesses include heat cramps and heat exhaustion. Major heat injuries include exertional heat injury (EHI), exertional rhabdomyolysis, and heat stroke. The diagnostic categories of heat exhaustion, EHI, and heat stroke have overlapping features and should be thought of as different
regions on the continuum rather than discrete disorders, each with its own distinct pathogenesis.

- Heat injury prevention.
  - Easier to prevent than treat.
    - Occurs most commonly in unacclimatized individuals.
      - Acclimatization to heat requires 7–10 days.
      - Predeployment training in artificially warm environments does aid heat acclimatization.
      - One hour of progressively more difficult exercise sufficient to induce moderate sweating each day will maximize acclimatization. (Regular strenuous exercise sufficient to stimulate sweating and increase body temperature will result in a significant degree of heat acclimation.) Aerobic fitness provides cardiovascular reserve to maintain the extra cardiac output required to sustain thermoregulation, muscular work, and vital organs in the face of heat stress.
  - Utilize published work–rest cycle guides (e.g., FM 21-10/MCRP 4-11.1D) or work–rest cycles tailored to the individual’s physical capacity by direct medical oversight.
  - Water restriction/discipline leads to increased heat injury and is contraindicated.
    - Acclimatization does not reduce, and may actually increase, water requirements.
    - Service members will on average not feel thirsty until 1.5 L (1%–2%) dehydrated.
    - Fluid intake should be monitored to ensure urine appears dilute. Additionally, soldiers should be monitored for body weight changes and orthostatic blood pressure changes due to hydration.
    - The GI tract can absorb only 1–1.5 L/h.
    - Daily rehydration should not exceed 12 L/d orally. **Too much hydration can also be dangerous and lead to water intoxication!**
    - Leaders must reinforce hydration by planning for all aspects of adequate hydration—elimination as well as consumption. (Soldiers may not drink at night to avoid awakening and having to dress to urinate, or soldiers may not drink prior to a convoy because no rest stops are planned.)
MOPP gear will increase fluid losses and the incidence of heat injuries.

In the first few days of acclimatization, sweat–salt conservation will not be fully developed. Salt depletion is a risk if soldiers are exposed during this time to sufficient heat or work stress to induce high sweating rates (> several liters per day), particularly if ration consumption is reduced. Salt depletion can be avoided by providing a salt supplement in the form of salted water (0.05%–0.1%). Acclimation should eventually eliminate the need for salt supplementation.

Salt supplements are not routinely required and are only recommended in rare instances where adequate rations are not consumed.

Coincidental illnesses increase heat casualty risk through fever and dehydration. Fever reduces thermoregulatory capacity leading to increased risk, even after clinical evidence of illness has disappeared. Requires increased command supervision and moderate work schedule.

Sunburn and other skin diseases of hot environments reduce the ability of the skin to thermoregulate. Sunburn must be prevented by adequate clothing, shade, and sunscreen. Skin diseases are best prevented by adequate hygiene.

Medications that effect thermoregulatory adaptations and increase risk of heat injury include anticholinergics, antihistamines, diuretics, tricyclic antidepressants, major tranquilizers, stimulants, and beta blockers.

Despite preventive measures, service members may suffer from heat illness. One case of heat illness is a warning sign that many others are imminent. The most life-threatening condition is heatstroke. Severity of heat illness depends on the maximum core temperature and duration.

- **Heatstroke.**
  Heat stroke is distinguished from heat exhaustion by the presence of clinically significant tissue injury and/or altered mental status. Degree of injury appears to relate to both the degree of temperature elevation and duration of exposure.
Emergency War Surgery

Clinical presentation.
♦ Heat stroke is a true emergency. Involves five organ systems: brain, hemostatic, liver, kidneys, and muscles.
♦ Encephalopathy ranges from syncope and confusion to seizures or coma with decerebrate rigidity. Profound neuropsychiatric impairments present early and universally in casualties of advanced exertional heat stroke.
♦ Coagulopathy: thermal damage to endothelium, rhabdomyolysis, and direct thermal platelet activation causes intravascular microthrombi. Fibrinolysis is secondarily activated. Hepatic dysfunction and thermal injury to megakaryocytes slow the repletion of clotting factors. Hepatic injury is common. Transaminase enzyme elevation (values 100 or more times the upper normal limit), clotting factor deficiencies, and jaundice (within 24–36 h of onset). Transaminase levels may be transient and reversible, but if they persist 48 hours, it is indicative of more severe injury. Hypoglycemia is a frequent complication of exertional heat stroke.
♦ Renal failure: myoglobinuria from rhabdomyolysis in exertional heat stroke, acute tubular necrosis due to hypoperfusion, glomerulopathy due to disseminated intravascular coagulation (DIC), direct thermal injury, and hyperuricemia.
♦ Muscles are often rigid and contracted: Rhabdomyolysis is a frequent acute complication of exertional heat stroke. Acute muscular necrosis releases large quantities of potassium, myoglobin, phosphate, uric acid, and creatine, and sequesters calcium in exposed contractile proteins.

If heat stroke is suspected and temperature is elevated, cooling should not be delayed to accomplish a diagnostic evaluation. Cooling and evaluation should proceed simultaneously.

The patient with heat stroke requires immediate evacuation to medical facilities with intensive care capabilities. Active cooling should be started immediately and continued during evacuation.
Prodomal symptoms include headache, dizziness (lightheadedness), restlessness, weakness, ataxia, confusion, disorientation, drowsiness, irrational or aggressive behavior, syncope, seizures, or coma.

Collapse is a universal feature of heat stroke.

An individual with a core temperature of $\geq 40^\circ C$ (104°F) and CNS dysfunction that results in delirium, convulsions, or coma has heat stroke.

Casualties who are unconscious and have a core temperature of $\geq 39^\circ C$ (102.2°F) have heatstroke.

Core temperature is often lower on arrival at a treatment area.

Seizures.

- Occur frequently (> 50% of cases) with heatstroke.
- Hinder cooling efforts.
- Treat with diazepam 5–10 mg.

Treatment.

- Rapid cooling can reduce heat stroke mortality anywhere from 50% down to 5%. Cooling by spraying cool water over the body and vigorous fanning can be effective though not as effective as ice water immersion. Any effective means of cooling is acceptable.
- A variety of techniques have been used, and, while evaporative cooling is less effective, the ice immersion method may prevent safe cardiac monitoring or rapid resuscitation.
- Cool water immersion (20°C) with skin massage is the classic technique. It provides rapid cooling. Closely monitor patient for, and prevent, shivering.
- Cooling with cool-water–soaked sheets or ice chips and vigorous fanning is highly effective.
- Do not use alcohol in the cooling solution because freezing of the skin can occur.

The goal of treatment is to effect a rapid lowering of the core temperature to 38°C (101°F), without inducing shivering.
Rectal temperature should be closely monitored during cooling. Discontinue cooling efforts when core temperature reaches 38.3°C (101°F) to avoid hypothermia.

Aspirin and acetaminophen should NOT be given to casualties of heatstroke.

Aggressive fluid resuscitation is not required. Fluid requirements of 1 L in the first 30 minutes, with an additional 2 L or more in the next 2 hours may be sufficient. Because heat stroke patients are frequently hypoglycemic, the initial fluid should include dextrose (chilled IV fluid is of limited benefit).

Base further hydration on fluid status/urinary output (Foley required).

Overhydration can lead to congestive heart failure, cerebral edema, and pulmonary edema in the heat-stressed lung.

If shivering develops, treat with diazepam (5–10 mg IV) or chlorpromazine (50 mg IV).

Patients are frequently agitated, combative, or seizing. Diazepam is effective for control and can be administered IV, endotracheally, or rectally, but should be used with caution.

Airway control is essential. Vomiting is common and endotracheal intubation should be used in any patient with a reduced level of consciousness, or otherwise unable to protect the airway. Supplemental oxygen should be provided when available.

Hypotensive patients who do not respond to saline should receive inotropic support. Careful titrated use of dopamine or dobutamine is reasonable and has the potential added advantage of improving renal perfusion.

Pulmonary artery wedge pressure monitoring should be used in patients with persistent hemodynamic instability.

Management of encephalopathy is supportive in nature and is directed at minimizing cerebral edema by avoiding fluid overreplacement and by assuring hemodynamic, thermal, and metabolic stability. IV mannitol has been used to treat life-threatening cerebral
edema, but is questionable unless renal function is adequate and the patient is fully hydrated. The efficacy of dexamethasone for treating heat-stroke–induced cerebral edema is not known.

Complications.

♦ Rhabdomyolysis and secondary renal failure due to myoglobinuria and hyperuricemia; hyperkalemia; hypocalcemia; and compartment syndromes due to muscle swelling.

◊ Elevated creatine phosphokinase (CPK) (in the thousands).

◊ Administer IV fluid and possibly furosemide to maintain urinary output > 50 cc/h. (Assurance of adequate renal perfusion and urine flow will moderate the nephrotoxic effects of myoglobin and uric acid.)

◊ Hyperkalemia can be managed by K/Na ion exchange resin (Kayexalate) given orally or rectally as an enema. If available, dialysis may occasionally be indicated.

◊ Hypocalcemia does not usually require treatment.

◊ Increasing tenderness or tension in a muscle compartment may represent increasing intracompartmental pressures. Direct measurement of intramuscular pressure or fasciotomy should be considered. Pain and paresthesia from a compartment syndrome may not be present until after permanent damage has occurred.

♦ Alkalinize urine with sodium bicarbonate IV (2 amps NaHCO₃/L D5W). Management of acute renal failure requires exquisite attention to fluid and electrolyte balance. Uremic metabolic acidosis and hyperkalemia require dialysis for control.

♦ Coagulopathy due to hepatic injury.

◊ Hepatic injury is common, resulting in transaminase enzyme elevation, clotting factor deficiencies, and jaundice. Transaminase levels may be transient and reversible, but if they persist 48 hours, then it is indicative of more severe injury.
◊ Worst prothrombin time occurs at 48–72 hours postinjury.
◊ Thrombocytopenia and disseminated intravascular coagulation (DIC) peak at 18–36 hours postinjury.
◊ Beware of the coagulopathy timeframe when planning evacuation.
◊ Subclinical coagulopathy does not require active management. Clinically significant bleeding is an ominous sign. Treatment is directed at reducing the rate of coagulation and replacement of depleted clotting factors. Intravascular coagulation can be slowed by cautious heparin infusion (5–7 U/kg/h), followed in 2–3 hours by FFP and platelets. Successful management leads to a decline in indices of fibrinolysis (eg, fibrin split products). Heparin is tapered gradually over 2–3 days as directed by laboratory evidence of control.
◊ Monitor for hypo- or hyperglycemia.
◆ Prognosis is worse in patients with more severe degrees of encephalopathy. Permanent neurologic sequelae can develop after heat stroke, including cerebellar ataxia, paresis, seizure disorder, and cognitive dysfunction.
◆ Neurologic deterioration after initial recovery may represent intracranial hemorrhage related to diffuse intravascular coagulation or hematoma related to trauma unrecognized at the time of initial presentation.
◆ Other complications include gastrointestinal bleeding, jaundice, aspiration pneumonia, noncardiogenic pulmonary edema, and myocardial infarction. Immune incompetence and infection are late complications, particularly in patients with severe renal failure.
◆ Hyperkalemia is the most life-threatening early clinical problem. Measurement of serum potassium is an early priority.
● Heat cramps.
  ◦ Clinical presentation.
    ◦ Brief, intermittent, recurring, and often excruciating tonic muscle contractions that last 2–3 minutes. Preceded by palpable or visible fasciculations.
♦ Typically involve muscles of the abdomen, legs, and arms (voluntary muscles of the trunk and extremities). Smooth muscle, cardiac muscle, the diaphragm, and bulbar muscles are not involved.
♦ Occur often with heat exhaustion. (Despite the salt depletion associated with heat cramps, frank signs and symptoms of heat exhaustion are unusual.)
♦ There are no systemic manifestations except those attributable to pain.
♦ Occur in healthy individuals who exercise for prolonged periods in warm environments.
♦ Occur in salt-depleted patients, generally during a period of recovery after a period of work in the heat.
♦ Differential diagnosis: tetany due to alkalosis (hyperventilation, severe gastroenteritis, cholera), hypocalcemia, strychnine poisoning, black widow spider envenomation, and abdominal colic.

o Treatment.
◆ Mild cases can be treated with oral 0.1%–0.2% salt solutions. Salt tablets should not used as an oral salt source.
◆ Most “sports drinks” (diluted 1:1 with water) effective for mild cases.
◆ IV NS provides rapid relief in more severe cases
◆ Patients with heat cramps usually have substantial salt deficits (15–30 g over 2–3 days, usual dietary intake). These individuals should be allowed 2–3 days to replenish salt and water deficits before returning to work in the heat.

♦ Heat exhaustion.

o Clinical presentation.
◆ Thirst, headache, dyspnea, lightheadedness (orthostatic dizziness), profound physical fatigue, anorexia, confusion, anxiety, agitation, mood change, chills, piloerection, nausea, and vomiting. There is no combination of presenting symptoms and signs that is pathognomonic.
◆ Often accompanied by heat cramps.
◆ Oliguria, clinical dehydration, ataxia, tachycardia, and
tachypnea resulting in symptomatic hyperventilation with acroparesthesia and carpopedal spasm.

♦ Syncope may occur.
♦ Core temperature is $< 39^\circ C$ ($102.2^\circ F$), even at time of collapse.

ο Treatment.
♦ Oral rehydration (if patient is not vomiting).
♦ Parenteral fluids produce more rapid recovery: no more than 250 mL NS bolus without laboratory surveillance; after 2.5 L of plain saline, add dextrose as a source of energy (D2.5$\frac{1}{2}$NaCl); subsequent fluid replacement should be D5$\frac{1}{2}$NS or D5$\frac{1}{4}$NS. Individuals with significant salt depletion have coincident potassium depletion, often amounting to 300–400 mEq of KCl. To begin restoration of potassium deficit, inclusion of potassium in parenteral fluids after volume resuscitation is appropriate if there is no evidence of renal insufficiency or rhabdomyolysis.
♦ Does not require active cooling; however, because symptoms are difficult to distinguish from heat stroke, the safest course is to provide active cooling for all casualties who are at risk for heat stroke.
♦ Removal from hot environment.
♦ Stop exercising, move out of the sun.

♦ Minor heat illnesses.
ο Miliaria rubra, miliaria profunda, and anhidrotic heat exhaustion.
♦ Subacute (miliaria rubra) pruritic inflamed papulovesicular skin eruption that appears in actively sweating skin exposed to high humidity. Becomes generalized and prolonged (miliaria profunda); lesions are truncal, noninflamed papular, with less evidence of vesiculation than the lesions of miliaria rubra.
♦ Each miliarial papulovesicle represents an eccrine sweat gland whose duct is occluded at the level of the epidermal stratum granulosum by inspissated organic debris.
♦ Eccrine secretions accumulate in the glandular portion of the gland and infiltrate into the surrounding dermis.
Pruritus is increased with increased sweating.

Miliarial skin cannot fully participate in thermoregulatory sweating, therefore the risk of heat illness increases in proportion to the amount of skin surface involved. Sweat does not appear on the surface of affected skin.

Sleeplessness due to pruritus and secondary infection of occluded glands has systemic effects that further degrade optimal thermoregulation.

Miliaria is treated by cooling and drying affected skin, avoiding conditions that induce sweating, controlling infection, and relieving pruritus. Eccrine gland function recovers with desquamation of the affected epidermis, which takes 7–10 days.

Miliaria profunda causes an uncommon but disabling disorder: anhidrotic heat exhaustion (or tropical anhidrotic asthenia). Miliaria profunda causes a marked inhibition of thermoregulatory sweating and heat intolerance similar to that of ectodermal dysplasia. That individual is more at risk for heat exhaustion and at high risk of heat stroke in conditions tolerated by others.

Evacuation to a cooler environment until restoration of normal eccrine gland function.

Heat-induced syncope.

Due to a reduced effective blood volume. (Thermal stress increases risk of classic neurally mediated [vasovagal] syncope by aggravating peripheral pooling of blood in dilated cutaneous vessels.)

Symptoms range from light-headedness to loss of consciousness.

Typically someone standing in a hot environment.

Greatest risk on first day of heat exposure, subsequent risk decreases daily.

Risk almost zero after 1 week of heat exposure; however, syncope occurring during or after work in the heat, or after more than 5 days of heat exposure, should be considered evidence of heat exhaustion.

Core temperature is not elevated or only very minimally so.

Patient regains consciousness immediately after syncope.
Clinical evaluation and management should be directed toward the syncopal episode, not potential heat illness. Treatment is oral hydration and continued acclimatization.

- Heat edema.
  - Seen early in heat exposure.
  - Plasma volume expanding to compensate for the increased need for thermoregulatory blood flow.
  - In absence of other disease, condition is of no clinical significance.
  - Will resolve spontaneously.
  - Diuretic therapy is not appropriate and may increase risk of heat illness.

- Sunburn.
  - Reduces thermoregulatory capacity of skin.
  - Systemic effect: hyperthermia.
  - Preventable.
  - Affected soldiers should be kept from significant heat strain until the burn has healed.

- Heat tetany.
  - Rare; occurs in individuals acutely exposed to overwhelming heat stress.
  - Extremely severe heat stress induces hyperventilation.
  - Manifestations include respiratory alkalosis, carpopedal spasm, and syncope.
  - Treatment: removal from heat source and control of hyperventilation (rebreathing into paper bag to reverse respiratory alkalosis).
  - Dehydration and salt depletion are not prominent features.

**Altitude Illness**
Exposure of troops to the hypobaric hypoxia of altitude results in a decrement of performance, as well as the possible development of altitude illness. Altitude illness spans a spectrum from high-altitude bronchitis, to acute mountain sickness (AMS), to death from high-altitude pulmonary edema (HAPE) and high-altitude cerebral edema (HACE).
Altitude basics.
The occurrence of altitude illness is based on altitude and rapidity of ascent. Contributory factors include level of exertion, physiologic susceptibility, age, and coexisting medical conditions.

- Physiologic changes due to altitude begin to occur at just over 1,500 m (4,900 ft).
- These changes are the body’s attempt to acclimatize to altitude.
- Symptoms occurring below 2,250 m (7,400 ft) are rarely due to altitude illness.
  - Rapid ascent to high altitudes results in a high incidence of altitude illness.
  - Climbing Mt. Rainier brings one from sea level to 14,500 ft (4,400 m) in 36 hours and results in a 70% incidence of altitude illness. An ascent to a similar height over the course of 5 days would only result in a 5% incidence of altitude illness.
  - 10%–20% of soldiers who ascend rapidly (< 24 h) to altitudes between 1,800 to 2,500 m (6,000–8,000 ft) experience some mild symptoms
  - Rapid ascent to elevations of 3,600 to 4,300 m (12,000–14,000 ft) results in moderate symptoms in over 50% of the soldiers, and 12%–18% may have severe symptoms.
  - Rapid ascent to 5,300 m (17,500 ft) causes severe, incapacitating symptoms in almost all individuals.

Descent basics.
- Almost everything improves with prompt descent.
- For illness requiring descent, one should try to descend at least 1,000 m (3,300 ft) if not more.
- A Gamow bag (USA) (portable fabric hyperbaric chamber) or Certec SA (Europe) can temporize a patient if evacuation/descent is not possible.
- Symptoms typically resolve quickly with descent, but may linger for several days.
- Victims of HACE and HAPE should not reascend until 72 hours after symptoms abate, and then must ascend much slower than previously.
Victims of HACE or HAPE should descend at the earliest sign, before they become moribund and incapable of aiding in their own descent.

There are no reliable predictors of susceptibility to AMS except prior experience at altitude.

Incidence and severity of symptoms vary with initial altitude, rate of ascent, level of exertion, and individual susceptibility.

Vigorous physical activity during ascent or within 24 hours after ascent will increase both the incidence and severity of symptoms.

- If a soldier became ill previously at a given altitude he or she will likely become ill at the same altitude unless the ascent is slower to allow for better acclimatization.
- Physical fitness level has no effect on susceptibility to altitude illness.
- Oral sildenafil (Viagra) 50 mg qd increases exercise tolerance in healthy volunteers at altitude (5,200 m [17,000 ft]), although it has not been approved for this purpose. The role of this drug in the treatment and/or prophylaxis of AMS and HAPE has not been established.
- If a rapid ascent to altitude must be made, use prophylaxis against AMS.

Acute mountain sickness.

- AMS is the most common form of altitude illness.
- Onset is shortly after arrival at high altitude. Onset occurs 3–24 hours after ascent. Symptoms reach peak severity in 24–72 hours and usually subside over the course of 3–7 days.
- Further ascent without an acclimation period usually exacerbates symptoms and can result in increased incidence of HAPE and HACE. The majority of AMS cases do not progress to more serious altitude illness without continued ascent.
- Symptoms.
  - Headache: Symmetric, global in location, and throbbing in character. Most intense during night and shortly after
arising in the morning, attributed to increased hypoxemia caused by altitude-induced sleep apnea.

♦ Anorexia.
♦ Nausea.
♦ Fatigue (weakness).
♦ General malaise.
♦ Decreased coordination.
♦ Dizziness or light-headedness.
♦ Oliguria.
♦ Emesis (vomiting).
♦ Lassitude.
♦ Insomnia: Sleep disturbances with periodic breathing with recurrent apneic periods during sleep are usually present, but are not necessarily a component of AMS.

Diagnosis.
♦ Occurrence of a headache and at least one other sign/symptom in an individual who ascended from low (1,524 m or < 5,000 ft) to high altitude, or high altitude to higher altitude in the previous 24–48 hours.
♦ Differential diagnosis includes viral gastroenteritis, hangover, exhaustion, dehydration, carbon monoxide poisoning, and HACE.
♦ Presence of neurologic symptoms such as incoordination, ataxia, and excessive lethargy or cognitive dysfunction is indicative of progression to HACE, which requires immediate therapeutic intervention.

Prophylaxis for AMS.
♦ Gradual acclimation.
  ◇ Staged ascent: Soldiers ascend to intermediate altitudes and remain there for 3 or more days before ascending further.
  ◇ Graded ascent: Limits daily altitude gain to allow partial acclimation. Sleep altitude is most important. Have soldiers spend 2 nights at 2,743 m (9,000 ft) and limit the sleeping altitude to no more than 305 m (1,000 ft) per day above previous night’s sleep altitude.
  ◇ Combination of both staged and graded ascent is the safest and most effective prevention method.
Emergency War Surgery

♦ Diet: High carbohydrate diet (< 70% of total energy intake as carbohydrates) (stimulation of ventilation through increased carbon dioxide produced from metabolism of carbohydrates).

♦ Acetazolamide, 250 mg qid or 500 mg bid po, starting 48 hours before ascent, continuing for 48 hours after ascent. Side effects include peripheral paresthesias, fatigue, increased urination (polyuria), and altered taste imparted to carbonated beverages. It prevents AMS in 50%–75% of soldiers and reduces symptoms in most others. Short-term use when changing altitude significantly (400 m). **Contraindicated in sulfa allergy.**

♦ Dexamethasone, 4 mg qid po is the prophylaxis of choice in sulfa-allergic individuals. Dexamethasone does not aid acclimatization and effects are gone when it is stopped. Dexamethasone +/- acetazolamide is also prophylaxis of choice for missions of a rapid, high (over 4,000 m [13,000 ft]), short-duration profile (raids, rescues).

♦ Cyanosis: Oxygen 2–6 L/min. Do not delay descent.

♦ AMS alone does NOT mandate descent.

♦ Remain at the same elevation; do **not** ascend until symptoms abate.

♦ Acetazolamide, 125 mg qid to 500 mg, tid, po—do not use in patients with sulfa allergies. (If already receiving a preventive dose of acetazolamide (1,000 mg/d) and still symptomatic, 500 mg can be added with caution.

♦ Dexamethasone in doses of 2–4 mg q6h (has the same potentially serious side effects as when used as a prophylaxis). Symptoms may recur when medication stopped.

♦ Oxygen by nasal cannula 2–6 L/min (severe headache).

♦ Do NOT advance sleeping altitude.

♦ Symptomatic treatment with ASA, acetaminophen, prochlorperazine for nausea and vomiting 5–10 mg tid–qid, po or IM, or 25 mg bid prn also stimulates respiration; ibuprofen for headache.

♦ Minimize utilization of sleeping agents at altitude; they
Environmental Injuries

can worsen illness. Acetazolamide for sleep disorders, 250 mg qid or tid po. Temazepam for insomnia 30 mg qhs po; triazolam for insomnia 0.125–0.25 mg qhs po. Short-term use only. Possible short-term memory loss.

- High-altitude pharyngitis and bronchitis.
  - Common condition occurring after 2–3 weeks at altitude.
  - Common at altitudes over 5,486 m (18,000 ft).
  - Sore throat, chronic cough, and severe cough spasms (severe enough to cause rib fractures).
  - Environmental, from breathing cold dry air.
  - Altitude-induced tachypnea aggravates the problem.
  - Cold-induced vasomotor rhinitis, especially at night, stimulates mouth breathing and also aggravates problem.
  - Usually not caused by infection, although infection can occur.
  - Patient will not have dyspnea at rest.
  - Symptomatic treatment with lozenges, mild cough suppressant, and decongestant nasal sprays. Personnel can use a mask or a porous, breathable silk balaclava as a mouth covering to reduce respiratory heat and moisture loss.
  - Maintain hydration.

- High-altitude peripheral edema.
  - Altitude-related edema of hands and face.
  - Hypoxia-induced retention of sodium and water.
  - Not considered related to AMS/HACE edema-spectrum or HAPE.
  - Decreased urine output and weight gain of 2.7–5.4 kg (6–12 lb) over several days; most evident upon awakening.
  - Diagnosis based on association of characteristic peripheral edema with ascent to high altitude; recurs consistently with repeat ascents; more common in females.
  - Differential diagnosis includes cardiogenic edema, allergic reactions, and edema of the upper extremities caused by pack straps or binding by tight clothes.
  - Prophylaxis includes salt restriction. The acetazolamide regimen used to prevent AMS is often successful in preventing peripheral edema.
Emergency War Surgery

- Treatment with diuretics (one 20–40 mg dose of furosemide, or 250 mg of acetazolamide every 8 h for 3 doses) and salt restriction.

- High-altitude retinal hemorrhage (HARH).  
  - Bleeding from retinal vessels during altitude exposure.  
    One of the manifestations of hypoxia-induced retinopathy.  
  - Caused by BP “surges” within the distended vessels. 
  - Usually asymptomatic; normally does not adversely affect military operations; however, can affect an individual soldier’s vision. 
  - Hemorrhages are self-limiting and resolve in 1–2 weeks after descent.

- Thromboembolic events.  
  - Increased possibility of thromboembolic event with ascent to high altitude: thrombophlebitis, deep venous thrombosis, pulmonary embolus, transient ischemic attacks (TIAs), and stroke.  
  - Probably result from hypoxia-induced polycythemia and clotting abnormalities but also may result from environmental and mission factors such as dehydration, cold, and venous stasis caused by prolonged periods of inactivity during inclement weather or by constriction of tight-fitting clothing and equipment.  
  - Unusual below 4,267 m (14,000 ft). At very high and extreme altitudes (> 4,200 m [13,700 ft]) these events are not uncommon, and thrombophlebitis appears to be relatively common.  
  - Clinical manifestations are similar to manifestations of thromboembolic events at low altitude, except for their occurrence in young and otherwise healthy personnel. 
  - Prevention relies on reducing the risk factors by maintaining adequate hydration and warmth and by avoiding conditions that might cause venous stasis.  
  - Evacuation to lower altitude is required. Treatment follows standard treatment guidelines, including appropriate anticoagulation. In the field setting, fractionated heparin (one dose of 250 IU / d) can be used prior to and during evacuation.

- Subacute mountain sickness.
Prolonged deployment (weeks to months) to elevations above 3,658 m (12,000 ft).
Common manifestations include sleep disturbances, anorexia, weight loss, fatigue, daytime somnolence, and subnormal mentation.
Caused by failure to acclimatize adequately.
Some relief of symptoms obtained from low-flow oxygen and from acetazolamide.
Evacuate to lower altitude as soon as practical.
Some degree of immune suppression and poor wound healing occurs in personnel at very high and extreme altitudes. Injuries resulting from burns, ballistics, and physical trauma should be considered more clinically significant at high altitude.

High-altitude pulmonary edema.
Potentially fatal, noncardiogenic pulmonary edema.
Occurs in < 10% of personnel ascending above 3,700 m (12,000 ft).
Onset 2–4 days after rapid ascent to altitudes greater than 2,438 m (8,000 ft).
Repeated ascents and descents above 3,700 m (12,000 ft) increase susceptibility.
Risk factors.
- Moderate to severe exertion.
- Cold exposure.
- Anxiety.
- Young age.
- Male sex.
- Obesity (possibly).

Early symptoms (pulmonary edema).
- Nonproductive cough.
- Rales (few).
- Dysepsia on exertion.
- Fatigue.
- Weakness with decreased tolerance for physical activity and increased time for recovery after physical exertion.
- Resting tachycardia and tachypnea greater than induced by altitude alone.
Once symptoms appear, HAPE can progress very rapidly (< 12 hours) to coma and death.

- Nail beds and lips may be more cyanotic than other unit members.

**Progressing pulmonary edema.**
- Productive cough of frothy and sometimes pink or bloodstained sputum.
- Rales more numerous and widespread.
- Wheezing may develop.
- Lung sounds become audible even without stethoscope, especially when individual is supine.
- Orthopnea may occur (< 20%).
- Progressive hypoxemia causes dyspnea and cyanosis.
- Arterial blood gas (if available) documents hypoxemia, hypocapnia, and slight increase in pH.
- Mental status deteriorates with progressive confusion and sometimes vivid hallucinations.
- Obtundation, coma, and death occur without treatment.
- Subfebrile temperature < 38°C (100.5°F) and a mild increase in white blood cell count may be present.
- Dyspnea at rest.
- Marked hypoxia by oximetry.
- **Dyspnea at rest and cough should be considered to be the onset of HAPE.**

**DELAY IN TREATMENT OF PROGRESSIVE PULMONARY EDEMA AT ALTITUDE USUALLY RESULTS IN DEATH.**

**Treatment.**
- Depends on severity.
- Immediate descent is mandatory! Descent of even a few hundred meters (300–1,000 m) can be helpful or even lifesaving in severe cases.
- Mortality can approach 50% if descent cannot be accomplished rapidly.
- Oxygen by cannula 2–6 L/min (mild), or by mask 4–6 L/min (moderate and severe). **DO NOT DELAY DESCENT!**
♦ Portable fabric hyperbaric chamber may be lifesaving—Gamow bag/Certec SA.
♦ Nifedipine, 10 mg tid sublingually, or 20 mg po. A second 10-mg, sublingual dose can be administered in 15–20 minutes if no improvement in symptoms is apparent, followed by 30 mg qid.

**Nifedipine should not be used in lieu of descent, supplemental oxygen, or treatment in a hyperbaric bag. It may be used in conjunction with other therapies.**

♦ Immediate descent to lower elevation; if symptoms resolve, wait at least 72 hours before attempted return to previous elevation.

**Neither furosemide nor morphine sulfate should be used in the treatment of HAPE unless other more effective treatment options are not available.**

♦ Treatment after descent, at an MTF, is directed toward ensuring adequate oxygenation and reducing pulmonary artery pressure; includes bed rest, supplemental oxygen, and nifedipine.
♦ Invasive diagnostic procedures such as bronchoscopy or pulmonary artery catheterization are **NOT** indicated unless clinical course deteriorates and the diagnosis is in doubt. Endotracheal intubation is seldom necessary.
  o HAPE Prophylaxis.
    ♦ Nifedipine, 20 mg tid, po, 24 hours before ascent, continuing 72 hours after ascent.
  • High-altitude cerebral edema.
    o Onset following ascent is highly variable and occurs later than either AMS or HAPE. Mean duration of onset 5 days with a range of 1–13 days.
    o Incidence lower than AMS or HAPE (< 1% of individuals making rapid ascent).
    o Potentially fatal, uncommon (< 2% above 3,700 m). Can occur as low as 2,430 m (8,000 ft) but vast majority of cases
above 3,600 m (12,000 ft). Untreated HACE can progress to death over 1–3 days or become more fulminant with death occurring in < 12 hours.

- Exacerbation of unresolved, severe AMS.
- Most often occurs in people who have AMS symptoms and continue to ascend.

- Signs and symptoms.
  - Most signs and symptoms are a manifestation of progressive cerebral edema.
  - Early signs resemble AMS (these symptoms are not invariably present).
  - Severe headache
  - Nausea
  - Vomiting.
  - Extreme lassitude.

- Progressing signs.
  - Mental status changes: Confusion, disorientation, drowsiness, and impaired mentation.
  - Truncal ataxia (swaying of upper body, especially when walking). As the edema progresses, soldier may also exhibit an ataxic gait in addition to the truncal ataxia.
  - Soldier appears withdrawn, and behavior is mistakenly attributed to fatigue or anxiety.
  - Cyanosis and general pallor are common.
  - Symptoms of HAPE.

- Untreated HACE.
  - Variety of focal and generalized neurologic abnormalities may develop: visual changes, anesthesias, paresthesias, clonus, pathological reflexes, hyperreflexia, bladder and bowel dysfunction, hallucinations, and seizures.
  - Papilledema may be present in up to 50% of the soldiers, but is NOT universal.

- Coma.

- Ataxia at altitude is HACE.

- Prophylaxis.
Environmental Injuries

No definitive evidence; however, due to similarity with AMS, prophylactic measures for HACE include use of staged or graded ascent, high carbohydrate diet, and use of acetazolamide.

Treatment.

♦ Immediate descent is mandatory. Definitive treatment of HACE is immediate descent. In general, the greater the descent the better the outcome. Descent of more than 300 m (1,000 ft) may be required for clinical improvement, and descents to altitudes of less than 2,500 m (8,000 ft) is optimal.

♦ If descent is delayed, treatment with a portable cloth hyperbaric chamber may be lifesaving. May require at least 6 hours of pressurization in chamber.

♦ Oxygen by mask or cannula 2–6 L/m; should not be used as a substitute for descent.

♦ Dexamethasone, 4–8 mg initially and then 4 mg qid, po, IV, or IM. DO NOT DELAY DESCENT! Few side effects if used only 3–4 days.

♦ Loop diuretics and osmotic diuretic agents, such as mannitol, urea, and glycerol, have been suggested, but there is little experience with them in this role. Careful attention is required before diuretics are used. Individual may have altitude-induced decrease in intravascular volume concomitant with cerebral edema.

♦ Hospital management consists of supplemental oxygen (if needed to maintain arterial oxygen levels), supportive care, and possibly diuretics. Comatose patients may require intubation and bladder catheterization.

HACE and HAPE often coexist. Individuals with HACE will often have HAPE; however, most individuals with HAPE do not have concomitant HACE.
Emergency War Surgery
Chapter 30

Radiological Injuries

The reader is strongly advised to supplement material in this chapter with the following two references:


Introduction
Radiological casualties on the battlefield may occur with improvised or conventional nuclear devices or radiological dispersal devices (“dirty bombs”) (Table 30-1).

- Conventional nuclear weapons.
  - The relative casualty-causing potential depends primarily on four factors:
    - Yield of the weapon.
    - Height of burst.
    - Environmental conditions in which the detonation occurs.
    - Distribution and shielding of troops in the target area.
  - A nuclear detonation generally causes injuries with the following distribution:
    - Blast injury: 50%.
    - Thermal injury: 35%.
    - Ionizing radiation injury.
      - Initial: 5%.
      - Residual: 10%.
A radiological dispersal device (RDD) is any device, including any weapon or equipment, other than a nuclear explosive device, specifically designed to spread radiation.

- RDDs contaminate conventional casualties with radionuclides, complicating medical evacuation.
- RDDs are ideal weapons for terrorism and are used to intimidate and deny access to an area by spreading radioactive material.

### Table 30-1. Radiological casualties.

<table>
<thead>
<tr>
<th>Weapon Effect</th>
<th>Weapon Yield (Kiloton)/Distance (Meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 kt</td>
</tr>
<tr>
<td>Blast (50% casualties)</td>
<td>140 m</td>
</tr>
<tr>
<td>Thermal radiation (50% deep burns)</td>
<td>370 m</td>
</tr>
<tr>
<td>Ionizing radiation (50% immediate transient ineffectiveness)</td>
<td>600 m</td>
</tr>
<tr>
<td>Ionizing radiation (50% lethality)</td>
<td>800 m</td>
</tr>
</tbody>
</table>

### Triage

- Different from conventionally injured patients, because survivable radiation injury is not manifested until days to weeks after exposure.
  - Based primarily on conventional injuries, then modified by radiation injury level.
  - Make a preliminary diagnosis of radiation injury only for those with exposure symptoms, such as nausea, vomiting, diarrhea, fever, ataxia, seizures, prostration, hypotension.
  - Radiation patient triage classifications.
  - **Delayed**: casualties with only radiation injury, without gross neurological symptoms (ataxia, seizures, impaired cognition). For trauma combined with radiation injury, all surgical procedures must be completed within 36–48 hours of radiation exposure, or delayed until at least 2 months after the injury.
♦ **Immediate**: those requiring immediate lifesaving intervention. Pure radiation injury is not acutely life-threatening unless the irradiation is massive. If a massive dose has been received, the patient is classified as Expectant.

♦ **Minimal**: buddy care is particularly useful here. Casualties with radiological injury should have all wounds and lacerations meticulously cleaned and then closed.

♦ **Expectant**: receive appropriate supportive treatment compatible with resources; large doses of analgesics as needed.

- Table 30-2 provides medical aspects of radiation injuries.

### Table 30-2. Medical aspects of radiation injuries.

<table>
<thead>
<tr>
<th>Probability/degree of exposure</th>
<th>Signs and Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nausea</td>
</tr>
<tr>
<td>Unlikely</td>
<td>–</td>
</tr>
<tr>
<td>Probable</td>
<td>++</td>
</tr>
<tr>
<td>Severe</td>
<td>+++</td>
</tr>
</tbody>
</table>

The lethal dose of radiation, which will kill 50% of a population within 60 days of exposure, is called $LD_{50/60}$. The $LD_{50/60}$ is approximately 3–4 Gray (Gy) for a population with radiation injury alone and with no significant medical care. The $LD_{50/60}$ for a population with radiation injury alone and the best available medical care (including antiemetics, antivirals, antibiotics, hematopoietic cytokines, and transfusion) may be 6 Gy or more. Combined injuries with radiation and trauma and/or burns will markedly lower the $LD_{50}$.  

Emergency War Surgery

Significant medical care may be required at 3–5 weeks for 10%–50% of personnel. Anticipated problems should include infection, bleeding, fever, vomiting, and diarrhea. Wounding or burns will markedly increase morbidity and mortality.

- **Treatment.**
  - o Fluid and electrolytes for GI losses.
  - o Cytokines for immunocompromised patients (follow granulocyte counts).
  - o Restricted duty. No further radiation exposure, elective surgery, or wounding. May require delayed evacuation from theater during nuclear war IAW command guidance.
  - o If there are more than $1.7 \times 10^9$ lymphocytes per liter, 48 hours after exposure, it is unlikely that an individual has received a fatal dose.

Patients with low (300–500) or decreasing lymphocyte counts, or low granulocyte counts, should be considered for cytokine therapy and biological dosimetry using metaphase analysis where available.

- Asymptomatic patients with lethal radiation dose may perform usual duties until symptomatic.

**Potential Injuries**

- **Thermal/flash burns** or thermal pulse burns are caused directly by infrared radiation. Close to the fireball, the thermal output is often so great that everything is incinerated, and even at great distances, thermal/flash burns will occur (see Chapter 28, Burns, for management).
  - o Burn mortality rates associated with radiation exposure are significantly higher due to bone marrow suppression and infection (a 50% TBSA burn associated with radiation exposure has a mortality of 90%).

- **Blast injuries** associated with a nuclear detonation include:
  - o Direct blast wave overpressure forces measured in terms of atmosphere overpressure.
  - o Indirect blast wind drag forces, measured in terms of wind velocity, which may displace large objects such as vehicles or cause the collapse of buildings.
Radiological Injuries

- **Radiation injuries** are due to ionizing radiation released both at the time of the nuclear detonation and for a considerable time afterward. The two types of radiation released are electromagnetic (gamma) radiation and particulate (alpha, beta, and neutron) radiation.
  - Alpha particles can be shielded against by clothing.
  - Beta particles shielding requires solid materials, like a wall.
  - Gamma and neutron radiation are the most biologically active, and require lead equivalent shielding for protection.
  - Fission products are the major radiation hazard in fallout, because a large number emit penetrating gamma radiation. This can result in injuries, even at great distances.
  - Fallout causes whole body irradiation from gamma-emitting isotopes, because they do not actually have to be on a person’s skin to cause damage.

- **Flash blindness** may occur as the result of a sudden peripheral visual observation of a brilliant flash of intense light energy. **Retinal burns** may also occur and result in scarring and permanent altered visual acuity.

#### Treatment of Combined Injuries

- Following the detonation of a nuclear device, the majority of resulting casualties will have sustained a combination of blast, thermal, and radiological injuries.
- The usual methods of treatment for blast injuries must be modified in those casualties simultaneously exposed to ionizing radiation.

Traditionally, combat wounds are left open. However, wounds left open to heal by secondary intention in the irradiated patient will serve as a nidus of infection. **Wounds exposed to ionizing radiation should be debrided and closed at a second-look operation within 36–48 hours.**

- Hypotension should always be assumed to be hypovolemia and not due to radiologic injury.
- Hyperthermia is common.
- Radiological injuries increase the morbidity and mortality of injuries due to compromise of the normal hematopoietic and
immune responses to injury. Surgical procedures may need to be delayed during bone marrow suppression if at all possible.

- Potassium iodide may be used for prevention of thyroid uptake of radioisotopes after nuclear reactor accidents.
- Chelating agents may be used to eliminate metals from the bloodstream before they reach target organs.
- Mobilizing agents are used to increase the excretion of internal contaminants.
- Prussian blue is used to remove radionuclides from the capillary bed surrounding the intestine and prevents their reabsorption. Delay until patient is stable. Treat ABCs first.

**Decontamination**

- No healthcare provider has ever been injured with radiation while performing ABCs on a radiation victim.
- Removal of the casualty’s clothing can remove as much as 90% of the radiological contamination.
- The first priority of surface decontamination should be to open wounds, then other areas.
  - To prevent rapid incorporation of radioactive particles, wounds should be copiously irrigated with normal saline for several minutes.
  - The eyes, ears, nose, mouth, areas adjacent to uncontaminated wounds, hair, and remaining skin surface should be decontaminated with soap and water.
  - Personnel providing decontamination must protect themselves from ionizing radiation exposure with:
    - Protective outer clothing.
    - Aprons, gloves, and masks.
- Amputation should be seriously considered when the contamination burden is great and severe radionecrosis is likely.

**Logistics of Casualty Management**

- If nuclear weapons are employed within the theater, the entire medical evacuation and treatment system will be severely overburdened and some system of classification and sorting of casualties must be added to the normal procedures of evacuation and hospitalization.
Patients entering a medical treatment facility should be routinely decontaminated if monitoring for radiation is not available.

These two requirements, the sorting of casualties and the holding of the excess numbers, must be planned for and drilled as part of the normal organization and operation of the health service support system in a theater of operations where radiation exposure potential is high.