

Assessment, Triage, and Early Management of Burns in Children

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This comprehensive overview provides the reader with an understanding of basic skin anatomy, priorities of care, wound assessment, physiologic considerations, and early management of burns in children. Special emphasis is placed on triage and assessment of severity as a guide to formulating a definitive treatment strategy. New treatment modalities can help optimize burn care for children. Understanding and applying the principles of triage, assessment, and early management in burn-injured children can help improve outcome. Clin Ped Emerg Med 7:82-93 © 2006 Elsevier Inc. All rights reserved.

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Each year in the United States, approximately 1.2 million people sustain burns. An estimated 45 000 individuals are hospitalized and 4500 die of burn-related injury [1]. One third of burn unit admissions and deaths involve children [2]. Flame and scald burns constitute the major mechanisms of injury in the pediatric population. In 2003, an estimated 83 300 children 14 years and younger were treated in hospital emergency departments for burn-related injuries—approximately 52 200 were thermal burns, 21 000 were scald burns, 6100 were chemical burns, and 1400 were electrical burns [3]. Children 4 years and younger are at greatest risk, with burn-related injury nearly twice that of all other pediatric age groups. Among children in the 4 years and younger age group, an estimated 65% are treated for scald burns and 20% for contact burns [3]. Although the death rate from burns has declined by 56% among children 14 years and younger from 1987 to 2000, burn injury remains the fifth leading cause of unintentional child injury-related death [3].

The purpose of this review is to provide an understanding of how a burn compromises the physiologic functions of the skin, to provide an overview of the modern burn classification system, and to discuss the early management of burns in children. Recognizing the basic elements of burn physiology in children is important for implementing a successful resuscitation. Assessing the extent and depth of a burn helps in determining initial triage and management, and understanding the modern

burn classification system allows physicians to correlate burn depth with an appropriate treatment strategy. New treatment modalities and bioengineered skin substitutes are available and are being effectively used in hospitals and burn centers. Combining traditional principles of treatment with new modalities can optimize burn care and improve outcome for burn-injured children.

Human Skin

The skin, also known as the cutis or integument, is the largest and one of the most complex organs in the human body. Skin provides structural support and serves important immune and thermoregulatory functions. In children, the total body surface area (TBSA) varies with age, weight, and body habitus, and the skin is thinner than in adults. Young children also have a larger body surface area–mass ratio, which makes them more prone

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to hypothermia. When a burn occurs, alterations in physiology are proportional to the severity of the injury. Because the ultimate goal of the physician is to restore normal physiology and function, both the extent and depth of a burn have important implications for management. Understanding the basic anatomy of the skin is essential to accurately assess burn depth and predict the ability of a wound to heal without surgical intervention.

The skin is composed of 3 distinct layers: epidermis, dermis, and subcutaneous fat (Figure 1). The epidermis is the outermost layer consisting of stratified squamous epithelial cells known as keratinocytes. It serves as primary protection against the entry of foreign matter and infectious agents, and minimizes heat and moisture loss from the body. Because the epidermis is avascular, nutrients and oxygen are received from the underlying dermis. Keratinocytes within the epidermis undergo a continuous process of proliferation, maturation, and cell death. During wound healing, epithelial cells migrate to the surface to help close wounds (Figure 2).

The epidermis is separated from the underlying dermis by a basement membrane. Protein junctions known as hemidesmosomes are located within the basement membrane and help stabilize the epidermis to the dermis.

Among the 3 layers of skin, the dermis is the most physiologically active and most important for wound healing. Fibroblasts are the principal cells in this layer. They secrete collagen and elastin, which provide tensile strength and elasticity to the skin. Other important structural components—including fibronectin, tenascin, proteoglycans, and glycosaminoglycans—are interwoven with the collagen lattice. Also located within the dermis are blood vessels, lymphatic channels, nerves, sebaceous and sweat glands, hair follicles, cytokines, and growth factors. Because the hair follicle does not extend deeper than the dermis, it is an important marker for determining burn depth and is used clinically to estimate the potential for wound healing. Perifollicular epithelial cells are the main source of epithelial cells during spontaneous wound closure. Although the entire process of wound closure and the functional restoration of damaged skin is not yet fully understood, dermal components are critical for wound healing.

Priorities of Care: The ABCs

Before assessing the extent and depth of a burn, one must first assess the overall physiologic status of the child. As

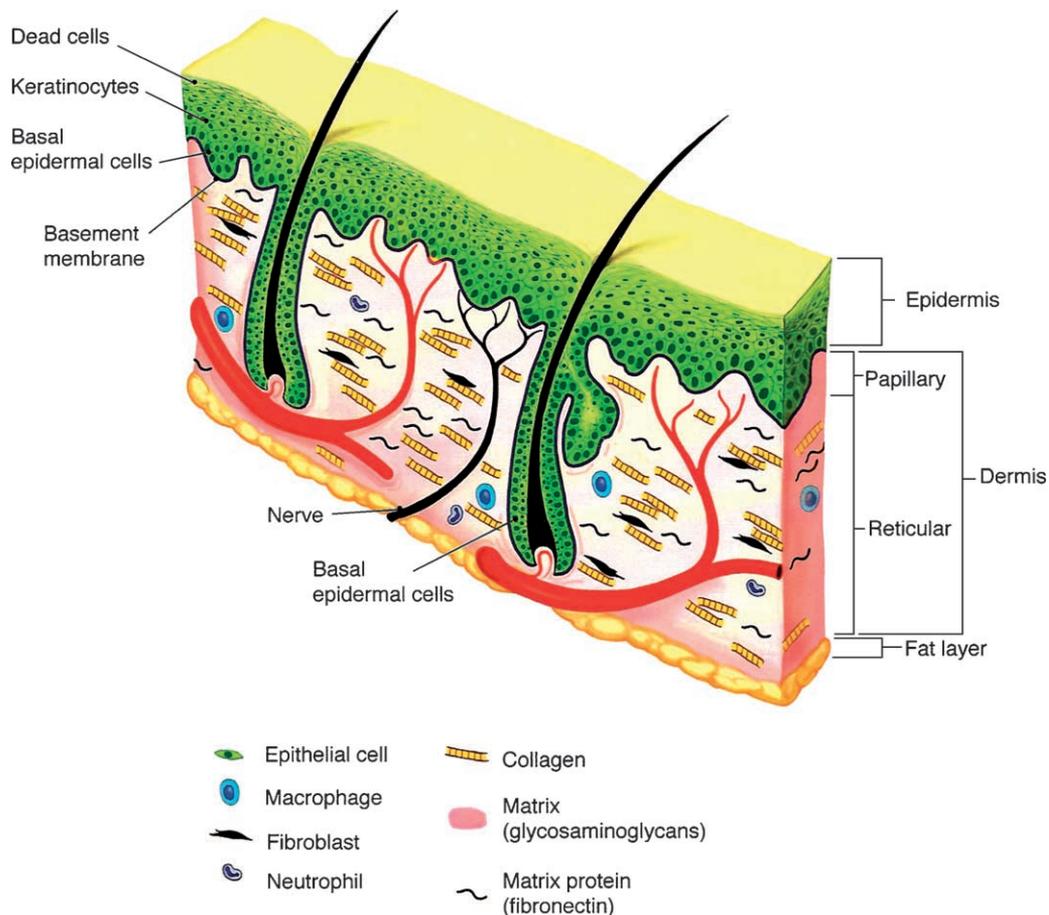


Figure 1 Normal skin anatomy. Note the position of the hair follicle within the dermis, which is used as a marker for burn depth. Reprinted with permission from Demling and DeSanti [12].

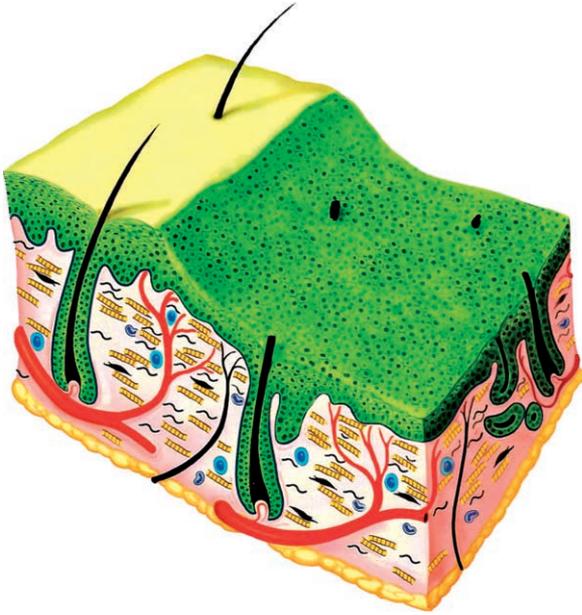


Figure 2 Healing wound. Epithelialization occurs from the basal epithelial cells around the hair follicle that migrate to the skin surface. Reprinted with permission from Demling and DeSanti [12].

with any trauma-related injury, the primary and secondary surveys are performed in accordance with Advanced Trauma Life Support standards as put forth by the American College of Surgeons. Early identification and treatment of immediately life-threatening injuries are essential. In a child with an isolated burn injury, most early emergencies involve the upper airway. After the primary assessment, a burn-specific secondary survey should be performed that includes a determination of the mechanism of injury, evaluation for the possibility of inhalation injury and carbon monoxide intoxication, and a detailed assessment of the burn wounds [4,5]. Approximately 10% to 20% of pediatric burns are a result of child abuse [2,6]. All children should be considered for the possibility of abuse, neglect, or an unsafe living environment that may necessitate social services intervention. After a thorough assessment, an appropriate triage decision can be made regarding admission to the hospital or referral to a burn center.

Understanding the mechanism of injury and the circumstances surrounding the burn incident is also important. If associated blunt trauma is suspected, as with a child involved in a building explosion, or a fire related to a motor vehicle crash, a full trauma evaluation takes priority over definitive burn assessment. Closed head injuries, spinal cord injuries, and musculoskeletal injuries can complicate evaluation and management [7]. Faulty assumptions without proper investigation can have grave consequences. For instance, a child with altered mental status from presumed carbon monoxide intoxication may also need to be evaluated for the possibility of a concomitant closed

head injury. Fluid requirements for the burn injury may need to be adjusted to compensate for trauma-related hemorrhagic or neurogenic shock. Although the tendency of physicians is to focus primarily on the burn wounds, following Advanced Trauma Life Support protocol helps to avoid oversight of associated injury.

Airway Management and Inhalation Injury

Airway is the first priority in the management of a burn-injured child. Although scald burns account for a significant number of injuries in young children, they usually do not compromise the airway unless there is extensive facial or neck involvement. A child that sustains a flame injury in a closed space, however, is at risk for upper airway inhalation injury that may require immediate intubation to secure the airway. Clinical markers for inhalation injury include respiratory distress, hypoxemia, hoarseness, stridor, wheezing, oropharyngeal blistering, tongue swelling, carbonaceous sputum, and singed eyebrows and nasal hairs [7]. A period of airway surveillance without intubation may be appropriate depending on the circumstances, but a high index of clinical suspicion is essential because the pediatric airway is much smaller and more easily occluded by edema [6]. An early decision to intubate is justified if there is any doubt about airway patency or the potential for airway deterioration. Progressive edema can complicate intubation, and conversely, multiple failed attempts at intubation can exacerbate swelling in an already tenuous airway. When possible, intubation should be performed by an individual skilled in difficult airway management, such as an anesthesiologist. Early intubation is preferable to an emergency cricothyroidotomy, especially in an edematous, burn-injured neck [7].

In managing a child with flame injury from an enclosed space, there is a possibility of carbon monoxide intoxication and acute lung injury from smoke inhalation. Any child with an isolated flame injury that presents obtunded is presumed hypoxic from carbon monoxide intoxication and needs to be treated for this condition. Carbon monoxide has a much higher (250-fold) affinity for hemoglobin than oxygen. Pulse oximetry and arterial blood gas measurements are not accurate for assessing carboxyhemoglobin levels and can be misleading. Such measurements assess the amount of bound hemoglobin in the bloodstream, but do not differentiate between oxyhemoglobin and carboxyhemoglobin [7]. For this reason, a child may appear to have normal oxygenation by pulse oximetry or arterial blood gas measurement, but in actuality, may be profoundly hypoxic. A blood carboxyhemoglobin level measures the degree of carbon monoxide intoxication and helps guide therapy. Treatment with high concentrations of inspired oxygen ($FI_{O_2} = 1.0$) displaces carbon monoxide from hemoglobin and allows for oxyhemoglobin formation. Although the half-life of carboxyhemoglobin is

approximately 240 minutes at an $\text{FIO}_2 = 0.21$ (room air), it is reduced to 40 to 60 minutes at $\text{FIO}_2 = 1.0$ [7]. Because delivery of 100% oxygen is most efficient by endotracheal tube, children with carboxyhemoglobin levels greater than 25% to 30% should undergo immediate intubation [7]. Treatment with 100% oxygen continues until the carboxyhemoglobin level is less than 10% of the total hemoglobin level. Patient severity disproportionate to the measured level of carboxyhemoglobin, profound metabolic acidosis, or the failure of clinical response to oxygen should prompt consideration of cyanide poisoning.

A prolonged oxygen requirement in the face of a normal carboxyhemoglobin level may signify acute lung injury from smoke inhalation. Acute lung injury results from toxin-induced injury to the lung parenchyma that impairs alveolar function and usually manifests 24 to 48 hours after the initial insult [2]. Management is supportive with oxygen and pulmonary toilet as the principal components of treatment. Children with acute lung injury may require prolonged ventilation to maintain adequate gas exchange until normal alveolar function is regained. The management is similar to adult respiratory distress syndrome and is likewise associated with increased morbidity and mortality.

Circulation and Fluid Resuscitation

After assessment of the airway and respiratory status, fluid resuscitation is the next priority in the initial stages of treatment. Intravenous fluid administration is the most expeditious way to correct the hypovolemia that results from capillary leak of the injured skin. Both local and systemic capillary leak may ensue in proportion to the extent and depth of the burn injury.

For minor burns with less than 10% to 15% TBSA that do not interfere with a child's ability to eat and drink, a trial of oral hydration is appropriate. Oral hydration requires close monitoring because food aversion and gastric ileus may compromise a child's ability to maintain adequate hydration and nutrition [7]. If oral hydration is inadequate, 1 intravenous (IV) catheter is usually sufficient for supplemental hydration. For more severe burns (>15% TBSA), at least 1 IV line is essential, but 2 or more may be required depending on the expected magnitude of the fluid infusion for resuscitation. Intravenous catheter placement through unburned skin is preferable, but a catheter may be placed through injured skin if necessary. Intravenous catheter placement distal to a circumferential burn should be avoided because of the constrictive effect from progressive swelling and subsequent eschar formation [7].

Fluid administration is guided by formulas such as the Parkland or the modified Brooke system, which recommend isotonic crystalloid solution, such as Ringer's lactate

solution, for initial resuscitation. The Parkland formula recommends 4 mL/kg per percentage of TBSA (%TBSA) burned, whereas the modified Brooke formula recommends 2 mL/kg per %TBSA burned. With both formulas, the total calculated amount is administered over the first 24 hours. Half the total is administered within the first 8 hours from the time of injury, and the remaining half is given over the next 16 hours. The most commonly used formula in clinical practice is the Parkland formula. Because formulas only provide estimates of fluid requirements, restoration of intravascular volume must be monitored by clinical parameters such as capillary refill, heart rate, blood pressure, and urine output. Ultimately, age-appropriate urine output (1-2 mL/kg/h) is the best marker for successful fluid resuscitation.

Adding colloid solution (albumin) to a fluid resuscitation regimen is controversial because research on this topic has not shown a consistent benefit. Nevertheless, a colloid bolus may be useful after 24 hours or with persistent hypotension and has been observed to help decrease edema. Judicious fluid infusion can help avert life-threatening complications such as pulmonary and cerebral edema. A child with lung injury from smoke inhalation sequesters fluid in the lungs; the resultant pulmonary edema can exacerbate the effects of acute lung injury on gas exchange. Acute fluctuations in serum sodium from volume infusion can cause seizures, cerebral edema with herniation, and central pontine myelinolysis—all of which are associated with increased mortality risk [6].

Burn Assessment and Treatment

General Considerations

Estimation of burn size helps in determining immediate fluid resuscitation requirements, which is essential to restoring normal physiology in the burn-injured child. Extent of injury is expressed as a calculated %TBSA. Percentage of TBSA is best estimated using the Lund-Browder chart (Table 1) that accounts for childhood changes in body proportion with growth [8]. Although the "Rule of Nines" is useful for estimating %TBSA in burned adults, the Lund-Browder chart should be used in the evaluation of all burn-injured children. In the pediatric population, the surface area of a child's hand approximates 1% of TBSA over a wide range of ages [9]. Estimating the %TBSA burned using this method is simple and convenient if the Lund-Browder chart is not available, and is very helpful in assessing burns that are nonconfluent or have an irregular shape.

When evaluating a burn injury, depth is important because it guides treatment and correlates with the probability of wound healing [10]. Although there are many sophisticated techniques to assess burn depth, including histologic examination, vital dyes, laser

Doppler, thermography, and ultrasound, these techniques are time-consuming, expensive, and require special equipment that is not readily available [10]. Clinical assessment by an experienced burn surgeon continues to be the most common and reliable technique for assessing burn depth [10]. Clinical determination of depth can be estimated by combining knowledge of the mechanism of injury with the wound characteristics outlined in Table 2. Aside from the immediate implications of burn depth, accurate assessment can help predict the quality of new skin, functionality, and cosmetic appearance [10]. Hypertrophic scar increases with burn depth and may adversely affect the functional range of motion and alter physical appearance.

Classifying a burn as first, second, third, or fourth degree is not precise because these terms do not accurately reflect depth. Although many physicians still use this terminology, health care professionals should describe a burn using the modern burn classification system. With this system, a burn is classified by increasing depth: superficial, superficial partial thickness, deep partial thickness, full thickness, and deep full thickness, also known as subdermal [4]. Here are a few guidelines to keep in mind when evaluating burn depth:

1. Do not include superficial burns when calculating %TBSA burned. Only partial thickness, full thickness, and deep full thickness burns are included in %TBSA assessment.
2. A typical burn wound has areas of varying depth, but usually one category of burn predominates.

3. A burn wound will often progress in depth over the course of hours or days. As a result, the initial assessment may be somewhat unreliable in formulating a definitive long-term treatment plan.
4. Propagation of depth has implications for fluid management and may influence the decision for hospital admission or burn center referral.

Superficial

A superficial burn is a burn of minor severity that affects only the epidermis and has the typical appearance of erythema without bullous formation, much like a sunburn. A superficial burn is commonly caused by ultraviolet radiation from the sun, but can also occur with a scald or contact burn. The injured skin is pink or red in appearance and painful, but there is no blister formation. Keratinocytes slough within a few days as they are replaced by underlying epithelial cells that migrate to the skin surface. A superficial burn usually heals within 1 week. Although no specific medical care is necessary, oral analgesics and topical moisturizer creams may help alleviate discomfort.

Partial Thickness

A partial thickness burn extends through the epidermis and into the dermis. Depending upon depth, it is characterized as a superficial partial thickness, middermal, or deep partial thickness injury (Figures 3-5). Most partial thickness burns in children are caused by flame and scald injuries [8]. A superficial partial thickness burn

Table 1 Lund-Browder chart.

Anatomic Region	Age (y)				
	0-1	1-4	5-9	10-15	Adult
Head	19	17	13	10	7
Neck	2	2	2	2	2
Anterior trunk	13	13	13	13	13
Posterior trunk	13	13	13	13	13
Right buttock	2.5	2.5	2.5	2.5	2.5
Left buttock	2.5	2.5	2.5	2.5	2.5
Genitalia	1	1	1	1	1
Right upper arm	4	4	4	4	4
Left upper arm	4	4	4	4	4
Right lower arm	3	3	3	3	3
Left lower arm	3	3	3	3	3
Right hand	2.5	2.5	2.5	2.5	2.5
Left hand	2.5	2.5	2.5	2.5	2.5
Right thigh	5.5	6.5	8.5	8.5	9.5
Left thigh	5.5	6.5	8.5	8.5	9.5
Right leg	5	5	5.5	6	7
Left leg	5	5	5.5	6	7
Right foot	3.5	3.5	3.5	3.5	3.5
Left foot	3.5	3.5	3.5	3.5	3.5

Note. The numbers in the columns under each age group represent the %TBSA for the respective body region.

Superficial Dermal Burn

Characteristics

1. Necrosis confined to upper third of dermis
2. Zone of necrosis lifted off viable wound by edema
3. Small zone of injury

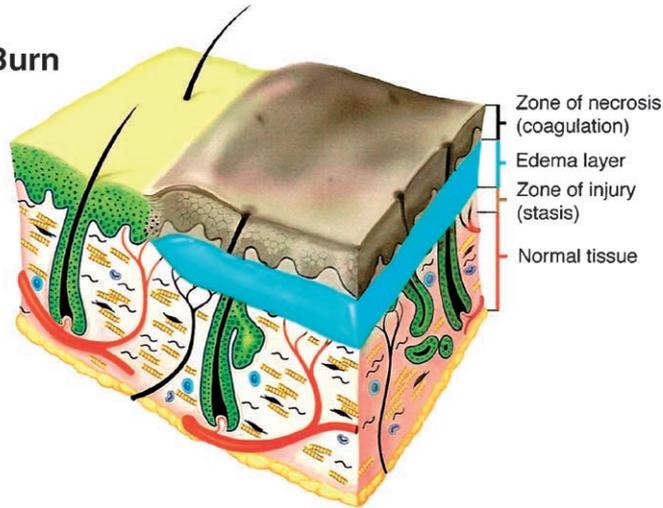


Figure 3 Superficial partial thickness burn. Reprinted with permission from Demling and DeSanti [12].

is usually pink or red; deeper burns are characterized by a white or yellow appearance. Blister formation is the hallmark and helps distinguish a superficial burn from a partial thickness injury. Blisters are often present in a superficial partial thickness or middermal burn, but are less frequent in a deeper injury. A partial thickness burn can be very painful because nerve endings are injured and exposed. As the depth of the burn increases, the amount of pain experienced decreases because more nerve endings are destroyed. Surgical debridement is necessary to remove the blisters and devitalized skin, and to allow for accurate wound assessment. Depending on the %TBSA involved, debridement is best accomplished with the administration of moderate sedation and analgesia, or in the operating room under general anesthesia. Many superficial partial thickness and middermal burns heal within 2 to 3 weeks with local wound care. A deep partial thickness burn can also heal spontaneously with local wound care, but the process takes 3 to 6 weeks or longer.

As depth increases, so does the probability of a poor functional and cosmetic outcome. Temporary coverage with a skin substitute may accelerate healing in a deep partial thickness burn, but the wound may ultimately require a skin graft.

Full Thickness

A full thickness burn extends through the entire depth of the dermis (Figure 6). In children, full thickness burns usually result from flame injury, prolonged contact burns with hot surfaces (eg, ovens, fireplaces, irons), and hot oil or grease. Cases of child abuse in which children are dipped in hot water for a prolonged period can also produce a full thickness injury. Deep dermal and full thickness burns occur more easily in children because the skin is much thinner than that of an adult. In a full thickness wound, the injured skin is white, yellow, brown, or black in appearance. Although there may be severe edema, there are no blisters, and the resulting

Mid-Dermal Burn

Characteristics

1. Necrosis to mid-dermis
2. Large zone of injury (potential conversion)
3. Eschar separated from viable tissue by edema layer

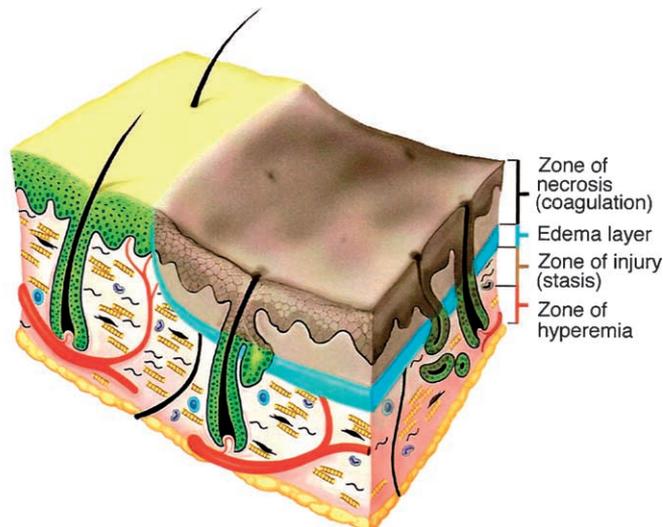


Figure 4 Middermal burn. Reprinted with permission from Demling and DeSanti [12].

Deep Dermal Burn

Characteristics

1. Necrosis involving majority of skin layers
2. Zone of necrosis adherent to zone of injury
3. Smaller edema layer

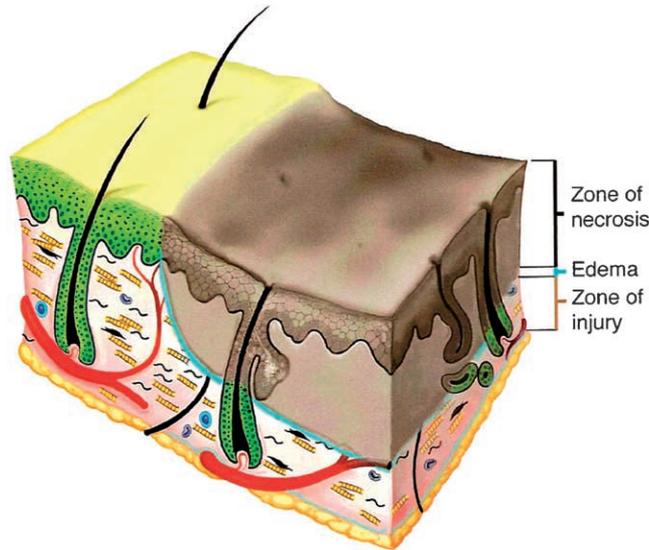


Figure 5 Deep partial thickness burn. Reprinted with permission from Demling and DeSanti [12].

eschar is hard and inelastic. Because the dermis and nerve endings contained within are destroyed, there is minimal or no pain despite the severity of the injury. A full thickness burn that is very small can heal spontaneously with local wound care, but most wounds require excision of the eschar and placement of a skin graft.

Deep partial thickness and full thickness injury can be difficult to distinguish from one another, even for the experienced burn surgeon. In these cases, the hair follicle is a useful marker for burn depth. Because the hair follicle is situated entirely within the dermis, depth can be judged by how much of the hair follicle has been spared. If the follicle remains visible after debridement, the burn is partial thickness, and there is potential for spontaneous regeneration from residual dermis. Even a small portion of dermis can provide enough matrix for revascularization and epithelialization. If the hair follicle is absent, the burn is full thickness and requires a skin graft.

Deep Full Thickness

A deep full thickness (subdermal) burn is the most severe and extends through all layers of the skin into underlying fascia and muscle with potential for tendon and bone damage. In children, most of these injuries occur during house fires in which there is prolonged contact with flames. Although relatively uncommon, treatment requires immediate hospitalization at a burn center, appropriate fluid resuscitation, debridement of the wound, and placement of temporary wound coverage to protect against infection and reduce the inflammatory response. A skin graft is ultimately required, and occasionally, a musculocutaneous flap is necessary for permanent wound coverage. Survival can be accompanied by significant functional and cosmetic impairment.

Physiologic Response to a Burn

Human survival depends greatly on the protective mechanisms afforded by normal skin [6]. Breach of the natural skin barrier causes alterations in physiology that are directly proportional to injury severity. Although the local response is caused by tissue damage at the burn injury site, subsequent release of cytokines into the circulation incites a graded systemic response characterized first by burn shock and later by hypermetabolism [6,11]. The degree of tissue damage after a thermal injury depends primarily on the temperature of the heat source and the duration of the exposure. For burns involving skin only without an inhalation component, the %TBSA and depth of the burn primarily determine the physiologic impact on the child. A significant burn compromises the immune function and the ability of the skin to regulate temperature and retain moisture. Surface colonization and infection of burn wounds coupled with local and systemic immune dysfunction make infectious complications one of the leading causes of death for children with extensive burn injury.

Local response to a burn can be characterized into 3 zones of injury: zone of coagulation, zone of stasis, and zone of hyperemia [6,12,13]. Local tissue trauma results in edema, fluid loss, and circulatory stasis. The zone of coagulation is the most central area of the wound that has maximum contact with the heat source. Cells in the zone of coagulation are permanently damaged (necrotic), require debridement, and lack the potential for regeneration. Extending peripherally from this central area is the zone of stasis where changes occur in the microcirculation causing cells to have a diminished blood supply. Cells in the zone of stasis require fluid administration in the first 24 to 48 hours to increase the chance for

Full Thickness Burn

Characteristic

No remaining viable dermis

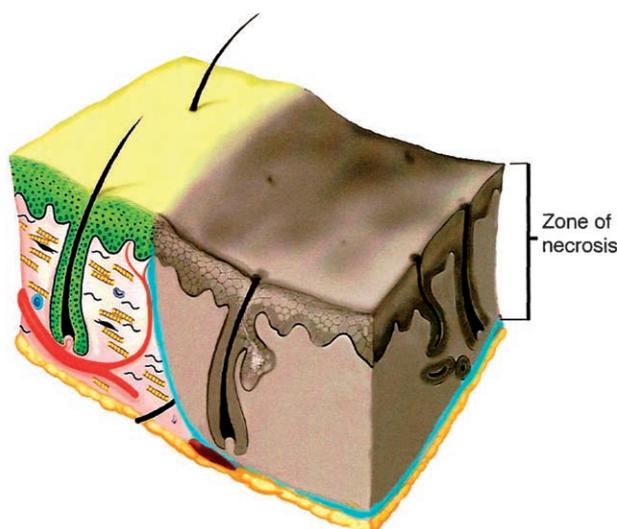


Figure 6 Full thickness burn. Reprinted with permission from Demling and DeSanti [12].

survival. Without proper initial management, this zone can progress from a superficial partial thickness to a deep partial or full thickness injury. One of the goals of fluid resuscitation is to minimize extension of the burn injury and limit burn depth. Located most peripherally from the zone of coagulation is the zone of hyperemia where cells sustain minimal injury and recover spontaneously within 7 to 10 days [6,12,13].

Injury to blood vessels in the zone of stasis and zone of hyperemia result in increased hydrostatic pressure secondary to vasodilation and increased capillary permeability. The increase in pressure and permeability results in leakage of water, protein, and electrolytes from the microvasculature into the wound. Loss of fluid from damaged skin is 5 to 10 times greater than that from undamaged skin [11]. Edema fluid accumulates very rapidly during the first 12 to 24 hours and reaches a maximum in approximately 24 to 48 hours [7]. Fluid shift from the microcirculation is enhanced by a decrease in oncotic pressure because protein is lost to the interstitial space. Avoiding fluid overload helps reduce edema and minimizes the adverse effects on wound healing. Mild to moderate edema is relatively innocuous and usually subsides over time with proper elevation, local wound care, and the natural healing process. Excessive edema, however, may cause a compartment syndrome in an extremity whereby the circulation is compromised by pressure from edema that exceeds the capillary filling pressure (25-30 mm Hg). Severe edema associated with compartment syndrome usually occurs within the first few days of fluid resuscitation. Failure to recognize this condition can result in limb ischemia that can lead to significant long-term functional disability or amputation. Fasciotomy relieves excessive compartment pressure and restores adequate perfusion. True compartment syndrome

in a burn-injured child is rare, but represents a severe complication of excessive local edema.

Compartment syndrome caused by the formation of burn eschar is a much more common clinical entity. Eschar is the hard and inelastic surface material formed when the injured skin is sealed by the heat of burning. Treatment of compartment syndrome from eschar formation requires escharotomy to relieve the excessive pressure, a procedure that can be performed at the bedside by an experienced surgeon. Escharotomy of an extremity is similar to bivalving a cast; it releases the constrictive effect of the eschar to help restore normal perfusion. For burns of the chest wall, extensive eschar can have a restrictive effect that may impair chest movement during breathing and cause respiratory insufficiency. If a child is receiving mechanical ventilation, the effect may be first manifest through a gradual increase in peak airway pressure. Chest escharotomy can be life-saving by allowing for expansion of the chest wall which helps restore adequate oxygenation and ventilation.

An extensive burn can also incite a systemic response. Although there is no exact threshold, burns that exceed 15% to 20% TBSA cause a significant systemic response that requires recognition and treatment [4,6,9]. Vasoactive mediators released from the wound, hypoproteinemia from catabolism, and decreased resistance to infection all contribute to systemic dysfunction. Changes in the circulation occurring immediately after a burn are called burn shock [6] and are mainly characterized by fluid loss and vasodilation. Fluid shifts deplete interstitial and intravascular volume, which ultimately reduces venous return to the heart. Reduced preload causes an initial decrease in cardiac output resulting in hypotension. Failure to restore normal cardiac output with appropriate fluid resuscitation leads to inadequate tissue

perfusion, progressive organ dysfunction, circulatory collapse, and death [8].

Although systemic dysfunction impacts all organ systems, the kidney is especially vulnerable to the effects of inadequate resuscitation. Inadequate renal perfusion causes renal vasoconstriction, leading to decreased renal blood flow and decreased glomerular filtration. Adequate fluid resuscitation can restore these rates to normal, but failure to do so may result in progressive renal failure with acid-base and electrolyte disturbances that further complicate management. The kidneys can also be directly affected by significant muscle damage from a deep full thickness (subdermal) burn or electrical injury. Destruction of muscle cells, or rhabdomyolysis, increases the amount of free myoglobin in the circulation. Myoglobin occludes the kidney tubules and impairs renal function. Treatment of acute renal dysfunction secondary to rhabdomyolysis requires fluid resuscitation and alkalization of the urine to help clear the myoglobin from the kidney.

After a successful resuscitation, a hypermetabolic response occurs during the first 24 to 72 hours postburn with an increase in resting energy expenditure and an increase in cardiac output [4,6]. Hypermetabolism results in gluconeogenesis, insulin resistance, and protein catabolism. Consequences include a decrease in body weight, negative nitrogen balance, and decrease in normal energy stores. Alterations of the endocrine system include increases in cortisol, glucagon, and catecholamine secretion. Diminished immune function of the gastrointestinal barrier increases the potential for translocation of intestinal flora and systemic infection. Enhanced heat loss occurs through trans-eschar fluid evaporation [14,15]. Although the hypermetabolic response is well recognized, the precise underlying cause is not well understood. Nevertheless, supporting the hypermetabolic state with adequate nutrition is crucial to keep pace with the increase in energy expenditure.

Topical Antimicrobial Agents

Traditional burn care consists of topical antimicrobial agents applied to a burn that has been debrided of devitalized skin. Because bacterial overgrowth and infection retard wound healing, the purpose of these medications is to limit colonization and prevent infection. Although topical antimicrobial agents do not contain growth factors, they foster an environment conducive to healing by helping to prevent infection. Typical medications include bacitracin, silver sulfadiazine (Silvadene, Kendall Co, Mansfield, MA), and mafenide acetate (Sulfamylon, Bertek Pharmaceuticals, Research Triangle Park, NC). Each of these medications has a slightly different indication for use and a different adverse effect profile [16].

A superficial burn does not require treatment with topical antimicrobial medication. A deep partial thickness or full thickness burn often requires a skin graft. An antimicrobial agent is best used for a superficial partial thickness burn that is expected to heal spontaneously within 2 to 3 weeks. Because topical medications are manufactured as an ointment or cream, they can be easily applied to anatomic crevices and skin folds. When applied to a deep partial or full thickness burn injury, antimicrobial agents help prevent infection in anticipation of a skin graft.

Bacitracin is an antibiotic derived from cultures of *Bacteroides subtilis* that exerts antibacterial action against various gram-positive and a few gram-negative organisms. Bacitracin is primarily used as a topical agent for small superficial partial thickness burns. Adverse effects are uncommon, but are mainly related to local skin irritation. Bacitracin is especially useful on the face because it does not cause staining of the skin that can occur with silver-based topical agents such as Silvadene.

Silvadene is the most common antimicrobial medication used in burn care. Silvadene is a white, water-soluble cream containing the antimicrobial agent silver sulfadiazine in micronized form. It has bactericidal activity against many gram-positive and gram-negative bacteria, and is also effective against yeast. Because Silvadene has broader antimicrobial coverage than bacitracin, Silvadene is commonly used on partial and full thickness burns to prevent wound sepsis. It is easy to apply and readily available in hospital and outpatient settings. Because Silvadene is a sulfa-based medication, it should not be used on children with known sensitivity to sulfa drugs. Similarly, it should not be used on children with glucose-6-phosphate dehydrogenase (G6PD) deficiency because severe hemolysis can occur. Because sulfonamide therapy can cause kernicterus, use of Silvadene on infants should be avoided. Silvadene has the potential to cause permanent silver staining of the skin rendering application to the face a contraindication.

Sulfamylon, or mafenide acetate, is a white, water-soluble cream with bacteriostatic activity against many gram-positive and gram-negative bacteria. Sulfamylon is also effective against *Pseudomonas aeruginosa* and certain anaerobes. Similar to Silvadene, it is used as a topical antimicrobial for a partial or full thickness burn. Sulfamylon is especially useful in a wound covered with eschar because it penetrates devascularized tissue and remains active in an acidic environment, such as in the presence of pus. Sulfamylon also provides better penetration of cartilaginous areas (eg, the ear) relative to Silvadene. Common side effects of Sulfamylon are local skin irritation and hypersensitivity. Severe pain resulting from application of sulfamylon to a wound may necessitate discontinuation in favor of a less painful topical therapy. Sulfamylon can also cause metabolic acidosis through inhibition of carbonic anhydrase in the kidney. Acidosis associated with

Table 2 Modern burn classification system.

Burn Depth	Color	Appearance	Pain	Treatment
Superficial	Pink	(-) Blisters (-) Eschar	Mild	Analgesic and moisturizer
Superficial partial	Red	(+) Blisters (-) Eschar	Moderate to severe	Topical antimicrobial
Deep partial	Red, white, yellow	(+/-) Blisters (+/-) Eschar	Mild to moderate	Topical antimicrobial; may require skin graft
Full	Brown, black	(-) Blisters (+) Eschar	None	Topical antimicrobial; skin graft
Deep full (subdermal)	Black	(-) Blisters (+) Eschar	None	Topical antimicrobial; skin graft or flap

+, present; -, absent; +/-, may or may not be present.

sulfamylon use is reversible and resolves with discontinuation of the medication and fluid resuscitation.

Newer Silver-Based Antimicrobial Delivery Systems

The routine use of topical agents such as silvadene has been the time-honored approach to antimicrobial coverage for burn wounds. Although very effective in protecting against surface infection, antimicrobial agents are usually applied at least twice daily to maintain their effectiveness. For children, these dressing changes can be quite painful and are associated with significant anxiety. Furthermore, the willingness and ability of parents and caretakers to effectively participate in wound care requiring daily dressing changes is highly variable. As a result, children with minor burns often spend a significant number of days in the hospital for wound management, when they could otherwise be treated on an outpatient basis.

New silver-based antimicrobial delivery systems have been recently developed that address the disadvantages of daily dressing changes. Examples of available products include Acticoat (Smith & Nephew Inc, Largo, FL), Contreet (Coloplast Corp, Marietta, GA), and Aquacel Ag (ConvaTec, Princeton, NJ). Essentially, these products consist of silver-containing pads or hydrocolloid fiber sheets that provide a sustained release delivery mechanism for silver and also function to absorb exudate from the wound. After appropriate debridement, these products are applied to the wound surface and can be left in place for several days. Eliminating the need for daily dressing changes reduces pain, lessens the emotional impact on children, and alleviates the primary caretaker of the responsibility for home burn care. Although there is no long-term data regarding efficacy and cost, the products appear to heal wounds with the same efficacy and cosmetic appearance as traditional antimicrobial agents. As a result, burn care for the partial thickness wound is shifting more

toward the outpatient setting, with dressing changes occurring once every few days instead of twice daily. Although use of these products is still being evaluated at burn centers, they may ultimately replace standard topical antimicrobial medications for minor burn wounds that are treated in the urgent or emergency care setting.

Triage of the Burn-Injured Child

Sometimes children with burn injury are initially transported to an acute care facility that is not equipped to

Table 3 Burn unit referral criteria.

1. Partial thickness burns greater than 10% of TBSA
2. Burns that involve the face, hands, feet, genitalia, perineum, or major joints
3. Full thickness 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 patients with burns and concomitant trauma (such as fractures) in which burn injury poses the greatest risk of morbidity and mortality. In such cases, if the trauma poses the greater immediate risk, the patient may be initially stabilized in a trauma center before being transferred to a burn unit. 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 long-term rehabilitative intervention

Data from the American Burn Association web site www.ameriburn.org [1], excerpted from Guidelines for the Operations of Burn Units, Committee on Trauma (1999), American College of Surgeons.

provide definitive long-term care. Transfer to a burn center is appropriate in this situation depending on the severity of the injury and the nature of the surrounding circumstances. The American College of Surgeons has developed burn unit referral criteria to help make decisions regarding the triage and disposition of burn victims based upon a standard set of guidelines (Table 3). Children should be stable for transfer and referring hospital personnel should provide the receiving institution with burn-specific details, including the extent and depth of the burn, the presence of circumferential burns, involvement of the face, hands, feet, genitalia, perineum, and major joints, and the index of suspicion for child abuse. Following these guidelines, children can be transferred to a pediatric burn center, or to an adult facility that treats children, where expert burn management can maximize potential for a positive outcome.

For children who are initially evaluated at a burn center, the main decision in management is often inpatient vs outpatient care. Numerous factors influence this decision, which is ultimately based on sound clinical judgment. Many of the guidelines listed for burn center referral criteria can be applied when deciding whether to admit a child for inpatient management. Superficial partial thickness burns of 10% or less can often be managed on an outpatient basis [17], though parents may be unable to provide the appropriate care. Involvement of certain anatomic areas (Table 3) may preclude outpatient management depending on the severity of the injury. Admission is warranted if a child cannot maintain adequate hydration and age-appropriate nutrition, if local wound care cannot be entrusted to the caregivers, and if pain and anxiety are not controlled with oral medication. Other special circumstances including autism, mental retardation, neurologic dysfunction, or emotional or psychologic disturbances are best managed in the hospital setting. Any suspicion of child abuse, neglect, or an unsafe home environment is an indication for admission.

Skin Substitutes and Evolving Burn Care

Wound healing requires regeneration of human tissue. Burn trauma is seldom accompanied by complete structural and functional restoration relative to normal tissue. Our standard approach to the burn wound is effective, but not ideal. Topical antimicrobial medications help create an environment conducive to wound healing, but the process can take several weeks. Dressing changes are both uncomfortable and associated with significant anxiety in children. Even the new generation of silver dressings requires intermittent dressing changes, and their long-term use has yet to be evaluated. A deep partial or full thickness burn can heal well with application of a skin

graft, but functional and cosmetic results are variable. Depending on the extent of the burn, autograft may be limited by available donor sites. Although traditional burn care is effective, the development of skin substitutes as alternatives for wound coverage can help improve care.

An ideal skin substitute closely mimics the natural functions of the skin and possesses the following qualities: nonantigenic, durable, flexible, inexpensive, easy to prepare and apply, conforms to irregular wound surfaces, requires one operation, does not become hypertrophic, and grows with children [18]. Current research is focused on creating skin equivalents that can be used for temporary and permanent wound coverage. Available skin equivalents are epidermal, dermal, or composite, and are applied to a burn wound based upon depth. A temporary substitute provides mechanical protection and transient wound closure, promotes new skin growth, and acts as a bridge to permanent coverage with a skin graft. Designing a useful full thickness skin equivalent has not been successful, but bioengineered dermal substitutes are currently available and being used effectively at pediatric burn centers [18].

Conclusion

Significant advancements in pediatric burn care and childhood injury prevention over the past few decades have improved survival for burn-injured children. Basic objectives of care have gradually shifted from survival to successful wound healing. Age, anatomic location, extent and depth of burn, concomitant injury, and comorbidity all affect ultimate prognosis. Understanding the basic elements of burn care can help physicians contribute to the trend toward decreased morbidity and mortality, and ultimately help improve functional and cosmetic outcome for burn-injured children.

Surgeons at burn centers and other hospitals are taking measures to ensure quality burn care based on new biotechnology. Some of these new treatment modalities are already being used in both the inpatient and outpatient setting, and widespread use in the urgent and emergent care setting will likely increase in the future. Early management and selection of an appropriate treatment strategy based on accurate assessment of burn severity and judicious use of biotechnology can contribute significantly to the effective delivery of burn care in children.

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