Chapter 28

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 (eg, 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.

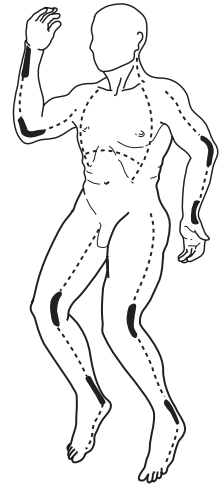

Fig. 28-1. The dashed lines indicate the preferred sites for escharotomy incisions. The bold lines in the figure indicate the importance of extending the incision over involved major joints. Incisions are made through the burned skin into the underlying subcutaneous fat using a scalpel or electrocautery. 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:

Total Volume = (2 mL) • (% burn) • (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 = (Total Volume /2) /(8h - elapsed time in hours since burn).

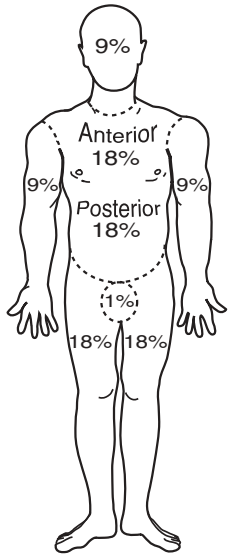

Fig. 28-2. Rule of nines, showing distribution of body surface area by anatomical part in the adult.

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 ½NS 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 (eg, 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:

5% albumin volume = (* mL) • (% TBSA burned) • (preburn wt, kg)

% TBSA burn	30–49	50–69	70+
* **mL**	0.3	0.4	0.5

For example, in a burn of approximately 40% in a 70 -kg patient:
Albumin volume = (* ml) • (40%) • (70kg) = (0.3) • (2,800) = 840 mL/24 h = **35 mL/h**

- 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.

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 (Bristol-Myers Squibb, NY), 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, Zeneca Pharmaceuticals, Wilmington, DE).
- One-percent silver sulfadiazine (Silvadene, Monarch Pharmaceuticals, Bristol, TN) and/or 11.1% mafenide acetate (Sulfamylon, Bertek Pharmaceuticals, Morgantown, WV) 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 anti-pseudomonal penicillin; apply Sulfamylon (Bertek Pharmaceuticals, Morgantown, WV) 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.

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:
  - o Elevate;
  - o Exercise burned extremities hourly;
  - o Evaluate pulses and neurologic status hourly; and
  - o 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.
- 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.
  - o 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.
  - o Increase the hourly LR rate until a urine output of 100 ml/h is achieved.
  - o 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.
  - o 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.
  - o Brush any dry materials off the skin surface before copious water lavage.
  - o In the case of alkali burns, lavage may need to be continued for several hours.
  - o 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.
  - o 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 (Bertek Pharmaceuticals Inc., Morgantown, WV). 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.