During the past 20 yrs, as burn care has evolved as a specialty of surgery, survival and outcome quality have soared. Public expectations for survival and long-term outcomes are at previously unprecedented levels. These changes are the result of a number of advances in aspects of burn care that have occurred in parallel and have fostered increasing regionalization of this resource-intensive activity into fewer specialized centers. These are complex hospitalizations and can be divided into four phases: initial evaluation and resuscitation, initial wound excision and biological closure, definitive wound closure, and rehabilitation and reconstruction.

**Key Words:** burn wound; sepsis; postburn deformity; fluid resuscitation; inhalation injury

The natural history of serious burns is characterized by burn shock, which is usually lethal to those with large burns during the first few postinjury days, burn wound sepsis, which commonly kills those who survive burn shock during the first few postinjury weeks, and postburn deformity in those who survive to heal their wounds by contraction and epithelialization. Each of these issues has been systematically addressed in recent years with varying but substantial success.

Burn shock has been a focus of study for 50 yrs. Stimulated by care of victims of the 1930 Rialto Concert Hall (1) and 1942 Coconut Grove (2) fires, various resuscitation formulas based on body weight and burn size were promulgated (3, 4). Recognition of the need to individualize resuscitation has resulted in burn shock being now an infrequent cause of death.

Control of burn wound sepsis had to wait until surgical, critical care, and blood banking techniques evolved to the degree that early identification, excision, and biological closure of deep wounds could be safely practiced. This was first systematically described in the 1970s in patients with small wounds, truncating hospital stays (5). In the 1980s and 1990s, with critical care and blood bank support, early surgery was subsequently used to address increasingly larger wounds, demonstrating markedly truncated hospital stays and enhanced survival in patients with large wounds, with burns over 30% of the body surface being commonly fatal before this (6, 7).

Postburn deformity remains a difficult clinical problem. Early wound excision and closure seems to reduce deformity by eliminating the degree of contraction otherwise required for spontaneous closure of deep wounds, but optimal function is only realized in many patients through a series of reconstructive operations in the months and years after initial recovery. The absence of an animal model of hypertrophic scarring has contributed to the paucity of clinical tools for modification of this inevitable process.

**LONG-TERM OUTCOMES**

Available data suggest that most survivors of serious childhood burns have a satisfying quality of life (8, 9). A recent report of 15-yr outcomes of children surviving massive burns confirmed this and demonstrated the importance of long-term involvement with an experienced multidisciplinary team (10).

**EPIDEMIOLOGY**

In America each year, approximately 2 million people are burned, 80,000 are hospitalized, and 6,500 die (11). Approximately 70% of pediatric burns are caused by hot liquid, whereas flame injuries more often cause burns in working-age adults (12). Younger children are at higher risk for burn injury (13), and up to 20% of injuries in this age group involve abuse or neglect (14). Large-scale burn prevention efforts have met with mixed success (15). Legislation seems more effective than education, with legislation on hot water heater temperature (16) and mandatory installation of smoke detectors being models. On the horizon is legislation involving fire-safe cigarettes and clothing flammability standards.

**ORGANIZATION OF BURN CARE**

Data exist linking volume with outcome in several complex surgical areas, including burn care (10, 17) and trauma care (18). It has been recognized that burn care requires expertise, personnel, and equipment that are not cost effectively maintained in low-volume programs. These issues have led to the formation of the burn center verification program, a combined effort of the American Burn Association and American College of Surgeons. Patients with serious burns are increasingly sent to regional programs for comprehensive care (Table 1, American Burn Association Burn Center transfer criteria).

**BURN INJURY PHYSIOLOGY**

A local response to burning involves not only direct tissue coagulation but also microvascular reactions in the surrounding dermis that may result in extension of injury (19). The systemic response to burning is driven by the loss of the skin barrier and release of vasoactive mediators from the wound and from subsequent infection. When burn size exceeds about 20% of the body surface, interstitial edema develops in distant organs and soft tissues secondary to a
combination of wound-released mediators (20) and hypoproteinemia (21).

After successful resuscitation, a hypermetabolic response occurs with near doubling of cardiac output and resting energy expenditure (22). Enhanced gluconeogenesis, insulin resistance, and increased protein catabolism accompany this and have major implications for the care of burn patients. The etiology of this physiology is not well understood but is assumed to involve a combination of factors including a change in hypothalamic function and increased glucagon, cortisol and catecholamine secretion (20), gastrointestinal barrier dysfunction and translocation (23), bacterial growth in the burn wound (24), and heat loss across the wound (25).

Elimination of hypermetabolism is of unknown value. β-Adrenergic blockade (26, 27), β-adrenergic supplementation (28), nonsteroidal anti-inflammatory agents (29), recombinant growth hormone (30, 31), and insuline-like growth factor-1 (32) are all under active investigation. The goal is to eliminate unfavorable aspects of the hypermetabolic response, particularly muscle catabolism, without inadvertently harming the patient. Currently, data seem inadequate to support the routine use of such therapies outside clinical trials.

PREHOSPITAL CARE AND TRANSPORT

Important issues to consider when transporting children with serious burns include control of the airway, appropriate venous access, placement of bladder and nasogastric catheters, maintenance of body temperature, fluid administration if transport time will be >1 hr, documentation of the events of the injury, notification of family members, identification of the child’s legal custodian, and documentation of administered medications and fluids.

Hypothermia is a particular problem during transport. Transporting children and receiving areas should be heated before patient arrival. Initial dressing should be dry rather than wetted. Immediate cooling of small wounds may help limit burn depth without causing systemic hypothermia, but by the time emergency response personnel have arrived, this window of opportunity is usually gone.

Delaying transport that is anticipated to be <1 hr to achieve venous access for fluid administration is probably not justified in most cases. In those circumstances in which longer transport times are anticipated, venous access should be obtained unless inordinate delay results.

PRIMARY SURVEY

All seriously burned children should be evaluated initially as multiple trauma patients, following the guidelines of the American College of Surgeons Committee on Trauma and the Advanced Trauma Life Support Course (33). A similar course, directed at the unique needs of the burned patient, is available from the American Burn Association. There is significant morbidity to missed injuries. Liberal use of computerized tomographic scanning of the head, chest, and abdomen is justified if the mechanism of injury is consistent with head or abdominal injury.

Airway security is the first priority issue during the initial evaluation. Usually, a few minutes exist in which to call for experienced help, which is advisable as these edematous airways can be difficult to intubate (Fig. 1). It is essential to secure the endotracheal tube well, as reintubation will become increasingly difficult as edema advances.

Second and third degree burns on >10% of total body surface area (TBSA) in patients under 10 or over 50 yrs of age
Second and third degree burns on >20% of TBSA in other age groups
Second and third degree burns that involve the face, hands, feet, genitalia, perineum, and major joints
Third degree burns on >5% of TBSA in any age group
Electrical burns including lightning injury
Chemical burns
Inhalation injury
Burn injury in patients with pre-existing medical disorders that could complicate management, prolong recovery, or affect mortality
Any patients 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 may be treated initially in a trauma center until stable before being transferred 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
Hospitals without qualified personnel or equipment for the care of children should transfer children with burns to a burn center with these capabilities
Burn injury in patients who will require special social/emotional and/or long-term rehabilitative support, including cases involving suspected child abuse and substance abuse

Table 1. American Burn Association Burn Center transfer criteria

| Second and third degree burns on >10% of TBSA in patients under 10 or over 50 yrs of age |
| Second and third degree burns on >20% of TBSA in other age groups |
| Second and third degree burns that involve the face, hands, feet, genitalia, perineum, and major joints |
| Third degree burns on >5% of TBSA in any age group |
| Electrical burns including lightning injury |
| Chemical burns |
| Inhalation injury |
| Burn injury in patients with pre-existing medical disorders that could complicate management, prolong recovery, or affect mortality |
| Any patients 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 may be treated initially in a trauma center until stable before being transferred 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 |
| Hospitals without qualified personnel or equipment for the care of children should transfer children with burns to a burn center with these capabilities |
| Burn injury in patients who will require special social/emotional and/or long-term rehabilitative support, including cases involving suspected child abuse and substance abuse |
BURN-SPECIFIC SECONDARY SURVEY

A burn-specific secondary survey complements the trauma secondary survey. It details burn-specific issues by systems: neurologic, otolaryngologic, chest, cardiac, abdomen, genitourinary, extremity issues, radiographs, and laboratory studies. This burn-specific secondary survey often occurs in the intensive care or burn unit.

Neurologic priorities are to exclude intracranial trauma, to assess for significant anoxic or carbon monoxide (CO) injury, and to address pain and anxiety. Intracranial trauma is excluded by history, supplemented by liberal use of computerized axial tomographic scanning. Patients with large injuries usually become obtunded from fluid shifts and medication over the days after injury, and its good to know that this change does not represent missed intracranial injury.

A depressed level of consciousness can also be due to drugs, alcohol, pain medications, hypoxia, and hypotension, but CO intoxication should be considered given appropriate injury mechanisms. CO binds to heme containing enzymes, including hemoglobin and mitochondrial cytochromes, interfering with their function (35). Significant CO poisoning may also cause lipid peroxidation in sensitive areas of the central nervous system (36). Breathing 100% oxygen will clear the blood of carboxyhemoglobin (half-life, 2.5 hrs on room air and 40 mins on 100% oxygen). However, CO also binds to mitochondrial cytochromes and thereby interferes with oxygen utilization. Patients with serious CO poisoning are at risk for delayed neurologic sequelae such as ataxia and choreiform movement disorders. The ability of hyperbaric oxygen treatment to reduce the risk of these sequelae is not entirely clear (37), but if it can be safely administered, it is reasonably considered in those with carboxyhemoglobin levels of >30% or with overt neurologic dysfunction not otherwise explained (36). Hemodynamic instability, wheezing or air trapping, and the need to effect transports inconsistent with good general burn care are contraindications (38).

Immediate eye and otolaryngologic issues include evaluation of the cornea and the external ear. If one waits until facial and ocular adnexal edema is advanced, it can be difficult to evaluate the globes. The eye evaluation should include fluorescein staining to detect more subtle injury. Burns of the external ear should be identified and treated with topical mafenide acetate to reduce the prevalence of suppurative chondritis (39).

The focus on the initial evaluation of the chest is ensuring adequate ventilation, which is usually compromised by decreased chest wall compliance secondary to circumferential eschar and by bronchospasm secondary to aerosolized irritants. Torso escharotomy is done using coagulating electrosurgery to make axial incisions along the flanks that are connected across the midline (Fig. 3). Bronchospasm is managed with aerosolized bronchodilators and ventilation strategies, minimizing the breath stacking and dynamic hyperinflation that can accompany increases in small airway resistance.

Initial evaluation of the abdomen is done to exclude associated injuries, to ensure torso compliance, and to reduce the prevalence of gastroduodenal ulceration and gastric dilation. Occult abdominal injury can explain excessive resuscitative fluid requirements or a paradoxically falling hemocrit during the early resuscitative phase and should be eliminated with liberal imaging given suspicious injury mechanisms. On occasion, circumferential torso eschar or massive accumulation of transudative intraperitoneal fluid or bowel edema can cause an abdominal compartment syndrome, with decreasing urine output and difficulty with ventilation. This is generally well managed with generous escharotomy and control of fluid resuscitation. In rare children with massive visceral edema, abdominal decompression may be necessary (40). In other children (equally rare), drainage of peritoneal fluid is adequate to effect abdominal decompression. Gastroduodenal ulceration can develop during burn resuscitation because of reduced splanchnic flow (41), and prophylaxis (generally histamine receptor antagonists) is indicated. Air swallowing and gastric dilation frequently occurs (Fig. 4) and is managed with nasogastric decompression.

Genitourinary considerations in the secondary survey include ensuring the...
foreskin in reduced over the bladder catheter after insertion to prevent the development of paraphimosis as soft-tissue edema progresses. Occasionally, it is necessary to section a deeply burned foreskin to allow access to the meatus to facilitate insertion of a bladder catheter.

Excluding associated nonburn injuries based on mechanism and monitoring peripheral perfusion in extremities at risk of ischemia is the important aspect of the extremity secondary survey. Extremity perfusion can be compromised by progressive soft-tissue edema within nonelastic compartments or beneath overlying eschar. Early identification of extremities at risk and serial examination are essential. Extremities at risk should be dressed to facilitate frequent examination and be regularly accessed for temperature, pliability, voluntary motion, pain with passive motion, named vessel pulsations, and low-pressure flow using capillary refill and Doppler signals in the digital vessels and digital pulp. Serial clinical examination will reliably determine the need for escharotomy or fasciotomy in most situations while eliminating any risk of seeding compartments by passing pressure monitoring catheters through contaminated wounds (42). Extremity escharotomies can be performed at the bedside using the coagulating electrocautery to minimize blood loss. Axially oriented medial and lateral incisions should be designed to completely section the deep eschar while avoiding injury to underlying superficial structures. Those superficial structures most at risk during escharotomy are the brachial artery in the upper arm, ulnar nerve at the elbow, superficial peroneal nerve at the knee, and the neurovascular bundles and extensors of the digits (Fig. 5). Fasciotomies should generally be done in the operating room.

Radiographic evaluation during the burn-specific secondary survey are limited to those needed to exclude other injuries, based on mechanism, and to document position of central venous catheters and endotracheal tubes. Spine fractures have been reported in association with high-voltage injury, either from fall or tetanic contraction of paravertebral muscles. Laboratory studies necessary to the initial evaluation are generally limited to routine chemistries, hemocrit, carboxyhemoglobin level in those injured in structural fires, and urine myoglobin in those with a history of electrical injury or pigmented urine.

Finally, the possibility of abuse should be considered in every child. Suspicious injuries must be filed with the appropriate state agency. Important data that should be obtained during the initial evaluation include tap water temperature, duration of contact, caretakers involved, documentation of conflicting reports from involved caretakers, delay in seeking treatment, and prior injuries. Important points of examination include uniformity of burn depth, absence of splash marks, sharply defined wound margins, porcelain-contact sparing, flexor sparing, stocking or glove patterns, dorsal location of contact burns of the hand, and localized very deep contact burns (Fig. 6) (43). These children should be admitted to the hospital for evaluation even if the injury itself is of little physiologic significance. Screening long bone series and computerized axial tomographic scanning of the head for occult injuries should be considered.

**FLUID RESUSCITATION**

In the hours after a serious burn, there is a systemic capillary leak that increases with injury size, delay in initiation of resuscitation, and the presence of inhalation injury. It typically “seals” after 18–24 hrs if resuscitation has been successful. Its thought that an initial release of vasoactive substances from the injured tissue and subsequent generation of highly reactive oxygen species after perfusion of marginally perfused or previously ischemic tissues drives the pathophysiology (44). The ability to block these mediators or otherwise modify this pathophysiology is not currently possible, although it remains a research focus (45, 46).

There is no formula that will accurately predict the volume requirements of individual patients. The inherent inaccuracy of formulas requires continuous re-
evaluation adjustment of infusions based on resuscitation targets (Table 2). The modified Brooke or Parkland formulas are reasonable consensus formulas and are used to determine the initial volume infusion. One half of the total calculated 24-hr volume is administered during the first eight postinjury hours. Should the resuscitation be delayed, this volume is administered so that infusion is completed by the end of the eighth postinjury hour. The importance of assessing resuscitation endpoints and appropriately increasing or decreasing the infusions hourly cannot be overemphasized. These consensus formulas are detailed in Table 3.

Most formulas recommend that all crystalloid be isotonic during the first 24 hrs, generally lactated Ringer’s solution. Hypertonic saline (47) has been recommended for resuscitation, but it has largely been abandoned because it is technically challenging and may compromise outcome (48). A slightly hypertonic solution made by adding sodium bicarbonate to lactated Ringer’s solution has some utility in resuscitation of children with very large injuries (49). A frequent question that arises is the minimum burn size at which a formal fluid resuscitation is required. As a general rule, burns of <15% of the body surface are not associated with an extensive capillary leak, and children with burns in this size range can be managed with fluid administered at 150% of a calculated maintenance rate, with close observation of the status of their hydration. Those who are able and willing to take fluid by mouth may be given fluid by mouth with additional fluid given intravenously at a maintenance rate. The gluconeogenetic capacity of older children and adolescents is such that no glucose-containing solutions are usually required during resuscitation. In smaller children, particularly those of <20 kg, hypoglycemia is a threat, and Ringer’s lactate with 5% dextrose should be administered at a maintenance rate.

Most resuscitation formulas recommend the administration of colloid when capillary integrity returns, generally by 24 hrs, as colloid is more likely to remain in the intravascular compartment at that time. In some circumstances, earlier use of colloid seems to improve hemodynamics and decrease volume needs. Most clinicians use 5% albumin in isotonic crystalloid; however, fresh frozen plasma is better used to correct coagulopathy to avoid disease transmission. Colloid is generally administered by continuous infusion at a dose graded by burn size (Table 3). It is ideal to begin enteral feedings at about this time, except in patients with massive injuries or in those who are under-resuscitated and are less likely to tolerate tube feedings because of ileus secondary to splanchic underperfusion.

It is a frequent observation that inhalation injury, delay in resuscitation, and unusually deep burns result in a higher fluid requirement. It has also been a common belief that young children require higher resuscitation volumes per body mass than older children and adults (50). However, to a certain extent this observation may be an artifact of setting an end point for urine output of 2 mL·kg⁻¹·hr⁻¹. In infants, whose renal concentrating abilities are immature, this is probably appropriate. However, in toddlers and older children, whose renal concentrating abilities are more mature, this may result in an excessive volume administration.

Sometimes resuscitation does not go well. If total resuscitation needs are estimated to exceed 6 mL/kg of the percent area of total body surface area burned per 24 hrs, it is often prudent to obtain more information regarding the status of the intravascular volume. This can be done with a directed physical examination, supported by measurement of central venous pressures or placement of a pulmonary artery catheter. If intravascular volume is felt to be adequate, dopamine, infused at “renal dose” (5 μg·kg⁻¹·min⁻¹), will sometimes improve renal perfusion enough to increase urine output without further increases in fluid administration. Early administration of colloid will some-

Table 2. Burn resuscitation end points

<table>
<thead>
<tr>
<th>Description</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensorium</td>
<td>arousable and comfortable</td>
</tr>
<tr>
<td>Digital temperature</td>
<td>warm peripherally</td>
</tr>
<tr>
<td>Systolic blood pressure</td>
<td>for infants, 60 mm Hg systolic; for older children, 70–90 plus 2 × age in yrs mm Hg; for adults, mean arterial pressure over 60 mm Hg</td>
</tr>
<tr>
<td>Pulse</td>
<td>80–180 per min (age dependent)</td>
</tr>
<tr>
<td>Urine output</td>
<td>0.5–1 mL·kg⁻¹·hr⁻¹ (glucose negative)</td>
</tr>
<tr>
<td>Base deficit</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>

Table 3. Consensus resuscitation formula

<table>
<thead>
<tr>
<th>Time (hrs)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>First 24 hrs</td>
<td>Adults and children &gt;20 kg</td>
</tr>
<tr>
<td></td>
<td>Ringers lactate: 2–4 mL·kg⁻¹·%burn/24 hrs (first half in first 8 hrs)</td>
</tr>
<tr>
<td></td>
<td>Colloid: none</td>
</tr>
<tr>
<td>Children &lt;20 kg</td>
<td>Ringers lactate: 2–3 mL·kg⁻¹·%burn/24 hrs (first half in first 8 hrs)</td>
</tr>
<tr>
<td></td>
<td>Ringers lactate with 5% dextrose: maintenance rate (approximately 4 mL·kg⁻¹·hr⁻¹ for the first 10 kg, 2 mL·kg⁻¹·hr⁻¹ for the next 10 kg, and 1 mL·kg⁻¹·hr⁻¹ for weight &gt;20 kg)</td>
</tr>
<tr>
<td></td>
<td>Colloid: none</td>
</tr>
<tr>
<td>Second 24 hrs</td>
<td>All patients</td>
</tr>
<tr>
<td></td>
<td>Crystalloid: to maintain urine output; if silver nitrate is used, sodium leaching will mandate continued isotonic crystalloid; if other topical is used, free water requirement is significant; serum sodium should be monitored closely; nutritional support should begin, ideally by the enteral route</td>
</tr>
<tr>
<td></td>
<td>Colloid: (5% albumin in Ringers lactate)</td>
</tr>
<tr>
<td></td>
<td>0–30% burn: none</td>
</tr>
<tr>
<td></td>
<td>30–50% burn: 0.3 mL·kg⁻¹·%burn/24 hrs</td>
</tr>
<tr>
<td></td>
<td>50–70% burn: 0.4 mL·kg⁻¹·%burn/24 hrs</td>
</tr>
<tr>
<td></td>
<td>70–100% burn: 0.5 mL·kg⁻¹·%burn/24 hrs</td>
</tr>
</tbody>
</table>
times help. Occasionally, children with very
large injuries demonstrate some degree of
myocardial dysfunction (51), and a therapeu-
tic trial of β-adrenergic agents may prove useful.

Pigmented urine is commonly seen in
the setting of high-voltage or very deep
thermal injury. To avoid renal tubular
injury, pigment should be cleared
promptly. This can usually be done in 2–3
hrs by administration of additional crys-
talloid to the end point of a urine output
of 2 mL·kg⁻¹·hr⁻¹. Judicious administra-
tion of bicarbonate may facilitate clear-
ance of myoglobin by preventing its entry
into the tubular cells. In rare circum-
stances, mannitol is a reasonable adjunct,
but its use obscures urine output as an
indicator of circulating volume, and cen-
tral venous pressures should be moni-
tored.

After 18–24 hrs, capillary integrity
generally returns if resuscitation has
been successful. At this point, fluid re-
quirements abruptly decrease, and it is
important to decrease fluid administra-
tion appropriately after resuscitation end
points. Over administration of fluid dur-
ing this time is associated with potential
morbidity.

After the capillary leak seals and fluid
infusions are reduced, wound manage-
ment has an increasing influence on the
amount of fluid and type of electrolyte
replacement required. Wounds treated
with nonaqueous topicals (such as silver
sulfadiazine) generate a free-water re-
quirement, generally provided as 5% dex-
trose in water or free water added to
enteral feedings. Extreme hypernatremia
can be associated with adverse central
nervous system effects, including intra-
cranial bleeding. Wounds treated with
aqueous topical agents (such as 5% silver
nitrate solution) are associated with elec-
trolyte leeching and secondary hypona-
tremia that requires isotonic crystalloid
and additional salt in enteral feedings.

Cerebral edema and seizures can occur
with severe hyponatremia (52, 53). Overly
rapid correction of hyponatremia may re-
sult in central pontine demyelinating le-
sions (54). There is serious morbidity as-
ociated with poor control of serum
sodium at this time, and it should be
monitored and kept in the physiologic
range. Serum ionized calcium and mag-
nesium should be monitored as supple-
mentation is commonly required during
this period.

**TOPICAL WOUND CARE**

Topical agents are applied to control
pain, decrease vapor loss, prevent desic-
cation, and slow bacterial growth. There
are an increasing number of options
available. Silver sulfadiazine is a white
opaque cream that is painless on applica-
tion, has fair to poor eschar penetration,
has no metabolic side effects, and has a
broad antibacterial spectrum. Mafenide
acetate, although painful on application
and a carbonic anhydrase inhibitor, has
excellent eschar penetration and a broad
antibacterial spectrum. Silver is an ex-
tremely effective topical agent and is gen-
erally applied as aqueous 0.5% silver ni-
trate. Applied in this fashion, silver is
painless on application but has poor es-
char penetration and leeches electrolytes.
It is popular because it has a broad spec-
trum of activity (including fungi) and can
be used on adjacent wounds, grafts, and
donor sites. Silver-impregnated dress-
ings, such as Acticoat (Westhaim Bio-
medical Inc, Voorhees, NJ), are also use-
ful in selected wounds. Debriding
enzymes have been applied to wounds in
an effort to soften and remove eschar (55,
56). New formulations of debriding en-
zymes that are deactivated by circulating
proteases are available and are designed
to liquefy necrotic tissue while avoiding
injury to healthy tissue (57). These sub-
stances may facilitate wound-depth eval-
uation and blood conserving removal of
eschar. At present, the role of these sub-
stances is limited.

Burns are tetanus-prone wounds, and
proper documentation of tetanus immu-
ne status is important. If in doubt,
active immunization should be adminis-
tered. In those who are not immunized or
who have incomplete or questionable tet-
anus immune status, passive immuniza-
tion is advisable. This is particularly true
if burns are extensive, deep, or heavily
contaminated.

**INITIAL WOUND EXCISION AND
CLOSURE**

Early identification, excision, and clo-
sure of full-thickness wounds change
the natural history of burn injury and are at
the heart of recent progress in burn care.
The objective of this phase of care is to
remove the bulk of the full-thickness in-
jury and to achieve biological closure.
When performed before the development
of wound colonization and infection, it
circumvents the development of wound
sepsis and systemic inflammation. These
operations have a reputation of being
bloody and physiologically stressful.
However, these negatives can be mini-
mized if operations are planned and exe-
cuted properly.

An early estimate of burn size and
depth is useful for planning (Table 4).
Burn diagrams are commonly central to
sequent litigation, and if, as is so often
the case, they are rough working dia-
grams, it is ideal to so note this on the
diagram so that inaccuracies are not the
focus of later confusion. Burn extent is
best estimated using a chart based on the
Lund-Browder diagram that compensates
for the changes in body proportions with
growth (Fig. 6). An alternative in adults is
the “rule of nines.” However, this is not
accurate in children because their body
proportions are different from those of
adults. For areas of irregular or noncon-
fluent area burns, the palmar surface of
the child’s hand can be used, as the area
of the palm only, not including the digits,
has been shown to represent 0.5% of the
body surface over a wide range of ages
(58). Burns are classified as first, second,
third, or fourth degree (Table 4). As a
general rule, burns are usually underes-
timated in depth on initial examination.
Circumferential, or near circumferential,
components should be noted because
they represent areas where special mon-
toring, and sometimes escharotomy, is

Table 4. Initial evaluation of burn wounds

<table>
<thead>
<tr>
<th>Extent</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lund-Browder chart: an age-specific chart that accounts for the changing body proportions with age; preferred in children</td>
<td></td>
</tr>
<tr>
<td>Rule of nines: assumes adult body proportions; head and neck, 9%; anterior chest, 9%; posterior chest, 9%; anterior abdomen, 9%; posterior abdomen (including buttocks), 9%; each upper extremity, 9%; each thigh, 9%; each leg and foot, 9%; genitals, 1%</td>
<td></td>
</tr>
<tr>
<td>Palmar surface of hand: Palmar surface of hand (without the fingers), approximately 0.5%</td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td></td>
</tr>
<tr>
<td>First degree: red, dry, and painful</td>
<td></td>
</tr>
<tr>
<td>Second degree: red, wet, and very painful</td>
<td></td>
</tr>
<tr>
<td>Third degree: leathery in consistency, dry, insensate, and waxy</td>
<td></td>
</tr>
<tr>
<td>Fourth degree: involves underlying subcutaneous tissue, tendon, or bone</td>
<td></td>
</tr>
</tbody>
</table>
needed. Accurate knowledge of the probability a wound will heal (different from the easier to measure burn depth) is central to operative planning. Examination by an experienced burn surgeon remains the most reliable method, despite the many devices developed to measure burn depth or burn blood flow (59, 60). The changes in wound appearance over the first few days after injury make serial examination a particularly useful tool in surgical planning.

Overall wound size is the most important factor in determining the need for early operation, as this correlates with the physiologic threat represented by the injury. Patients with small burns rarely need operative closure, but with medium to large burns, the ability a wound will heal (different from the easier to measure burn depth) is central to operative planning. Examination by an experienced burn surgeon remains the most reliable method, despite the many devices developed to measure burn depth or burn blood flow (59, 60). The changes in wound appearance over the first few days after injury make serial examination a particularly useful tool in surgical planning.

An initial nonoperative approach to such wounds is widely practiced and is associated with minimizing the need for operation (61). At the end of the first postburn week, it is often quite clear which areas, if any, need to be excised and grafted, and this is then done. In this way, all grafts, donor sites, and second-degree burns are fully healed by 3 wks, and the child can resume normal activities.

Patients with larger injuries generally do better if their wound is addressed surgically early, the full-thickness component being identified, excised, and closed during the first postburn week. When the wounds are >40%, this may require staged procedures. If the wounds involve >50% of the body surface, it is often impossible to achieve immediate autograft closure. When autograft is exhausted, temporary biological closure is achieved with human allograft or other temporary wound closure material. Wounds are later resurfaced with autograft when donor sites have healed.

Techniques of burn-wound excision have evolved substantially over the past decade. Most children can be managed with layered excisions that optimize later layers, which allows for optimal wound healing. In this way, all grafts, donor sites, and second-degree burns are fully healed by 3 wks, and the child can resume normal activities.

SKIN SUBSTITUTES

Temporary skin substitutes, or biological dressings, provide transient physiologic wound closure, which implies protection from mechanical trauma, a barrier similar to skin, and a physical barrier to infection (63). Split-thickness human allograft is procured from organ and tissue donors and remains the standard by which other temporary skin covers are judged. These membranes contribute to moist wound environment with a low bacterial density that is consistent with optimal wound healing. There membranes are typically used in one of four settings: as a dressing on donor sites to facilitate pain control and epithelialization from skin appendages, as a dressing on clean superficial wounds to a similar end, to provide temporary physiologic closure of deep dermal and full-thickness wounds after excision while awaiting autografting or healing of underlying widely meshed autografts, and as a “test” graft in questionable wound beds. There are an increasing variety of such materials available, with none clearly superior. It is important to monitor for submembrane infection if these materials are used.

An inexpensive, reliable, and durable permanent skin substitute would profoundly change burn care. Although no such substitute exists presently, a number of devices have been recently developed that contribute to permanent coverage of burn wounds. They can be classified as epidermal substitutes, dermal substitutes, and composite substitutes. Autologous epithelial cells grown from a single full-thickness skin biopsy have been available for nearly two decades and are useful in children with very large wounds (66), although they provide imperfect cover (67), which may be improved by combination with a vascularized remnant of allogenic dermis (68). Dermal analogs have been made available for clinical use in recent years. Integra (Integra Life Sciences, Plainboro, NJ) was recently approved by the United States Food and Drug administration for use in life-threatening burns (69). The inner layer of this material is a 2-mm-thick combination of fibers of collagen isolated from bovine tissue and the glycosaminoglycan chondroitin-6-sulfate that has a 70–200 μm pore size that facilitates fibrovascular ingrowth from the host and then undergoes biodegradation. The outer layer is 0.009-inch polysiloxane polymer with vapor transmission characteristics that simulate normal epithelium. Post-marketing trials are in progress at this time. Allogenic dermis designed to be combined with a thin epithelial autograft (Alloderm, LifeCell Corporation, The Woodlands, TX) is manufactured from split-thickness skin allografts procured from properly screened cadaver donors. Clinical experience with this material in acute and reconstructive burn wounds is still early but has been favorably reported (70, 71). The truly successful permanent skin substitute will probably be a laboratory-derived autologous composite. Exciting work is underway in many centers, but the solution is not yet on the horizon.

INHALATION INJURY

The diagnosis of inhalation injury is primarily clinical, based on a history of closed-space exposure, facial burns, singed nasal hairs, and carbonaceous debris in the mouth and pharynx or sputum (Fig. 7). Chest radiographs are routinely normal until complications (usually infection) have developed. If fiberoptic bronchoscopy reveals carbonaceous debris, ulceration, or erythema (72), it supports the diagnosis, but a normal study does not exclude it. Technetium scanning has also been used to confirm the diagnosis of inhalation injury (73, 74). No technique will reliably stratify injury severity or predict subsequent clinical course.

The clinical consequences of inhalation injury include upper airway edema from direct thermal injury exacerbated by systemic capillary leak, bronchospasm

Figure 7. The diagnosis of inhalation injury is based on a history of closed-space exposure, facial burns, singed nasal hairs, and carbonaceous debris in the mouth and pharynx or in the sputum.
from aerosolized irritants, small airway occlusion from sloughed endobronchial debris and loss of the ciliary clearance mechanism, increased dead space and intrapulmonary shunting from alveolar flooding, decreased lung and chest wall compliance from interstitial and alveolar edema and swelling or burn of the chest wall, and infection of the denuded tracheobronchial tree (tracheobronchitis) or pulmonary parenchyma (pneumonia).

Management is supportive only. Upper airway edema usually resolves in 2 to 3 days and can be facilitated by elevation of the head of the bed and avoidance of excessive fluid administration. Bronchospasm generally responds to inhaled β-agonists. If mechanical ventilation is required, air trapping should be anticipated and managed by ensuring adequate expiratory times and being alert for dynamic hyperinflation (75). Inflating pressures to >40 cm H2O should be avoided, unless there is severely impaired chest wall compliance, implying that the inflating pressures are not transpleural. Children with even severe inhalation injury typically have normal gas exchange and compliance for 48–72 hrs after injury. During this period, it is ideal to effect interhospital transfers or needed operations, as deteriorating gas exchange may complicate both.

In the days after inhalation injury, endobronchial debris collect, alveolar segments flood, compliance suffers, infection occurs, and gas exchange deteriorates. This is managed with vigorous pulmonary toilet and ventilator support designed to prevent secondary lung injury by capping inflating pressures at 40 cm H2O and concentrations of oxygen at 60% if possible. Both have been demonstrated to cause pulmonary injury (76, 77). The end points of oxygenation and ventilation should be reset to physiologically acceptable ventilation (any PaCO2 with a pH of >7.2) and oxygenation (any PaO2 consistent with an SaO2 of >90%). This approach, permissive hypercapnia, is associated with excellent outcomes (78, 79). If the reset physiologic end points cannot be achieved without violating pressure and oxygen caps for significant lengths of time, innovative methods of support such as inhaled nitric oxide (80), high-frequency percussive ventilation (81), or extracorporeal life support (82) should be considered, or these caps will be transiently violated.

Pneumonia or tracheobronchitis occurs in about 30% of these children secondary to loss of the ciliary clearance mechanism, small-airway occlusion, alveolar flooding, and endotracheal intubation (83). Signs of pulmonary infection include fever and purulent endobronchial secretions. Radiographic infiltrates or lobular consolidation suggest pneumonia. In the absence of radiographic changes, a diagnosis of tracheobronchitis is made. Neither bronchoalveolar lavage nor protected specimen brush specimens are routinely required for diagnosis and management (84). Antibiotic therapy is directed by sputum Gram-negative stain, and cultures and should not be prolonged beyond a 7–10 day therapeutic course. Vigorous pulmonary toilet, with toilet bronchoscopy in selected patients, is a very important component of therapy.

The role of tracheostomy in the management of inhalation injury is controversial. It can be very useful, particularly if prolonged intubation or difficult weaning is anticipated (85) or if unusually thick secretions are unmanageable through an endotracheal tube. Tracheostomy in children is associated with a higher prevalence of serious structural problems requiring prolonged cannulation and reconstruction and is ideally avoided when possible (86). Although there are data suggesting modest long-term exercise intolerance (87), most inhalation injury survivors do extremely well, with clinically normal long-term pulmonary function.

**UNIQUE ASPECTS OF PEDIATRIC BURN CRITICAL CARE**

Although most issues that arise in critically ill burned children are not different from children with other primary diagnoses, there are a few unique problems that merit discussion. These will be addressed briefly by systems.

Neurologic issues include occult injuries, seizures, neuropathies, and pain control. Children with large burns, although often alert in the first hours after injury, predictably become obtunded over the ensuing hours and days secondary to fluid shifts, pain medication, sleep deprivation, and exhaustion. Occult head injury should be excluded by early computed axial tomographic scanning, if the mechanism of the accident is consistent. Cerebral edema and seizures are associated with rapid development of hyponatremia, especially in small children. Overly rapid correction of hyponatremia is associated with demyelination in the central nervous system. This problem are ideally avoided by close attention to serum electrolytes (52–54). Peripheral neuropathies occur in about 5% of serious burns (88, 89) secondary to direct thermal injury or metabolic derangements. Some may be avoided by tight control of electrolyte disturbances, prompt decompression of ischemic extremities, attention to the fitting of splints, and careful intraoperative positioning. Adequate management of pain and anxiety is as essential as it is difficult (90). A unit-specific guideline is useful. One such guideline divides patients into four types: mechanically ventilated acute, spontaneously breathing acute, acute rehabilitation, and reconstructive. It addresses background pain, procedural pain, and transition issues for each patient group by using a limited formulary and dose ranging (91).

Hemodynamic issues that arise after resuscitation are predictable. A hyperdynamic state occurs, characterized by a high cardiac output and low peripheral resistance. This physiology is effected by wound colonization, translocation of bacteria and their byproducts from the gut (92), and the neurohumoral changes associated with the open wound (20). It can be difficult to know the status of intravascular volume and perfusion during this time, particularly during episodes of sepsis, which are often preceded by an increase in capillary leak and subtle increased fluid needs. This is best judged by careful serial physical examinations, with consideration of intravascular pressures and selected laboratory data. Findings of particular importance include soft-tissue edema, hepatic size, central venous pressure, urine output, serum osmolality, and serum sodium concentration. It is important to have clearly in mind age-appropriate fluid administration targets and to include all catheter flushes and medications into fluid calculations to avoid inadvertent volume overload. In most situations, hypoperfusion is related to inadequate preload, improved by administration of additional volume, or inadequate afterload, improved by cautious infusion of α-adrenergic agents. In those exceptional circumstances in which these agents need to be used, simultaneous infusion of renal dose dopamine may protect the splanchnic bed from the adverse effects of excessive vascular tone.

Serum electrolyte concentrations are strongly influenced by transechar flux of water and small molecules. If nonaqueous topical medications are applied to
wounds, particularly in a dry environment or high air loss beds, free water loss becomes a prominent influence on serum electrolyte concentrations. If aqueous topicals are used, such as 0.5% silver nitrate, transeschar leeching of sodium (approximately 350 and 25 mEq/m²-24 hrs⁻¹) requires continued administration of isotonic crystalloid (93, 94). Rapid swings in serum electrolytes are associated with significant morbidity, so diligent electrolyte monitoring and replacement is a critical component of care. As patients are fed, glucose enters the cells and is phosphorylated. This may in part explain the frequent occurrence of hypophosphatemia in those with serious injuries. When looked for, hypomagnesemia is quite common as well (95). Both are associated with surprising morbidity if not corrected with enteral or parenteral supplements.

The physiology of injury includes a reduction of hepatic albumin synthesis at the transcriptional level in favor of acute phase protein production (96). This reduced synthesis combined with enhanced albumin loss through open wounds results in predictable hypoalbuminemia. How low one should allow serum albumin to fall has been an area of controversy for many years (97). It has been our practice to tolerate levels of >1.0 g/dL as long as there is no significant enteral feeding intolerance (98) or pulmonary dysfunction (99), as these two problems may potentially be exacerbated by hypoalbuminemia. If serum albumin is <1.0 g/dL, or 1.5 g/dL in the presence of enteral feeding intolerance or pulmonary dysfunction, supplemental infusion of 1–2 g·kg⁻¹·day⁻¹ to a target value of 2.0 g/dL is probably warranted (100).

Chronic central vascular access is essential to the successful management of serious burns. The importance of careful technique cannot be overemphasized if life- and limb-threatening complications, reported to occur in 4% of insertion attempts, are to be minimized. Central veins are limited and will clot if cannulated with large catheters. The prevalence of thrombosis of these valuable sites may be reduced by using the smallest diameter catheter that will reasonably meet the patient’s needs. Rotation of catheters, in an effort to diminish the prevalence of catheter sepsis, remains an area of significant controversy, with little data to support individual practices. Unit policies vary from replacement at a new site every 48 hrs to replacement only for clear evidence of catheter sepsis or malfunction in some pediatric units. Although data are not conclusive, we are convinced that at least weekly rotation of catheters is a reasonable compromise that minimizes both catheter-related sepsis and the mechanical complications associated with catheter insertion (101, 102). Arterial catheters are not routinely required, but are useful in the patients with respiratory failure who requires frequent arterial blood gas monitoring or in hemodynamically labile patients who require minute-to-minute blood pressure monitoring. Those intubated primarily for airway protection can be very well managed with a pulse oximeter to monitor arterial oxygen saturation and an extremity spychromometer. Probably because of the relatively high flow rates around arterial catheters, they are less likely to become infected and are not routinely rotated, as are central venous catheters, unless the site becomes inflamed or there is some reason to suspect infection (19). Appropriate sites are the dorsalis pedis artery, the femoral artery, and the radial artery. It is extremely important to use careful technique when inserting femoral arterial catheters to avoid limb-threatening ischemia. Brachial and axillary arterial catheters should be used with extreme caution because of the risk of ischemia to the hand and the risk of cerebral embolization with vigorous flushing in small children.

Support of the hypermetabolic response is characterized by fever, increased metabolic rate, increased minute ventilation, increased cardiac output, decreased afterload, increased gluconeogenesis that is resistant to glucose infusion, and increased skeletal and visceral muscle catabolism (103, 104). Patients remain hypermetabolic until wound closure is complete and for a variable period thereafter. Accurate support of this physiology is essential. Overfeeding is associated with hepatic steatosis, leading to hepatic dysfunction and increased CO₂ production exaggerating respiratory insufficiency. Underfeeding results in anaphylaxis and poor wound healing. Patients managed with prompt wound excision and biological closure have a reduced energy expenditure compared with historic controls (105), and multiple studies have demonstrated that standard formulas do not accurately predict energy requirements in individuals. For these reasons, expired gas indirect calorimetry is commonly used to monitor nutritional support. Total energy expenditure can be roughly estimated by using expired gas indirect calorimetry to determine a resting energy expenditure and then multiplying resting energy expenditure by a factor of 1.3 to 1.7 (106). Protein administration of 2.5 to 3.0 g·kg⁻¹·day⁻¹ will adequately support the needs of burn patients (107). The route of nutritional support is ideally enteral tube feeding beginning during resuscitation. Not only does this provide immediate protein and calorie needs, but enteral feedings may better support the gut barrier, possibly decreasing the prevalence of bacterial translocation (108). Some children, particularly those with very large burns during the early resuscitation period or those with intervening sepsis, will not tolerate enteral feedings at goal rates, and supplemental parenteral nutrition, in addition to enteral feedings at low rates, is justified to ensure delivery of all needed nutrients. The use of anabolic agents is an area of active investigation. Recombinant human growth hormone in daily subcutaneous doses has been reported to accelerate donor site healing and restore earlier positive nitrogen balance (109, 110). The use of recombinant human growth hormone and other anabolic agents such as β-agonists (28, 111), β-antagonists (111), and anabolic steroids (112) in seriously burned children remains an important area of ongoing investigation. Available data do not seem sufficient to support their routine use.

Seriously burned children have a degree of global immunosuppression and have violated epithelial barriers and multiple invasive devices. Consequently, they are prone to a host of septic complications until all of their wounds are closed. Constant vigilance is required to allow early detection and treatment of these complications (113–116). In burn patients, the sequence of multiple organ failure is commonly increasing obtundation, progressive intrapulmonary shunting, and hypoxia, ileus, nonoliguric renal failure, rising cholestatic chemistries, thrombocytopenia, anuria, vsomotor failure, and death (118). Treatment involves support of failing organs and a thorough search for occult infection. Certainly, wound sepsis is an obvious potential source. However, this should be rarely seen if deep wounds are promptly excised and closed. When an underlying infectious fo-
DEFINITIVE WOUND CLOSURE

In this phase of care, allograft and other temporary wound closures are replaced with permanent covers, and small but complex wounds are addressed. By this time, the patient should have bulk physiologic wound closure and is generally in a stable systemic state. The first objective is to achieve bulk wound closure with definitive covers, generally reharvested autograft. When this has been achieved, attention is turned to small, complex wounds, particularly the head and neck, hands, feet, and genitalia. These are areas of small physiologic size, but great functional and aesthetic importance. A studied and careful approach to these wounds is essential.

The face should be rendered functional, with good coverage of the globes and competence of the mouth and access to the airway (Fig. 8). Portions of the face that need to be grafted should be resurfaced with thick split-thickness grafts of optimal color match in cosmetic units as long as this does not require the sacrifice of significant areas of healed burn or unburned skin. It is important to be watchful for the occurrence of globe exposure, caused by retraction of burned periorbital tissues. This should be addressed promptly when it occurs, initially through intensive ocular lubrication and then with early lid release if keratitis develops in the face of ocular lubrication. Not to do so will risk loss of the globe through corneal ulceration and infection (Fig. 9).

Serious hand burns should be a focus of attention from the onset of resuscitation, or ultimate function will be compromised (119). During the first 72 hrs, the team must ensure that hand perfusion is not compromised by near circumferential eschar or elevated compartment pressures. If consistent with critical care needs, the hands are ideally taken through a full range of motion twice daily and at other times splinted in a position of function, with the metatarsophalangeal joints at 70 to 90 degrees, the interphalangeal joints in extension, the first web space open, and the wrist at 20 degrees of extension. Hands should be elevated to minimize edema and ranged twice daily. Deep dermal and full-thickness burns should undergo prompt excision and sheet autograft closure. At 7 days after surgery, passive and, if consistent with patient condition, active hand therapy should begin. Even very destructive hand burns should be managed with an expectation of a functional result consistent with activities of daily living. The key features of this focus are surgical efforts to maintain normal flexion at the metacarpophalangeal joints and to achieve opposition between the remnant of the thumb and one or more digits (119, 120)

SPECIAL SITUATIONS

A number of special situations that can be expected as burn center referrals are detailed in Table 5) (121). These include high-voltage electrical injuries, chemical burns, burns from tar and other thermoplastic road materials, cold injuries, toxic epidermal necrolysis, purpura fulminans, soft-tissue injuries and infections, and injuries caused by abuse or neglect. Exposures to >1000 V are considered high voltage. It is uncommon for compartment syndromes, loss of consciousness, or myoglobinuria to be seen in patients exposed to <500 V. Children sustaining good electrical contact with mid-range voltage sources (200–1000 V) can sustain quite destructive local injuries. Locally destructive injuries are managed with early excision and closure. Flap closure is often an attractive option in those patients with very destructive injuries of limited extent (122). An exception to this approach is in the child with a commissure burn (Fig. 10). Such children are best managed conservatively, awaiting eschar separation and spontaneous healing and delaying reconstruction, as they will often heal surprisingly well. Parents should be advised to be alert for bleeding that can occur with separation of the eschar. If it occurs, bleeding is controlled with pressure en route to the hospital (123). High-voltage injuries are commonly associated with other problems, including loss of consciousness, falls, fractures, myoglobinuria, compartment syndromes, and arrhythmias. These patients should initially be approached as a polytrauma patient. After appropriate airway and vascular access have been achieved, a systematic secondary survey should be done, with a directed effort to look for visceral injuries, long bone and

Figure 8. A deeply burned face should be addressed in a studied manner, using thick-sheet autograft placed in cosmetic units when possible.

Figure 9. It is important to be watchful for the occurrence of globe exposure caused by retraction of burned periorbital tissues. This should be addressed promptly when it occurs, initially through intensive ocular lubrication and then with early lid release if keratitis develops in the face of ocular lubrication. Not to do so will risk loss of the globe through corneal ulceration and infection.

Figure 10. Commisur burn is best managed conservatively. Parents should be advised to be alert for bleeding that can occur with separation of the eschar.
Electrical injury
Monitor cardiac rhythm in high (>1000 volt) or intermediate (greater than 220 V) voltage exposures for 24–72 hrs
Low and intermediate voltage exposures can cause locally destructive injuries, but uncommonly result in systemic sequelae.
After high-voltage exposures, delayed neurologic and ocular sequelae can occur, so a carefully documented neurologic and ocular examination is an important part of the initial assessment.
Injured extremities should be serially evaluated for intracompartmental edema and promptly decompressed when it develops.
Bladder catheters should be placed in all patients with high-voltage exposure to document the presence or absence of pigmenturia; this is treated adequately with volume loading in most patients.

Chemical
Irrigate wounds with tap water for at least 30 mins; irrigate the globe with isotonic crystalloid solution.
Exposures to concentrated or anhydrous hydrofluoric acid may be complicated by life-threatening hypocalcemia; such patients should have serum calcium closely monitored and supplemented; subeschar injection of 10% calcium gluconate solution is appropriate after exposure to highly concentrated or anhydrous solutions.

Tar
Tar should be initially cooled with tap water irrigation and later removed with a lipophyllic solvent.

Toxic epidermal necrolysis
Diffuse epidermal slough at the dermal-epidermal junction, usually associated with progression of a drug eruption.
The degree of mucous membrane and conjunctival involvement varies.
Differentiation from staphylococcal scalded skin syndrome can usually be made on clinical grounds.
Treatment involves prevention of wound desiccation and superinfection with topical antimicrobials with xenografting of clean confluent areas.
Ophthalmologic care is critical.
Those with severe oropharyngeal involvement may require intubation for airway protection with enteral tube feeding.

Purpura fulminans
Typically a complication of meningococcal sepsis.
Likely secondary to transient protein C deficiency; therefore, fresh frozen plasma should be considered as a resuscitative colloid.
Frequently accompanied by organ failures.
Treatment involves management of organ failures and excision and grafting of wounds to prevent inevitable wound sepsis.
Can be associated with adrenal necrosis.
Long-term morbidity secondary to major amputation and epiphysial arrest is common.

Staphylococcal scalded skin syndrome
Reaction to a staphylococcal exotoxin that causes a separation in the granular layer of the epidermis, most commonly seen in young children.
This superficial wound generally heals quickly if superinfection and desiccation is prevented.
Mucous membrane and conjunctival involvement are not seen.
A detailed search for a focus of staphylococcal infection is warranted.

Soft-tissue infections
Serious morbidity associated with delay in diagnosis and management.
Essential first steps are suspicion, exploration of suspicious soft tissues, and aggressive excision of nonviable or infected tissue.

Table 5. Special situations

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spine fractures</td>
<td>Myelopathy, paraplegia, quadriplegia, neurological deficits</td>
</tr>
<tr>
<td>Myoglobinuria</td>
<td>Renal failure, dyspnea, acidosis</td>
</tr>
<tr>
<td>Compart ment syndromes</td>
<td>Myoglobinuria, acute renal failure</td>
</tr>
</tbody>
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Figure 11. Toxic epidermal necrolysis results in both a cutaneous and a visceral wound. Often, the latter is the more difficult to manage unless they have complicating comorbid conditions.

**REHABILITATION AND RECONSTRUCTION**

This final phase of burn care has assumed a rapidly increasing importance as survival has improved and public expectations have increased. Until the recent past, survival was the principal measure.
Successful burn care requires the focused efforts of a team of experienced people committed to the entire continuum of acute burn care and recovery.

of success in burn care. Now that the majority of those suffering even serious injuries are surviving, the bar is higher and the quality of function and appearance is the new standard of success. To deliver a high-quality functional and cosmetic result absolutely requires the intensive involvement of interested and knowledgeable physical and occupational burn therapists who are involved through the entire spectrum of care, from the intensive care unit through the outpatient clinic. The field of burn therapy is rapidly evolving and has become highly specialized.

In the critical care setting, there are three priorities for the therapist: ranging, splinting and antideformity positioning, and establishing initial contact with the patient and his or her family. If a body part is left immobile for a protracted period of time, capsular contraction and shortening of tendon and muscle groups that cross the joints occur. Even in young children, if extremities are left immobile, this will occur over the course of days. It is therefore important that this be prevented by passive ranging. This is ideally done twice daily, with the therapist taking all joints through a passive range of motion. The therapist needs to be sensitive to the wounds, the status of extremity perfusion, the state of pain and anxiety, and essential airway and vascular access devices. Within the bounds of safety, it is appropriate to medicate patients so they can tolerate any discomfort and anxiety associated with ranging. It will not be effective if it is painful and frightening. Ideally, ranging can be timed to coincide with medications administered for dressing changes and wound care.

The burn therapist should be knowledgeable about airway and vascular access devices used in the intensive care unit. There is substantial morbidity, and even mortality, associated with unexpected loss of these devices. Therefore, before initiating ranging, therapists should communicate with the intensive care unit team regarding the location and security of endotracheal tubes, nasogastric tubes, central venous catheters, arterial catheters, and other monitoring devices. Routine in-servicing of therapists will facilitate adherence to necessary precautions. The presence of such a device is clearly not a contraindication to passive ranging. However, the activity should be done with the security of these devices in mind.

Antideformity positioning and splinting during the phase of critical illness will prevent the occurrence of some very common contractures. The common contractures seen to develop in the critically ill tend to be associated with the flexed position of comfort, except in the hands, and include the flexed neck, the adducted axilla or shoulder, the flexed elbow, the flexed hip, the flexed knee, and the extended ankle deformities.

As the seriously burned patient is extubated and weaned from the critical care environment, the demands placed on the burn therapists increases. In many ways it becomes more difficult for the therapist to provide the needed care. Children are aware of what has happened to them, have been sensitized to uncomfortable procedures, and may become fearful of the therapist. There are several key components to therapy during this period, including continued passive ranging, increasing active ranging and strengthening, minimizing edema, activities of daily living, and preparation for work or play and school.

Important aspects of acute rehabilitation after discharge include ongoing and progressive ranging and strengthening, ongoing evaluation of evolving problem areas, specific postoperative therapy after reconstructive operations, and scar management. It is quite common to see some loss of range and strength between the discharge and the first clinic visit. This is particularly true if there is an inadequate outpatient rehabilitation plan or if the rehabilitation therapy is turned over to a therapist inexperienced with burns. If substantial range and strength has been lost due to inadequate therapy, readmission for focused rehabilitation efforts is appropriate.

Scar management is an essential aspect of outpatient burn therapy. The most virulent hypertrophic scarring is seen in very deep dermal burns that heal spontaneously in >3 wks. This is particularly true in those areas of highly elastic skin, such as the submental triangle and anterior neck, and in areas where joint motion results in tension across burn scars (128). Initial wound hyperemia typically begins to resolve about 9 wks after injury. In those wounds destined to become hypertrophic, there is a marked increase in neovessel formation, resulting in increasing erythema after this period (129, 130). Ideally, therapies to minimize hypertrophic scarring are begun as soon as burns are well healed, ideally by the time posthealing wound erythema begins to increase.

There are no completely effective tools to control hypertrophic scar. Available methods include scar massage (131), compression garments (132), topical silicone (133), steroid injections, and surgery. Serial casting (134) has a limited role in management of established scars that limit joint motion. Properly done, scar massage is perhaps the most effective and can be done by patients and family members. This consists of firm, slow massage and stretching of evolving hypertrophic areas after application of bland skin emollients, and it is ideally done several times each day.

An acute reconstructive plan for those with serious burns should be made collaboratively with the patient and the patient's family, the patient's therapists, and the surgical team. Although one should not rush in to these procedures, the concept of waiting until all scars have completely matured for two or more years before embarking on any reconstructive operations will interfere unduly with function and development. A balance must be drawn between the repeat trauma of surgery and the patient's functional and cosmetic needs.

**CONCLUSION**

Ideally, the objective is to have the child return to his or her family, schoolmates, and community as if the injury had never occurred. Having this goal means respecting school schedules for reconstructive operations and giving priority to operations that are important for development or favorite activities. For many, the child's burn represents an enormous stress affecting all members of the extended family. Many children will benefit from transient psychotherapy and...
pharmacotherapy to help deal with the trauma they’ve sustained. Posttraumatic stress disorder is common (135, 136). Signs and symptoms include hyperalertness, nightmares, and chronic fearfulness. The burn inpatient and outpatient teams should have sensitivity to this common problem and have a strategy to address it. Not doing so may protract recovery. Extended family members, teachers, coaches, playmates, daycare center staff members, and relatives all can have an impact on recovery. Burn care has evolved greatly over recent decades. An intensive care unit with the care has evolved greatly over recent decades. An intensive care unit with the care has evolved greatly over recent decades.

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