Burns

69

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Contents

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J.M. Abzug et al. (eds.), *The Pediatric Upper Extremity*,
DOI 10.1007/978-1-4614-8515-5_68

Overview

Burn injuries are a common event around the world. They cause considerable morbidity and mortality. For these reasons, it is incumbent upon physicians to be familiar with the complexity of burn management. Physicians, as leaders of the care team, must be aware of the various mechanisms of injury, the systemic management of the burn patient, and the implications of the early management on reducing long-term functional morbidity associated with these injuries. Failure to recognize both the short-term and long-term implications of these issues creates a disservice to our patients and increases the burden of these injuries on the victims and society at large.

The causes of burn injuries fall into several categories:

Thermal – flame, scald, cold, and explosion
Chemical – acid and alkali
Electrical – low voltage and high voltage

Whenever one is confronted with an injured child, child abuse must be considered as a causative factor until ruled out. Failure to do so could subject the child to future abuse and injury.

Worldwide, burns rank as the fourth most common etiology of all injuries (Peck 2011). In 2004, there were approximately 11 million burns in the world (Peck 2011). The incidence of burn injuries in the United States in 2012 totalled about 450,000. Of these, 3,400 patients died (7.5 %). There were about 40,000 hospitalizations due to burn injury, of which 75 % were treated in burn centers. In the United Kingdom, burns contributed to 5.4 % of all serious injuries. The frequency of pediatric burn injuries may be related to the economic level of the country. For example, 1 % of all pediatric injuries in Scotland were burns, while the incidence in Cape Town, South Africa, is 11 %. According to the World Health Organization (WHO website), the disability-adjusted life year estimates of burn injuries is significantly greater in low-income countries (1.1 %) than in high-income countries (0.2 %).

Pediatric burn injuries have a bimodal distribution (Toon et al. 2011). About half the injuries occur in children under the age of 4. The number then rises as children enter adolescence and become of working age. Boys are more likely to be burned than girls. The majority of pediatric burns occur in the home. Of these, 80 % result from scalds due to hot liquids. In fact, scald burns are five times more frequent than flame injuries in the first 3 years of life (Agran et al. 2003). Many burns in children are related to their curiosity about surfaces or objects that cause contact with noxious items resulting in thermal or electrical injury. Still other burns are directly related to child abuse (Toon et al. 2011).

The causative factors in burn injuries also vary with the economic status of the country in which they occur. Scald injuries are more common in the developed world, while cooking fires are the main cause of pediatric burn injury in developing countries (Van Niekerk et al. 2004). Asymmetrical injuries are more often associated with abuse and should raise the level of inquiry regarding the patient's injuries (Toon et al. 2011).

Optimal treatment for pediatric burns is performed in a burn center. While hospital stays are longer in burn units than non-burn centers, the outcomes are better when patients are treated in a burn unit (Wolf and Arnoldo 2013).

Management of systemic issues must take precedence in early treatment of these injuries. This includes fluid resuscitation, hemodynamic support, airway management as needed, and optimization of pulmonary function along with prophylaxis and treatment of infection. Early infections are often Gram positive, but later infections tend to be Gram negative, especially in patients with bloodstream infection (Wolf and Arnoldo 2013). However, it is incumbent upon physicians to recognize the potential obstacles to functional rehabilitation early and start aggressive measures to preserve and optimize function of large and small joints while providing soft tissue coverage to minimize risks of infection and tissue loss.

In addition to functional concerns, the psychological well-being of young burn patients is an important consideration from the start. While early psychological support is common in burn centers, non-burn centers that treat these patients must provide appropriate counseling or consider transfer to a burn unit when the child is medically stable. Support should extend beyond the hospitalization time. For example, children who attended a burn camp, in which children with similar injuries had the opportunity to interact, had significant psychological improvement when compared with children who did not have the same opportunity (Wolf and Arnoldo 2013).

The goals of care of the burned child require consideration of acute management and chronic management simultaneously to optimize outcome.

The acute goals are as follows:

- Stabilize the patient based on the Advanced Trauma Life Support (ATLS) criteria (ATLS 2012; Table 10).
- Assess the injuries and burn wounds understanding the depth of the wound from first- to fourth-degree burn and the quantity of the wounds using the rule of 9's in adolescents and the Lund and Browder chart in younger children. An alternative in smaller children is to use the child's palm as an estimate of 1 % of the total body surface area (TBSA). The rule of 9's used for adults is inaccurate in smaller children due to the fact that head size is proportionally larger and limb size proportionally smaller in children than in adults (Toon et al. 2011). Therefore, a pediatric rule of 9's should be used (Armour and Billmire 2009; Diagram 1a, b).

Urine output is one of the key determinants of resuscitation. General urine output guidelines are for infants and children 2 cc per kilogram (kg) per hour, for adolescents 1 cc/kg/h, and for adults 0.5 cc/kg/h.

In terms of fluid resuscitation of the burned child, there are many guidelines published by various centers (Armour and Billmire 2009). Most will use crystalloid initially and then transition to some form of colloid.

It is critical to determine the need for transfer to a burn center. The American Burn Association has a specific list of criteria, which are as follows:

- Partial thickness burns >10 % TBSA
- Burns involving face, hands, feet, genitalia, perineum, or major joints
- Third-degree burns (any age group)
- Electrical burns (including lightning injury)
- Chemical burns
- Inhalation injury
- Burns in patients with preexisting medical conditions
- Burns and concomitant trauma where the burns pose the greater risk of morbidity/mortality
- Burned children in hospital without qualified staff or equipment for care of child
- Burn injury in patients who will need special social, emotional, or rehabilitative intervention

Even in the acute setting, the hand surgeon must be prepared for the chronic phase of care because burn care in children constantly requires planning for the next phase of care. This planning includes assessment of not only the actual deficits and defects but the potential ones that the reconstruction can create. By following these concepts, physicians can help to optimize recovery of the burn victim from the initial encounter. Failure to consider these issues may prolong recovery and reduce functional outcome.

It is critical that the hand specialist should be involved from the outset in the management of these patients. However, the hand specialist must also be aware of etiology of the injury and the real risk for concomitant trauma to other systems of the body. For that reason, the hand specialist must be familiar with the fundamental ATLS guidelines (Advanced Trauma Life Support (ATLS) Student course manual 9th edition 2012).

Burn: Anatomy and Physiology

The hand is one of the most delicate instruments of the body. It is responsible for connecting to the outside world that includes work, touch, and communication. The anatomy of the hand is precise, and a detailed knowledge of the anatomy and function of the hand and its complex structures is essential for anyone charged with caring for these patients.

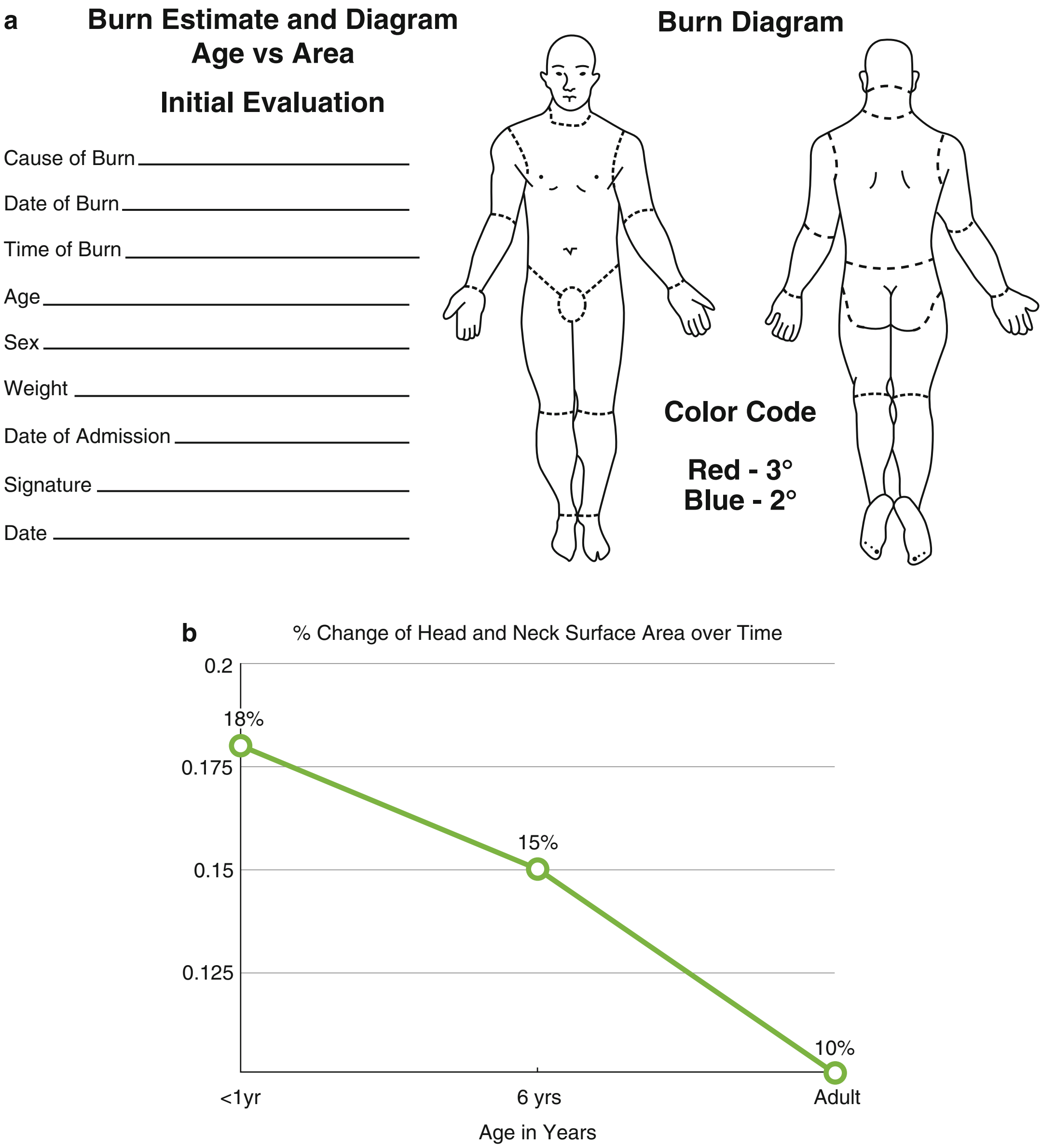

Diagram 1 Burn charting (Adapted from Armour and Billmire 2009)

Assessment of Burn Depth

In the burn victim, an understanding of the anatomy and pathophysiology of burns is critical to patient management. Burns are characterized by the depth of injury into four categories (Table 1; Young 2006).

A first-degree burn is a superficial injury. The skin appears red and may be painful. The dermis is unaffected in these injuries. A sunburn is an example of a first-degree burn. These injuries require supportive care and will heal without scarring within 5–7 days (Fig. 1).

Second-degree burns can be superficial or deep (Fig. 2). Superficial second-degree burns are injuries to, but not through, the dermis. The skin is red, blistered, and swollen. Pain is prominent with a superficial second-degree burn. A superficial

Table 1 Classification of burn injuries

Burn type	Depth	Skin changes	Healing
First	Epidermis	Red coloration	Spontaneous in 3–5 days
Second – superficial	Into upper dermis	Red, blistered, swollen	7–14 days
Second – deep	Into deep dermis	Red, swollen, blistered	Often requires intervention
Third	Through deep dermis	White, charred, or translucent	Grafting or flap needed
Fourth	Full thickness	Necrosis	Grafting or flap

Fig. 1 Blistering of hand indicating superficial injury. Minimal care is needed beyond supportive measures (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 2 Superficial injury. First-degree bordering on early second-degree injury. Note the redness akin to a bad sunburn. Treatment priorities are to return functional status as soon as possible. Silvadene was used to allow for a moist healing environment (Courtesy of M. Baumholtz, MD FACS)

second-degree burn should heal spontaneously in 7–14 days. A deep second-degree burn is one that does not heal within 7–14 days. The dermis is injured in its full thickness and scarring will likely occur as a sequela.

Third-degree burns may appear whitish, charred, or translucent. Pinprick sensation is absent in the burned tissue because the nerve endings have been damaged by this injury, which traverses the dermis in its entirety. Because there are no dermal appendages to support wound healing, scar formation is inevitable and reconstruction using flaps or grafts is essential if the quantity of tissue loss is considerable.

Fourth-degree burns include full-thickness tissue loss to and including bone. Electrical injuries often cause fourth-degree burns. In these injuries, all overlying structures are dead and should be debrided.

As a general rule, all burns that are deep second degree, third degree, and fourth degree will require early excision and reconstruction. The nature of the reconstruction will depend on the location of the anatomic defect along with the functional deficit.

This section is concerned with the intersection of burn pathophysiology and hand function. To that end, the anatomy pertinent to caring for hand burns will be reviewed. Hand anatomy entails some unique features that will impact the manner in which burns are treated.

The volar, palmar skin of the hand provides padding for hand function with thick glabrous skin. However, there is relatively little room for swelling and expansion. This increases the risk for compartment syndromes.

The nail and nail bed are an often overlooked component of hand injuries, especially the burned hand. The nail and nail bed are specialized structures, which require both the matrices to make the nail and the proper support and surrounding tissues, which comprise the nail folds and distal phalanx.

The dorsal structures are more at risk due to the thin skin coverage and relatively little subcutaneous tissue. Specifically at risk is the PIP joint (Germann and Weigel 2011) due to its thin skin surface and the associated ligaments that arise from the extensor mechanism. Disruption of these structures can have devastating effect on function of the entire finger, even if the distal joint is uninvolved with the injury.

Physiology of Burn

A burn is divided into three areas of injury called zones. These three zones are described as:

- Zone of coagulation
- Zone of stasis
- Zone of hyperemia

Irreversible tissue damage occurs in the zone of coagulation, while the zone of hyperemia will return to normal. The zone of stasis, however, is an area of tissue around the central coagulation zone, where the outcome can be modulated based on treatment. Proper resuscitation and care can salvage tissue in this zone, whereas inadequate resuscitation and treatment can lead to a worsening and loss of this tissue.

Mechanism of Thermal Injury

Heat injuries occur from the outside in and from superficial to deep. Injury is caused by flame or heat contact. The actual injury creates direct cellular destruction due to the thermal energy.

Cold injuries also occur from the outside in and from superficial to deep. However, at the cellular level there is cellular dehydration and crystal formation. Moreover, there is also the risk of cell damage that can occur during the rewarming phase as the crystals thaw and fluid shifts result in substantial edema.

Chemical burns can occur from acid, alkali, or specific chemicals common to hand burns. Knowledge of the causative agent is extremely valuable in treatment planning. The treatment for most chemical burns begins with copious irrigation. There are some exceptions to that. Hydrofluoric acid (HF) is one example. Exposure to HF often causes pronounced pain in the hands. This chemical is common in products used in auto detailing. Treatment may require either topical application or direct injection of calcium until the pain abates.

For management of several other specific chemical exposures, see Table 2.

With regard to electrical injuries, the mechanism of damage continues to be debated. However, as would be expected, the majority of the damage is often the consequence of high-voltage energy passing through the tissues, especially the deeper structures. Whether it is due to the fact that the bone heats the surrounding tissue due to its resistance or that the electrical current flows through the deep muscle and nerves more easily, severe deep tissue injury can occur in the presence of seemingly innocuous superficial wounds.

Management of Acute Burns

Upper extremity burn injuries require long-term plans from their initial evaluation. Gone is the model of only excision and grafting for burns that are deep second degree and deeper. Instead, a carefully orchestrated plan that ultimately returns the patient to maximal function and minimal morbidity (both at the site of the burn and the donor sites) is essential.

The most important step is to stop the burn. This is done by extinguishing the fire and/or removing the offending agents and clothing. Placing the burned hand or finger under cool water can

Table 2 Management of specific chemical burns (Adapted from McAdams 2006)

Chemical agent	Treatment
Chromic acid	Dilute sodium hyposulfite
Sodium hypochlorite (common bleach)	Milk, egg white, starch
Potassium permanganate (oxidizer)	Egg white
Phenol (medication)	Mineral oil
White phosphorous (smoke)	2 % copper sulfate, oil
Lye (degreaser)	Vinegar (acetic acid) or other weak acids such as lemon juice or orange juice
Formaldehyde	Ammonium salts
Mustard gas (chemical weapon)	Kerosene, gasoline, or mineral oil
Hydrofluoric acid (wheel cleaner)	Calcium chloride
Hydrochloric acid (swimming pool)	Soda lime, liquid soap
Sulfuric acid (drain cleaner)	Magnesium oxide, liquid soap
Elemental sodium	Mineral oil

mitigate some of the secondary injury and can be comforting to the patient. However, as the wounds get larger, this becomes not only impractical but risks hypothermia in the burn patient. Therefore, one must be judicious in the use of large amounts of cooling.

Simple dry dressings are often the best first dressing. Keep the patient warm and use non-adherent dressings. This is especially true if the patient is to be transferred to a burn center where all the dressings will be removed as part of the initial survey. Once the wounds have been examined by the appropriate treating physicians, they can be dressed. Typical dressings in the acute period involve a non-adherent layer such as Adaptic®, Xeroform®, or Telfa® and often the application of some cream or ointment at the same time. A burn wound can be incredibly painful. For large areas or young children, dressing changes under sedation may be necessary.

Controversy exists regarding the use of systemic antibiotics for burn patients. In the initial period, there is little evidence to support the need for systemic antibiotics. Instead, centers mostly

Table 3 Characteristics of skin grafts

	STSG	FTSG
Dermis	Partial	Complete
Primary contraction	Minimal	Moderate
Secondary contraction	Significant	Minimal
Ease of take	Higher	Lower
Expandable by meshing	Yes	No

Table 4 The reconstructive ladder (Adapted from Thorne 2007; Mathes and Nahai 1997)

Free tissue transfer (including composite tissue transfer – transplant)
Distant tissue transfer
Local tissue transfer
Tissue expansion
Skin grafting
Skin substitutes
Sew it closed/primary intention
Negative pressure wound therapy
Let it heal/secondary intention

Fig. 3 Patient referred from a burn center after catching both hands in a hot press. On presentation, both hands are markedly edematous with full-thickness eschar on each palm (Courtesy of M. Baumholtz, MD FACS)

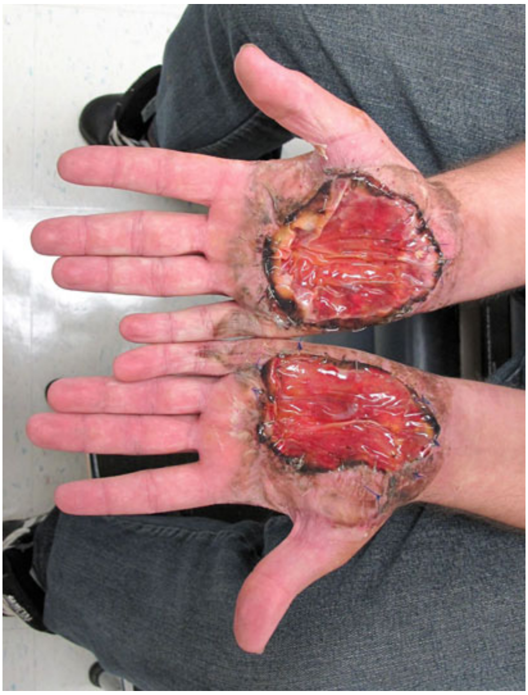

Fig. 4 After 21 days, the outer layer of Integra® is removed and meshed split-thickness skin grafts were used (Courtesy of M. Baumholtz, MD FACS)

Fig. 5 Following course of intensive hand therapy, full function is regained with durable coverage (Courtesy of M. Baumholtz, MD FACS)

use a topical application based on depth and location of the burn. Below are some common choices for topical treatments (Palmieri and Greenhaigh 2002).

Common topical antimicrobials and their side effects:

Bacitracin ointment: This product has the advantage of being simple, cheap, and available. It has a broad spectrum of coverage, including Gram-positive and Gram-negative organisms. However, there is erythema following overuse that is not a true allergy but rather a reaction to a component in the product, which causes the skin to be red. While it is not an infection, it is often mistaken for one leading the patient or provider to use more and more ointment thinking that the ointment is treating the infection. Typically bacitracin is used for about 3–5 days after injury as the wounds heal. Subsequently, the patient may switch to using a bland entity such as Vaseline or A&D ointment. If the wound is worsening, it is necessary to change to a different treatment regimen.

Bactroban: This is an antimicrobial that is derived from pseudomonas species. It has good Gram-positive coverage and was originally intended for MRSA but resistance is emerging.

Silvadene: This is cheap and easy to apply. Its application is not painful. It is supplied as a white cream that takes on a yellowish tan color after being on the wound for a day or so. It provides good coverage for Gram-positive bacteria and good yeast coverage but demonstrates variable efficacy for Gram-negative organisms. There is a small risk of neutropenia and thrombocytopenia with prolonged use. Simple blood tests can monitor for this.

Fig. 6 Following course of intensive hand therapy, full function is regained with durable coverage (Courtesy of M. Baumholtz, MD FACS)

Sulfamylon: This is unique in that it provides good penetration of eschar. It is especially helpful for wounds near or involving cartilage because of this property. Sulfamylon provides coverage for both Gram-positive and Gram-negative organisms, but poor control of yeast. It is often prepared as an aqueous solution and patients will frequently feel pain during the application process. This property has led sulfamylon to be known as white lightening. Sulfamylon application can lead to metabolic acidosis because it inhibits carbonic anhydrase. For these reasons, it is not a first-line choice of treatment for most burn specialists.

Silver nitrate: This is an agent that predates all of the other agents described above. It stains tissue and clothing but provides good coverage for Gram-positive and Gram-negative organisms as well as yeast. Application is painless.

Fig. 7 10-year-old child was severely burned following a house fire. Injuries included hands and feet. Initial treatment with skin grafting was complicated by graft loss and severe contracture. After transfer to our facility, she underwent a thumb-index web space release, palmar release, and application of Integra® (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 8 Four weeks after the initial application of Integra®, her hand was ready for grafting. A full-thickness skin graft was used for increased durability and risk of future contracture in this child (Courtesy of Shriners Hospital for Children, Philadelphia)

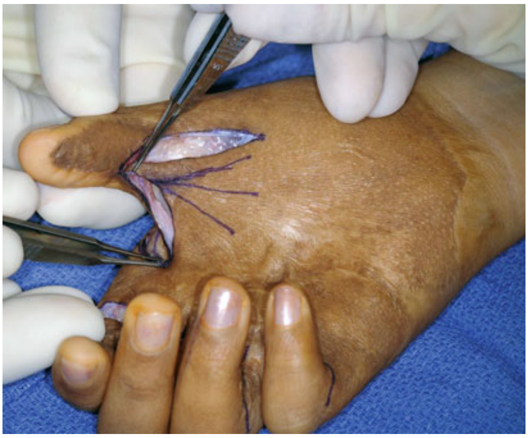

Fig. 9 Five months later, her right hand was treated with Z-plasty of the fingers and thumb-index webs pace with immediate skin grafting (Courtesy of Shriners Hospital for Children, Philadelphia)

The use of silver nitrate carries a remote risk of methemoglobinemia and argyria. Other more common risks include electrolyte abnormalities.

Nutrition and the Burn Patient

Nutrition plays a major role in patients' ability to heal and fight infection. Nutritional support is critical in management of the burn patient. Most calorie estimations of oral intake alone are grossly inadequate. Moreover, the formulas used for nutritional support are often insufficient in the face of burn and multiple trauma victims. It remains generally accepted that the patient's own intestinal tract is the best route for nourishment whenever possible. Albumin and prealbumin are lab markers that can help guide nutritional support. The condition known as refeeding syndrome is exceedingly rare and many of the current-day fears about this process are unfounded. Nevertheless, all patients who can eat are encouraged to do so. The patient's albumin and prealbumin are used to drive their nutritional support. A blood albumin level less than 2.7 g/dL is a reason to delay elective reconstructive surgery. For patients that are below 2.7d/dL and unable to take enough by mouth, a nasogastric feeding tube is routinely placed with around-the-clock feeds until the lab markers begin to correct and there are signs of

Fig. 10 Transposition of the Z-plasty flaps in the first web space (Courtesy of Shriners Hospital for Children, Philadelphia)

healing. Patients who can eat are still encouraged to do so around the tube. The process is employed even for patients who must remain supine. Although these patients are monitored for aspiration, a properly placed and monitored feeding tube is a safe means to restore the nutritional balance.

Indications for Early Surgical Intervention for Patients with Upper Extremity Burns

Compartment Syndrome

Compartment syndrome is a clinical condition in which swelling within an anatomic compartment creates ischemia by first reducing blood inflow and later outflow from the compartment. Ultimately, the contents of the compartment will suffer irreversible ischemic damage if the pressure is not released through compartment fasciotomy.

Fig. 11 Z-plasty of the fingers (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 12 Final functional result of the left hand with thumb movement (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 13 Final functional result of the right hand with thumb movement (Courtesy of Shriners Hospital for Children, Philadelphia)

Diagnosis of compartment syndrome is typically a clinical one, but there are some tests that can be of aid to the clinician. Compartment pressure can be measured using commercial devices or a standard arterial catheter. The pressure gradient is calculated as the difference between diastolic blood pressure (DBP) and the compartment pressure (CP). When the difference between these numbers (DBP-CP) is less than 30 mmHg, there is further evidence for compartment syndrome.

Management of compartment syndrome requires an understanding that escharotomy and fasciotomy are not the same thing. Escharotomy is typically used in circumferential chest wounds to allow chest expansion for breathing. Severe burns

Fig. 14 Final functional results of the left hand at rest with no contracture (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 15 Final functional result of the left hand at rest with no contracture (Courtesy of Shriners Hospital for Children, Philadelphia)

can create a leathery inelastic eschar that must be released when it involves a structure circumferentially. Depending on the severity of the burn and the condition of the patient, escharotomy can be done at the bedside with minimal sedation as the area is often insensate. However, should escharotomy be needed around the arm, hand or finger, fascial release (fasciotomy) may still be required to alleviate the compartment pressure.

A fasciotomy in a burn patient is most commonly performed for electrical injuries and in those patients who develop compartment syndrome due to over-resuscitation. Typically an escharotomy may precede fasciotomy (if deep external burn is involved) but fasciotomy seeks to release the deep fascial compartments to allow the muscle room to swell. Escharotomy will not accomplish this task. Failure to perform complete and timely fasciotomies will lead to loss of function and even loss of limb.

It is critical to understand that children express ischemic pain differently from adults. Adults in ischemic pain follow a pattern known as the 5 P's, which represent pain, paresthesia, paralysis, pallor, and pulselessness. Loss of pulses is the last sign and often the harbinger that damage has already occurred. In contrast, the typical presentation in children involves what is known as the 3 A's, which represent agitation, anxiety, and analgesia. A warning to the physician would be a worsening in agitation, a worsening in the child's anxiety, and an increasing need for analgesia.

Fig. 16 This child suffered severe flame burns to his torso, neck, and upper extremity. He was referred for management of his neck and hand contractures. As he grew, he experienced tension between the grafted and normal skin. The bands on his neck caused limitation of his head rotation and the axillary bands were problematic with sports (Courtesy of Shriners Hospital for Children, Philadelphia)

Principles of Fasciotomy by Location

In the fingers, there are no true compartments but circumferential injury can disrupt flow. A mid-lateral incision to release the constricting

Fig. 17 Neck treated with Z-plasty (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 18 Early healing and improved range of motion (Courtesy of Shriners Hospital for Children, Philadelphia)

eschar may be all that is needed. One should begin with just one side and assess flow. Releasing incisions for the hand should proceed from proximal to distal assessing for flow at each step.

The volar hand has several true compartments that must be considered for release. These are the thenar, hypothenar, and palmar. A wide carpal

Table 5 Z-plasty angles and gain in length (%) (Adapted from Thorne 2007)

Angle	Gain in length
45°	50 %
60°	75 %
75°	100 %
90°	125 %

Table 6 The pectoralis major flap (Adapted from Mathes and Nahai 1997)

Pectoralis Major Myocutaneous Flap Preoperative Planning
□ OR Table: Regular
□ Position / positioning aids: Arms abducted
□ Dominant Pedicle: thoracoacromial artery
□ Equipment: handheld doppler is used to confirm patency and flow prior to transfer / inset.

Pectoralis Major Flap Surgical Steps
• A line is drawn from the acromion to the xyphoid (course of the vascular pedicle). Alternatively - divide the clavicle into thirds and identify the junction of the middle and lateral third as the pedicle origin.
• A skin paddle is designed to cover the defect in the axis of the pedicle
• The flap is incised and the underlying muscle exposed without undermining the paddle of the flap itself.
• Once the skin paddle is released and the muscle exposed, the muscle is elevated from distal to proximal toward the pedicle's origin. The pedicle should be visible in the midportion of the muscle on its undersurface.
• Length may be increased by (1) releasing the muscle off the clavicle (Protecting the pedicle) and (2) releasing the muscle from it's humeral attachment.
• Wound is closed in layers over drains.

Pectoralis Major Flap Postoperative Protocol
□ Flap checks follow surgery
□ Drains removed with output <30cc / 24 hours

tunnel approach to relieve pressure on the median nerve can often release enough pressure to allow flow into the hand. However, if flow is not restored and the other compartments appear or feel tense, release may be needed.

Splinting

The use of splints is critical for any hand burn of deep second degree or deeper. A competent hand therapist and early motion are equally important. When the hand is at rest between therapy and surgery, a splint provides a means to reduce edema, reduce pain, and keep deeper structures, such as the intrinsic muscles, at their proper resting tension. Occasionally it is necessary to internally splint the fingers with k-wires, but this technique must be used judiciously as there is an increased risk of infection related to the pin tract. After flap or graft surgery, immobilization is often needed to allow for healing at the surgical site. Therapy is continued for the surrounding joints whenever possible to minimize stiffness and disuse atrophy.

Fig. 19 Patient suffered liquid nitrogen burn resulting in restricted movement of both axillae and shoulders. Given the extensive damage to his back, the traditional latissimus, scapular, and parascapular flaps were not feasible. A pedicled pectoralis major flap was used to bring vascularized, pliable tissue into the axilla (Courtesy of M. Baumholtz, MD FACS)

Surgical Options for Reconstruction

The options for reconstruction of burned upper extremities include the use of skin substitutes, skin grafts, and/or a variety of flaps. In addition, tendon transfers, nerve repairs and grafts, and ligament and joint reconstruction may all be required in any given patient.

Skin Substitutes

While there are many skin substitutes, none serves the same function as Integra® in terms of mimicking the natural epidermis and dermis. The product has a silicone layer that serves as a vapor barrier for the wound as well as protection for the underlying neodermis during incorporation. Integra® is expensive but in a clean wound and the appropriate patient, it can fundamentally change the approach to burn wound. Experience has clearly demonstrated that the indications for Integra® application go well beyond its initial indications (Armour and Billmire 2009, Tenenhaus and Rennekampff 2007, Chalmer et al. 2010). Our practice has been to use this “off the shelf product” to stabilize the wound bed and apply a graft only when the bed is ready and mature. For wounds that need flap coverage, Integra® is not routinely used. However, in a patient who is not ready for flap coverage, either due to polytrauma or severe malnutrition, Integra® can provide temporary wound coverage – especially for critical structures like tendon, nerve, and/or bone (Armour and Billmire 2009, Tenenhaus and Rennekampff 2007, Chalmer et al. 2010).

Allograft dermal grafts can be used as a temporary cover following removal of eschar. They can be used to stabilize wounds as a bridge to further grafting. While costly, they can be less

Fig. 20 Shoulder abduction limited by scarring (Courtesy of M. Baumholtz, MD FACS)

expensive than Integra® and may be valuable in temporary coverage of wounds (Stanton and Billmire 2002).

Grafts

Skin grafts are a useful tool in upper extremity burn reconstruction. Both full-thickness and split-thickness grafts can be utilized. Split-thickness skin grafts can be used after staged management with skin substitutes as well as for final repair of defects over surfaces where contracture is not a concern. For example, meshed grafts can be used following forearm fasciotomy to manage a wound that won't close. Full-thickness grafts are useful in the hand and fingers. Splints are a useful adjunct to skin grafts in order to protect the grafts while healing and protect the joints at the same time. Table 3 reviews the distinctions between full- and split-thickness grafting.

Fig. 21 Design of the skin paddle along the axis of the vascular pedicle (Courtesy of M. Baumholtz, MD FACS)

Flaps

The entire complement of flaps can be used in upper extremity burn reconstruction. Finger and hand flaps, both random and axial pattern, can play a role in management of burn injuries. Fasciocutaneous, muscle, and myocutaneous flaps play important roles in providing coverage and maximizing joint action at the same time. Classification of flaps is based on their vascular supply as described by Mathes and Nahai (Table 9). The use of flaps is generally delayed in burn reconstruction patients unless the injury is isolated and there is no reason to delay the final stage of reconstruction. Flaps derived from tissue expansion are useful in late repairs where increased amounts of tissue are needed. (Mathes and Nahai 1997; Dotan et al. 2009; McCraw and Arnold 1986).

Reconstructive Choices Based on Involved Structure

There are many factors that are involved in the method of reconstruction of a particular wound.

In the early phase, obtaining a healed wound is the primary goal. Yet even at this point, hand function must be considered. A healed wound in a functionless extremity is of little value to the patient, so future function is always a consideration. Even if there is to be a period of immobility or non-function, the surgeon should be thinking many steps ahead as to how the reconstruction of today will help the function of tomorrow. To achieve the healed wound, the surgeon must consider the structures involved and the tissue (s) available for reconstruction. This approach balances the concepts of the reconstructive ladder with functional needs of the hand (Table 4). It is important to consider those injuries that cross joints as needing sufficient coverage to maintain joint mobility. This is true for both small and large joints. Protection of these functions may require periods of temporary immobilization and even use of buried flaps, such as groin flaps, early on in a patient's management. The age of the child may make some of these choices very challenging. Joint function, however, must remain a primary goal, regardless of the child's age.

Fig. 22 Postoperative picture demonstrating the flap's ability to reach the posterior axillary fold

Management of Chronic Burn Deformities

Patients often present following treatment of acute injuries and subsequently require delayed reconstruction. Presentation reasons vary but include stiff painful hands or joints and/or chronic or unstable wounds.

In the chronic situation, it is critical to understand the residual defect and functional deficit as

Fig. 23 Healed donor site (Courtesy of M. Baumholtz, MD FACS)

Table 7 The latissimus dorsi flap (Adapted from Mathes and Nahai 1997)

Latissimus Dorsi Myocutaneous Flap Preoperative Planning
□ OR Table: Lateral with bean bag support or prone
□ A mayo stand is draped and the arm is included in the field to allow for manipulation during harvest
□ A hand-held doppler is used intraoperatively to confirm patency as needed
□ A pre-operative angiogram may be needed in cases of severe trauma to the axilla.

Latissimus Dorsi Flap Surgical Steps
• In the sitting position, the tip of the scapula and the iliac crest are marked and a line is drawn from the posterior axillary fold to a point midway between the iliac crest laterally and the posterior midline.
• A skin paddle if needed can be drawn along this line
• The flap is incised around its edges and the surrounding skin lifted off the muscle exposing the flap in its entirety.
• Harvest begins at the scapular tip and proceeds posteriorly - releasing the muscle off its posterior attachements. Care is taken to control the paraspinal perforators and avoid elevation of the serratus.
• Prior to dividing the branch to the serratus, flow is confirmed in the main pedicle to the flap with handheld doppler.
• Once completely mobilized, additional length can be achieved by dividing the humeral attachment (care is taken to protect the pedicle).
• The donor wound is closed in layers over 2 large drains.

Latissimus Dorsi Flap Postoperative Protocol
□ Drains are removed when the output is <30cc / 24 hours
□ Simple dressings for the donor site included gauze and tape

well as the adaptive measures the patient has learned. It is paramount not to operate on a hand that works just to improve its appearance. Children are remarkably good at adaptation in terms of function. Consequently, before considering surgery, it is critical that patients spend time with occupational therapists. Therapists can provide both surgeon and patient with a functional evaluation and a reconstructive road map in terms of what needs are obtainable through therapy and what needs require additional surgery.

A sensate burned hand with gross motor function that functions as a helper hand is currently still better than the best available prostheses. All prostheses lack sensation and need visual cues to function. When treating a burned limb, the goals of reconstruction are stable coverage, mobile joints and tendon structures, functional muscle, and sensation. Typically, this is approached in a proximal to distal fashion but there can be exceptions.

Amputation

While often a last resort, amputation remains a valuable part of reconstructive ladder. There are certain situations where an amputation will serve the patient better than an insensate, stiff, functionless digit or part. Patient and facility factors to consider in terms of an amputation are the extent of damage, patient compliance, financial concerns, and lack of access to needed resources including rehabilitation. Before embarking on any complex salvage or reconstruction of the limb, the possibility of amputation should be discussed with patients and their families.

Fig. 24 Adult patient who suffered an injury to her anterior axilla and shoulder. She presented with a large anterior wound with exposure of the neurovascular bundle and secondary infection. A pedicled latissimus dorsi myocutaneous flap was used to cover the defect in one stage (Courtesy of M. Baumholtz, MD FACS)

Chronic Wounds

Wounds that recur or remain unhealed after a reasonable period of time warrant a biopsy. This tenet especially applies to the patient who seeks care for a wound years after the initial injury. Although burn-related malignancy is unlikely to occur in the pediatric population, patients who were burned as children do have this risk as young adults. The astute clinician must be aware of the possibility of a malignancy arising from a chronic burn wound (Marjolin's ulcer). The phrase "biopsy your infections and culture your cancers" is important to consider when confronted with a wound that has not healed in the expected manner and time frame.

Heterotopic Ossification

This is a difficult problem following burns, head injury, or trauma. It is especially problematic in the burned upper extremity. When present, the heterotopic bone can be removed to liberate the underlying joint but the timing of that type of

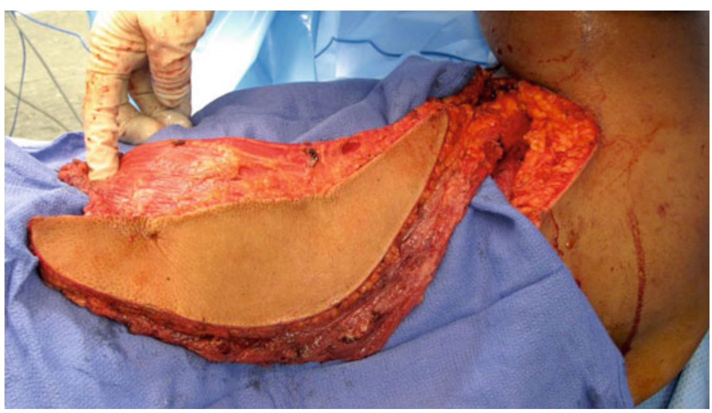

Fig. 25 The latissimus dorsi flap can be taken with a large skin paddle (Courtesy of M. Baumholtz, MD FACS)

Fig. 26 Healed wound (Courtesy of M. Baumholtz, MD FACS)

Fig. 27 Sixteen-year-old male suffered significant electrical injury outside of the United States. He was referred for management of both the extensive scarring and the lack of elbow flexion. Examination revealed an amputation distal to the elbow with no elbow flexion (Courtesy of Shriners Hospital for Children, Philadelphia)

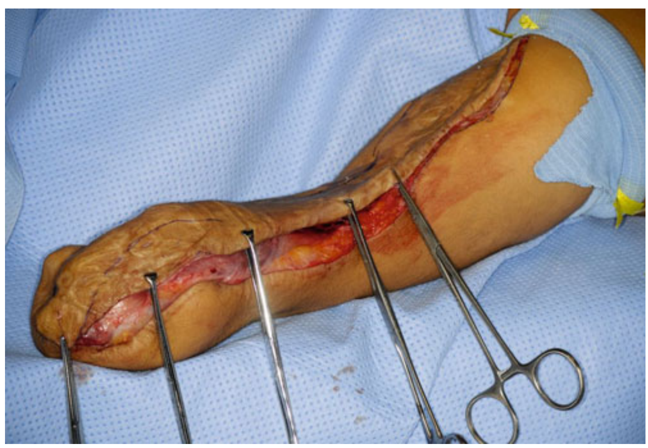

Fig. 28 The scar is excised, the defect modeled and then transferred to the back for design of the latissimus dorsi myocutaneous flap in preparation for a functional muscle transfer (Courtesy of Shriners Hospital for Children, Philadelphia)

surgery remains controversial and recurrence remains extremely high. Different centers have different protocols as to how to manage heterotopic ossification (HO), and it is beyond the scope of this chapter to discuss management in detail.

Scar Management

The literature is replete with scar management protocols in both the acute and chronic setting. In general, scars mature over the course of 1–2

Fig. 29 The flap is designed to both provide a functional motor for the elbow as well as a large skin paddle for wound coverage (Courtesy of Shriners Hospital for Children, Philadelphia)

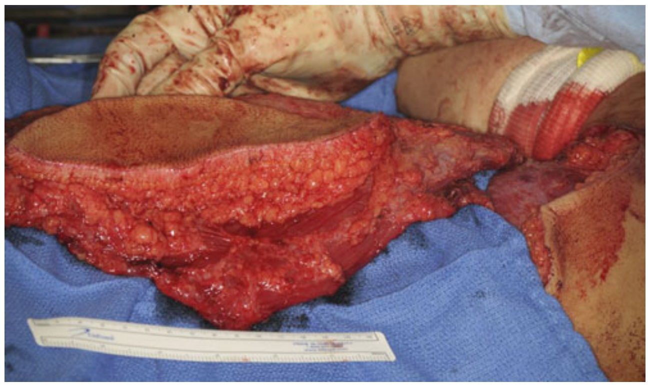

Fig. 30 The flap is elevated with the patient in the lateral position. Handheld Doppler is used to confirm vessel patency. Given the extensive injury, we did opt to study the vascular pedicle preoperatively with a CT-angiogram. No defect was found (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 31 Large elbow wound following liquid nitrogen burns. He was referred after multiple rounds of skin grafting and bone drilled failed to achieve a healed wound (Courtesy of M. Baumholtz, MD FACS)

years following any form of full-thickness injury (burn, surgery, trauma, etc.). There are many products that claim to have beneficial properties that positively affect the final scar appearance without having any real supporting scientific data. As a general guideline, patients with scars find benefit from the following instructions: (1) protect the scars from ultraviolet (UV) exposure for a year following the injury, (2) massage the scars daily, and (3) apply topical silicone when the wounds are dry. In the pediatric population, there seems to be better compliance with the topical formulation when compared to silicone sheeting; pressure garments should be used if they

Fig. 32 Elbow wound with bone and joint exposure with contamination. Surgically debrided in preparation for flap coverage (Courtesy of M. Baumholtz, MD FACS)

Fig. 33 Healed radial forearm flap with total coverage of elbow (Courtesy of M. Baumholtz, MD FACS)

provide comfort to the patient. Recent data (Juckett and Hartman-Adams 2009) suggests that pressure garments may not be as useful as were once thought.

For scar pruritus, a course of triamcinolone injections can be helpful although the literature is mixed on this treatment. Newer literature suggests that Botox® (Allergan, Irvine, CA) may have a role in the management of scar pruritus (Wolf and Arnoldo 2013).

Burn Reconstruction

The importance of early and aggressive intervention for the burned hand cannot be overemphasized. While it is absolutely imperative that the ATLS guidelines be followed for the assessment and management of the entire patient, no structures are more at risk for long-term deficit from inadequate or inappropriate management than the hand and upper extremity.

Hand and upper extremity burns should be comanaged by a hand specialist from the outset whenever possible.

The hand and upper extremity represent a symphony of vasculature, nerves, joints, functional muscle, tendons, and soft tissue coverage that all must work together to achieve a functional outcome. To address only one of those concerns is to fail to understand the intricacy of the system as a whole.

As described above, burn injuries and burn reconstruction begin in the acute setting and progress through an intermediate phase and finally into a chronic reconstructive phase. Issues addressed at each stage must include not only that particular problem but the future. Dealing with hand burns, especially in children, is far more akin to the game of chess than of checkers with ample deliberation of your subsequent moves.

In the acute phase, once the child has been stabilized, the specialist should assess the defect

Table 8 Radial forearm flap (Adapted from Mathes and Nahai 1997)

Radial Forearm Fasciocutaneous Flap Preoperative Planning
□ OR Table: Regular
□ Position / positioning aids: hand table
□ handheld doppler on the field
□ Equipment: micro-instruments including Acland clamps (or similar)
□ Tourniquet: pneumatic

Radial Forearm Flap Surgical Steps
• Draw a line from the radial styloid to the mid-portion of the antecubital fossa on the volar forearm. This approximates the course of the pedicle.
• Design the flap either antegrade (distal skin paddle) or retrograde (proximal skin paddle).
• Confirm vascularity of the hand using the handheld doppler to confirm the Allen test
• For a distal skin paddle: gentle exsanguination. incise the skin 1-2cm proximal to wrist crease. Identify the radial artery and place a vessel loop around. Release the tourniquet and using the Acland clamps, once again confirm flow to the hand when the radial artery is occluded. Once confirmed, reinflate the tourniquet and harvest the flap in the distal to proximal manner. The flap can include the entire circumferential forearm if needed but this would be a significant donor defect.
• For a proximal skin paddle, the procedure is similar except care is taken to identify the radial artery after it has bifurcated away from the ulnar artery.
• Unless the flap is designed as a fascia only, closure will require some form of graft (skin or synthetic)

Radial Forearm Flap Postoperative Protocol
A well padded volar splint is fabricated with kerlex, mother's cotton, and plaster. A window is made to facilitate flap checks
A bolster is used to secure the Integra or skin graft and left in place for 7 days.
A penrose may be used under the flap
□ Protective wrist splinting until 8 weeks after surgery.

and plan for the immediate management. In many ways, reconstruction for the burned hand will follow the traditional concepts of the reconstructive ladder but with the combined need for simultaneous preservation of range of motion.

The Reconstructive Ladder

Conceptually the ladder arises from the notion that there is a stepwise sequence of repairs for a given wound that range from the very simple to

Fig. 34 Twenty-five-year old woman suffered a friction burn of her dorsal wrist in a rollover motor vehicle accident. She presented with joint and tendon damage (Courtesy of M. Baumholtz, MD FACS)

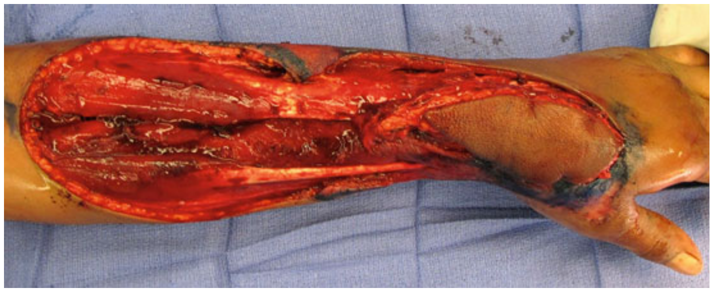

Fig. 35 A reverse radial forearm flap was performed (Courtesy of M. Baumholtz, MD FACS)

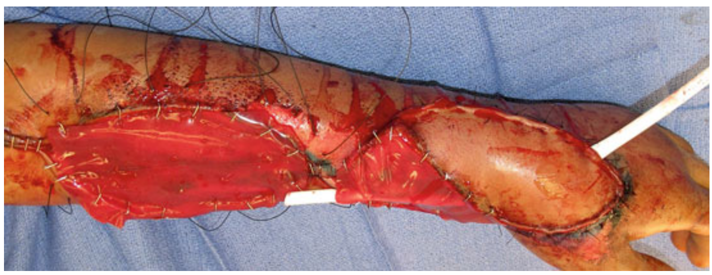

Fig. 36 Integra® was used on the donor defect to minimized the aesthetic defect (Courtesy of M. Baumholtz, MD FACS)

Fig. 37 Healed flap with good functional recovery (Courtesy of M. Baumholtz, MD FACS)

Fig. 38 Healed flap with good functional recovery (Courtesy of M. Baumholtz, MD FACS)

Fig. 43 Flap insetting is with absorbable sutures. A well-padded soft cast or splint which extends above the elbow will be used for 2 weeks (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 44 Nine-year-old male with flame burn injury. Scar contracture has resulted in a markedly abducted thumb (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 45 Thumb hyperabduction due to contracture (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 46 Design of the groin flap. A handheld Doppler is used to confirm presence of pedicle (Courtesy of Shriners Hospital for Children, Philadelphia)

the very complex. Typically a reconstruction of any kind should at least consider the simpler options before employing the more complex (Table 4).

In the acute phase there is either partial- or full-thickness damage to the skin or perhaps missing tissue altogether. Conventional teaching is that if a wound would not heal on its own by 14 days (i.e., a deep 2nd-degree injury or worse), it should be excised and grafted. However, grafting does not always mean skin grafting (Figs. 3, 4, 5, and 6). There are many cases where a patient would be better served by using a skin substitute (such as Integra® (Integra LifeSciences, Plainsboro, NJ)) as the initial means of coverage and beginning range of motion or immobilization for joint protection while the clinical situation and tissue bed improve (Tenenhaus and Rennekampff 2007, Chalmer et al. 2010, Stanton and Billmire 2002). Patients may need resuscitation, nutritional support, or additional surgery on other systems. The use of skin grafts to provide coverage in the absence of maintaining optimal function is of little value for these patients and may squander precious autologous tissue that will be needed later.

Skin substitutes can also be used in the chronic setting of burns and contractures. The combination

Fig. 39 This 40-year-old man suffered extensive electrical injury to his hand and forearm rendering the hand with limited function and sensation. His forearm wound had previously been skin grafted at an outside institution. An exploration was undertaken. The skin graft was removed, and after extensive tenolysis and neurolysis, a large defect of the volar forearm required coverage with vascularized supple tissue (Courtesy of M. Baumholtz, MD FACS)

Fig. 40 A free anterolateral thigh flap was selected. The donor site and flap design are shown (Courtesy of M. Baumholtz, MD FACS)

Fig. 41 Following his flap surgery and after extensive hand therapy, the patient experienced a significant improvement in function and sensation (Courtesy of M. Baumholtz, MD FACS)

Fig. 42 This 5-year-old child injured his right hand when it was caught in a moving treadmill. He was referred when conservative treatment led to thumb-index webs pace contracture. A 4-flap Z-plasty was designed to widen the web space and create a more rounded contour (Courtesy of Shriners Hospital for Children, Philadelphia)

of contracture release, application of a skin substitute, and delayed skin grafting has improved the care of burns. The skin substitute provides immediate coverage and allows time for the bed to mature before application of a skin graft (Figs. 4, 5, 6, 7, 8, 14, 15, 36, 37 and 38).

In this clinical scenario, return to the acute phase and consider the patient who presents with a third-degree burn of the torso and upper extremity. From the hand specialist perspective, the goal is to work alongside the burn team providing the necessary support for the critical structures of the hand. For this case, a skin substitute

Fig. 47 After the defect is created, it is modeled with an Esmarch bandage. The model will then be used to design the actual flap. For the groin flap, we use the outside of the model to mark the flap (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 48 Flap is elevated lateral to medial above the level of the fascia. Once the lateral border of the sartorius muscle is reached, the dissection plane transitions to subfascial to avoid injury to the pedicle (Courtesy of Shriners Hospital for Children, Philadelphia)

like Integra® is a good choice to cover the freshly excised wounds. If the child were unconscious, splinting the hand and wrist in the position of safety, with the elbow in slight flexion, and the arm in abduction is performed. Of equal importance is the early involvement of occupational therapists not only for proper splint fabrication and fitting but for early passive range of motion. Once the child has stabilized and the Integra® had matured, skin grafting is a reasonable solution as long as joints remained supple and functional. If there was tendon involvement or the need for revision surgery, a flap might be a better choice than a skin graft, since it would allow for better a gliding surface and would be more resilient to additional surgery. However, the experience is changing views about Integra® and its use directly onto tissues (bone, tendon) that previously were thought to be contraindicated for Integra®.

Z-Plasty Description

Z-plasty is a geometric flap design employed to rearrange tissues. Z-plasty is useful to treat chronic scar contractures. Different angles are used to achieve different theoretical gains in length along the long axis of the design. Typically, a 60° angle is most commonly chosen as this will yield a 75 % increase. Z-plasty is most commonly used to reorient scar bands to break up scar patterns (Figs. 16, 17, and 18; Tables 5).

Management of Chronic Injuries by Anatomic Location

Management of Axillary Wounds

Axillary scarring is particularly problematic to the patient and the surgeon. The patient has inability to reach overhead and has limited access to his or her axillary. The surgeon is often unable to perform simple Z-plasties due to extensive scarring. Pedicle transfers, such as the latissimus dorsi and pectoralis major, can provide adequate coverage after release of the axilla (Table 6).

The pectoralis major flap remains a workhorse for the reconstructive surgeon. Although often overlooked in the modern era, it provides a substantial amount of muscle and tissue for pedicled flap coverage of the axilla, chest, and head and neck. It can be used for coverage or as a functional muscle. It is a smaller, mirror image of the latissimus muscle extending from the humerus to the clavicle and sternum to the rectus abdominis fascia. It is a Mathes and Nahai Type V with the thoracoacromial artery as the dominant vessel. There are multiple medial perforators as well. It can be harvested as muscle only or with skin and even bone (Figs. 19, 20, 21, 22, and 23; Table 7).

The latissimus dorsi flap remains one of the most important workhorse flaps in reconstructive surgery. It can be harvested for an array of purposes from simple wound coverage to functional muscle transfer. It can be reliably used as either a pedicle or free flap transfer. The latissimus is the largest muscle of the back and flaps can range to 25× 35 cm. This fan-shaped muscle extends from the humerus to the posterior iliac crest fascia to the lower six ribs of the thorax. The main pedicle is the thoracodorsal artery which is a branch of the subscapular artery. The vessel can be typically found about 10 cm below the

Fig. 49 Groin flap following division and inset. The hand approximates the position it is in during the delay period when the flap was still attached. We allow a minimum of 2 weeks before division (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 50 Two-year follow-up. Flap has been debulked by suction lipectomy. Good range of motion and function (Courtesy of Shriners Hospital for Children, Philadelphia)

Fig. 51 Twenty-five-year-old man who sustained massive tissue damage when he came in contact with high-voltage electricity at railroad yard. His hands were incinerated upon contact. He was referred from an outside institution for management of his extensive upper extremity wounds (Courtesy of M. Baumholtz, MD FACS)

Fig. 52 Ultimately, the patient came to have bilateral above elbow amputations. After the wounds had healed, he was trained in the use of prosthetic hook devices and regained a significant amount of functional independence (Courtesy of M. Baumholtz, MD FACS)

muscle's humeral insertion. The flap can be designed with or without a skin paddle (Figs. 24, 25, and 26).

Management of Proximal Arm Wounds

Proximal arm burns can encompass the skin only or involve the muscular compartment. Coverage is dependent upon the extent and depth of the burn. The latissimus dorsi flap remains the workhorse for coverage with or without skin. The muscle can be used to generate elbow flexion (Figs. 27, 28, 29, and 30).

Table 9 Mathes and Nahai classification of muscle flaps (Adapted from Thorne 2007; Mathes and Nahai 1979)

Type	Description	Example
I	A single dominant pedicle	Tensor fascia lata
II	A single dominant pedicle and a minor pedicle	Gracilis
III	Two dominant pedicles	Gluteus maximus
IV	Segmental vascular supply	Sartorius
V	A single dominant pedicle and secondary segmental supply	Latissimus dorsi

Management of Elbow Wounds

The elbow is notoriously difficult to cover with local flaps (Jensen and Moran 2008). There is limited skin available and the coverage must accommodate motion. Pedicle flaps are the mainstays for coverage (Figs. 31, 32, and 33). One of the most common flaps is the radial forearm flap (Table 8). The radial forearm flap remains one of the most versatile flaps for reconstructive

Table 10 ATLS overview (ATLS 2012) Wikipedia

A	Airway maintenance and cervical spine protection
B	Breathing and ventilation
C	Circulation with hemorrhage control
D	Disability/neurologic assessment by Glasgow Coma Scale
E	Exposure and environmental control

surgeons. The flap can be taken as a pedicle (reverse or antegrade) or free flap, as a fascia only or with skin. When needed, tendon and bone can be incorporated in its design. The radial forearm flap's primary blood supply is the radial artery. It can include a considerable amount of tissue. Caveats to its harvest include checking an Allen's test before considering the flap and protecting the radial sensory nerve during harvest. The donor can at times be problematic with either cosmetic concerns or exposure of tendons (typically the FCR). Our practice has been to use a piece of Integra® over the donor area and skin graft later. When tendon exposure becomes troublesome, we will either imbricate the surrounding muscles over the tendon or excise the exposed portion of the tendon. Typical uses for the antegrade flap would be elbow or proximal arm coverage or as a free flap. The reverse radial forearm is typically used to cover defects of the hand and wrist.

Management of Forearm Wounds

The forearm offers a myriad of possibilities for burn coverage. The choice is dependent upon the extent and depth of the burn. The entire gamut of options needs to be available to select the correct operation (Figs. 34, 35, 36, 37, and 38).

Free Tissue Transfer: Anterolateral Thigh Flap

At the top of the reconstructive ladder, there is free tissue transfer (FTT) (Karans and Buntic 2009). FTT is a microsurgical procedure whereby tissue of any type is harvested based on a single vessel. That vessel and tissue is then anastomosed microsurgically to another vessel in the region of the defect. This allows movement of a tremendous amount of tissue in a single stage. Microsurgery requires specialized training and equipment as well as the necessary resources to support surgeries of this type.

The anterolateral thigh flap (ALT) is typically a fasciocutaneous flap but can be harvested as a musculocutaneous flap as well (Wei et al. 2002). It is located on the middle 1/3 of the thigh. Its major pedicle, a branch of the profunda femoris artery, is the descending branch of the lateral circumflex femoral artery. This vessel typically runs between the rectus femoris and the vastus lateralis muscles. It can be taken in a variety of configurations and sizes. A caveat to successful harvest is a thorough understanding of the vascular anatomy in this region which can be variable (Figs. 39, 40, and 41).

Management of Hand Wounds

Hand burns are managed by similar principles detailed above. The treatment can range from simple soft tissue rearrangement to complex tissue reconstruction (Figs. 42 and 43) (Wu and Gottlieb 2005).

As the complexity of the reconstruction increases, alternative coverage options are needed. The groin flap is an integral part of the reconstructive ladder (Figs. 44, 45, 46, 47, 48, 49, and 50). A groin flap is a fasciocutaneous flap centered approximately on a line about 3 cm below the inguinal ligament extending from the femoral vessels to the posterior iliac spine. While the groin flap was one of the first free flaps described in the literature, it is now rarely considered a first-line choice for free tissue transfer. However, it remains a stable, reliable way to provide a significant amount of soft tissue as a pedicle flap. The dominant vessel for this flap is the superficial circumflex iliac artery which is a branch of the superficial femoral artery. There are some of the caveats to successful harvest and implementation: the flap is designed based on the size of the defect. Once the flap is designed on its axis, a handheld Doppler is used to confirm pedicle patency. The flap is elevated in a lateral to medical direction. Great care is taken upon reaching the sartorius as the plane of dissection must now be below the investing fascia of the sartorius to avoid pedicle damage. The medial edge of the sartorius is typically the medial extent of flap harvest. The donor defect is closed up to the base of the pedicle which itself can be left open or tubularized. The flap is then inset to the defect with plans for a second stage division at 2–3 weeks.

Amputations

In cases of high-voltage electrical burns, one or both arms can be lost. Prosthetic fitting may be the only option available to increase function (Figs. 51 and 52; Fergason et al. 2010).

Long-Term Outlook/Conclusions

The following concepts are central to the management of children with upper extremity burns:

1. Burns, as a mechanism of injury, are unlikely to subside worldwide, given the curiosity of the pediatric population and the ubiquitous sources of injury.
2. Assess for signs of abuse or neglect in children as a contributing factor to a child's burns.
3. Each stage of management must prepare the child for reintegration into school and society with as much function as possible.

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