Rehabilitation Methods for the Burn Injured Individual

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Burn injury is not a new problem. Since ancient times, humans have known the tragedy of severe burn injuries. Hippocrates described treatments for burn injury in his early works [1]. During the first century of Rome, Cornelius Celsus described a technique for surgical excision of burn scar [2].

The economic and human cost of burn injuries is enormous. Excluding the tragedy of September 11, 2001, on average more than 3900 persons die from fire each year. An additional 750 persons die from motor vehicle and airplane crashes, contact with electricity, chemicals, or other causes of burn. In 2005, more individuals died secondary to fire than all natural disasters combined. The direct cost of burn injuries is staggering, exceeding more than $10 billion in the year 2005 alone [3]. Residential fires account for most burn injuries. Cooking fires account for 47% of residential fires, and heating fires account for 19% [3,4]. The incidence of fires involving persons over age 65 is increasing as the population of the United States ages [4].

Age impacts survival, with mortality highest in very young and very old persons. Thirty-five percent of burn injuries occur in children. Burns are also the primary cause of accidental death in children younger than age 2 and the second cause of death for children younger than age 4. The most common type of childhood burn is a scald injury, which accounts for 72% of pediatric burns [5]. Most (85%) pediatric burns occur in residential settings. Nationally, approximately 20% of pediatric burn injuries are nonaccidental burns and result from abuse or neglect. It is critical for clinicians to differentiate between burn injuries caused by child abuse and those caused by accidental injuries [6].

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Approximately 50,000 persons (4%) who sustain a burn injury each year require hospitalization, and approximately 95% survive a burn injury [7]. In individuals who have equivalent sizes of burn, the presence of an inhalation injury reduces survival rate 30% to 50% [6,8]. Most victims of fire die of inhalation injury, not burns [9].

The integument

As the largest organ of the body, the skin provides a mechanical barrier that protects internal organs. The skin also provides an immunologic defense, supports fluid homeostasis, and assists with thermoregulation. Skin is a complex organ composed of two major layers—the epidermis and dermis—and a network of collagen, elastic fibers, blood vessels, and nerve endings. The biomechanical properties of skin allow for normal body motion. Skin demonstrates a complex response to mechanical loading. It elongates with low loads; however, once the limit of extensibility is reached, the tissue tears. This limit is called the yield point. The skin also demonstrates preconditioning. After several repetitive applications of a low load, it demonstrates a variable relationship between stress and strain. After several repetitions, the stress-strain relationship stabilizes, which means that the initial rapid elongation with stretch slows and the tissues become stiffer.

Medical care

Burn injury causes necrosis and damage of tissue secondary to exposure to an external agent. It can result from thermal, electrical, frostbite, chemical, or radiation exposure. Response to injury involves a series of complex physiologic events. In addition to local tissue responses, systemic responses involve the cardiovascular, pulmonary, metabolic, endocrinologic, and immunologic systems.

Most burn injuries (> 90%) are thermal in nature [5]; the rest are secondary to other causes, including chemical, electrical, and radiation burns. In addition to managing the airway, breathing, and circulation, initial management includes removing the source of the burn injury and determining causes, the size/extent, and the body location of the injury. Thermal injury ceases once the source is removed, but chemical reactions continue until the offending agent is neutralized or the chemical reaction with the tissues is complete. The presence of an inhalation injury or other coexisting injuries must be determined because these comorbidities impact medical and surgical management.

Serious burns require care by burn care specialists at a burn center that has multispecialty and multidisciplinary staff who are experienced in managing burn injuries. The criteria established by the American Burn Association for transfer of patients who have burn injuries to a burn center include burns that cover more than 10% of the total body surface area (TBSA), electrical injuries, chemical burns, and injuries to specialized body regions, such as the face and genitalia.
Classification of burns

The severity of a burn is determined by the age of the injured individual, the extent and depth of burn injury, and the presence or absence of associated injuries.

*Burn depth*

The extent to which the epidermis and dermis are injured determines the depth of injury. Describing a burn injury as superficial or partial or full thickness is increasingly preferred over the traditional classification of first-, second-, third-, and fourth-degree burns. Partial- and full-thickness burns impact fluid homeostasis, thermoregulation, and the body’s defense against infection. Loss of tissue integrity and disruption of normal microcirculation allow fluid loss and microbial invasion.

First-degree burn or superficial burn is limited to the epidermis. The skin is erythematous and tender. No blistering occurs. These injuries heal within a few days and are not associated with scarring. The damaged epithelium usually exfoliates in 5 to 10 days. Second-degree burns can be classified as superficial, partial-thickness, or deep partial-thickness injuries. These injuries involve the entire epidermis and varying depth of injury to dermis. Superficial partial-thickness burns are limited to the upper third of the dermis. Microvascular damage and increased capillary permeability occur, causing blistering. These wounds are painful because sensory nerve endings are exposed. They typically heal in 7 to 14 days.

In deep partial-thickness burns, the epidermis and dermis are injured and only the skin appendages, such as sebaceous gland and hair follicles, are spared. The wound is red and blanches with pressure. Typically these wounds are less painful because most nerve endings are destroyed. A marginal residual blood supply exists. A few epithelial cells survive in the hair follicles and other skin appendages. Repopulation by epithelial cells is slow. Regeneration with eventual wound closure can take weeks and months depending on the wound size. Wounds that heal in this manner demonstrate a poor cosmetic and functional outcome. Skin grafts are used to expedite wound closure and healing. Early closure prevents complications such as infection and leads to better cosmetic and functional outcomes [10].

In full-thickness burns, the entire dermis and epidermis are lost. The wound bed is avascular, the texture is dry and leathery, and the wound is insensitive to pain. These burns have a white, brown, or tan waxy appearance and may appear charred. The skin does not blanch or refill because the blood vessels are thrombosed or destroyed (Figs. 1 and 2). Distinguishing a full-thickness burn from a deep partial-thickness injury is often difficult, particularly during the first 3 to 5 days. When the depth of the wound is in question, the wound is treated as a full-thickness injury. Infection or inadequate circulation can convert a partial-thickness injury to a full-thickness wound. Re-epithelialization does not occur because no
epithelial cells remain. These wounds require skin grafting unless the wound is small. Thick, dense scarring results. Fourth-degree burns extend to deep structures such as muscle, tendon, and bone. This type of burn is a severe injury that may require amputation or extensive deep débridement.

Extent of the burn injury

The extent of the injury is determined by the TBSA involved. The Rule of Nines is a commonly used as an estimate of injury in adults (Box 1) [11]. The surface area of the palm of the hand is approximately 1% of the patient’s body surface area and can be used as a quick estimate.

For children, the Rule of Nines is not an accurate measure because a child’s body proportions are not the same as an adult’s. For instance, a child’s head is proportionately larger than an adult’s and an infant’s legs are proportionately smaller (approximately 13%). The Lund and Browder chart is more accurate and provides some correction for developmental differences (Fig. 3) [12]. When calculating the TBSA of a burn injury, only partial- and full-thickness areas of injury are included. Superficial wounds are not calculated in TBSA percent determination.
Medical and surgical care

The long-term goal of burn wound care is to restore skin integrity, function, and appearance. Immediate goals are to prevent infection, decrease pain, prepare wounds for grafting if needed, prevent contracture, prevent and suppress scarring, while maintaining strength and function.

Burn wound care

Wound débridement, the process of removing devitalized tissue and creating a viable base for wound healing and grafting, is typically required. Eschar is a coagulum of necrotic tissue composed of denatured collagen, elastin, and protein. Eschar and devitalized tissue are excellent media for bacterial growth and must be removed. There are several techniques of débridement. Mechanical débridement includes such things as wet-to-dry dressing and

Box 1. Rule of Nines

Head and neck, 9%
Each upper extremity, 9%
Each lower extremity, 18%
Anterior trunk, 18%
Posterior trunk, 18%
Perineum, 1%

Fig. 2. Typical pattern of a scald burn. Note the uneven depth and irregularity of the burn.
hydrotherapy via water immersion or spraying. Enzymatic débridement uses commercially available topical enzymes, such as sutilains, to induce proteolysis, fibrinolysis, and collagenolysis. These agents may result in local pain and cellulitis in some individuals. Their use is limited to small areas requiring débridement. Surgical débridement procedures include sequential and fascial débridement. Sequential or tangential wound débridement removes thin slices of tissue until a viable tissue bed is identified. Fascial débridement involves surgical removal of tissue down to fascia. Although a viable wound is virtually ensured, a significant soft tissue defect occurs.

Deep skin burns are inelastic. In the case of a circumferential wound of the leg, the burned skin does not expand to allow for increasing edema. In circumferential burns, a tourniquet-like phenomenon can occur and create a tissue compartment with pressure that reaches 40 mm Hg or higher. In this situation, surgical decompression of these compartments must be urgently done or necrosis of the underlying tissues occurs. Escharotomy is a surgical intervention performed to relieve the tourniquet effect of devitalized nonextensible burn tissue. This procedure is critical to limb salvage in full-thickness circumferential injuries of the arms or legs. Incisions are
made medially and laterally throughout the length of the extremity involved. It is performed with the arms supinated (Fig. 4). If this procedure is not successful, fasciotomy is performed.

**Wound dressings and skin grafts**

Biologic dressings are biologic tissues used for wound closure. These dressings provide for early wound coverage, reduce pain, decrease infection, and limit evaporative fluid loss. Cadaveric tissue and human fetal membranes are termed homografts. Porcine grafts, which are heterografts or xenografts, are also used. In addition to the goals mentioned, these temporary grafts are used as test grafts to determine if a wound will accept an autograft. Often a patient’s immune system rejects these grafts. Typically these grafts are changed after several days. Synthetic wound dressings include polyvinylchloride and polyurethanes and other plastic membranes that are water and gas permeable. These temporary dressings are used until the wound has healed or autografting is possible. Bilaminate analogs, composed of thin sheets of silastic and epidermal/dermal analogs, are available. Biobrane and Integra are probably the two most commonly used analogs. Autografting is the surgical transfer of skin from one body site of the patient to another. Autografts are applied once the wound bed is free of devitalized tissue and is not infected. A wound biopsy with a bacterial count of less than $10^6$ is needed for the wound to accept a skin graft [13].

Split-thickness grafts, which are grafts of partial-thickness skin, are applied in sheets or meshed. Meshed autografts undergo a process of creating small, staggered parallel slits in the sheet of skin. Meshing expands the size of the graft from 1.5 times its original area to several times its normal surface area. One disadvantage is that the greater the degree the graft is meshed and expanded, the poorer the cosmetic outcome. The epithelialization of the interstices creates a mesh pattern that persists after the wound is healed. Sheet grafts are more cosmetic because no interstices are cut into the

![Fig. 4. Example of an escharotomy performed to improve chest expansion.](image)
graft. Sheet grafts are typically used for cosmetically important areas, such as the face and hands. Full-thickness skin grafts are used for small areas or critical areas, such as the palms of the hands, and are used in reconstructive procedures. These grafts, as the term implies, involve removing the entire skin thickness from one area and moving it to another [14]. Cultured epidermal autographs are sheets of cultured keratinocytes that show some promise but are currently under development and are not commonly used [14].

Rehabilitation

The ultimate goal of rehabilitation after a burn injury is to assist an individual in achieving optimal function and independence. This is a multi-stage process that requires months—even years—of treatment and patient commitment. The goals of the acute period of burn rehabilitation are to promote wound healing and scar suppression, reduce pain, and prevent complications. Patient goals are individualized by burn location, depth of injury, percent of body surface injured, associated injuries and complications. An individual’s age, previous functional level, and health also play a significant role in determining a rehabilitation plan.

Joint care and protection

Proper positioning of the body is fundamental to preventing the development of contractures. This also prevents compression neuropathies and decubitus ulcers. The primary underlying principle of positioning is to keep tissues in an elongated state, which can be difficult because an injured individual typically assumes a position of comfort (ie, flexion and adduction). Extension and abduction are usually the most appropriate positions, but positioning must be individualized in accord with each person’s specific injuries. Joints with deep partial-thickness or full-thickness burns overlying them are at high risk for developing contracture and must be kept in an elongated state (Fig. 5).

Splints are used to prevent joint contractures, maintain proper positioning, protect skin grafts, and prevent or assist motion. Splints should be “user friendly” for the patient, nursing staff, and other caregivers. Poorly applied splints can cause nerve injury, loss of skin grafts, and worsening of a burn wound and cause new wounds. An effective splint avoids pressure over bony prominences and is compatible with wound dressings and topical medications. Splints fabricated of re-moldable materials can be modified as a patient’s needs change. Factors to consider when prescribing a splint include the area of the body injured, extent and type of injury, the functional goal, and the ability of the patient to participate.

If normal range of motion (ROM) of a joint is maintained, a splint is typically not indicated. Exposed tendons require splinting in a slack
position. If a joint is exposed, a splint is indicated to provide protection. Joints that have not sustained an overlying or direct injury typically do not require splinting. Splinting or a positioning device may be needed in some additional situations, such as preventing ankle contractures during prolonged bed rest. During the acute period, many types of splints can be prescribed. Upper and lower extremity splints include knee extension splints to prevent knee flexion contracture and posterior foot drop splints to maintain neutral ankle dorsiflexion. In the case of axillary burns, a splint that holds the upper extremity at 90° abduction to the side, often called an “airplane” splint, is used to prevent shoulder adduction contracture. Custom splints can be designed for virtually all parts of the body. Commercially available designs, which may reduce costs, are also available but often need modifications to fit appropriately.

Exercise

Establishing a therapeutic exercise plan requires an understanding of the location, depth, and TBSA of an individual’s burn injury. Pre-existing medical problems, such as coronary artery disease, impact the exercise prescription for an individual patient. The strength and endurance of burn patients also are compromised because of bed rest. Loss of strength in an inactive muscle is approximately 3% per day and 22% by 1 week [15,16]. The
goal of exercise is to maintain normal ROM, strength, and endurance. If a patient is alert and able to participate, a program of active and active-assisted exercise is appropriate. For obtunded or critically ill patients, passive ROM exercises that emphasize the end of ROM are prescribed. In the event that full ROM is not maintained, a program of stretching is prescribed.

ROM can be performed with a patient under anesthesia. It is often a good choice for pediatric cases and for patients who cannot tolerate the pain of ROM. Anesthesia allows accurate determination of ROM without inducing pain. Effective stretching requires a slow sustained stretch. Stretching skin is not equivalent to stretching muscle, in which active contraction and relaxation of the tissue is under patient control. Skin, a tissue without active contractile elements, requires sustained mechanical stretch to facilitate alignment lengthening of the underlying collagen and other fibers.

Skin demonstrates preconditioning, that is, initially it shows increasing elongation at repetitive low loads but then the change in length plateaus. Once this stage of preconditioning is reached, a prolonged stretch is applied to maximize the stretch. In short, the joint is repeatedly moved slowly to its end range several times before applying a prolonged stretch. When prolonged stretch is performed, the stretch is maintained until the tissue blanches. Blanching is a clinical sign that capillary blood flow is impeded and the tissue’s yield point is approaching [17].

Strengthening exercise begins as soon as a patient can tolerate it. Strengthening programs include a wide range of programs, including progressive resistive exercise. Fatigue and loss of endurance are major issues as a patient recovers. It is important to include endurance training and monitor cardiopulmonary response.

Immediately after autografting, active and passive exercises are not performed on the limb. Depending on the type of graft, condition of the graft wound, and the judgment of the surgeon, no exercise or ROM is performed for approximately 3 days for mesh grafts and 5 days for sheet grafts. Splints are used to protect the graft and maintain tissue length. Heterografts, synthetic dressings, escharotomies, and surgical débridements are not contraindications to exercise.

**Ambulation**

Walking is an important activity. Ambulating patients have fewer lower extremity contractures, endurance problems, and venous thromboses. Early ambulation maintains independence, balance, lower extremity ROM, and function and decreases the risk of deep venous thrombosis. Once a patient’s condition allows, ambulation should begin. Although the expertise of a physical therapist may be needed initially for many patients to resume ambulation, nurses and family can be taught to assist and encourage patients to ambulate. Physical therapy sessions should not be the only time a patient ambulates.
Autografts to the lower extremities are a contraindication to ambulating until stable circulation to the graft sites is established. Typically, depending on the surgeon and the condition of the graft, the patient may not be permitted to put lower extremities in a dependent position for 5 to 7 days after grafting. Once a patient is cleared by the surgeon to resume lower extremity weight bearing, a program of dangling the lower extremities is initiated as a preambulation exercise. Dangling also helps to determine if the graft tolerates the dependent position. Elastic wraps or other forms of compression are used to avoid venous pooling, which can lead to graft sloughing. The graft is evaluated before and after dangling. Initially, the limb is dangled for 5 minutes and the duration is progressively increased. If the graft tolerates dependency, walking with ace wraps or other support is begun. Ambulation time is increased daily if no untoward effects on the graft occur. Gait deviations are common. There are multiple causes, including abnormalities caused by the location of the injury, pain, focal or generalized weakness, contractures, impaired sensation, and central nervous system causes. Although some gait deviations resolve as wounds heal, some persist if not addressed early.

Scoliosis and kyphosis may occur because of asymmetrical burn injuries of the trunk, pelvis, and shoulder regions. This type of injury can result in abnormal posture. Aggressive exercise and positioning are critical to prevent these abnormalities, which is especially important during the growing years of childhood. Gait devices are used to protect, reduce pain, or assist with weight bearing of injured lower extremities. These devices also can prevent or correct abnormal posture or gait caused by burns of the chest, back, or other areas that cause the patient to stand or move abnormally.

Finally, during periods when a patient cannot ambulate, wheelchairs provide mobility and can be adapted to patients needs, including using elevating leg rests and attaching splints and other position devices to the chair.

**The hand**

The hand is a highly specialized body part that not only allows fine and gross motor function but also has great social importance in communication and human interaction. Injuries to the hand require intense and specialized attention. Hand splints are used to preserve function and prevent contracture. The resting hand splint positions the wrist in slight extension, 60° to 80° of metacarpophalangeal flexion, full interphalangeal extension, and thumb abduction. This position places the flexors and extensor, tendons, and ligaments under maximal stretch to avoid the soft tissue shortening associated with contractures.

Hand edema leads to deformation, which makes edema control a major priority. Edema is an interstitial protein-rich substance that forms a gel-like consistency and impedes vascular clearance. Mechanical joint and soft tissue motion is inhibited and contracture develops. Elevation of the hand and arm
is accomplished using splints, casts, bedside troughs, or other devices used to inhibit edema formation (Fig. 6). Web spacers can be placed between digits to prevent fluid collection and edema formation. Once the wounds of the hand are closed, compression gloves are placed to control edema further.

Postacute rehabilitation

Once wound care is no longer the primary focus, the stage of intense rehabilitation begins and is geared toward maximizing an individual’s independent functioning and optimizing quality of life.

Skin care

Damaged skin is sensitive to sun and chemicals. Once healed, the skin is fragile and easily abraded. Patients should be taught to monitor skin for breakdown or injury from splints pressure garments, clothing, and other irritants. Education also includes the use of sun blocking agents and appropriate clothing to protect skin from sunburn or other injuries.

In the first few months after injury, partial-thickness burns lack the natural lubrication of sebaceous glands and the epidermal lipids. In full-thickness burns, the skin appendages needed for lubrication are lost and do not regenerate. Consequently, areas of full-thickness burn lack natural lubricants. Moisturizers such as cocoa butter must be applied to healed skin several times a day. Prolonged submersion in water, especially hot water, and use of detergents or perfumed soaps are to be avoided. Skin should be washed with mild soap and warm water and dried, and moisturizer should be applied.

Fig. 6. (A) Split-thickness sheet graft. Web spacers are placed to preserve interdigital web spaces. (B) Custom compression gloves are placed over web spacers to control edema and scarring.
**Pruritus**

Many patients experience intense problematic itching after a burn. Clinically it seems that the larger the burn the more likely pruritus is a problem. Pruritus is treated with pressure garments and topical or oral antihistamines. Doxepin hydrochloride cream is also effective. Finally, some clinicians prescribe oral gabapentin and pregabalin, which have been reported anecdotally as an effective treatment.

**Scar suppression**

Immediately after deep partial-thickness and full-thickness burns heal, the appearance is acceptable. With the passing of approximately 1 to 3 months, however, hypertrophic scarring typically appears. These red, raised, rigid scars create a wide range of cosmetic and functional problems. The scarring may develop into heavy rope-like scars that are inflexible and limit joint motion or soft tissue motion. Histologically, hypertrophic scarring is collagen arranged in random orientation with whorls and nodules [17]. In nonhypertrophic scarring, collagen is parallel to the skin surface similar to normal skin. Mechanical pressure facilitates the alignment of the collagen fibers in a more parallel, normal orientation [18].

Clinically, it is generally accepted that scars treated with pressure result in better function and appearance. Custom-fitted garments, elastic bandages, or rigid clear face masks are applied over the areas of scarring (Fig. 7). It is believed that 25 mm Hg is needed to improve the collagen orientation and exceed capillary pressure. The pressure garments and devices are worn at least 23 hours a day. Areas in which it is difficult to provide pressure, such as the web space between fingers, require additional inserts of silicone or moldable materials to ensure an intimate fit. As a side note, silicone seems to have intrinsic properties that aid in scar suppression [19]. Once the scar has matured—usually after 18 to 24 months—the use of pressure garments and devices is discontinued. Scars are considered mature when they are soft and no longer indurated and red.

![Fig. 7](image-url) (A) Custom-made breast shield. The shield provides compression over the burned chest wall. (B) The breast shield is worn under the custom pressure garment to suppress scar formation.
Neuropathy after burn injury

Peripheral neuropathy is not uncommon after severe burn injury. Henderson and colleagues [20] were among the first to study postburn neuropathy. Using nerve conduction studies to evaluate 249 patients, their studies reported electrodiagnostic evidence of peripheral polyneuropathy in approximately 18% of patients during acute hospitalization. They reported that 15% had continued evidence of polyneuropathy, including weakness, numbness, tingling, and deafness after discharge, and the neurologic deficits were not directly related to the injured body region [20].

Helm and colleagues [21] found that a generalized peripheral neuropathy was the most common neuromuscular abnormality and presented as distal weakness in the upper and lower extremities. Their incidence of neuropathy was similar (15%) to that of Henderson and Kowalske and colleagues [22]. Dagum and colleagues [23] found that 7.4% of patients with more than 40% TBSA thermal burns developed multiple mononeuropathies. Helm reported that the most common sites of neuropathy were the peroneal, ulnar, brachial plexus, and median nerves. Helm and colleagues [21] suggested that poor positioning in the bed and on the operating table and the presence of bulky dressings over superficial nerves increase the risk of developing a mononeuropathy.

The cause of the generalized peripheral neuropathy associated with a severe burn is likely multifactorial. Although the cause is unclear, it may be a variant of critical care neuropathy seen in other groups of critically ill patients. Henderson and colleagues [20] speculated that metabolic factors related to pancreatic, renal, or hepatic dysfunction after burns were possible contributors. Medications used during burn treatment, such as neuromuscular blocking agents, also may contribute to neuropathy development [20]. Dagum and colleagues [23] isolated a high molecular weight lipoprotein in patients with more than 25% TBSA burns and hypothesized that this “neurotoxin” may be a contributor. Margherita and colleagues [24] suggested that thermal injuries may induce an inflammatory cascade that results in alterations of nerve function. Marquez and colleagues [25] theorized that vascular occlusion of the vasa nervorum, direct thermal injury, or a disseminated neurotoxin also may be possible mechanisms.

Animal studies that investigated the causes of peripheral neuropathy after burns included the work of Higashimori and colleagues [26]. They studied full-thickness burns in mice and found that functional and morphologic deficits were produced in peripheral axons at sites distant to the site of burn injury. In another study, Higashimori and colleagues [27] found that early wound excision in mice with full-thickness 20% TBSA burns reduced nerve conduction deficits, and they hypothesized that nitric oxide and tumor necrosis factor may play a role.

Risk factors for development of neuropathy after burns include older age and burns over more than 20% TBSA [20,22,28]. Marquez and colleagues
[25] found that the length of hospitalization also correlated with the number of nerves affected after burn injury. Kowalske [22] likewise reported an association between the number of days in the intensive care unit and days on the ventilator. A history of alcohol abuse or premorbid neuropathy also increases risk.

**Electrical injury**

Saffle and colleagues reported that 6.1% of burns recorded in the American Burn Association patient registry were caused by electrical injury, a similar rate seen in other studies [7,29,30]. Electrical injuries are divided into high-voltage (>1000 V) and low-voltage (<1000 V) injuries [31]. Electrical current causes unique injuries that may be progressive, delayed in onset, and remote from the site of entry into or exit from the body. Solem and colleagues [32] stated that electrical injuries are largely the result of the conversion of electrical energy into heat. As Solem and colleagues pointed out, the susceptibility of individual tissues to current does not necessarily correlate with the amount of heat generated by the current. Tissues of the central nervous system, peripheral nervous system, cardiac system, and vasculature seem to be particularly sensitive to electrical injury. Other mechanisms that cause additional pathology after electrical injuries are poorly understood.

Patients with electrical injury are susceptible to neuropathy. Habernal and colleagues [33] followed 25 patients with electrical burns for years after their initial injuries, clinically and electrodiagnostically. They found that the most common electrodiagnostic abnormality was multiple nerve conduction abnormality (36%). Weakness was the most prominent clinical finding (24%). Solem and colleagues [32] found that 13% of their population had peripheral nerve injuries, including median nerve, peroneal nerve, ulnar nerve, and brachial plexus neuropathy. All of the patients had evidence of some permanent deficit. Smith and colleagues [34] noted that peripheral nerve injury seemed to be associated with third- and fourth-degree burns. They cited three cases of low-voltage electrical injury that had no clinically significant cutaneous burns but demonstrated symptoms and findings of peripheral nerve compression. Because Smith and colleagues found bilateral deficits on qualitative sensory testing in upper and lower extremities, they proposed systemic electrical injury as a cause of the peripheral neuropathy-like syndrome.

Lower motor neuron disease has been reported after electrical injury. Jafari and colleagues [35] reported six cases. Although the pathology started at the site of trauma, the individuals later developed symptoms of lower motor neuron disease. One individual developed a lower motor neuron syndrome, another presented with a spinal cord injury syndrome, and another had amyotrophic lateral sclerosis. The remaining three developed symptoms similar to amyotrophic lateral sclerosis. The onset of these
Abnormalities ranged from weeks to years after the initial injury. Multiple examples of central nervous system injury have been reported. Arevalo and colleagues [36] reported two cases of spinal cord injury after high-voltage electrical injury that presented with signs of acute transverse myelopathy despite normal CT and MRI evaluation at the time of diagnosis. Similarly, Kalita and colleagues [37] reported a case of a woman with a normal spinal MRI who developed spastic paraparesis with loss of pinprick sensation below T2 after a high-voltage injury. Ko and colleagues [38] followed 13 patients who developed delayed spinal cord injury and reported that the level of paralysis related to the entry and exit sites of electric current.

Kanitkar and Roberts [39] proposed the following mechanisms of spinal cord injury after electrical injury:

1. Thermal damage of the nerve is caused by the electrical current, and leads to injurious heat production
2. Vascular damage causes thrombosis and hemorrhage
3. Direct mechanical trauma from fracture or dislocation results from intense muscle spasm
4. Changes in proteins after passage of electrical current leads to secondary vascular changes

The exact mechanisms are poorly understood, however.

Patients with electrical injury are vulnerable to cardiac complications. Barrash and colleagues [40] documented that cardiac arrest was common (57%) after high-voltage injury. Hussmann [29] reported that cardiac arrhythmias were the most serious medical problem associated with low-voltage electrical injury. Arrhythmias occurred in 29% of high-voltage injuries. Solem and colleagues [32] found that approximately 20% of patients who received electrical burns experienced cardiac complications, with almost half of those patients developing major cardiac arrhythmias.

Cognitive deficits occur after electrical injury, but it is not well understood how electrical injury affects the central nervous system. Pliskin and colleagues [41] reported significant neuropsychological sequelae after electrical injury, including cognitive and emotional deficits. They stated that almost half of the patients questioned reported difficulty with concentration, slowed thinking, and decreased memory. Barrash and colleagues [42] studied 18 survivors of high-voltage electrical injury and found deficits in verbal learning and delayed recall spanning acute, short-term, and long-term periods after injury. Martin and colleagues [43] documented global neuropsychological impairments in a case after electrical injury and subsequently documented a progressive decline on follow-up evaluation. In another case study, Martin reported a decline in global intellectual functioning when comparing the results of testing at 6 months after electrically injury with repeat studies 4 years later. Finally, Kalita and colleagues [37] reported a case study in which a patient with memory loss after electrical injury had a hyperintensity of T2-weighted MRI in the right putamen. Kalita and
colleagues [37] suggested that the lesions found in the putamen were consistent with anoxic brain injury and attributed them to cardiorespiratory arrest after the electrical injury.

Mood disorders after electrical injury also seem common. Pliskin and colleagues [41] reported emotional difficulties, such as depression and anxiety, in nearly half of the patients. Similarly, Janus and Barrash [40] documented that 92% of patients who were followed after electrical injury showed cognitive dysfunction and affective disorders, including anxiety, depression, irritability, and poor frustration tolerance. Sixty-two percent of the patients had problems with physically aggressive outbursts that were not present before injury [40]. Consequently, neuropsychological monitoring is needed during short- and long-term follow-up after electrical injury.

**Burns and amputations**

Amputation after a severe burn injury is not uncommon. Limb loss results from several factors and occurs most commonly after electrical burns. Amputation that results from low-voltage electrical injuries (<1000 V) generally results in minor amputations, such as the toes, wrist, and fingers. High-voltage injuries are associated with major amputations in 10% to 50% of patients [44,45]. In severely burned limbs, escharotomy and fasciotomy are performed if there is ischemia or neurovascular compromise of muscle compartments. Failure to adequately decompress the affected limbs leads to neurovascular compromise and increased the risk of amputation [46]. Patients who are transferred to a specialized burn center more than 5 days after injury are more likely to require amputation. Sepsis and extensive tissue death from inadequate decompression are cited as the main reasons [47–49].

**When to amputate**

Surgical decision making for amputation is based on the presence of non-viable tissue, life-threatening sepsis, or a limb that is insensate and nonfunctional [50,51]. Most burn patients who undergo amputation survive and become successful prosthetic users [52–54]. The decision to amputate usually falls into two groups: immediate amputation and delayed amputation [48]. Immediate or early amputation occurs within 72 hours of admission and is commonly associated with electrical burns. Tissue destruction is readily apparent and the decision for amputation is obvious. In contrast, the depth or severity of injury associated with thermal burns is difficult to determine initially. The extent of damage is often only apparent after surgical débridement. Patients with thermal burns who require early amputation have severe and extensive injuries. Amputation from thermal burns typically occurs 2 to 4 weeks after injury and is usually a response to infection or devitalized tissue [48,52].
Quality of life is an important criterion in the decision-making process. The potential for successful prosthetic use, ambulation, and activities of daily living must be considered in the decision to amputate. Ideally, the patient and family are included in the decision to amputate a severely injured limb [15]. A well performed amputation results in a limb with preservation of the proper bone length, adequate soft tissue coverage, appropriate bone beveling, and sharp nerve transection. However, at times, the specifics of the injury may not allow for adequate muscle, fascia, or skin to preserve ideal bone length and provide full-thickness skin coverage of the residual limb [53]. Although less desirable, the burn surgeon may find it necessary to use split-thickness skin grafts to achieve closure [55]. Free tissue transfers may help prevent amputation [56,57]. Recent advances in bioengineered materials for wound coverage, the development of vacuum-assisted closure, and advances in secondary grafting have allowed some patients to avoid amputation [58–60].

Skin grafts

Does greater residual limb length outweigh the disadvantage of the grafted residual limb? It depends. Split-thickness skin grafts are prone to breakdown and may require revision if problems persist [15,53,61]. Intermittent breakdown of the skin graft usually presents within the first year of prosthetic use. The split-thickness graft shrinks over time and may pull normal thickness tissue over the previously injured area, increasing the amount of normal thickness skin covering the residual limb (Fig. 8) [55]. Breakdown of the split-thickness skin graft usually occurs within 1 month of initial prosthetic fitting. Grafts applied directly over bone frequently require revision [55]. Children seem more tolerant of split-thickness skin grafts, particularly if they are less than 25% of total surface area. A total surface area of 26% to 50% is more prone to skin breakdown, which complicates prosthetic usage [55].

Fig. 8. Transtibial amputation with meshed split-thickness grafts for closure.
Rehabilitation and preprosthetic management

Residual limb contractures result from postoperative soft tissue retraction, hypertrophic scarring, and muscle tightness from inactivity [15]. ROM and strengthening exercises of all joints and musculature proximal to the amputation site are indicated to maximize the likelihood of successful prosthetic use. Education in residual limb shaping and edema control pre- and post-amputation improves outcomes. Edema control can be managed by using elastic bandage wraps, off-the-shelf “stump shrinkers,” or custom-made elastic cotton stump shrinkers. Massage also helps prevent skin adherence and prevents further problems of pain and skin breakdown at a later phase in prosthetic restoration.

Adjustment

Psychological issues pertaining to burns and amputation need monitoring [53,62]. Pain, depression, activity avoidance because of physical limitations and social anxiety secondary to disfigurement are medical and psychological issues associated with burns [63–65]. Literature shows that young amputees seem to have more difficulty with adjustment and depression than older amputees [53,62]. Adjustment often improves with successful use of a prosthesis. Some authors propose that improvement occurs because the prosthesis provides a visual replacement of the absent limb and increases function [45,62,66]. Burn patients often report intermittent use of their prosthesis [52,54,66]. The decision to discard or not routinely use a prosthesis does not necessarily indicate a psychological maladjustment to the amputation or burn [53].

Prosthetic fitting

The majority of burn patients who have an amputation experience successful prosthetic restoration and rehabilitation. Minor delays may be unavoidable because of full- or split-thickness skin grafts and their location. Modern prosthetic materials and techniques allow less-than-optimal residual limbs to succeed with prosthetic restoration and rehabilitation.

Fitting with an initial provisional prosthesis may be delayed as tissues and grafts heal and mature [61]. The delay ranges from 6 to 14 weeks for the upper extremity and 10 to 26 weeks for the lower extremity. The timing of fitting depends on healing and the mechanical tolerance of the residual limb. In the case of lower limb loss, the use of a thigh corset or ischial weight-bearing socket allows earlier ambulation without full weight bearing [56]. Dynamic sockets fabricated with rigid frames and soft, flexible liners coupled with 6- to 9-mm silicone gel liners allow more intimate socket fit for irregularly contoured limbs. The silicone gel liners allow skin protection and close adherence to the stump. The liner also offers decreased friction between the stump surface and prosthetic socket [67]. Optimal suspension, prosthetic comfort, and skin protection enhance prosthetic usage [67–70].
Complications and outcomes

Complications that prevent successful prosthetic use include skin fragility, skin breakdown, painful scars, bone spurs, joint contractures, muscle weakness, and heterotopic ossification. Individuals with full-thickness burns of the upper extremity and persons with 20% or more TBSA are predisposed to heterotopic ossification [71–73]. The elbow is the most common site of heterotopic ossification in the burn population; the second most common site is the shoulder in adults and the hip in children [74]. Heterotopic ossification interferes with joint mobility, prosthetic fitting, and comfort [75]. Wounds on other parts of the body can interfere with successful prosthetic use as well [54].

Phantom pain may be problematic, but successful prosthesis use is associated with decreased phantom limb pain [76]. Individuals with electrical injuries are more likely to report phantom limb pain than persons with thermal injuries [77]. Clinicians should take a careful history to differentiate phantom pain from phantom sensations. Phantom sensations are not painful and do not require treatment.

Upper extremity prosthetic use ranges from 13% to 50% in burn survivors [54]. In general, most (71.3%) upper extremity amputees report difficulty using their prosthesis. Individuals who have burn injuries have additional difficulties, such as pain or contractures, that impact successful use [78]. Lower extremity prosthetic use is reported at 39.6% to 67% for transtibial and 32.1% to 50% for transfemoral amputees [54,79]. Patients who were not successful prosthetic users identified pain and skin breakdown as major barriers to use [48,52,54].

Most burn amputees return to work [48,54,80]. Only 5.3% of patients injured by high-voltage trauma are able to return to their previous occupation [48]. Most amputees return to gainful employment, but only a few return to the same position [48]. Many individuals seek alternate positions and require assistive devices at home and work [81].

Work and school

Finally, individuals who have experienced a serious burn face the challenge of reintegrating into their family, community, and vocational setting. Work or school issues depend on an individual’s age, subsequent impairments, and the location and extent of injury. Loss of hand function, reduced fine motor function, impaired sensation, impaired coordination, heat and cold intolerance, pruritus, skin fragility, and limb loss are all factors to be weighed when return to work, school, or vocational rehabilitation is considered. Adjustment to a burn injury and the resulting problems require ongoing evaluation. Many burn injuries occur at work, and an individual may find it difficult to return to the place of injury.

Once an individual leaves the hospital or inpatient rehabilitation unit, recovery is not complete. Ongoing scar suppression therapy continues as
does increasing emphasis on endurance, strength, and maintenance of ROM. Psychological adjustment, reintegration into the community, and return to work and school require ongoing periodic evaluation to ensure success.

Summary

The field of burn rehabilitation requires multispecialty evaluation, diagnosis, and management. Physiatrists are in a unique position to facilitate optimal recovery and function across all spheres of human function and lifespan.

References


