

Chapter 11

THE MANAGEMENT OF BURN INJURY

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INTRODUCTION

The interest that medical officers currently have in burns is disproportionately greater than the previous incidence of combat-related burns. One reason for this heightened interest is that, although the incidence of combat-related burns has historically been about 3%, in recent wars the incidence is higher because mechanized modern warfare—tanks and other armored vehicles—actually places soldiers at higher risk of being burned than they were previously. During the Yom Kippur War, burns comprised 10.5% of all injuries; during the Falkland Islands Conflict, 18% of British casualties were burned.^{1,2} Furthermore, medical officers should know that in the United States military, burns and inhalation injuries have always been far more important sources of morbidity and mortality in both the navy and the air force than in the army.

Another reason that burns receive greater attention in military medicine than their numbers would predict is that medical officers spend more time per casualty caring for burn patients than they do for other casualties. Many ballistic casualties will die within a few minutes from exsanguination, and blast casualties from air embolism, unless they receive immediate attention on the battlefield. Because the morbidity and

mortality of surviving casualties evolve more slowly with burns than they do with other types of combat injuries, burn treatment is prolonged. Therefore, more extensive measurements can be made of the pathophysiology of burn injuries, and a comprehensive body of knowledge on burn trauma exists as a result. In fact, the pathophysiology of the human response to burns can perhaps serve as a model for the human response to all traumas."

This chapter goes beyond considering the treatment of a typical combat casualty. The same fires and chemical or electrical incidents that injure soldiers may also cause collateral damage, and American medical personnel may be called upon to treat civilian casualties at the extremes of age—children and the elderly—in addition to the soldier population. Therefore, this chapter contains information that medical officers may require to treat these additional casualties.

Descriptions of the biophysics of thermal burn injury and the equipment available to protect soldiers from burns can be found in the TMM volume *Battlefield Environment*, and the epidemiological aspects of burns are discussed in great detail in *The Casualty*.

TREATMENT OF BURNS

One of the characteristics of military medicine is its provision of medical care by echelon. As this concept applies to caring for casualties with thermal burns, the first and second echelons have as their responsibilities (a) assuring that the airway is open and (b) covering the burn to prevent further environmental contamination. While the immediate care for burned casualties consists of not only that treatment necessary for any trauma patient, but also that treatment specific for burns, the care the casualty actually receives before being evacuated from the battlefield to a first- or second-echelon MTF depends upon the battlefield conditions. Ideally, the first responder will administer 100% oxygen, and if ventilatory exchange is impaired, place an endotracheal tube.

On the battlefield, thermal burns may occur in association with mechanical trauma and chemical and electrical burns, which can not only complicate the treatment but also increase both the morbidity and the

mortality of patients with these combined injuries. Maintaining both the airway and the hemodynamic stability are priorities in treating burned casualties, as they are with any other trauma patient. Life- or limb-threatening injuries must be treated first, with the burn addressed only after the life-threatening problems have been adequately stabilized. The burning process **must be stopped: Extinguish the flames, dilute and wash away the chemicals, or remove the casualty from contact with the electrical current.** Initiate cardiopulmonary resuscitation if indicated.

After field emergency care, casualties with significant burns should promptly be transported to an MTF. If the casualty can be evacuated promptly, and if the evacuation will require no more than 35–40 minutes, initiation of intravenous fluid therapy can be delayed until evacuation is completed. If evacuation from the field echelons will be delayed, begin fluid resuscitation with Ringer's lactate. Most casualties are

already dehydrated, not only because of their injuries but also because field conditions predispose to dehydration.

Burns should be covered with a clean sheet or dressing to prevent further contamination, and the casualty should be covered with a blanket to conserve body heat. If evacuation from the first or second echelons is likely to be delayed, consider applying a topical antimicrobial like Sulfamylon before dressing the burn. Wet dressings may decrease the casualty's body temperature and should be avoided. Burned extremities should be elevated, if possible, to prevent edema.

Although all U.S. troops should have been actively immunized against tetanus, foreign nationals may not have been; they may require both tetanus toxoid and immune globulin. Administer absorbed tetanus toxoid, 0.5 ml, and human tetanus immunoglobulin, 250 or more units, at separate sites and complete the casualties' active immunization in standard fashion.

Because careful wound observation is difficult during the evacuation period, administer prophylactic penicillin to attempt to prevent beta-hemolytic streptococcal infections.

Burn care at third and higher echelons consists of definitive fluid resuscitation, which is discussed below. Definitive wound care may be started at the third echelon, but will not be completed there. Most casualties with second- and third-degree burns and more than 20% TBSAB will require a longer time to recuperate than the combat-zone evacuation policy allows. They will need to be evacuated to a fourth-echelon MTF or CONUS, where excision and grafting will take place. Because burns frequently occur in accidents that may occur in proximity to third- and fourth-echelon hospitals, these facilities also must be prepared to render emergency, as well as definitive, care.

Fluid Resuscitation

Either in the field or upon the casualty's arrival at the closest aid station or larger facility, medical personnel should quickly establish intravenous access by inserting a large-caliber venous cannula in the largest available vein. The cannula should be placed through unburned skin, if possible, but if such a site is unavailable, then the intravenous line will have to be placed through the burn. Central venous access is not required for the immediate resuscitation of the thermally injured patient. Commence resuscitation by administering lactated Ringer's solution or another balanced salt solution.

Children with burns of less than 10% TBSAB and

adults with burns of less than 20% TBSAB can often be successfully resuscitated with oral fluids only. However, even patients with such limited burns may have emesis if they drink large volumes of fluid rapidly. Oral fluids should be given in small amounts over an extended period of time. If emesis occurs, oral fluids should be restricted and resuscitation continued parenterally.

Burns greater than 20% TBSAB produce significant plasma-volume deficits that can lead to shock if untreated. The ileus that accompanies burns usually precludes oral resuscitation and mandates using intravenous therapy. Burn patients' fluid needs are related both to the extent of the burn and of (Figures 10-1 and 10-2 in Chapter 10).

Fluid Resuscitation—Colloid or Crystalloid?

Many formulae exist for estimating the fluid needs of burn patients in the first 2448 hours after they are injured, all based upon the weight of the patient and the extent of burns (Table 11-1). Each formula recommends different amounts of electrolyte-free water, salt-containing fluids, and colloid-containing fluids, and each has proven to be effective in treating a large number of patients.

Because capillary leakage occurs in burned tissue, no discernible benefit has been noted when colloid-containing solutions were administered during the first 24 hours after the injury; some investigators have also reported that colloid-containing solutions have a detrimental effect on late pulmonary function.⁴ Proponents of colloid resuscitation claim that (a) cardiac output is restored to normal sooner, and (b) the plasma-volume deficit is reduced earlier. However, by 2448 hours after the injury, no clinically significant difference in cardiac output or plasma-volume deficit can be seen between those patients resuscitated with colloid-containing fluids and those given crystalloid fluids, and this treatment remains controversial.

The U.S. Army Institute of Surgical Research recommends using a balanced electrolyte solution, such as Ringer's lactate, during the first 24 hours of resuscitation and estimate the amount of fluid required by an adult as 2 ml/kg of body weight/ % TBSAB. Because the capillary leakage is greatest during the first 8 hours, one-half of this volume is given during that period, with the second half administered during the next 16 hours. Fluid needs of children (who have a greater surface area) as 3 ml/kg of body weight/% TBSAB.⁵

Regardless of which formula is used to resuscitate the patient, the rate that the fluid is administered must be adjusted according to the patient's response (Figure 11-1). The goal of fluid resuscitation is adequate tissue perfusion.

TABLE 11-1

COMMONLY USED BURN RESUSCITATION FORMULAE FOR ADULT PATIENTS

Formula	First 24 Hours			Second 24 Hours		
	Electrolyte-Containing Solution	Colloid-Containing Fluid Equivalent to Plasma*	Glucose in Water	Electrolyte-Containing Solution	Colloid-Containing Fluid Equivalent to Plasma*	Glucose in Water
Bum budget of F.D. Moore	Lactated Ringer's 1,000-4,000 ml 0.5 normal saline 1,200 ml	7.5% of body weight	1,500-5,000 ml	Lactated Ringer's 1,000-4,000 ml 0.5 normal saline 1,200 ml	2.5% of body weight	1,500-5,000 ml
Evans	Normal saline 1.0ml/kg/%TBSAB	1.0ml/kg/%TBSAB	2,000 ml	One-half of first 24-hour requirement	One half of first 24-hour requirement	2,000 ml
Brooke	Lactated Ringer's 1.5ml/kg/%TBSAB	0.5 ml/kg/%TBSAB	2,000 ml	One-half to three quarters of first 24-hour requirement	One half to three quarters of first 24-hour requirement	2,000 ml
Parkland	Lactated Ringer's	—	—	—	20%-60% of calculated plasma volume	As necessary to maintain urinary output
Hypertonic sodium solution	Volume of fluid containing 250 mEq of sodium per liter to maintain hourly urinary output of 30 ml	—	—	One-third isotonic salt solution orally up to 3,500 ml limit	—	—
Modified Brooke	Lactated Ringer's 20 ml/kg/% TBSAB	—	—	—	0.3-0.5 ml/kg/%TBSAB	As necessary to maintain urinary output

*Administered as 5% albumin solution in lactated Ringer's

Hypertonic Resuscitation. Some investigators use hypertonic saline to decrease resuscitation volume in patients at the extremes of age.^{6,7} The goal, in these volume-sensitive patients, is to limit the fluid loading that occurs during resuscitation. Only partial success has been achieved with this method, because either hypernatremia or cellular dehydration may occur. Both sodium levels in excess of 160 mEq/dl and cellular dehydration in excess of 15% appear to be detrimental. A study comparing standard resuscitation using isotonic salt solutions to resuscitation using hypertonic salt solutions showed that by 48 hours after the burn, most patients had received the same amount of free water and salt, regardless of the formula that was used.⁸

Assessing the Adequacy of Resuscitation. Urinary output, as an index of renal and overall tissue perfusion, is used to monitor resuscitation. In adults, a urinary output of 30-50 cc/hour indicates adequate renal perfusion. In children, a goal of 0.5-1.0 ml/kg

body weight/hour is optimal. Urinary output greater than these amounts suggests excess fluid administration, and the rate of intravenous flow should be decreased if an osmotic diuresis can be excluded. The rate should be decreased by approximately 10% per hour until the urinary output falls within the guidelines mentioned above. Conversely, oliguria in the first 24-48 hours after the injury is almost always secondary to inadequate volume resuscitation and not to acute renal failure, and thus the rate of fluid administration should be increased. Blind adherence to any resuscitation formula will cause some patients to be either over- or under-resuscitated, with the morbidity that accompanies each.

Invasive monitoring is rarely indicated during routine fluid resuscitation of patients with thermal injuries. Periodic scheduled assessments of the patient's mental status, hourly urinary output, and vital signs usually indicate its adequacy. A tachycardia above 130 beats per minute usually indicates a volume deficit,

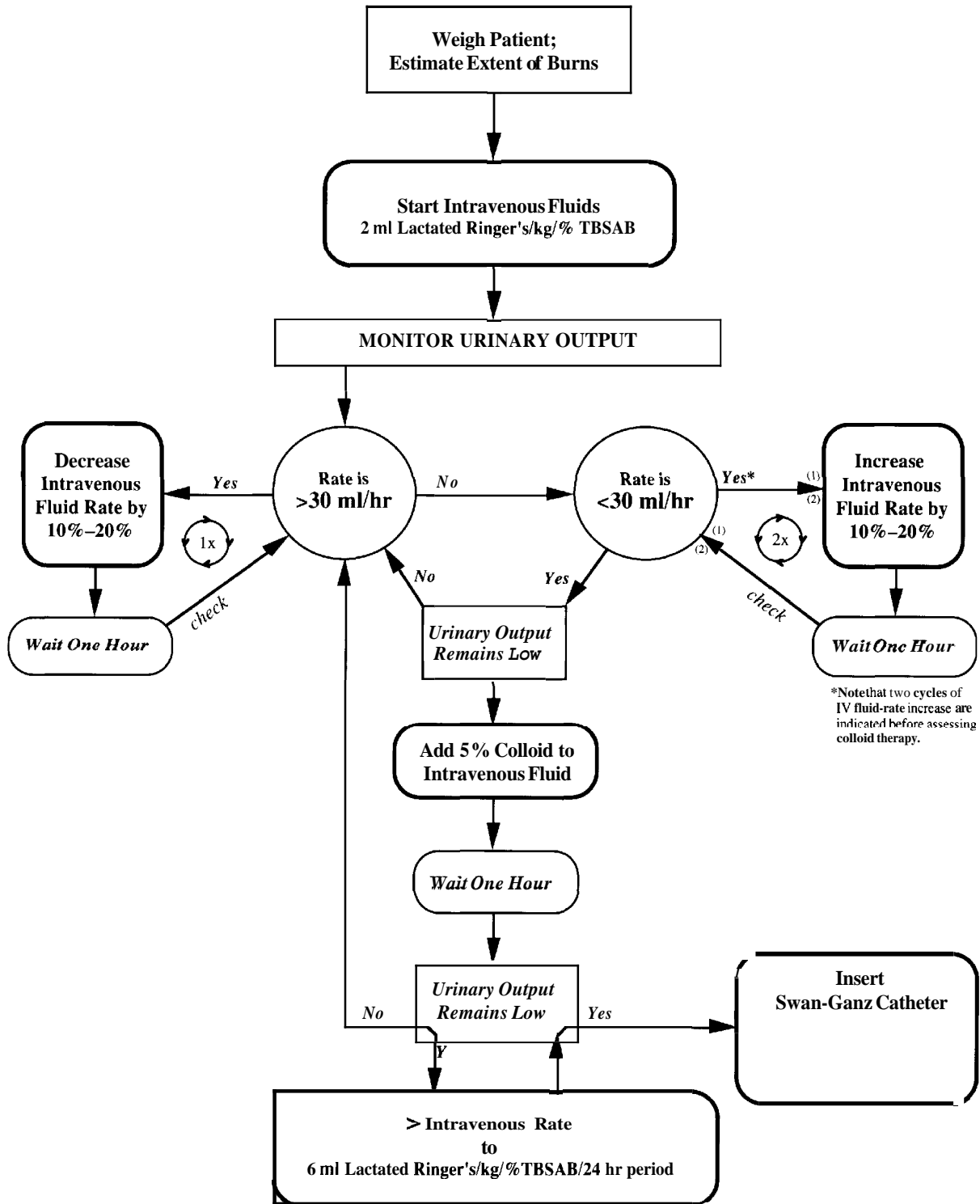


Fig. 11-1. Algorithm for fluid therapy during the first 24 hours after thermal injury

while rates of 110–130 beats per minute are commonly observed in adequately resuscitated adult burn patients. Noninvasive blood pressure measurements are unreliable in a burned extremity, and intraarterial monitoring may be required. However, this invasive monitoring should be reserved for elderly patients with cardiopulmonary disease, polytrauma patients, and those patients who fail to respond within 4–6 hours to hourly intravenous infusion rates that should have resulted in infusion of 6 or more ml/kg body weight/% TBSAB in the first 24 hours after the injury.

Resuscitation during the Second Day. In the second 24 hours after the injury, 5% dextrose in water is administered in an amount necessary to maintain an adequate urinary output. In addition, administering colloid-containing solutions will replace the plasma-volume deficit. The U.S. Army Institute of Surgical Research recommends using physiological concentrations of albumin reconstituted in lactated Ringer's solution. The volume of colloid administered depends upon the size of the burn, with 0.3 cc/kg body weight/% TBSAB administered to patients with up to 50% TBSAB, 0.4 cc/kg body weight/% TBSAB to patients with 50–70% TBSAB, and 0.5 cc/kg body weight/% TBSAB to patients with greater than 70% TBSAB. The patient's serum electrolytes should be frequently monitored, and the infusion rate and the salt concentration of the administered fluid adjusted if necessary to prevent a precipitous drop in the serum sodium. In pediatric patients, who have a relatively small blood volume, urinary output is maintained during the second 24 hours with 5% dextrose in half-normal saline in place of 5% dextrose in water. Hyponatremia during this time is usually secondary to total body water excess and not to total body sodium deficit, and should be treated by decreasing the rate of intravenous fluid administration.

After the casualty has been resuscitated, fluid therapy should facilitate the excretion of the large sodium and fluid loads that were administered during the resuscitation phase, with the expectation that the patient's weight will return to normal by the tenth day after the burn. Electrolyte-free evaporative water losses should be replaced with 5% dextrose in water. Total daily water losses in resuscitated burn patients may reach 3.0 cc/kg body weight/% TBSAB, with daily losses as great as 6–10 liters possible in patients with large burns.

Insensible water losses can be estimated by the formula: $\text{Insensible water loss (ml/hr)} = (25 + \% \text{ body surface area burn}) \times (\text{m}^2 \text{ of total body surface area}).^9$

Elevated serum sodium usually indicates a free-water deficit, not a total-body sodium excess, and should be treated by administering more free water.

Miscellaneous Early Care

A nasogastric tube should be inserted to decompress the stomach and to decrease the likelihood of emesis and subsequent aspiration.

The analgesic requirements of burn patients are inversely related to the depth of the burn. While full-thickness burns are insensate, partial-thickness burns can be especially painful. Analgesia should be administered by the intravenous route and should be carefully titrated, using small-bolus injections of narcotics. Intramuscular or subcutaneous injections of narcotics should be avoided during the period of systemic hypovolemia and hypoperfusion, since these injectates will not be absorbed in a predictable fashion. Once perfusion has been established, the mobilization of multiple doses of a drug can result in respiratory depression and cardiovascular collapse.

Using anesthesia during resuscitation is hazardous. The vasodilatory effect of general anesthesia may precipitate cardiovascular collapse if the burned casualty is only marginally resuscitated. Anesthesia, if needed, should be delivered at the level of the evacuation hospital or higher and requires close physiological monitoring.

When the casualty reaches a general hospital or burn center, routine admission laboratory tests to be obtained include (a) arterial blood gases with a carboxyhemoglobin level, (b) electrolytes, including blood glucose and blood urea nitrogen, (c) hematocrit, and (d) hepatic and renal profiles.

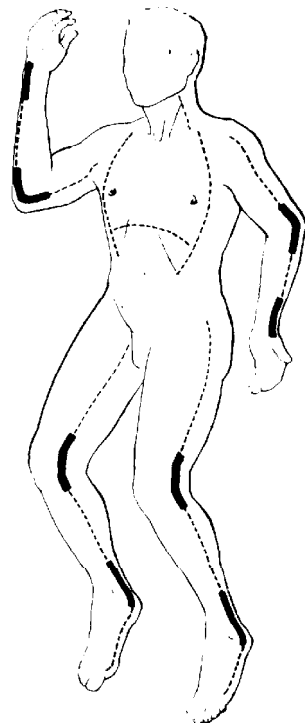
Escharotomy

Circumferential third-degree burns of an extremity may impede blood flow to underlying or distal unburned tissue. As edema develops beneath the inelastic eschar, tissue pressure will increase until it exceeds capillary pressure and may approach arteriolar pressure. This will restrict blood flow not only to this area but also to distal tissue, and ischemia and cell death will occur. Constant elevation of the affected extremity and active exercise of the extremity for 5 minutes every hour are required to minimize edema.

Although the value of escharotomy in relieving compression and restoring blood flow is well established, precise indications for performing escharotomy are not. The pulses should be monitored hourly in circumferentially burned extremities with the Doppler Ultrasonic flow meter. The most common signs that identify patients who will benefit from escharotomy are diminution or *loss* of pulses in the palmar arch of the upper extremity and the posterior tibial artery in the lower extremity, but one should be

certain that reduced blood flow is not secondary to hypovolemia before proceeding to escharotomy. Some authorities advocate using compartmental-pressure measurements to identify the limbs that will benefit from escharotomy earlier. A compartment pressure above 30 cm H₂O has been identified as the critical level at which escharotomy should be performed."

Escharotomy can be performed as a ward procedure using either a scalpel or an electrocautery. Since the incision is made only through the burned skin in an area of insensate full-thickness burn, anesthesia is unnecessary. The incision should be made in the midlateral or midmedial line of the anatomically positioned burned limb or digit, and should extend from the distal to the proximal margin of the encircling full-thickness burn (Figure 11-2). The depth of the incision should be limited to the eschar, just exposing the underlying subcutaneous tissue (Figure 11-3). Since bacteria will rapidly colonize the exposed unburned subcutaneous tissue, their proliferation should be controlled by applying the topical antimicrobial agent that is being used on the burn.



PREFERRED SITES OF ESCHAROTOMY

Fig. 11-2. The preferred sites for placing escharotomies. Note that escharotomies should extend across the major joints.

Occasionally, escharotomies of the neck, penis, or chest may be necessary because of encircling full-thickness burns. If full-thickness circumferential burns of the chest impair ventilation, bilateral, anterior, axillary-line escharotomies extending from the clavicle to the costal margin should be performed and, if abdominal-wall eschar necessitates, the axillary-line incisions should be connected by a costal-margin escharotomy. If the burn includes the hand, midlateral and midmedial escharotomy should be extended to the base of the metacarpophalangeal joint of the thumb or the little finger, or both. Longitudinal incisions on the dorsum of the hand and digits may only expose the extensor tendons and should be avoided.

Escharotomy should always be performed when indicated, but prophylactic escharotomies should not be performed, especially during the early phase of resuscitation. Inappropriate escharotomies extending deep into the subcutaneous tissues can risk increased blood loss as resuscitation proceeds and intravascular volume is restored. Extensive bleeding may occur but be unrecognized as the casualty progresses through the evacuation chain. If the tactical situation delays evacuation and escharotomies are clinically indicated, they should be performed even if the casualty is at a treatment level at which replacement blood is not available. These patients' incisions should be monitored for bleeding on a scheduled basis (for example, hourly), and a pressure dressing should be applied if bleeding is excessive.

Burn-Wound Management

Initial Wound Care. Initial wound care should be performed at the level of the combat-support hospital or higher. It includes (a) cleansing of all wounds with any available surgical disinfectant, (b) debriding all nonviable tissue that can easily be removed, and (c) shaving the body hair from the areas involved. Bullae greater than 2 cm should be excised to prevent their serving as infection foci. If the patient is to be transferred to another treatment facility after the burns have been cleansed and debrided, the burns should be covered with lightweight, sterile dressings impregnated with the topical antimicrobial agent of choice, if available. If the patient is at the level of definitive burn care, the wounds can be covered with a topical antimicrobial agent and left exposed if environmental temperatures permit.

Controlling Infection. The goal of burn care is to control infection until the injury either spontaneously heals or is surgically closed. Nonviable tissue within the injury predisposes it to bacterial colonization and



Fig. 11-3. Appropriately placed escharotomies were performed to relieve decreased distal perfusion, indicated by diminished pedal pulses. Edema beneath the encircling full-thickness eschar caused this condition. Note that the incision extends only through the superficial fascia, permitting the wound edges to separate. Liberal application of a topical antimicrobial agent is necessary to control bacterial proliferation in the incision.

subsequent infection. Topical antimicrobial agents decrease the incidence of invasive infections in burns! Three effective chemotherapeutic agents that are frequently used to treat burn infections (Table 11-2) are Sulfamylon, Silvadene, and silver nitrate.

Sulfamylon burn cream is an 11.1% suspension of mafenide acetate in a hydrophilic cream. Mafenide acetate is water soluble, bacteriostatic for both Gram-positive and -negative organisms, and is particularly effective against pseudomonal and clostridial infections. Its solubility allows mafenide acetate to penetrate the eschar. There are significant disadvantages to using Sulfamylon, including pain following its application to partial-thickness burns and carbonic anhydrase inhibition, which may lead to renal bicarbonate wasting and a metabolic acidosis.

Silvadene burn cream is a 1% suspension of silver sulfadiazine in a hydrophilic base. Its solubility is limited and it does not penetrate the eschar well. Enterobacter and *Pseudomonas* are frequently resistant to this agent. Furthermore, neutropenia and occasionally pancytopenia may occur during its use. Silvadene's major benefits include the absence of post-application pain and freedom from acid-base disturbances.

Silver nitrate is used as a 0.5% solution. It is painless upon application and is active against a broad spectrum of bacteria. Because of its total lack of penetration, however, silver nitrate must be applied

before a dense microbial population develops within the eschar. In addition, silver nitrate has a significant major side effect: It leaches excessive amounts of sodium, chloride, potassium, and calcium from the burn. Silver nitrate also irreversibly stains tissue, clothing, and equipment.

Managing Burn-Wound Infections. Despite their current reduced incidence, invasive burn-wound infection remains the most common cause of morbidity and mortality in patients with extensive burns.¹² Diagnosing these infections is difficult, due to a variety of wound and systemic factors. Hyperthermia, tachycardia, and hyperventilation are characteristic of the hypermetabolic response to burns and are not reliable signs of sepsis. The finding of leukocytosis is likewise unreliable, since postburn leukocytosis typically is followed by leukopenia and subsequent rebound leukocytosis.

Scheduled surveillance is the best way to identify changes indicative of invasive infection in the wound (Figure 11-4). Changes consistent with burn-wound infection (Table 11-3) should prompt immediate wound biopsy to verify the diagnosis. Quantitative cultures taken from the burn wound merely identify the resident flora and are useful only for epidemiological monitoring.^{13,14,15} Furthermore, even quantitative cultures of a biopsy specimen do not enable a differentiation to be made between contamination and invasive

TABLE 11-2

TOPICAL CHEMOTHERAPEUTIC AGENTS FOR BURN-WOUND CARE

	Mafenide Acetate	Silver Nitrate	Silver Sulfadiazine
Active component concentration	11.1% in water- miscible base	0.5% in aqueous solution	1.0% in water- miscible base
Spectrum of anti-bacterial activity	Gram-negative: good Gram-positive: good Yeast: minimal	Gram-negative: good Gram-positive: good Yeast: good	Gram-negative: selectively good Yeast: good
Method of wound care	Exposure	Occlusive dressings	Exposure or single-layer dressing
Advantages	Penetrates eschar, wound appearance readily monitored, joint motion unrestricted, no Gram-negative resistance	Painless upon application, no hypersensitivity reactions, no Gram-negative resistance, dressings reduce evaporative heat loss, requires painful dressing changes	Painless, wound appearance readily monitored and joint motion unrestricted when exposure method used
Disadvantages	Painful on partial-thickness burns, acidosis as a result of inhibition of carbonic anhydrase, hypersensitivity in 7 8 of patients	Deficits of sodium, potassium, calcium, and chloride, no eschar penetration, limitation of joint motion by dressings, methemoglobinemia: rare, argyria: rare, staining of equipment and environment	Neutropenia, hypersensitivity: infrequent, limited eschar penetration, resistance of certain Gram-negative bacteria and clostridia

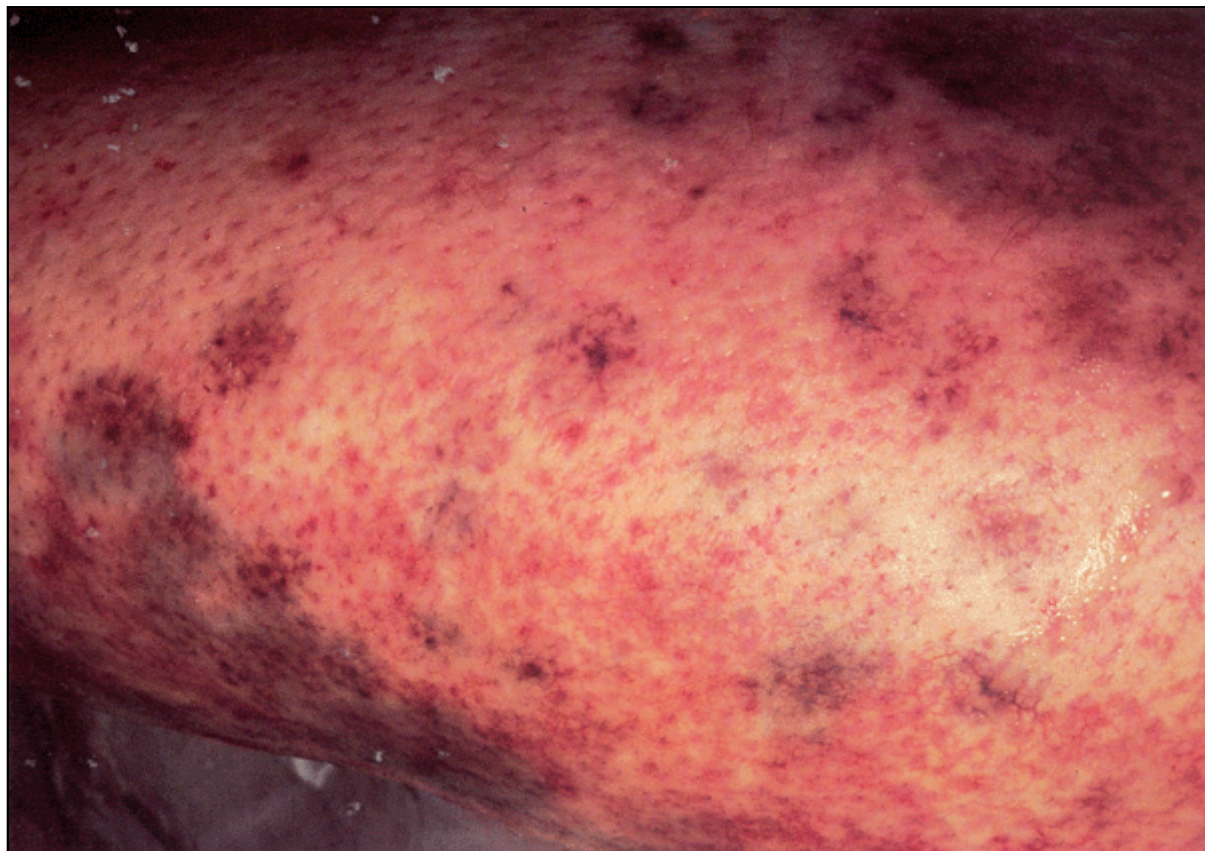


Fig. 11-4. The foci of discoloration in this full-thickness wound characterize invasive wound infection and should prompt immediate burn-wound biopsy.

infection, since high microbial counts are frequently observed in the absence of invasive infection.¹⁶ Histological examination of biopsied tissue is the most rapid and reliable method of diagnosing an invasive burn-wound infection (Table 11-4).

The incidence of invasive infection in burns has steadily decreased over the past decade. However, once generalized sepsis has developed, the patient's chance for survival is markedly reduced. In general, invasive infection is rarely encountered during the first 2 weeks after the burn.

The treatment of burn-wound infection depends upon the invading organism.¹⁷ Streptococcal infections do not deeply invade the tissues and usually are manifested by erythema and lymphangitis. Systemic penicillin administration controls most of these infections promptly. Staphylococcal infections invade more **deeply, but are often surrounded by a thick membrane** that (a) prevents further spread of the infection but (b) also prevents parenteral antibiotics from reaching the focus of infection. Local excision is essential for adequate management. Gram-negative infections have

the propensity to spread widely via the hematogenous and lymphatic routes. Once the diagnosis of invasive Gram-negative infection has been made, mafenide acetate should be applied (if it is not already being used). Systemic antibiotics to which the invading organism is sensitive should be administered.

Treating the burn wound with subeschar injections of one-half of the recommended total daily dose of a broad-spectrum semisynthetic penicillin 6–12 hours prior to, and again immediately before, surgery limits further microbial proliferation and decreases the risk of hematogenous dissemination during the excision.¹⁸ If all nonviable and infected tissue has been excised, the wound should be covered with a biological dressing to prevent desiccation. If nonviable tissue remains, dressings soaked in either 0.5% silver nitrate or 5% mafenide acetate solution should be used. **Autografting of the wound should be delayed until** is certain that the wound infection has been adequately controlled.

Invasive fungal infections are rare and usually occur late in the course of treatment. Typically, the

TABLE 11-3
CLINICAL SIGNS OF INVASIVE BURN-WOUND INFECTION

-
- Focal areas of dark red, brown, or black eschar discoloration
 - Conversion of partial-thickness injury to full-thickness necrosis
 - Hemorrhagic discoloration of sub-eschar tissue
 - Green pigment visible in subcutaneous fat*
 - Erythematous, necrotic lesions (ecthyma gangrenosum) in unburned skin*
 - Edema and/or violaceous discoloration of unburned skin at wound margin
 - Accelerated separation of eschar**
 - Rapid centrifugal expansion of subcutaneous edema with central necrosis**
 - Vesicular lesions in healing or healed partial-thickness burns***
 - Crusted, serrated margins of partial-thickness burns of the face***
-

*Characteristic of *Pseudomonas* infection
 **Characteristic of fungal infection
 ***Characteristic of herpes simplex infection

TABLE 11-4
HISTOLOGIC STAGING OF MICROBIAL STATUS OF BURN WOUNDS

Stage	Characteristics
I. Colonization	
A. Superficial	Microorganisms present on wound surface
B. Penetration	Microorganisms present in variable thickness of eschar
C. Proliferation	Multiplication of microorganisms in subeschar space
II. Invasion	
A. Microinvasion	Microscopic foci of microorganisms in viable tissue adjacent to subeschar space
B. Generalized	Multifocal or widespread penetration of microorganisms deep into viable subcutaneous tissue
C. Microvascular	Involvement of small blood vessels and lymphatics

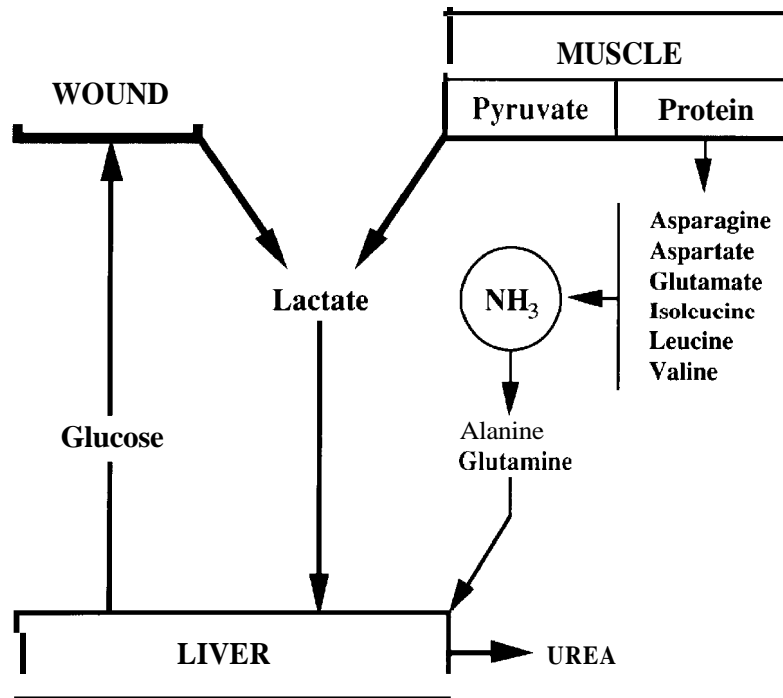


Fig. 11-5. The wound uses glucose (principally by anaerobic, glycolytic pathways) as its primary energy source. This produces large amounts of lactate. In the liver, lactate is extracted and used for glucose synthesis via the Cori cycle. Amino acids from the casualty's peripheral muscle mass are the major source of the three-carbon fragments needed for hepatic gluconeogenesis. After they are deaminated, the amino acids alanine and glutamine are shuttled to the liver for glucose production. This cycle also yields increased ureagenesis.

process is localized and the definitive treatment is excision, with the addition of topical antifungal therapy. Systemic amphotericin is reserved for patients with either fungemia or evidence of vascular invasion in the excised tissue.

Metabolic Support of Burned Patients

Severely burned patients may lose as much as 40 g of protein per day in the form of urea nitrogen, secondary to the extensive peripheral proteolysis that accompanies the hypermetabolic response.^{19, 20} This erosion of lean body mass provides alanine and glutamine to the liver, where they are utilized as three-carbon-fragment substrates for gluconeogenesis (Figure 11-5). Wound-produced pyruvate and lactate are utilized in the Cori cycle to provide additional substrate for glucose production. Although catabolism continues until the wound is closed, appropriate nutritional support may increase the synthesis of visceral and muscle protein and protect lean body mass. Nutritional support should be delayed until the casualty reaches an MTF, where he or she can be properly monitored for both the therapy's adequacy and any

complications. Nutritional support should be administered enterally, if gastrointestinal function has returned to normal. Parenteral nutrition, which is not usually available until the patient reaches a general hospital, can be used, but it requires more extensive monitoring and is associated with a higher rate of mechanical and infectious complications.

Caloric requirements can be estimated by any of several commonly used formulae (Table 11-5) or measured by indirect calorimetry. Proteins should be administered in sufficient quantity to promote positive nitrogen balance. A calorie-to-nitrogen ratio of 100–150:1 is usually required to achieve this goal. Carbohydrates should supply the major portion of the patient's caloric requirement, but administration rates should not exceed 5–7 mg/kg body weight/min.²¹ Rates that exceed this level may cause both hepatic lipogenesis and fat deposition, which not only may impair hepatic function but also are associated with a marked increase in carbon dioxide production. Lipids should supply the remaining calories. Enterally administered medium-chain triglycerides are well tolerated and serve as an effective source of energy. Because mitochondrial oxidation is impaired after a casualty is

TABLE 11-5

FORMULAE FOR ESTIMATING DAILY CALORIC REQUIREMENTS
IN ADULT BURN PATIENTS

Curreri

$$(25\text{kcal} \times \text{body weight in kg}) + (40 \text{ kcal} \times \% \text{ TBSAB})$$

Artz, Moncrief, and Pruitt

$$(2,100\text{kcal} \times \text{body surface area } m^2) \text{ For patients with burns of } > 40 \text{ TBSA.}$$

Galveston

$$(1,800\text{kcal} \times \text{body surface area } m^2) + (2,000\text{kcal}) (m^2 \text{ burn})$$

U. S. Army Institute of Surgical Research

$$54.33782 \cdot (1.9961 \times \text{age}) + (0.025488 \times \text{age}^2) - (0.00018 \times \text{age}^3) \\ 12.33764 - (11.33764 \times e^{-0.02866 \times \text{burn area}}) \} (\text{body surface area } m^2) (24) (1.25)$$

burned, the long-chain triglycerides contained in parenterally administered lipid emulsions cannot be efficiently utilized as energy sources.²² Almost all burn patients with greater than 30% TBSAB will require nutritional supplements to meet their increased metabolic demands.

Burn-Wound Closure

Historically, burn wounds were closed by placing cutaneous autografts on the granulation tissue that had formed after the eschar spontaneously separated. Current treatment includes excising the burn wound and then covering the viable tissue below with autograft skin, which decreases the risk of burn-wound infection and shortens the patient's stay in the hospital. However, excision and grafting require that considerable resources such as blood products be expended²³ and should be reserved as a treatment modality employed at fixed hospital facilities such as a general hospital or higher-echelon facility.

Excision. Full-thickness or deep partial-thickness burns (wounds that will not heal within 21 days) are amenable to surgical excision. Once resuscitation is complete and the patient is hemodynamically stable,

excision should be considered if the hospital can support the procedure. These limits should not be exceeded unless invasive wound infection has been documented.

Excessive blood loss and hypothermia are the two most significant factors limiting excision. Blood loss associated with scalpel excision is surprisingly large; the surgeon should anticipate a two-blood volume replacement in children with a 30%–50% excision and a one-half-blood-volume replacement in adults with a 30% excision. The blood loss is even greater with tangential excision, and up to 9% of the blood volume can be lost per 1% of the body-surface area excised.²⁴ Accordingly, the extent of each surgical excision should be limited to either 20% of the total body-surface area or 2 hours of operative time, whichever occurs first.²⁴ The operating room should be kept warm and the infused fluids should also be warmed to minimize the loss of body heat and to prevent hypothermia from developing during the operation. If possible, excision should be performed during the first week after the burn, since the blood loss from more mature wounds will be greater. Using tourniquets during limb excisions can limit blood loss, but their use requires that the surgeon have significant experience in determin-

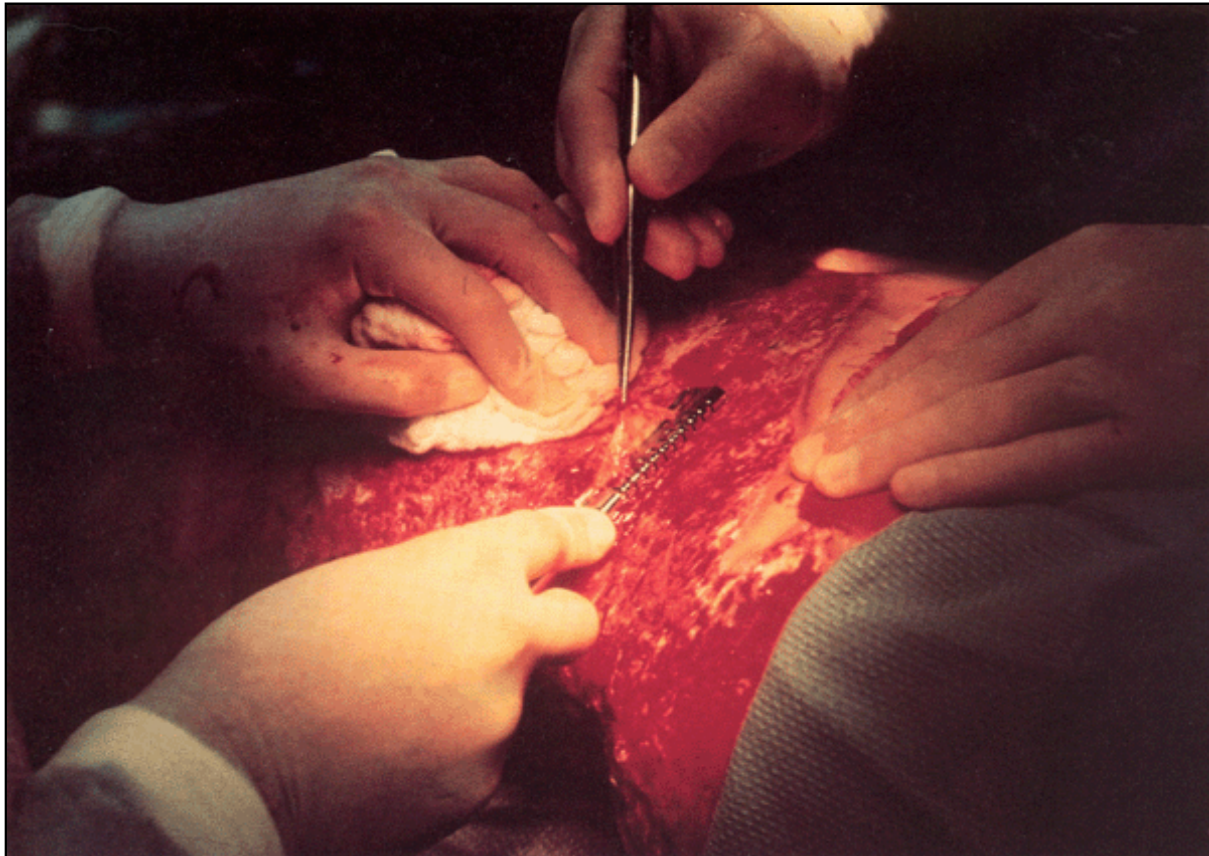


Fig. 11-6. Burns that (a) are deep dermal or (b) extend just into the superficial fat are best treated by tangential excision with guarded knives or dermatomes. A dense bed of brisk capillary bleeding indicates viable tissue and adequate wound excision.

ing tissue viability, since capillary bleeding is also abolished.

The depth of the injury and the stability of the patient dictate the method of excision that the surgeon should use. Tangential excision is utilized for partial-thickness burns and is accomplished using a guarded skin knife or a dermatome to remove thin layers of eschar until viable tissue is encountered (Figures 11-6 and 11-7). The benefit of this form of excision is maximal salvage of uninjured subcutaneous tissue.

Deep full-thickness burns are best treated by scalpel or electrocautery excision at the level of the investing fascia (Figure 11-8). This technique can be performed more rapidly and with less loss of blood than tangential excision. The major disadvantage of this form of excision, however, is its final cosmetic result, because all subcutaneous fat and lymphatics are removed. However, the percentage of graft take (that is, deeper layers of tissue establish continuity with the graft, supply it with nutrients, and assure its survival) on the excised fascial bed is usually excellent, espe-

cially when compared to those grafts that are placed on subcutaneous fat.

Early surgical intervention in patients with extensive burns should be directed toward excising and covering large planar areas, in an attempt to reduce complications related to the size of the burn. This should be followed first by excising the extremities, and then specific body parts such as the hands. Early excision and grafting of third-degree burns of the hands should be performed only in patients with small burns that are not life threatening. The goal is to elicit early motion and to minimize functional deficits.

Deep burns of the face should not be excised. Because of the thickness of facial skin, many deep-appearing burns will heal spontaneously and save facial tissue, which will maintain contour and may improve later cosmetic results.

Burns to the perineum are a particularly difficult challenge. The cutaneous injury should be treated conservatively, with definitive closure accomplished after the wound has formed granulation tissue. Di-



Fig. 11-7. After hemostasis has been achieved, areas of viable dermis intermingled with fat may be covered with autograft or any other readily available biological dressing.

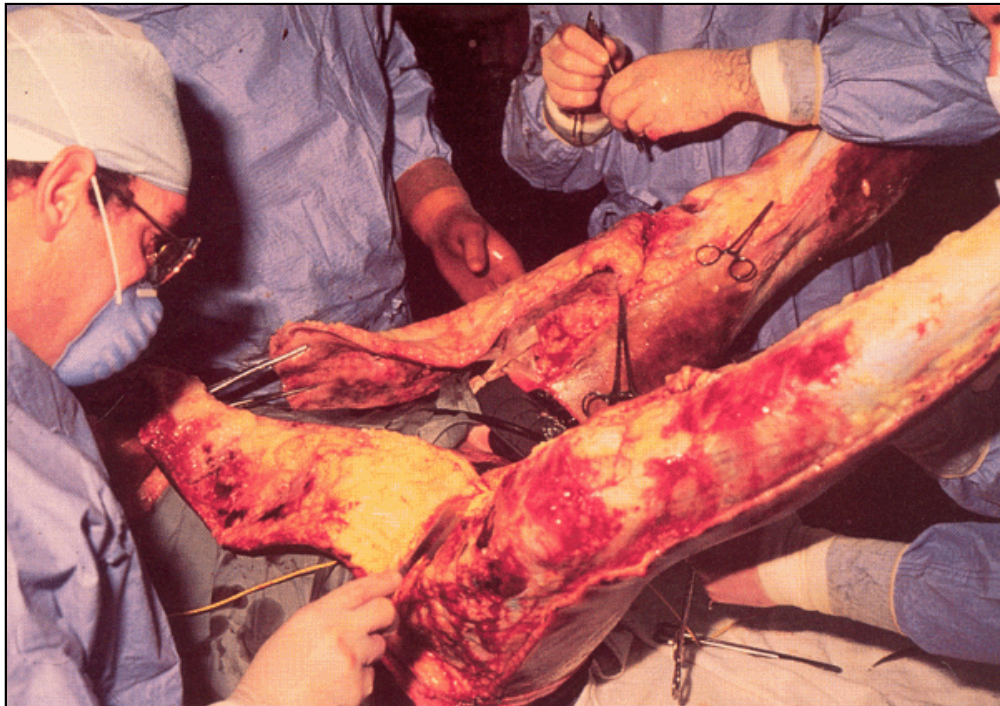


Fig. 11-8. Extensive, deep, full-thickness burns are best treated by excising to the level of the investing muscle fascia. This excision can be performed rapidly with minimal blood loss, but it leaves a significant cosmetic deformity.