10

Burns

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Major burn injury is considered by many to be one of the most horrifying of all injuries, a perception that is all too often correct. To patients, acute burns are the “ultimate agony,” and the long-term consequences of burn injury present enormous psychological, social, and physical challenges to meaningful recovery. Burn treatment is long term, labor intensive, both physically and psychologically challenging. Burn injury encompasses virtually every facet of surgical care. As such, major burn injury is often used as a paradigm for the most severe physiologic derangements that can accompany trauma.

Burns are also a major public health problem. In the United States, more than 450,000 patients seek medical attention for burns every year. Over 3,700 people die every year of burn-related injuries, primarily from house fires, and about 40,000 patients are hospitalized. In addition, several recent disasters, both nationally and internationally, have involved major fires with subsequent burn injuries. This chapter presents basic burn pathophysiology and practical guidelines for the treatment of acute burns.

A *note on illustrations*: Burns are uniquely *visual* injuries, and the ability to assess burns by sight is an essential skill both for planning initial burn care and for making decisions about such things as the need for surgery, the presence of infection, and the extent of scarring. Clinicians who cannot assess burn extent and depth accurately often make significant errors in burn evaluation and treatment. For that reason, familiarity with the appearance of burn injuries is an important objective of this chapter.

PATHOPHYSIOLOGY OF BURN INJURY

The skin can be injured by a variety of agents, including direct heat from flames or scalding liquids, contact with hot objects or corrosive chemicals, and electrical current. Burns are classified according to the depth of injury. Figure 10-1 shows these injuries in relation to the structures of the skin, knowledge of which will help the reader understand the physiologic effects of burns of various depths, and the findings seen on examination.

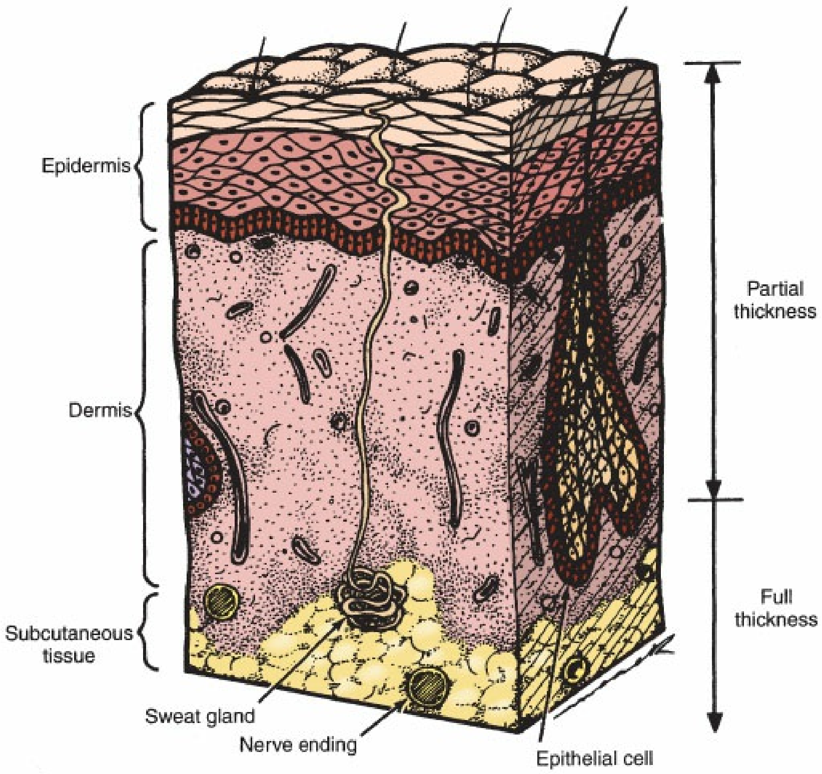

Figure 10-1 **Anatomy of the skin showing major skin structures and their relation to partial and full-thickness burns.** Epithelial cells make up the lining of hair follicles and sweat glands, and these structures penetrate deeply into—sometimes through—the dermis. Even very deep partial-thickness burns can heal if these "epidermal appendages" survive. Dermal capillaries and nerve endings also reside in the deep dermis and survive most partial-thickness burns.

Epidermal burns ("first-degree burns") involve only the epidermis. Within minutes of injury, dermal capillaries dilate, so that these burns present as red, moderately painful areas that blanch with direct pressure, indicating the continued presence of dermal perfusion. Blistering is absent from true epidermal injuries, and the initial erythema usually resolves within a few hours. Epidermal burn injuries are limited in their physiologic effects, and even extensive burns usually require only supportive care, which consists of pain control (oral analgesics), adequate oral fluids, and application of a soothing topical compound such as neomycin sulfate ointment to prevent infection. Healing occurs within a few days because the injured epidermis peels off, revealing new skin beneath. Because scarring occurs in the dermis, epidermal burns do not form the scar tissue. Sunburns are often limited to the epidermis, although deeper injuries can result.

Partial-thickness burns ("second-degree burns") extend into but not through the dermis. These injuries vary greatly in both appearance and significance, depending on their exact depth. Superficial partial-thickness burns (Figure 10-2) typically present with reddened skin that forms distended blisters comprised of epidermis and filled with proteinaceous fluid that escapes from damaged capillaries. The underlying dermis is moist, blanches on direct pressure, and is usually very painful, because cutaneous nerves, which reside in the deeper dermis, are intact.

Figure 10-2 **Superficial partial-thickness burns that occurred when this child reached into a pot of hot water. A,** Distended, fluid-filled blisters that are characteristic of superficial injuries (deeper burns will form blisters, but usually they do not contain much fluid). **B,** After debridement of blisters, the underlying dermis is bright red, moist, and painful, and blanches readily with direct pressure. Removing blisters from these wounds is uncomfortable, but facilitates wound care. In addition, the removal of blistered skin permits a more accurate assessment of burn extent and depth.

Deep partial-thickness injuries look very different from more superficial burns. Coagulation necrosis of the upper dermis often gives these wounds a dry, thickened texture. Erythema is often absent, and these wounds may be a variety of colors but are most often waxy white. Because epidermal appendages penetrate far into—sometimes through—the dermis, even a very deep dermal burn can heal if followed long enough. These wounds also vary in the amount of pain they produce; very deep wounds cause the destruction of many dermal nerve endings and are less painful than more superficial injuries. Such wounds heal badly, however, because damaged dermis does not regenerate; instead, it is replaced by the scar tissue, which is often rigid, tender, and friable. For this reason, many deep dermal burns are best treated with an excision of the burned tissue and skin grafting. An example of a deep partial-thickness burn is illustrated by Figure 10-3.

Figure 10-3 **Partial-thickness injuries can vary greatly in appearance depending on the etiology and duration of exposure.** This photograph shows a deep burn of the dorsal hand from an electrical flash injury. The epidermis is loose and slides off almost like a glove, revealing waxy white dermis, which has relatively little remaining sensation. Note that there is no fluid beneath the blistered epidermis.

During the first 24 to 48 hours after injury, burn wounds develop a coating of dead tissue, coagulated serum, and debris called eschar. The exact depth of partial-thickness burns is often difficult to judge, particularly after eschar forms. The appearance of the wound changes dramatically as eschar develops and again as it separates during wound healing. Superficial partial-thickness burns should demonstrate eschar separation within 10 to 14 days, revealing punctate areas of new epidermal growth called skin "buds," which develop from the epidermal linings of hair follicles and sweat glands (Figure 10-4). Burns of "indeterminate" depth—those that have some features of both partial-and full-thickness injuries—can often be treated conservatively for 10 to 14 days; wounds that remain unhealed should undergo grafting.

Figure 10-4 **This burn of the dorsal hand is about 10 days old.** Areas of different burn depth are apparent. There is still some fairly solid eschar over the dorsal hand and fingers, but eschar has separated over the proximal (wrist) edge, revealing pink healing tissue. Regularly spaced, small, darker-red spots are epidermal appendages ("skin buds"), where epidermis is growing upward from hair follicles. The appearance of uniform skin buds indicates that the wound will heal reliably within about 14 days.

Full-thickness burns ("third-degree burns") occur when all layers of the skin are destroyed. These wounds are usually covered with dry, avascular coagulum, which is relatively insensate due to the destruction of nerve endings. The wound surface may be almost any color, from waxy white in the case of chemical burns, to a completely black, charred surface from flame injury. Full-thickness scald burns are often a dark cherry red color, but the surface is dry and does not blanch with pressure. In addition, as dermal proteins are coagulated, they contract, often forming a tight, tourniquet-like constriction, which can cause circulatory compromise in the extremities. Very small, full-thickness burns can heal by contraction, but larger injuries require skin grafting because even the deepest epidermal appendages are destroyed. Figure 10-5 illustrates the appearance of full-thickness burns, which can be very dramatic. An additional category of burn injury, termed "fourth-degree" burns, is sometimes used to describe injuries that extend to the bone.

Figure 10-5 **Full-thickness burn of the leg.** This little boy was playing with matches and gasoline, and ignited his paint leg. The wound is a variety of colors, from dull white to black, but almost the entire wound is dry, leathery, and insensate. The contraction of dermal proteins, causing a tourniquet-like effect, is apparent.

PATHOPHYSIOLOGY OF INHALATION INJURY

Inhalation injury is a unique complication of injury from flames and smoke that is an important facet of burn treatment. Although inhalation injury is often less apparent than other manifestations of burn injury on initial presentation, it can cause severe morbidity and mortality that may overshadow those of cutaneous burns. These injuries most commonly occur during a fire in an enclosed space, so detailed information regarding the location of the patient during the fire is a critical point in the history. The treatment of inhalation injury is largely supportive. Endotracheal intubation to secure the swelling airway is mandatory. Ventilator support with positive end-expiratory pressure (PEEP) is most helpful in combating the airway collapse.

Inhalation injury can present in three different ways in burn patients. First, patients exposed to large amounts of toxic smoke frequently present with *carbon monoxide (CO) poisoning*. CO poisoning is a common cause of immediate death in patients injured in building fires, and often accounts for the majority of deaths in mass casualty incidents. CO is produced from an *incomplete* combustion of normal household items such as wood and cotton. CO competitively binds to oxygen receptors on the hemoglobin molecule to produce carboxyhemoglobin (COHb), which cannot transport oxygen. The tissue delivery of oxygen consequently decreases and severe hypoxia ensues. Oxygen-enriched tissues, such as the heart and brain, are the most vulnerable. At low levels, CO poisoning is initially asymptomatic, but as the COHb level rises, symptoms increase. CO poisoning is particularly deadly because of its tendency to impair mental function. The patient will initially experience headache, progressing to dizziness, weakness, and syncope. In the later stages, coma, seizures, and death result (see Table 10-1). CO poisoning should be strongly suspected in any patient who presents with altered mental status following exposure to smoke. Remember that pulse oximetry is not accurate in detecting CO poisoning; an arterial blood gas with direct measurement of hemoglobin saturation must be obtained to detect CO toxicity.

TABLE 10-1 Signs and Symptoms at Various Concentrations of Carboxyhemoglobin

COHb Concentration (%)	Symptoms
0–10	None (normal value may range up to 10% in smokers)
10–20	Tightness over forehead, mild headache, dilation of cutaneous blood vessels
20–30	Headache and throbbing in the temples
30–40	Severe headache, weakness, dizziness, dimness of vision, nausea, vomiting, and collapse
40–50	As above; syncope, increased pulse, and respiratory rate
50–60	Syncope, tachycardia, tachypnea, coma, intermittent seizures, Cheyne–Stokes respirations
60–70	Coma, intermittent seizures, depressed cardiac and respiratory function, possible death
70–80	Bradycardia, slow respirations, death within hours
80–90	Death within an hour
90–100	Death within minutes

COHb, carboxyhemoglobin.

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The treatment of CO poisoning should consist of ventilation with 100% oxygen, and must begin as soon as possible, ideally before the patient reaches the hospital. Endotracheal intubation may be needed both to protect the impaired airway and to adequately deliver such high levels of oxygen. If a more rapid decrease in COHb concentration is deemed necessary (usually because of acute neurologic symptoms), hyperbaric oxygen therapy (HBO) may be used. HBO works by providing higher concentrations of oxygen to compete with CO for hemoglobin binding. Oxygen administered at three atmospheres of pressure produces a PaO_2 as high as 1,500 mm Hg. This provides a significant amount of dissolved oxygen for immediate use and reduces the half-life of COHb from about 80 minutes at one atmosphere of pressure down to about 20 minutes. Appropriate equipment and personnel are required to perform hyperbaric therapy, and its use must be prioritized with other important aspects of care for acutely burned patients, including fluid resuscitation.

Burn patients may also present with *upper airway injury*. Unlike other forms of inhalation injury, which are chemical injuries, upper airway injury is produced by heat. Flash burns and explosions may produce instantaneous deep burns of the face and oropharynx, which lead to rapid, life-threatening airway edema. Swelling occurs progressively over the 24 hours following injury, and facial/airway edema can arise very precipitously. Massive facial swelling can accompany scald or chemical burns even in the absence of flames or smoke. Figure 10-6 illustrates this process. The assessment of airway patency and swelling is an important component of the initial evaluation of every burn patient (see Figure 10-6). Early endotracheal intubation is essential to support the airway during acute care of these patients.

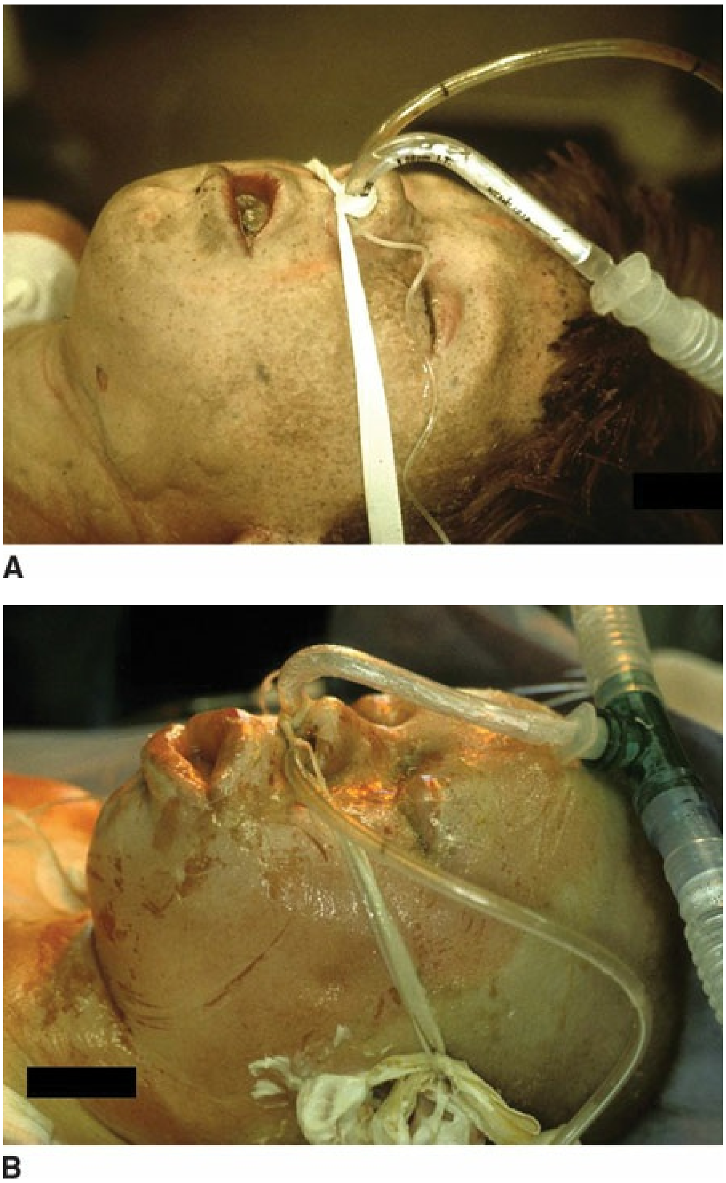

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Figure 10-6 **This young man suffered an extensive burn injury from a glass explosion. A,** About 45 minutes after injury. He has extensive deep burns of the face, which are indicated by the grayish, dry skin and charring about the lips. Although he was breathing normally, prophylactic intubation was performed. **B,** A few hours after the first photo. He has massive facial edema affecting his lips, eyelids, and neck. Without an endotracheal tube, it is likely that his airway would occlude. In treating extensive burns of this nature, it is important to consider intubation early, before an evidence of airway compromise develops. Also note that this patient has been nasally intubated. These are old photos; nasal intubation is rarely used today.

Patients who inhale significant quantities of smoke can suffer *lower airway injuries*, the so-called “true” inhalation injury. Cotton, wood, and paper are the most abundant fuels burned during a house/building fire. Large amounts of CO, formaldehyde, formic acid, cyanide, and hydrochloric acid are produced from the incomplete combustion of these materials. The inhalation of toxic compounds causes severe damage to the mucosal cells of the airway. Cyanide, generated as a byproduct of burning plastics, has been reported as a cause of death following smoke inhalation. The hallmark of cyanide toxicity is a persistent metabolic acidosis that is not responsive to fluid resuscitation. The treatment is the administration of hydroxocobalamin,which turns urine a dark purple color. In smoke inhalation injury, the dead/damaged lung parenchyma cells slough, producing plugging, segmental collapse, and bronchiectasis. Pneumonia can occur in multiple lung segments in these patients. However, this cascade of events often takes several days to develop; symptoms may be completely absent for the first 24 to 48 hours of care, so a high index of suspicion is critical for the detection and timely treatment of these injuries. The performance of fiberoptic bronchoscopy is an important part of the initial evaluation of patients trapped in enclosed spaces.

INITIAL CARE OF THE BURN PATIENT

Burn patients should be considered victims of multiple trauma, and many of the same treatment priorities and algorithms apply to their care as to other trauma patients. It will be assumed that the reader is familiar with the principles of Advanced Trauma Life Support outlined in Chapter 9; this chapter on burns focuses on the aspects of care that are unique to burn injuries.

Stop the Burning Process

A unique problem of burn trauma is the tendency for burns to continue producing tissue damage for minutes to hours after the initial burn has occurred. This process can further injure the patient as well as endanger medical personnel. For example, placing an oxygen mask on a victim of flame injury runs the risk of reigniting smoldering clothing. Stopping the burning process before proceeding with any other measures is critical. Flame burns should be extinguished completely by dousing with water, smothering, or rolling patients on the ground. Hot liquids—especially viscous liquids like tar or plastics—can remain hot enough to burn for some time; they should be cooled immediately with cool water or moist compresses. Once cooled, such compounds can then be left in place on the patient if necessary. Caustic chemicals must be diluted immediately and completely with copious amounts of water. In recent years, widespread concern over possible acts of terrorism and mass casualty incidents involving toxic chemicals has heightened awareness of the need to decontaminate patients thoroughly both to protect the care team and to spare victims further harm.

Victims of electrocution can themselves conduct current to rescue workers. Such patients cannot be approached until the source of current is shut off.

Primary Survey

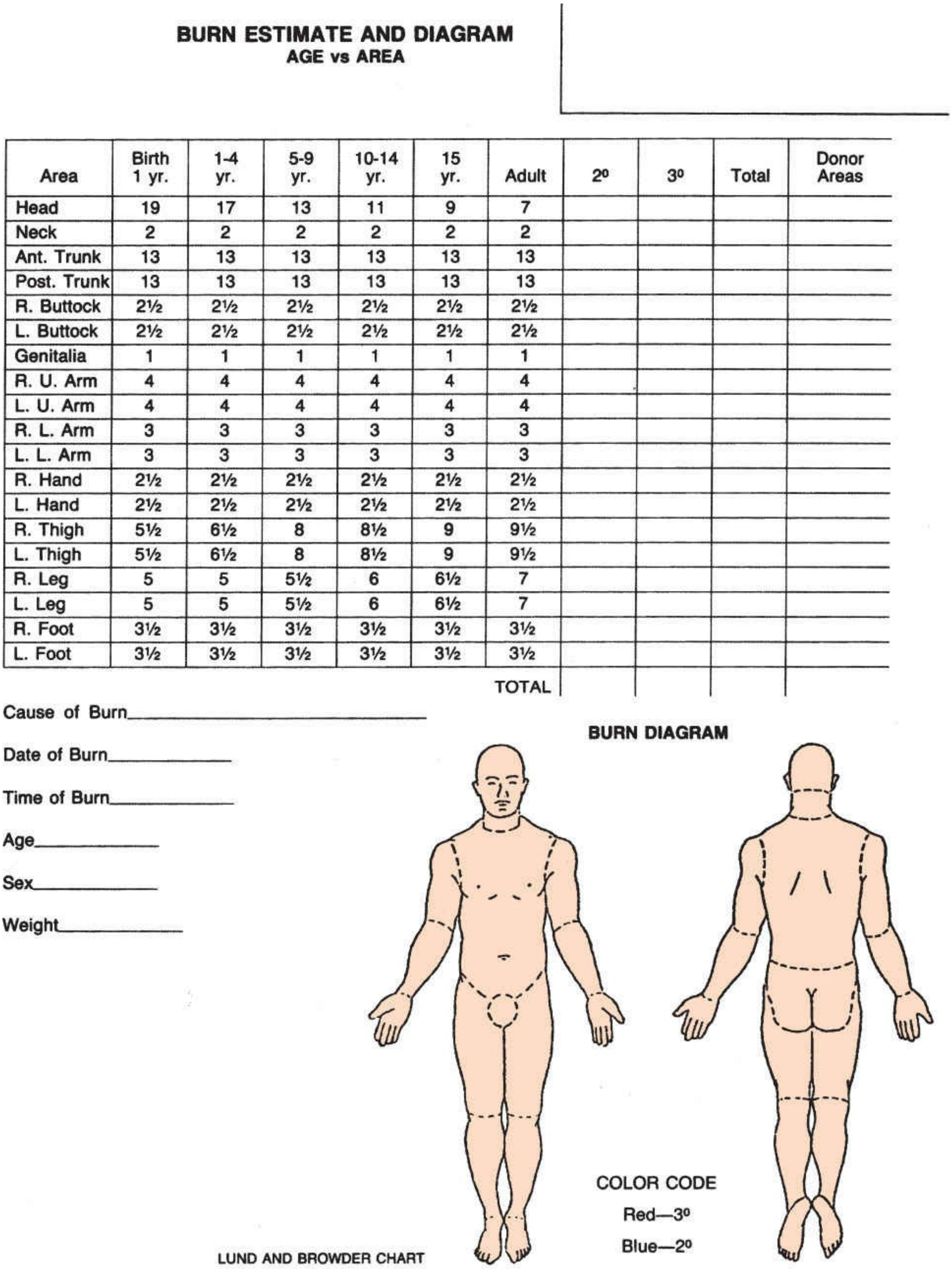
The primary survey is a quick examination designed to detect and treat immediately life-threatening conditions, beginning with the evaluation of *airway, breathing, and circulation* (the ABCs). In performing the primary survey in burn victims, special attention should be paid to the possible existence of smoke *inhalation injury*, which is a major source of both immediate and long-term morbidity and mortality. As discussed previously, inhalation injury should be suspected whenever the patient has been exposed to smoke. All three types of inhalation injury—CO poisoning, upper airway swelling, and lower airway obstruction and hypoxemia—may be present simultaneously, or any of the three may occur alone. Even in the absence of smoke exposure, patients with severe facial burns can develop massive swelling that can lead to an obstruction of the supraglottic airway. Remember again that edema is progressive, and the signs of airway compromise may be absent until several hours following injury; patients should be followed and reexamined regularly for this. Also during the primary survey, the examiner should note the evidence of circulatory compromise in extremities caused by severe edema and constricting burn wounds. See Chapter 9 for a more detailed review of the signs and symptoms of vascular compromise accompanying trauma to the extremities.

Resuscitation

Initial resuscitation of burn victims is similar to that of other patients. If injuries appear to be major, two large-bore lines placed intravenously should be secured. A Foley catheter should be placed to aid in resuscitation and blood drawn for laboratory studies. Formal calculation of fluid requirements should not be performed until after the secondary survey is completed. The performance of fluid resuscitation is an important ongoing part of the definitive treatment of burn injuries and will be discussed in detail in the following paragraphs.

Secondary Survey

All too often, the presence of a dramatic burn wound distracts the examiner from detecting other, more urgent injuries. In addition, the swelling, discoloration, and pain that accompany burns can obscure underlying abdominal tenderness, extremity fractures, or cyanosis. For these reasons, it is imperative that a comprehensive, head-to-toe exam of every burn patient be conducted. Only after completing the secondary survey should burns be debrided by removing blistered skin and washing the burn wound thoroughly. The location, extent, and depth of burn wounds should be documented. Two mechanisms exist for doing this. One, the “Rule of Nines” is performed by dividing the body into its component parts and assigning 9% of the total body surface area (TBSA) to each part. As an alternative, many providers use the Lund and Browder chart (Figure 10-7). These charts are used to calculate the total burn size, expressed as *percent total body surface area* (%TBSA). Only partial-thickness (second-degree) and full-thickness (third-degree) burn wounds should be included in this estimate of total burn size. An easy way to estimate small burns is to remember that the palm of the patient’s hand (with fingers) is approximately 1% of the body surface area (BSA). This estimate of burn size is used to guide fluid resuscitation, nutrition, and other aspects of care. Wounds should not be dressed with antibiotic creams or ointments, or wrapped with dressings, until a secondary assessment has been completed and the burn has been evaluated.



BURN ESTIMATE AND DIAGRAM
AGE vs AREA

Area	Birth 1 yr.	1-4 yr.	5-9 yr.	10-14 yr.	15 yr.	Adult	2°	3°	Total	Donor Areas
Head	19	17	13	11	9	7				
Neck	2	2	2	2	2	2				
Ant. Trunk	13	13	13	13	13	13				
Post. Trunk	13	13	13	13	13	13				
R. Buttock	2½	2½	2½	2½	2½	2½				
L. Buttock	2½	2½	2½	2½	2½	2½				
Genitalia	1	1	1	1	1	1				
R. U. Arm	4	4	4	4	4	4				
L. U. Arm	4	4	4	4	4	4				
R. L. Arm	3	3	3	3	3	3				
L. L. Arm	3	3	3	3	3	3				
R. Hand	2½	2½	2½	2½	2½	2½				
L. Hand	2½	2½	2½	2½	2½	2½				
R. Thigh	5½	6½	8	8½	9	9½				
L. Thigh	5½	6½	8	8½	9	9½				
R. Leg	5	5	5½	6	6½	7				
L. Leg	5	5	5½	6	6½	7				
R. Foot	3½	3½	3½	3½	3½	3½				
L. Foot	3½	3½	3½	3½	3½	3½				
						TOTAL				

Cause of Burn____________________

Date of Burn____________

Time of Burn____________

Age____________

Sex____________

Weight____________

BURN DIAGRAM

COLOR CODE
Red—3°
Blue—2°

LUND AND BROWDER CHART

Figure 10-7 **Lund and Browder chart.** This diagram was developed during World War II to help document and estimate the extent of burn injuries. Following initial debridement, the examiner should draw the burn injuries on the figure, calculate how much of each body area is burned, and then add all areas to produce a total burn size. Inexperienced providers tend to overestimate burn size and underestimate depth. We hope that the figures included with this chapter will help readers evaluate burn wounds more accurately.

Burn Center Referral

Over the past 50 years, specialized burn facilities have been developed to care for patients with serious burns. The American Burn Association and the American College of Surgeons have defined criteria for burn centers, similar to those developed for trauma centers. These criteria require that institutions maintain significant multidisciplinary expertise in all phases of burn treatment, and commit space, resources, and personnel to the care of patients with burns. In addition, specific guidelines for referral of patients to burn centers have been developed; these are contained in Table 10-2. The guidelines are widely used as standards for treatment. As a more general rule, surgeons who do not work in burn centers should treat only patients with burns they are experienced in treating and should consider consultation with a burn center for *any* questions regarding patient management.

TABLE 10-2 Criteria for Referral to a Burn Center

1.	**Partial-thickness burns >10% TBSA**
2.	**Burns that involve the face, hand, feet, genitalia, perineum, or major joints**
3.	**Third-degree burns in any age group**
4.	**Electrical burns, including lightning injury**
5.	**Chemical burns**
6.	**Inhalation injury**
7.	**Burn injury in patients with preexisting medical disorders that could complicate management, prolong recovery, or affect mortality**
8.	**Any patient with burns and concomitant trauma (such as fractures) in which the burn injury poses the greatest risk of morbidity or mortality. In such cases, if the trauma poses the greater immediate risk, the patient's condition may be stabilized initially in a trauma center before transfer to a burn center. Physician judgment will be necessary in such situations and should be in concert with the regional medical control plan and triage protocols.**
9.	**Burned children in hospitals without qualified personnel or equipment for the care of children**
10.	**Burn injury in patients who will require special social, emotional, or rehabilitative intervention**

TBSA, total body surface area.

Referral Criteria. American Burn Association. **Advanced Burn Life Support Provider Manual.** *Chicago, IL: American Burn Association; 2005:76. Used with permission.*

DEFINITIVE CARE OF BURN INJURIES

Following initial assessment, burn patients require treatment for a number of physiologic consequences of injury. Support for several different problems may be required simultaneously, although the importance and magnitude of these problems change at different times post burn. To help in organizing treatment priorities and protocols, many physicians divide burn care into three periods: *resuscitation*, *wound closure*, and *rehabilitation*. It should be emphasized, however, that these distinctions are somewhat artificial, that many aspects of care overlap, and that careful attention to the individual patient's needs is essential at all stages of treatment.

Resuscitation Period

This period lasts for the first 24 to 48 hours following injury. Once an acutely burned patient has been evaluated and stabilized, as described previously, fluid resuscitation is the most important goal of initial treatment. Burn injury produces a loss of capillary integrity, which results in edema formation. With large (≥15% to 20% TBSA) injuries, capillary leakage becomes systemic, producing total body edema, and severely depleting circulating volume, a phenomenon known as *burn shock*. In general, patients with burns of 10% to 15% TBSA or greater require formal fluid resuscitation. These fluid losses can exceed those of any other injury or disease; truly remarkable amounts of fluid may be required for the successful resuscitation of patients with very large injuries.

A host of algorithms have been developed for burn resuscitation, but most successful regimens share several basic concepts. These are illustrated in Table 10-3, by the Consensus formula, a widely utilized, simple, and relatively generous resuscitation formula.

TABLE 10-3 Principles of Fluid Resuscitation for Burns: The Consensus Formula

Principles	
A.	**Resuscitation should consist primarily of isotonic crystalloid solution because it is inexpensive, readily available, and can be given in large quantities without harmful side effects.**
B.	**Because injured capillaries are porous to proteins for the first several hours after injury, colloid-containing fluids are not used initially.**
C.	**Resuscitation requirements are proportional to burn size and the patient's body weight.**
D.	**Edema formation is most rapid during the first hours after injury but continues for at least 24 hr. Therefore, half the calculated fluid is given in the first 8 hr following the burn.**
E.	**Formulas only tell you where to BEGIN resuscitation, which must then be guided by patient response: urine output, vital signs, and mental status.**
Practice: The Consensus Formula	
A.	**The formula: 2–4 mL lactated Ringer's × body weight (kg) × %TBSA burns = total fluid for the first 24 hr.**
B.	**For the first 8 hr after injury, give half the total calculation.**
C.	**For the second and third 8 hr after injury, give one-fourth the total calculation.**
Example	
A.	**A 220-lb (100 kg) man is burned while filling the gas tank on his boat. He is wearing a swimming suit and is burned over all of both legs, his chest, and both arms. Calculated burn size is 65% TBSA.**
B.	**Calculated fluid requirements: The Consensus formula offers a range of options, from 2 to 4 mL/kg/%TBSA. Therefore, calculations range between the following:**
	Minimum: 2 mL × 100 kg × 65% TBSA = 13,000 mL in 24 hr
	= 6,500 in first 8 hr = 812 mL/hr
	= 3,250 mL in each of the second and third 8 hr = 406 mL/hr

	Maximum: 4 mL × 100 kg × 65% TBSA = 26,000 mL in 24 hr
	= 13,000 mL in first 8 hr = 1,625 mL/hr
	= 6,500 mL in each of the second and third 8 hr = 812 mL/hr
C.	**Adjust according to patient response.**
1.	**You select an initial rate of 812 mL/hr on the basis of a calculation of 2 mL/kg/%TBSA. After 6 hr, the patient has received 4,872 mL of lactated Ringer's. Urine output, which was initially good, has fallen to 20 mL in the past hour. Heart rate is 132 beats/min and BP is 106/50 mm Hg.**
2.	**At this point, you should increase the fluid rate, typically by about 10%–20%. All indications point to inadequate resuscitation.**
3.	**You increase fluids by 20%, to 974 mL/hr. Two hours later, urine output again drops, to 15 mL/hr. Heart rate is 128 beats/min and BP is 98/52 mm Hg.**
4.	**You should again increase fluids. Most experts would NOT consider the use of a diuretic at this point in time. Individual fluid requirements vary significantly, and this man appears to need more than the minimum requirements. Even if you had selected an initial rate of 1,625 mL/hr, your response to decreasing urine output should be the same—to increase fluids.**
5.	**Three hours later, urine output has increased to 95 mL/hr. Heart rate has dropped to 90 beats/min and BP is 135/85 mm Hg.**
6.	**You should now begin to decrease fluids by 10%–15% per hour, with continued attention to urine output and vital signs. Fluid resuscitation is a dynamic process and requires continuous attention to detail.**

BP, blood pressure; TBSA, total body surface area.

This formula calls for isotonic crystalloid fluid (lactated Ringer's solution) to be given at an initial rate determined from burn size and body weight. Because even experts disagree on the optimal quantity of fluid to be used, the formula provides a range of choices (from 2 to 4 mL of lactated Ringer's solution per kilogram body weight for every percent TBSA that is burned). Edema formation occurs throughout the first 24 hours post burn, but is most pronounced during the first 8 hours, so half the total fluid is given during that period. However, because inhalation injury, multiple trauma, and other factors can influence an individual's fluid requirements, regimens like the Consensus formula really only tell you where to *begin* resuscitation. Fluid administration should thereafter be guided by frequent and repeated evaluation of the patient. The maintenance of adequate urine output (≥30 mL/hour in adults; 1 to 1.5 mL/kg/hour in children) is used as an indicator of appropriate fluid intake and an important goal of treatment. The infusion rate is adjusted according to urine output and gradually decreased until a maintenance rate is reached. Vital signs, hematocrit, and other laboratory tests should be carefully monitored as well.

Fluid resuscitation does not stop fluid leakage into the interstitium; it is intended only to keep up with ongoing losses, which decrease over time. As resuscitation proceeds, therefore, so does tissue swelling. Fluid accumulating beneath the constricted eschar of a deep burn increases tissue hydrostatic pressure, sometimes to the point that circulation is compromised. Frequent evaluation of extremity pulses, sensory and motor function, and pain is essential to diagnose the progressive ischemia of a compartment syndrome. The treatment of compromised circulation in a circumferential burn is escharotomy. An escharotomy is an incision made through the rigid, leathery eschar to relieve the compression produced by ongoing edema, and thus, restore distal circulation. Figure 10-8 illustrates an escharotomy of the upper extremity. Compression by edema can also affect the chest and abdomen, resulting in respiratory compromise. Escharotomies can be performed on the torso and should provide immediate relief. Because escharotomies are always made through burn wounds, they are repaired during burn wound excision and skin grafting, and usually leave no additional scars.

Figure 10-8 **Escharotomy of the upper extremity.** This extensively burned arm and hand developed progressive tense edema, numbness and tingling, and deep throbbing pain. Intramuscular pressures were measured using a sterile needle connected to a pressure transducer and were in excess of 30 cm H_2O. Escharotomies were performed at the bedside using deep sedation and electrocautery. The wound edges have separated markedly because of the underlying edema. It should be remembered that escharotomy does not reduce the *swelling* associated with the burn injury, but it is done to relieve the *compression* produced by edema accumulation beneath the unyielding surface of a deep burn injury.

However, escharotomies do not always provide adequate relief of edema-related pressure. When burns of the extremity are particularly deep, incisions through the underlying muscle fascia ("fasciotomies") may be required to produce adequate decompression. This is more commonly required for high-voltage electrical injuries (Figure 10-9). In addition, massive fluid accumulation within the tissues of the abdomen can produce an abdominal compartment syndrome and require laparotomy to relieve this compression.

Figure 10-9 **High-voltage electrical injury of the hand.** Charring and full-thickness injury of the base of the palm is apparent. The fingers and wrist are "fixed" in flexion because of coagulation necrosis of the flexor

muscles of the forearm. Brownish necrosis of the flexor tendons and distal muscles are apparent. Note the dramatic separation of the skin edges following fasciotomy. The hand is unsalvageable; the blue line indicates the approximate level of amputation to be performed.

RESPIRATORY SUPPORT

Resuscitation of the patient with moderate to severe inhalation injury usually requires modifications. An inhalation injury is essentially a burn to the inside of the lungs, and the Consensus formula must be adjusted appropriately. The amount of fluid given should still be adjusted according to patient response, but it is common for the patient with inhalation injury to have higher intravenous fluid requirements from unseen fluid loss caused by lung injury. Ventilatory support and close monitoring of systemic arterial pressure, lactic acid, and urine output must be used to help titrate the amount of fluids the patient is receiving. The development of acute respiratory distress syndrome (ARDS) is very common with a severe inhalation injury. Overresuscitation with intravenous fluids can worsen the ARDS and should be avoided if at all possible. ARDS is diagnosed by a "ground-glass" appearance on chest radiograph coupled with the clinical syndrome of worsening respiratory failure. Aggressive modes of ventilator support are necessary to combat hypoxemia in patients with ARDS. Conventional ventilator settings must have adequate PEEP and low tidal volumes to minimize barotrauma. Newer ventilator modes, such as airway pressure release ventilation and pressure regulated volume control, may be useful in ARDS, as they reduce barotrauma. The treatment team must remain vigilant with respiratory care and patient positioning to reduce the risk of pneumonia from inhalation injuries. ARDS secondary to inhalation injury can progress to chronic respiratory failure; these patients may require tracheostomy and long-term ventilator support.

Wound Coverage Period

This phase of treatment begins immediately following fluid resuscitation and lasts for days to weeks until the burn wound either heals primarily or is successfully replaced with skin grafts. This period comprises most of the patient's hospital care and is the period of most intensive treatment. Patients who attain successful wound closure usually survive, although they may face prolonged rehabilitation following this period of care.

EXCISION AND SKIN GRAFTING

Deeply burned skin is a great liability to the patient. Not only does burn eschar serve as a site for infection, but the loss of skin integrity causes increased evaporative fluid losses, severe pain, and an intense inflammatory response that can escalate, leading to multiple organ failure and death. If followed conservatively, deep eschar will eventually separate spontaneously, but this can take weeks or months, during which the patient is exposed to ongoing stress and the risk of infection. For these reasons, most burn centers now employ early excision, in which burned skin is cut off the underlying tissue. Two techniques are used: fascial and tangential excision. In fascial excision, the scalpel or cautery is used to excise the entire skin and subcutaneous tissue, usually to the level of the underlying fascia. Although this procedure is easy to perform, relatively bloodless, and permits good skin graft "take," it is disfiguring and leads to joint stiffness and poor mobility (Figure 10-10). For the past two decades, the technique of "layered" or tangential excision has gained popularity. In this technique, sequential thin slices of skin are removed with a dermatome until viable tissue is encountered. This technique requires skill and produces significant bleeding. However, the cosmetic and functional results of grafting this type of wound are often superior to those of fascial excision. Tangential excision of deep partial-thickness burns permits salvaging intact dermal elements, which improves the results of skin grafting. Most surgeons wait until fluid resuscitation has been completed before beginning excisional therapy in order to permit the stabilization of cardiovascular function and intravascular volume, which can be further compromised by surgical blood loss. Limited burns of mixed or indeterminate depth can be followed for 10 to 14 days before the decision to proceed with surgery must be made.

Figure 10-10 **The long-term result of fascial excision and skin grafting.** Fascia is well vascularized and will "take" skin grafts well. However, the resulting wound is stiff, and the lack of subcutaneous padding results in chronic discomfort and poor joint mobility, as well as the obvious problems with appearance.

Skin grafting is usually performed at the same time as excision. At present, permanent coverage of an excised wound can be achieved only with the patient's own skin, called an autograft. Autografting can be performed using full-thickness or split-thickness skin grafts. Full-thickness grafts are obtained by excising an ellipse of skin from the groin or flank, which is closed with sutures. Split-thickness grafts are obtained by using a dermatome to harvest intact skin at the level of the superficial dermis, typically 0.004 to 0.015 inches in depth. This yields a graft with sufficient dermis for secure coverage of the excised burn, while leaving a wound superficial enough to heal spontaneously in 7 to 14 days. In treating very large burns, the urgency to remove eschar often requires that excision be performed even if no donor sites are available for grafting. Although the best functional and cosmetic results are obtained when sheet grafts are placed, when insufficient autograft is available, several techniques can be used to obtain wound coverage. First, skin can be expanded by meshing or cutting multiple small slits in the skin. Many skin grafts are meshed to facilitate application and graft “take.” These grafts leave a permanent mesh pattern in the skin but produce durable coverage. Widely meshed autografts will cover larger areas, although the interstices of the mesh are prone to desiccation. The most widely used skin substitute is cadaver allograft, skin obtained from tissue banks. Other skin substitutes include freeze-dried pigskin, human amniotic membrane, and various synthetic materials. In recent years, considerable research has been devoted to the development of a man-made “artificial dermis,” which could be taken off the shelf and used to cover large burn wounds. Some of these products are used routinely, particularly in reconstructive surgery, but they still require coverage with thin autografts. Finally, it is possible to grow a patient’s own epidermal cells in culture. These cultured epidermal allografts are expensive, fragile, and easily lost because of infection. Nonetheless, they have proved lifesaving in some patients with massive burns.

INFECTION CONTROL

Although the skin surface after burning is virtually sterile for 24 to 48 hours, it is gradually repopulated with bacteria. Burn eschar—especially the thick, avascular eschar of deep burns—is an ideal culture medium for bacteria, which will rapidly multiply on such a surface. These bacteria may colonize burn eschar harmlessly, or, by penetrating through the burn wound, invade intact tissues and overwhelm local defenses, producing invasive infection, termed burn wound sepsis. Infection is also exacerbated by the immunosuppression that accompanies severe burn injury. Burn wound sepsis is often fatal and, until recently, has been the most common cause of death in hospitalized burn victims. With modern methods of wound management, however, it is now an infrequent occurrence in burn centers.

Much of the increased survival from burns achieved in the past 50 years is due to improved understanding and the treatment of burn wound infections. Beginning in the 1940s, systemic antibiotics like penicillin, as well as some topical agents, were used to control microbial contamination of burn wounds. The first widely used topical antimicrobial, silver nitrate solution, proved particularly effective in controlling infections caused by *Staphylococcus* and *Streptococcus* species. A variety of gram-negative infections then began to predominate as causes of burn wound infection. The development in the 1960s of two powerful topical agents, mafenide acetate (Sulfamylon) and silver sulfadiazine, helped control many gram-negative bacteria, which were then replaced by resistant *Pseudomonas* as a leading cause of infection. More recently, a host of powerful systemic antibiotics, and numerous other topical agents, have helped control *Pseudomonas* infections. This success has been followed by—and to some extent, caused—the emergence of multiply resistant bacteria (such as methicillin-resistant *Staphylococcus aureus*, *Acinetobacter*, and vancomycin-resistant *Enterococcus*), as well as fungi and other exotic organisms, as important clinical pathogens in burn victims. This problem is magnified by the development in many burn centers of entrenched, endemic microbial populations, which have proven very difficult to eradicate. Thus, because the medical community has developed evermore powerful antimicrobials for burn care, we have seen the microbial fauna adapt and continue to present new and unforeseen problems.

The most effective technique in the battle against burn wound infection is early burn excision and skin grafting, discussed previously. Meticulous wound care is an essential part of burn treatment during the repair phase. Beginning immediately post burn, wounds must be washed regularly and carefully debrided of old topical creams and ointments, dried serum, and bits of loose eschar. Topical antimicrobials are effective only for a few hours, and most experts agree that their replacement, as well as regular and thorough debridement, should be performed at least twice daily. There are some new products that adhere to wounds and release antibiotics (usually silver) slowly; their use should be supervised by an experienced clinician because infection developing beneath these products can be particularly difficult to diagnose and treat. This is also true for freshly grafted burn wounds and skin graft donor sites.

As the prevention and treatment of burn wound infection has become more successful, other problems have gained prominence as causes of morbidity and mortality in burn victims. Pneumonia has emerged as the most common, and often the most troublesome, infection seen in burn patients. The bronchiectasis and mucous plugging that accompany inhalation injury create an environment rife for the development of infections and render them difficult to clear. Pneumonia, in turn, often serves as a stimulus for systemic inflammation and infection, leading to the development of multiple organ failure. Other infectious complications can occur in burn victims as well, including wound, urinary tract, and bloodstream infections. Septic thrombophlebitis can even occur in veins cannulated for vascular access.

NUTRITIONAL SUPPORT

As part of the hormonal response to burn trauma, metabolic rate rises dramatically and can exceed twice normal for prolonged periods, with a corresponding increase in nitrogen excretion. The massive catabolism post burn can result in a fatal degree of inanition within a few weeks if left untreated. Protein malnutrition causes both wasting of respiratory muscles and immune compromise, with resulting pulmonary infection and death. For this reason, burn patients require aggressive nutritional support and close nutritional monitoring throughout the wound closure phase of treatment. Enteral feeding is clearly superior to intravenous nutrition in burn victims; patients with large injuries should have the placement of enteral feeding tubes as soon as possible and the infusion of a high-protein liquid diet until they can demonstrate adequate oral intake. A variety of formulas have been used to predict the caloric requirements of burn patients. None is entirely satisfactory, due in large part to the wide variation seen among individuals and the fluctuations in energy expenditure that occur during the postburn course. Many experts recommend the routine measurement of energy expenditure using indirect calorimetry and of protein utilization by determining nitrogen balance at least weekly. The technique of indirect calorimetry calculates the energy requirements of an individual by measuring the oxygen consumed during normal breathing. The provision of a basic high-protein diet (1.5 to 2.0 g protein/kg body weight daily), in quantities sufficient to satisfy caloric requirements, remains the most important principle in the nutritional management of such patients.

The Rehabilitation Phase

Once burns are closed, major emphasis is shifted to rehabilitation. Providers should remember the adage that *rehabilitation begins at the time of injury*; do NOT wait for wound closure. As burn wounds heal, they contract because of the presence of myofibroblasts that begin to accumulate within wounds shortly after injury and continue to proliferate within the scar. If unopposed, burn scar contractures can immobilize extremities completely and produce significant disfigurement. Much of the therapy provided during burn rehabilitation is aimed at preventing and correcting contractures. This therapy is more effective if begun soon after injury, while the scar tissue is still pliable, and before it can "set" into significant contractures. The scar tissue remains inflamed and continues to remodel and reshape itself for at least a year following injury. Burn patients are usually followed for at least that long. In addition to motion and stretching exercises, tight-fitting garments are frequently used to retard the growth of hypertrophic scars. These custom-made garments are worn until the scar tissue softens and erythema fades. Figure 10-11 shows a custom-made clear facemask used for the same purpose. The process of recovering completely from a major burn is long and labor-intensive, but the vast majority of burn victims can return to active and useful lives with appropriate therapy. The vast majority of patients return to work or school, even following burns of 70% TBSA or greater.

Figure 10-11 **Compressive face mask.** The child was burned in an automobile fire and required extensive skin grafting to her face. Long-term use of elastic face masks tends to produce deformities of the mandible in children; these masks are unattractive and socially stigmatizing. Instead, a rigid mask of clear plastic, which the patient wears for most of every day, was custom-made. This compresses the skin grafts as they remodel, resulting in a smoother result with fewer contractures. Such masks are typically worn for at least a year following injury.

Reconstructive surgery may be needed to correct particularly difficult contractures, resurface areas of unstable wound coverage, or improve cosmesis. This surgery is usually postponed until burn scars mature and soften. However, many reconstructive procedures can be avoided by early and continued application of physical therapy and other rehabilitative techniques.

SPECIAL PROBLEMS IN BURN CARE

Comprehensive care of burn patients often involves a number of issues that either are not regularly encountered in other surgical practices or present themselves in unique ways. These include the unique features of electrical and chemical injuries, the care of patients with minor burns, problems with pain control and itching, and the increasing trend for burn centers to treat other nonburn conditions. These are reviewed here.

Chemical and Electrical Burns

Both chemical and electrical injuries can present unique problems in diagnosis and treatment. The degree of tissue damage produced by chemicals is determined by the nature of the agent, its concentration, and the duration of skin contact. Three classes of chemicals commonly produce skin injuries. Alkalis dissolve and combine with the proteins of the tissues to form alkaline proteinates, which contain hydroxide ions. These ions induce further chemical reactions, penetrating deeper into the tissue. Acids induce protein breakdown by hydrolysis, which results in an eschar that does not penetrate as deeply as the alkalis. These agents also induce thermal injury by heat generation with contact of the skin, further causing tissue damage. Organic compounds such as petroleum products, phenols, and others injure tissue by their fat-solvent action, which dissolves cell membranes. All three types of agents also pose the risk of systemic absorption and toxicity to both patients and providers.

A careful history should be obtained to identify the responsible chemical. Prompt treatment is imperative in minimizing tissue damage. Providers should wear protective gear and detoxify the patient completely before other care is delivered. All patient clothing should be removed, any dry powders should be brushed off the skin, and all chemicals should then be thoroughly irrigated with copious volumes of water. Hot chemicals such as tar can be left in place once cooled completely. If the chemical composition is known, monitoring of the pH of the irrigated solution will give a good indication of irrigation effectiveness and completion. The local poison control center may provide important information on specific chemical injuries, their severity, and possible adjunctive treatment, but initial detoxification—with appropriate protection of personnel—should always be instituted as quickly as possible.

Patients may have metabolic disturbances from pH abnormalities or from specific chemical toxicities (such as organophosphates). An arterial blood gas, electrolytes, and hepatic enzymes should be obtained. If the patient's condition deteriorates—such as obvious progression of the wound and/or progressive metabolic deterioration—urgent surgery may be needed to remove the wound entirely. Resuscitation should be guided by BSA involved. The depth of injury can be difficult to determine with chemical injuries: some may be more superficial than they appear, particularly in the case of acids, whereas alkaline injuries may penetrate beyond that which is apparent on exam and will require more fluid for effective resuscitation volume. Once initial care and resuscitation are completed, chemical wounds are managed in the same way as other burn injuries are done.

Electrical injuries occur when current enters a part of the body, such as the hand, and proceeds through tissues with the lowest resistance, generally nerves, blood vessels, and muscles, to exit through ground. Electrical injuries are classified as low-voltage (<1,000 V) and high-voltage (>1,000 V) injuries. Low-voltage injury, which typically results from household (120 V) current, is generally limited to the area surrounding the injury. The skin has high resistance to electrical current, and many low-voltage injuries produce only small cutaneous burns. However, with high-voltage injuries, typically from industrial current contact, the skin involvement may be limited, but associated underlying soft tissue damage may be extensive. Current travels preferentially beneath the skin, because deeper tissues have less resistance; tissues having the highest resistance generate the most heat. Deep tissues appear to retain heat so that the tissues next to the bones, especially between two bones, often sustain more severe injury than more superficial tissue does. In fact, the superficial muscle may appear uninjured while the deeper muscle near the bones may be damaged. Thus, the true extent of tissue damage with high-voltage injury may be impossible to determine on initial inspection. See Figure 10-9 for an example of a high-voltage electrical injury.

Electrical injuries can cause a variety of wounds. Current flow through tissues, as described earlier, can result in deep tissue damage. In addition, current passing from its source to ground can generate an electrical arc or "flash" injury. Flame injuries can also result from an ignition of clothing without actual current flow through the patient. Electrical injury may also be associated with falls and can produce blunt trauma from tetanic muscle contractions. Lightning injuries are a type of very high-voltage direct current injuries. The blast associated with lightning strikes can produce significant trauma, including ruptured eardrums. Late complications include the development of cataracts and peripheral neuropathy.

In assessing a victim of electrical injury, the first step is to be sure that no potential for continued electrical damage exists. Current sources must be disconnected before the patient can be approached. Electrical injury can result in dysrhythmia, and many patients die from electrically induced ventricular fibrillation or cardiac standstill, so immediate attention to resuscitation is essential. All victims of electric shock should have an electrocardiogram (ECG) obtained; victims of high-voltage injury (and low-voltage injuries associated with abnormal ECG findings) should be monitored on telemetry for at least 24 hours. Because of the potential for multiple trauma from falls and muscle tetany, patients should be immobilized and treated as multiple-trauma victims. Victims of high-voltage injury should be referred to a burn center and will require formal resuscitation. These injuries often result in muscle damage and rhabdomyolysis; if untreated, this will lead to compartment syndromes and renal failure. Pigmented urine with myoglobin will appear tea colored. Intravenous fluid should be given to maintain adequate urine output, which should be 100 mL/hour or greater until the urine is clear or myoglobinuria is resolved. The use of bicarbonate to alkalinize urine and mannitol as an osmotic diuresis to enhance renal clearance of myoglobin has not been proven in prospective studies. Therefore, the use of these adjunct treatments should be individualized according to practitioners' experience.

When compartment syndrome is suspected or myoglobinuria does not improve with resuscitation, emergent fasciotomy or exploration of muscles and debridement of the necrotic muscle may be needed. Early amputation of an affected limb may be required in severe cases. Figure 10-9 illustrates such a case.

Care of Outpatient and Minor Burns

Although burn centers concentrate on the care of patients with major injuries, many burn wounds are small and can be managed on an outpatient basis. More than a half million emergency department visits annually are related to burns, and over 75% are limited injuries (less than 10% TBSA). Even such small burns, however, can be important injuries, with significant associated pain, potential for infection, and disability. The overarching goals of treatment are to relieve pain, prevent infection, and encourage optimal healing with the least amount of scar formation.

Burns that involve small areas of injury can often be treated in a primary care or emergency department setting. Any burn patient with the evidence of inhalation injury, circumferential burns, burns to the face, hands, or perineum, or significant comorbidities is best referred to a burn center. Minor burns in children or in the elderly are less than 5% TBSA. The size of burns is often overestimated, and the use of standardized tools such as the Lund and Browder chart (see Figure 10-7) is helpful in deciding on the most appropriate location and method of treatment.

As with major burns, treatment begins with removal of the offending agent and cooling the injury. It has been shown that ice water or ice cubes increase necrosis in experimental burns but that tap water at 12°C to 25°C is effective at reducing damage and providing initial pain relief. However, cooling should be applied only for a short time, because complications such as frostbite and hypothermia can result from prolonged cooling. After patient assessment and calculation of the burn depth and size, a decision is made regarding treatment in the outpatient setting, hospital admission, or burn unit transfer. Criteria for referral of burn injuries to specialized centers for care are listed in Table 10-2.

Epidermal burns without blistering do not require topical care. The treatment of superficial partial-thickness injuries should begin by thoroughly washing the wound. Although controversy exists regarding the treatment of blisters, they can often be left intact. However, once they rupture, blisters should be debrided to facilitate cleansing of the wound. Once washed and debrided, burns can be covered with a variety of topical agents, including antibiotic creams (silver sulfadiazine, mafenide acetate) or ointments (neomycin sulfate, bacitracin). Commercial products containing aloe vera have also been used with success. Historically, silver nitrate and silver sulfadiazine have been used to inhibit bacterial growth in burns. Because these substances are inactivated in a burn wound environment, they require frequent reapplication. Although the evidence for the direct benefits of such topical care for minor burns is lacking, it is unquestionably true that dressing these wounds relieves discomfort and provides psychological benefit to the patient. Encouraging frequent washing and reapplying topical compounds may provide their most important benefit. More recently, a variety of other silver-containing dressings (silver imbedded in hydrofibers or on polyethylene mesh, and nanocrystalline silver) have been developed for burn care. These dressings can be left on wounds for longer periods, lengthening the time between dressing changes, which reduces pain and the incidence of infection compared with traditional silver preparations. They are also cost-effective, considering the need for fewer dressing changes.

Oral antibiotics are not required for uninfected burns. Topical antibiotics and absorptive dressings are useful for most contaminated burns. Burns should be inspected daily to assess for infection and changes that become evident rapidly when infection occurs.

Deep partial-thickness burns or third-degree burns are covered initially with an antibiotic ointment and dressed. Depending on local expertise and size of the burn, they should be considered for local excision and grafting. Because these wounds heal by contraction and generate considerable scar formation, all but the smallest burns should be excised. The depth of the burn may be difficult to determine initially, so frequent examination is required. Burns can deepen during the first few days because of infection or desiccation. As described previously, small burns should heal within a few weeks; burns taking longer than 3 weeks will likely form hypertrophic scars and provide an unstable epithelium. For this reason, early excision is optimal.

Treatment of Itching and Pain

Morbidity from burns extends beyond the acute phase of treatment. The pain and anxiety associated with burn injury is a significant problem. Control of pain is essential to quality patient care. Pain should be assessed whenever other vital signs are taken and treated promptly and effectively. A variety of standard scales are available to quantify pain by both patients and providers.

Analgesics are most effective for acute burn pain when given on a scheduled basis, before pain can escalate. The intravenous route is preferred during the resuscitation phase; intramuscular injections should be avoided because of highly unpredictable absorption and plasma levels and the pain of the injections themselves. Once resuscitation is completed, oral or enteral medications can be used to supplement injections as needed. The dose, route, and type of medication should be evaluated frequently to make sure pain is satisfactorily controlled.

The most commonly used analgesics for controlling acute burn pain are opioids. Morphine is most widely used. Fentanyl is shorter-acting and avoids oversedation following a procedure. Oral formulations of both agents are available in addition to intravenous preparations. In addition to opioid analgesics, anesthetic agents such as ketamine and nitrous oxide can be used to provide short-term relief of pain and anxiety during procedures. For outpatient treatment, combinations of hydrocodone or oxycodone with acetaminophen are often sufficient. Nonsteroidal anti-inflammatory drugs can be used for the relief of mild to moderate pain or as adjuncts to hydrocodone/oxycodone.

Anxiety is prevalent in burn patients and can exacerbate pain. Lorazepam, diazepam, and midazolam are the main anxiolytics used in the treatment of burn-related anxiety and are often used in combination with opiate analgesics; α_2-adrenergic agonists such as clonidine and dexmedetomidine can also have excellent sedative, analgesic, and anxiolytic effects and have been used in burn patients with good results. Table 10-4 lists a number of medications commonly used for analgesia and sedation in burn centers. It should be noted that many of these agents should be used only in an inpatient, monitored setting.

TABLE 10-4 List of Analgesia and Sedatives Typically Used in Adult Burn Treatment

Agent	Recommended Dosages	Comment
Opiates		
Morphine sulfate	**0.03–0.1 mg/kg IV**	**Morphine, fentanyl, and hydromorphone (Dilaudid) are the most widely used acute analgesics. All three agents can be used with patient-controlled analgesia devices for effective pain control. Oral preparations of these and other narcotics are preferred for long-term and outpatient use, but remember to use equi-analgesic doses when transitioning from intravenous to oral agents.**
Fentanyl	**50–100 μg IV, 0.5–1 μg/kg IV**	
Hydromorphone	**1–2 mg IV, 0.02 mg/kg IV**	
Oxycodone	**5–10 mg PO q 4–6 hr**	**These two widely used oral analgesics are less powerful than morphine and fentanyl but share the same risks of respiratory depression and dependency. They are often used in the rehabilitative phase of burn care and for outpatients. A long-acting form of oxycodone is available.**
Hydrocodone	**5–10 mg PO q 4–6 hr**	
Benzodiazepines		
Midazolam	**0.03–0.1 mg/kg IV**	**These are widely used benzodiazepines for sedation and relief of anxiety. They are not good analgesics, however, so other medications should be used to provide adequate pain control.**
Lorazepam	**1–4 mg IV, 0.04–0.08 mg/kg IV**	
Diazepam	**2–10 mg IV, 0.04–0.3 mg/kg IV**	
Other Agents		
Propofol	**0.5–1 mg/kg IV**	**Frequently used for short-term sedation for procedures and for sedation of mechanically ventilated patients. Airway support is required for use.**

Ketamine	**0.5–1 mg/kg IV**	**Can be given intramuscularly for short procedures in the outpatient setting. Associated with emergence problems, including delirium and nightmares. Can be used at a very low-dose continuous infusion (0.1 mg/kg/hr).**
Dexmedetomidine	**0.3–0.7 μg/kg/hr IV**	**Increasingly popular both for short-term sedation and for a more prolonged sedation of ventilated patients.**
Clonidine	**0.1–0.3 mg q 6–12 hr PO**	**Also available as a sustained-release patch. Should not be used as a single agent for pain control.**

IV, intravenous; PO, by mouth.

Medications by themselves often do not control pain and anxiety completely. A variety of nonpharmacologic therapies have been tried to alleviate pain associated with burn injury, including cognitive techniques (breathing exercises, reinforcement of positive behavior, use of age-appropriate imagery, and behavioral rehearsal). Another approach to pain control is distraction. Distracting patients' attention using music therapy, movies, and games can help them better tolerate pain. Virtual reality systems can immerse patients' attention in a computer-generated world and engage them in multisensory interactions with that world, including touch, sight, and sound, providing profound relief of pain and anxiety. Studies have shown a significant reduction in pain in burn patients during dressing changes and rehabilitative therapies using virtual reality systems. Augmented virtual reality involves a virtual image being overlaid onto the physical world instead of immersion into an artificial virtual world to focus patient perception away from a noxious stimulus. Hypnosis can reduce pain and can be used as an effective nonpharmacologic approach to burn pain. Hypnosis uses a combination of relaxation, imagery, and cognitive-based approach.

In addition to pain, itching can be a severe, prolonged problem in burn patients. In a study from one outpatient burn clinic, 50% of the patients recalled moderate to severe pruritus. This often interfered with sleep and with the quality of life in general. At times, it causes wound breakdown because of scratching. Pruritus occurred in 32% of the cases with burns smaller than 2% TBSA, almost as frequent as pruritus in major burns. Although pruritus recedes with time, it can last for up to 12 years after the burn. Treatment is often not effective, with only 36% of patients in that study reporting benefit. Topical drugs (tricyclic histamine receptor blockers, doxepin) as well as gabapentin, dapsone, ondansetron, and H_1/H_2 blocker combination therapy have been employed. Simple cooling, transcutaneous electrical nerve stimulation, and massage have also been useful.

Burn Unit Treatment of Other Injuries

As burn units have evolved into centers for multidisciplinary expertise, they have often been used to treat other conditions that require critical care, specialized wound management, physical therapy, and rehabilitation. Among the conditions often referred to burn centers are the major exfoliative skin disorders and necrotizing soft tissue infections.

SKIN DISORDERS

Toxic epidermal necrolysis (TEN) and Stevens–Johnson syndrome (SJS) are rare, life-threatening exfoliative disorders involving the skin. They are caused by cell-mediated immune reactions resulting in the destruction of basal epithelial cells by CD8-positive cells and macrophages in the superficial dermis. T cells then migrate into the epidermis, causing keratinocyte injury and epidermal necrolysis, analogous to the graft-versus-host disease that occurs in bone marrow transplant recipients. The disorders are distinguished primarily by the extent of cutaneous involvement: TEN is defined as >30% BSA desquamation, whereas SJS has less than 10% BSA involvement. Patients with 10% to 29% BSA involvement have an SJS/TEN "overlap." Because TEN is the most severe form of this disorder, it is most frequently referred to burn centers for care.

Drug exposure causes 80% of all TEN cases. Dilantin and sulfonamide antibiotics are involved in 40% of all cases; however, other agents, such as nonsteroidal anti-inflammatory agents, other antibiotics, upper respiratory tract infections, and viral illness have also been implicated. High-risk groups include patients with seizure disorders, metastatic cancer (particularly brain metastases), urinary tract infections, allogenic bone marrow transplants, and HIV infections.

A viral-like prodromal phase consisting of fever and malaise is frequently reported shortly after exposure to the inciting agent. Following this, a macular rash develops that spreads, often becoming confluent. The syndrome may involve any mucosal surface, including the oropharynx, eyes, gastrointestinal tract, and tracheobronchial tree. Patients have evidence of epidermal necrosis with large areas of epidermal detachment on physical examination. Nikolsky sign, the separation of the epidermis with moderate digital pressure, is a common physical finding. This is illustrated in Figure 10-12.

Figure 10-12 **Severe toxic epidermal necrolysis.** This child demonstrates confluent epidermal sloughing, which is readily removed with gentle pressure (Nikolsky sign).

TEN and SJS treatment begins with immediate discontinuation of the inciting agent. Skin biopsy at the edge of the blistered area and adjacent uninvolved skin should be performed to distinguish TEN/SJS from infectious (staphylococcal scalded skin syndrome, viral exanthem) or immunologic disorders. Once diagnosis is confirmed, wound management is a critical component of treatment, as secondary skin infections are the major cause of death. Because TEN involves separation of the dermal–epidermal junction, it is similar to a partial-thickness burn wound, which can heal without operative intervention, provided that appropriate supportive therapy is given. Debridement of devitalized tissue and the use of appropriate temporary wound coverage are vital. A wide range of regimens for temporary wound coverage have been proposed, including xenograft, biosynthetic wound dressings, allograft, Xeroform gauze, 0.5% silver nitrate soaks, and antimicrobial wound dressings. Sulfa-containing topical agents are generally avoided because of their involvement in the etiology of TEN. To date, there are no clinical trials that prove the superiority of any given regimen. What does appear to make a difference is protocol-driven care by an experienced burn center. This includes fluid therapy, ventilator support when needed, aggressive nutrition, and physical therapy. Ocular involvement is frequent, and as many as half of the survivors have severe long-term sequelae. Ophthalmologic consultation should be obtained early in the course of the disease in order to diagnose and treat pseudomembranous or membranous conjunctivitis.

A number of systemic therapies for TEN and SJS have been proposed as well. Although systemic steroids reduce the inflammatory response, they have not improved survival in TEN or SJS after the development of desquamation. The use of immunoglobulin was recommended because of its inhibition of CD95 in an experimental model. However, clinical studies have not demonstrated the benefit of immunoglobulin administration.

Mortality from TEN ranges from 20% to 75%. A multicenter review of 199 patients treated in U.S. burn centers reported a mortality of 32%. Mortality risk from TEN has been associated with multiple factors, including age more than 40 years, the presence of malignancy, >10% TBSA of sloughed epidermis, elevations in blood urea nitrogen level and serum glucose, acidosis (serum bicarbonate < 20 mEq/L), and heart rate more than 120 beats/minute. Mortality is due primarily to sepsis, multisystem organ failure, and cardiopulmonary complications. Long-term sequelae include abnormal pigmentation, a loss of nail plates, phimosis in men, vaginal synechiae in women, dysphagia, conjunctival scarring, lacrimal duct damage with decreased tear production, ectropion, and symblepharon (adhesion of the eyelid to the eyeball). Close follow-up and referral to appropriate specialists is needed to optimize long-term outcomes.

SOFT TISSUE SURGICAL INFECTIONS

The term *necrotizing soft tissue infections* encompasses a variety of severe infections of the skin, subcutaneous tissue, and muscle that require immediate surgical excision. The continued use of other terms such as *necrotizing fasciitis*, *Fournier gangrene*, and *Meleney gangrene* has led to substantial confusion in the literature. Regardless of terminology, these infections share several characteristics: most are rapidly progressive, produce severe toxicity, and lead to a necrosis of involved tissues, which may spread rapidly. These infections are discussed in more detail in Chapter 8, but are mentioned here because their appropriate treatment often results in large wounds that burn centers are well equipped to treat. Like burn victims, such patients often require aggressive fluid resuscitation, meticulous wound care and surgery, critical care support, and prolonged rehabilitation.

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Sample Questions

Questions

Choose the best answer for each question:

1. A 63-year-old man with chronic obstructive pulmonary disease caught his home on fire while smoking in bed. He was trapped in the house for an unknown time period before firefighters extricated him. He presents to the emergency department with severe facial blistering, singed nasal hairs, black intraoral mucosa, a swollen tongue, and carbonaceous sputum. His pulse oximetry reads 85% on room air, and he is obtunded. What is the next best step in management?
   A. Administer racemic epinephrine and steroids.
   B. Draw an arterial blood gas for COHb levels.
   C. Secure his airway by endotracheal intubation.
   D. Place him on 10 L oxygen by humidified facemask.
   E. Transfer him to the hyperbaric oxygen chamber.

2. A 25-year-old man suffers burns to 40% of his TBSA in an explosion at a natural gas drilling site. He requires emergent intubation and fluid resuscitation. During his first week of hospitalization, he undergoes a major operative procedure for excision and skin grafting. By the end of the third week in the hospital, his weight (which originally increased with resuscitation) has come back down, and he weighs 12 lb less than before the injury. What is the most likely cause for his weight loss?
   A. Decreased nitrogen excretion and resulting catabolism
   B. Increased nitrogen excretion and resulting catabolism
   C. Protein malnutrition with respiratory muscle building
   D. Immune system building with increased risk of pneumonia and bacteremia
   E. Indirect calorimetry readings to support positive nitrogen balance

3. A 27-year-old man is sprayed with concentrated sulfuric acid while working in an oil refinery, sustaining burns to his face, hands, and forearms. He is brought immediately to the emergency room. On initial exam, he is awake and in pain. His clothes are soaked with acid. In addition to providing appropriate protection for all healthcare workers, the first step in management should be to:
   A. debride his burns and complete a Lund and Browder chart.
   B. immediately place the patient in a decontamination shower.
   C. perform a secondary survey.

D. begin fluid resuscitation.
E. contact the local burn center for referral.

4. A 6-year-old girl was burned in a house fire from which she was unable to escape. She was found unconscious by firefighters, who intubated her at the scene. On arrival in the burn center, she is found to have carbonaceous sputum, elevated COHb levels, and burns to 30% TBSA. You should inform her parents that inhalation injury significantly increases the mortality rate of patients with major burns *mostly* due to:
A. increased metabolic rate and protein–calorie malnutrition.
B. persistent pulmonary infection and eventual development of multiple organ failure.
C. hypoxia.
D. airway obstruction.
E. increased fluid requirements for resuscitation.

5. A 19-year-old man is seen in the emergency department 20 minutes after a high-speed head-on collision with a tree, in which his car caught fire. He was not wearing a seat belt and was ejected from the vehicle. In the emergency department, he is alert, but he does not remember what happened. He admits to drinking a few beers earlier. His blood pressure is 75/40 mm Hg, and his heart rate is 140. His airway is patent. Breath sounds are equal bilaterally. Arterial blood gases reveal a PaO_2 of 140, a SaO_2 of 98%, a $PaCO_2$ of 34, and a pH of 7.33. He has burns to 15% TBSA, involving his anterior trunk and legs. His abdomen is covered with burns but appears distended; tenderness is hard to determine because of painful burn wounds. What is the most likely cause of his hypotension?
A. Smoke inhalation injury
B. Burn shock
C. Intra-abdominal hemorrhage
D. Ethanol intoxication
E. Closed head injury

Answers and Explanations

1. Answer: C

This man presents with every manifestation of inhalation injury, which is the most frequent cause of death in victims of structural fires. Oxygen therapy is essential, but this man likely does not have an adequate airway. Securing his airway is the first principle of treatment. For more information on this topic, please see the section on Primary Survey.

2. Answer: B

In response to the increased metabolic demands of a major burn, skeletal muscle is broken down to provide an available energy substrate. This results in increased nitrogen excretion and a loss of lean body mass, which can exceed a half pound per day. Cardiac muscle and respiratory muscles are not immune from these effects, and as muscle wasting continues, both heart failure and respiratory failure can occur. A loss of as little as 15% lean body mass can lead to a fatal degree of inanition within a few weeks of injury. For more information on this topic, please see the section on Nutritional Support.

3. Answer: B

The patient illustrates the danger that healthcare workers face when dealing with hazardous material spills. Unwary physicians and nurses who attempt to help this man could suffer serious burns from the acid on his clothing, which is continuing to burn the patient as well. This chemical must be neutralized before a primary survey can be conducted safely. All of the other answers are appropriate steps in treatment but should not be performed until after the patient is decontaminated. For more information on this topic, please see the section on Chemical and Electrical Burns.

4. Answer: B

Although inhalation injury can produce immediate death from CO poisoning and hypoxia, patients who survive the initial event should survive this problem. Similarly, airway obstruction is usually a treatable problem with a limited time course. Pneumonia is the most worrisome complication of smoke inhalation because it is often persistent/recurrent and difficult to treat. Persistent infection—including pneumonia—often leads to development of the multiple organ failure syndrome, which is usually fatal. For more information on this topic, please see the section on Pathophysiology of Inhalation Injury.

5. Answer: C

This patient illustrates the importance of the secondary survey in victims of burn injury. This man's burns are too limited in extent to cause severe shock, especially so soon after injury. Smoke inhalation is doubtful, especially with good blood gases. There is no evidence for ethanol intoxication or closed head injury. Unless a second injury (i.e., abdominal trauma) is *considered*, it will not be diagnosed. For more information on this topic, please see the section on Secondary Survey.