Chapter 13

REHABILITATION OF BURN CASUALTIES

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INTRODUCTION

Rehabilitation is critical to the long-term survival of the burn casualty.[1] For the most favorable outcomes to occur, endurance, active range of motion (AROM), fine motor dexterity, coordination, and psychosocial and community reintegration must be achieved, and strength must be integrated into purposeful activity. After a major burn injury, casualties depend on a comprehensive, interdisciplinary rehabilitation treatment plan designed to expeditiously recover their premorbid level of independence, the end goal being return to duty and other activities with maximum functional independence.[1] Additional rehabilitative interventions implemented along the continuum of care help minimize edema and infection, promoting durable, soft, supple, flat, properly colored, and pain-free wound coverage.

Following stabilization from an acute burn injury, battlefield casualties are rapidly evacuated from the theater of operations to the burn center at the US Army's Institute of Surgical Research (USAISR) at Fort Sam Houston, Texas. The establishment of comprehensive burn centers and advancements in treatment have resulted in a significant decline in burn injury mortality.[2] The LD_{50}, or total-body surface area (TBSA) burned that is lethal to 50% of casualties, has improved dramatically, from 65% in 1984 to over 81% in the early 1990s (Figure 13-1).[3] This improvement in survival, combined with efforts to improve long-term function, is the clinical focus of burn centers.[4]

The healing process is impeded by battlefield and regional conditions (eg, extremes of climate and contaminated environments), dehydration, inadequate nutrition, psychological and physiological stressors, and burn pain. Managing and recovering from a burn is a demanding material and human resource endeavor. Casualties with serious burns stress the assets available to deployed combat support hospitals in a theater of operations.[5]

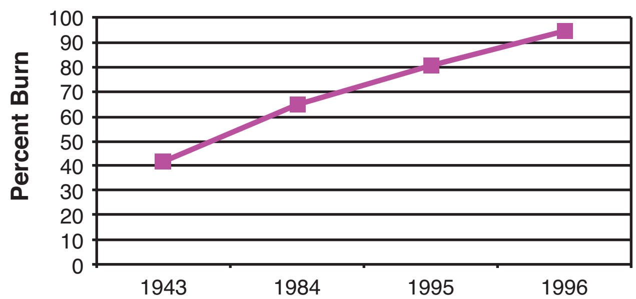


Figure 13-1. Graph of burn patient mortality.
Data source: Saffle JR, Davis B, Williams P. Recent outcomes in the treatment of burn injury in the United States: A report from the American Burn Association Patient Registry. *J Burn Care Rehabil*. 1995;16(3 pt 1):219–232.

PATHOPHYSIOLOGY OF BURNS

Inflammatory Response and Burn Shock

Thermal insult results in physiological changes affecting both injured and noninjured tissue.[6] Burn shock begins at the cellular level, decreasing cellular transmembrane potential.[7] Inflammatory and vasoactive mediator release, activated by thermal injury, results in increased capillary micropermeability and hypovolemia, leading to cellular edema.[7,8] Over the 48 hours following injury, fluid continues to be lost through the wound and edema continues to form.

As the burn wound exceeds 20% to 25% TBSA, capillary permeability and intravascular volume deficits can exceed the body's compensatory mechanisms and result in circulatory compromise.[7] If distance and time of transport are lengthy, casualties may suffer burn shock by the time they arrive at a treatment facility, and self-aid or buddy aid will be ineffective. During evacuation, casualties must receive emergency medical treatment by providers trained in burn management.

Burn Resuscitation

A fluid resuscitation program is designed to overcome the acute period of massive fluid shifts, electrolyte derangements, acid–base imbalance, edema formation (see further discussion below), and fluid and protein losses. Replenishing circulatory volume using one of several formulas restores and maintains organ perfusion and function (Table 13-1).

A key component in most resuscitation fluids is the sodium ion; the fluid (free water) is the vehicle that delivers the sodium. Depending on the choice of formula, fluid volumes range from 2 to 5 mL/kg/% TBSA. Burn resuscitation formulas are similar in the milliequivalents of sodium they provide.[9] Some formulas use only crystalloid fluids and omit colloid, while others vary the amount and timing of colloid administration. The role of crystalloid or colloid resuscitation remains an ongoing debate. However, a prescribed formula is a guideline to help resuscitate a burn casualty. The individual response to a prescribed formula may be unpredictable and variable, requiring continual corrective adjustments. None of these formulas reflects evolving trends that add a sophisticated medical resuscitation component to the already existing fluid protocol. Several components are currently being used or investigated to improve resuscitation and decrease edema and the inflammatory response in the early phase, including:

- low molecular weight dextran,
- fresh frozen plasma,
- pentastoid,
- mannitol,
- ibuprofen,
- cimetidine,
- vitamin C, and
- vitamin E.[9–18]

The current approach to fluid therapy has led to reduced mortality rates.[7] Not long ago, approximately 50% of deaths occurred within the first 10 days following burn injury because of multiple organ failure syndrome and devastating sepsis. A principal cause, particularly of multiple organ failure syndrome, is inadequate fluid resuscitation and maintenance. Because burn shock is both hypovolemic and cellular in etiology, fluid management following successful resuscitation is as important as that performed during the initial revival process.[19] Multiple organ dysfunction resulting from inadequate resuscitation has become less common with the use of weight- and injury-size based formulas.[7] However, increased fluid regimens, known as "fluid creep," are also associated with adverse outcomes, including edema formation, increased compartment pressures, acute respiratory distress syndrome, and multiple organ dysfunction.[7] The goal of proper fluid resuscitation is to prevent burn shock.[7]

TABLE 13-1

FLUID RESUSCITATION FORMULAS

Formula	Fluid Composition	Calculation
Brooke	Ringers lactate; Na 130, Cl 130, Lactate 28, K 4, Ca 3	2–4 cc/kg/% TBSA
Parkland	Ringers lactate; D5W + 0.5–2.0 L	4 cc/kg/% TBSA
Hypertonic saline	Na 200–300 mEq/L, Cl 100 mEq/L, HCO3 150 mEq/L	2 cc/kg/% TBSA

D5W: dextrose 5% in water
TBSA: total-body surface area

CLASSIFYING AND ASSESSING BURNS

Burn casualties typically comprise between 5% and 20% of service members wounded during conventional warfare.[19–22] Burn injury occurs in a young population, with a high incidence of inhalation injury and Injury Severity Score (an anatomical trauma severity measure that can be used to predict mortality).[23] Military burn injuries have a broad impact, affecting everything from the individual to the overall status of military operations.[24]

Burns are classified by mechanism of causation (ie, thermal, chemical, electrical, or radiation), as well as size, depth, and location of the burn and other associated trauma. Regardless of mechanism or severity, rehabilitation goals for burn casualties are the same.

Thermal Injuries

Thermal injury accounts for approximately 95% of military burn casualties, with chemical and electrical making up the most of the remainder.[20,24] Burns resulting from flash fire and flame are the most common in wartime.[20,24] The detonation of explosive devices, such as landmines, artillery munitions, mortar rounds, and improvised explosives, has been a significant source of combat burns.[20,24,25] The most common causes of noncombat burns in service members are related to burning waste materials, inappropriately handling ammunition and pyrotechnics, and misusing fuels. Efforts to prevent noncombat injuries continue to reduce their impact on military operations.[20,24] Other causes of military burn injury include exposure to hot liquids or superheated steam, typically from ship or submarine boilers, resulting in scald burns. Inhalation injury is frequently associated with superheated steam burns.

Chemical Injuries

Chemical burns appear to be uncommon in military casualties,[26] with reported incidences ranging from 0.9% to 6.5% (Figure 13-2).[20,27–29] However, the widespread use of chemicals and their ready availability creates the potential for a large number of this type of casualty. Chemical burns are caused by acids, alkalis, or organic compounds.[26] Except for white phosphorus,[26,27] most chemical burns should be immediately treated with copious water lavage. Wounds caused by white phosphorus, which ignites on contact with air, should be covered

Figure 13-2. Chemical burn to the lower extremities of a burn casualty.

with water or saline until the wound can be debrided of all chemical.[26] Powdered chemical should be brushed away prior to water lavage to decrease the quantity of exposure. The process of neutralization generates heat, which can add thermal injury to the chemical insult. The duration of irrigation is variable depending on the agent. In general, alkalis require a much longer period of irrigation than acids. At a minimum, 30 minutes of continuous irrigation are required for all burns, and at least 1 hour of irrigation is necessary for alkali burns.[28] A period of up to 6 hours of irrigation has been recommended for acid burns, and one of up to 48 hours has been suggested for ocular alkali burns. A good rule of thumb is to irrigate at least until there has been a significant decrease in pain.[29]

Chemical agents produce direct tissue damage by a variety of reactions. Acid burns tend to be superficial in depth, whereas alkali burns tend to burrow into the tissues and cause more significant destruction. Acids cause coagulation necrosis, whereas alkaline materials cause liquefaction necrosis. Hydrofluoric acid requires copious water lavage, followed by topical calcium gluconate, which, when injected into the area, may decrease the severity of the injury. Using intraarterial calcium gluconate on wounds of the hands and feet is beneficial. Mustard agent, a chemical previously used in warfare, is rapidly absorbed by the skin, conjunctiva, and mucous membranes, and within minutes irreversibly combines with tissue proteins, damaging the lungs, eyes, and skin.[30] Over time, the exposed tissues blister and ulcerate.[31] Ophthalmic injuries are best treated with copious water irrigation. Skin should be decontaminated with 0.5% hypochlorite. In general, skin burns from mustard are superficial and heal without difficulties; injuries to the mucosal linings are much more serious and disabling.

Electrical Injuries

Electrical injuries result from the conduction of electrical energy through tissue or from heat that is released as the current arcs through the air (Figure 13-3). Current arcs may generate temperatures as high as 3,000°C. As they arc, they ignite clothing, which results in a combination electrical and thermal injury. Injuries caused by low voltage current (< 1,000 V) are occasionally fatal because of immediate ventricular fibrillation. Survivors rarely have significant tissue damage. High voltage (> 1,000 V) current can damage tissue anywhere along its route.

Electrical injuries are heat related. Electrical energy is converted to heat energy as expressed by Joule's law: power or heat equals amperage squared times resistance ($P=I^2 \bullet R$). As voltage or amperage increases, so does the heat produced. Measurement of tissue temperature experimentally reveals that it is highest directly underneath and adjacent to the contact site of the wounds. Deep tissue destruction is always greatest in areas of the body with small volume, such as the fingers, toes, wrists, or ankles. The farther away the tissue is from the contact point, the lower the current density, and the less heat is generated. Various tissues have different resistance to current flow; for example, nerves and blood vessels have low resistance, while cartilage and bone have high resistance. Because bone is highly resistant, current tends to flow at its surface, making temperature greatest at the periosteum. Thus, muscle damage is often extensive adjacent to the bone,

Figure 13-3. Electrical burn to the upper extremity of a burn casualty. Note the extent of injury indicated by the presence of exposed subcutaneous structures on the dorsum of the hand.

and many times the periosteum and portions of the outer cortex of the bone may not be viable. For these reasons, the extent of electrical injury is often not well reflected in the cutaneous burn size.[20] An electrical injury may be deceiving and not initially appear severe, with only small areas visible superficially, but the casualty may have severe limb injury that will ultimately lead to amputation.[32]

A sensitive indicator of total muscle damage following electrical injuries is serum creatine kinase (CK). Ahrenholz et al[33] found that casualties with a total CK concentration of under 400 international units (IU) had no significant tissue loss; a few casualties with total CK concentration ranging between 400 IU and 2,500 IU required digit amputations or skin grafts. Casualties with a CK total greater than 2,500 IU had a high risk of major amputation, and those with a CK total greater than 10,000 IU had an 84% risk of major amputation or permanent neurologic deficit. More recently, Cancio et al reported age, myoglobinuria, and fasciotomy are independent predictors of amputation following high voltage electrical injuries.[20]

SEVERITY OF BURNS

The overall severity of a burn is related to the casualty's age, TBSA affected, burn depth, associated injuries, and, to a lesser extent, associated illnesses.[34]

Age

The very young and the very old do not tolerate illness and trauma (particularly burn trauma) as well as those between 10 and 50 years of age. Military burn casualties typically range from 18 to 48 years of age.[5, 24,25,35] Individuals at the extremes of age are generally more physiologically fragile and poorly tolerate the massive fluid shifts and infectious complications associated with burn and its treatment. These factors should be considered during triage when the number of casualties exceeds available resources.

Burn Size

Evaluating and treating a burn requires an accurate assessment of the injury's size. The three most commonly used methods of determining burn size include using the casualty's palm as a reference, the rule of nines, and the Lund and Browder chart. The area of the palm, excluding the digits, represents approximately 0.5% of the body surface over a wide range of ages.[36] Using a casualty's palm to determine burn size is particularly useful for spotty burns in multiple areas. The rule of nines is a convenient way of estimating adult TBSA (Figure 13-4). Developed in the 1940s by Pulaski and Tennison, it is easily remembered because it divides the body surface into areas of 9% or multiples of 9%. The head and neck equal 9%, each upper extremity is 9%, the anterior and posterior trunk are 18% each, each lower extremity is 18%, and the perineum is 1%. The rule of nines is easily applied in field situations, but is relatively inaccurate.[37] The Lund and Browder chart, developed over 50 years ago, more accurately defines burn size and is commonly used in most burn centers (Figure 13-5). This chart assigns a percent of surface area to body segments,[38] taking into account the disproportionate growth of the trunk, head, and lower extremities based on the age of the casualty. However, the chart is not always readily available and is too complex to commit to memory.

Recent reports show that the average burn size for both combat and noncombat injuries is between 7% and 15%.[20,23–25] Despite the low average burn size for military casualties, the use of unconventional incendiary devices has resulted in casualties with large burns exceeding 95% TBSA.[24]

Burn Depth

Historically, burns have been classified into degree categories (ie, first, second, third, and fourth).[39] More recently, however, burns have been classified by depth in relation to the tissues involved (epidermal, superficial partial-thickness, deep partial-thickness, full-thickness, or subdermal; Table 13-2). For example, a sunburn is a standard epidermal burn, and typically heals in 3 to 6 days without long-term sequelae (Figure 13-6).[40] Superficial partial-thickness burns are deeper than epidermal burns (Figure 13-7). They are best treated with daily dressing changes and heal without surgical intervention. A superficial partial-thickness burn may heal with minor color and texture changes, but it does not develop hypertrophic scarring.[41] In contrast, a deep partial-thickness burn results in fragile skin, requires increased time to heal, and may create severe scarring (Figure 13-8). This type of burn is best treated with early excision and grafting.[39] A full-thickness burn larger than 3 cm in diameter is best treated with early excision and grafting to prevent significant scarring (Figure 13-9).[39] Subdermal burns should be treated by debriding devitalized tissues, ensuring exposed bone and tendons are covered by soft tissue, and expeditiously grafting skin to prevent significant scarring (Figure 13-10).[39] Extensive soft tissue reconstruction may be required to cover these wounds.

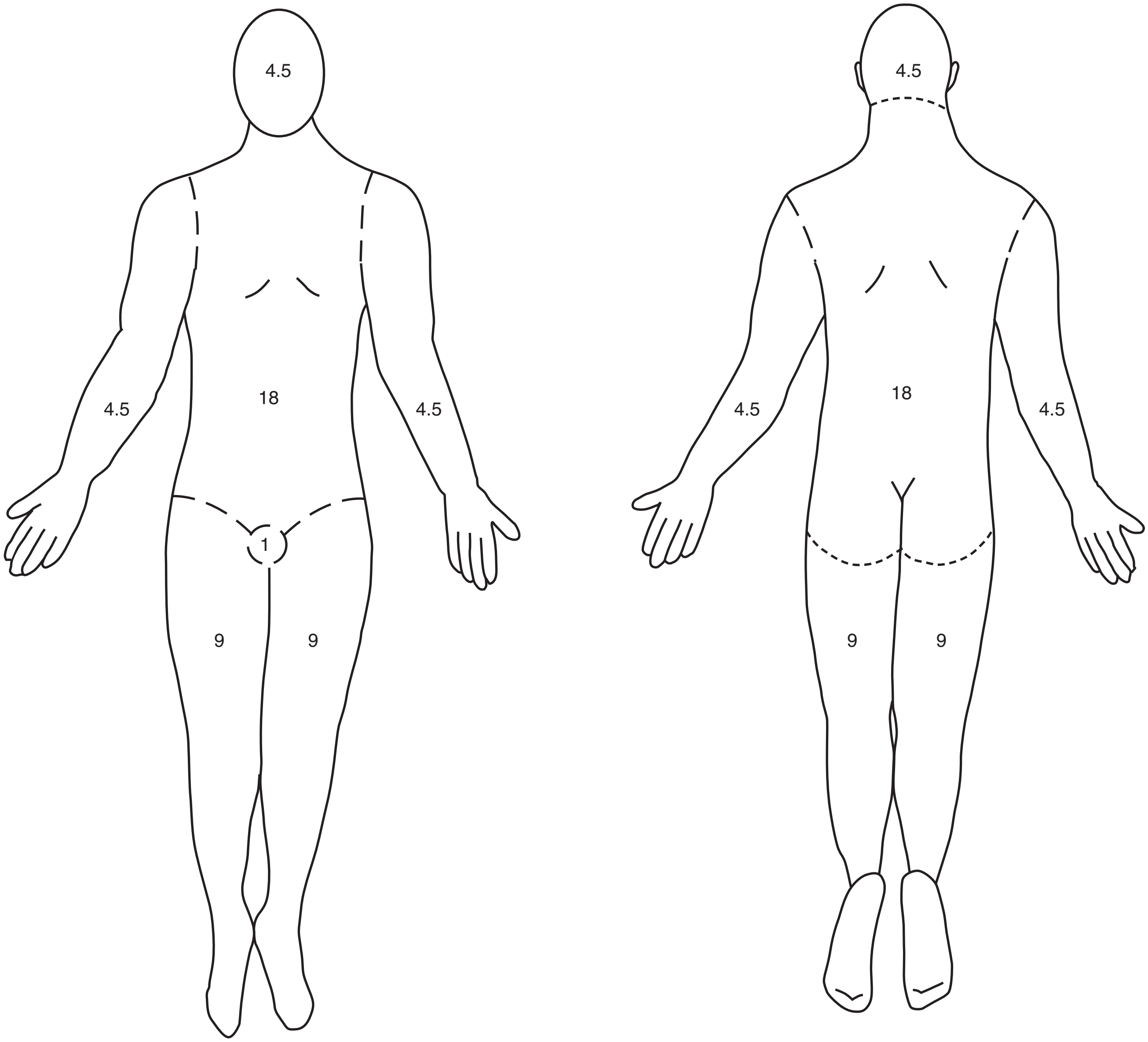


Figure 13-4. Rule of nines body chart for estimating burn size.
Reproduced from Pulaski EJ, Tennison CW. Exposure (open) treatment of burns. *U S Armed Forces Med J*. 1951:2;769.

In the case of a hand burn, knowledge of wound depth and location is imperative to determine an appropriate treatment plan. In particular, the presence of a deep palmar burn should be noted and taken into consideration when designing a splinting program. The location of eschar should also be noted prior to burn excision. If tendon involvement is suspected with a full-thickness burn, precautions should be made as if tendon involvement is confirmed.[42]

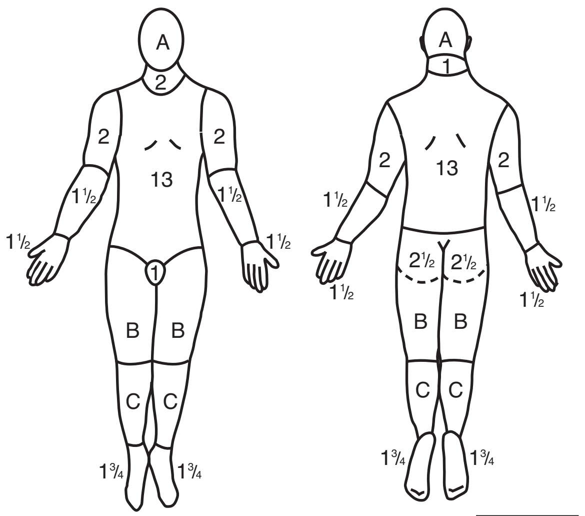
The dorsal hand is one of the most common sites for tendon exposure, especially over the proximal interphalangeal (PIP) joint. Hunt and Sato found that damage to the extensor tissue over the PIP joint resulted in the worst functional outcomes.[43] Damage to the central slip of the extensor mechanism can lead to a boutonnière deformity. If tendon exposure is suspected or confirmed, care must be taken to protect the integrity of the tendon; exposed tendons can desiccate rapidly.[44] A moist environment must be maintained with antibiotic ointments and petroleum-based gauze to prevent drying.

Reports from current military operations indicate the average TBSA full-thickness burn is between 4% and 8%.[23,24] The impact of combat versus noncombat injuries on burn depth has been shown to be insignificant.[24]

CHART FOR ESTIMATING SEVERITY OF BURN WOUND

NAME ____________ WARD _____ NUMBER ____ DATE ____
AGE ______ ADMISSION WEIGHT ______

LUND AND BROWDER CHARTS



REGION	% PTL	% FTL
HEAD		
NECK		
ANT.TRUNK		
POST.TRUNK		
RIGHT ARM		
LEFT ARM		
BUTTOCKS		
GENITALIA		
RIGHT LEG		
LEFT LEG		
TOTAL BURN		

KINDRE SIMPLE ERYTHEMA

- Partial thickness loss (PTL)
- Full thickness loss (FTL)

RELATIVE PERCENTAGE OF BODY SURFACE AREA AFFECTED BY GROWTH

AREA	AGE 0	1	5	10	15	ADULT
A = ½ OF HEAD	9½	8½	6½	5½	4½	3½
B = ½ OF ONE THIGH	2¾	4¼	4	4½	4½	4¾
C = ½ OF ONE LEG	2½	2½	2¾	3	3¼	3½

Figure 13-5. Lund and Browder chart for estimating burn size.
Adapted from Cioffi WG Jr, Rue LW III, Buescher TM, Pruitt BA. A brief history and the pathophysiology of burns. In: Bellamy RF, Zajtchuk R, eds. *Conventional Warfare: Ballistic, Blast, and Burn Injuries*. Part 1, Vol 5. In: *Textbooks of Military Medicine*. Washington, DC: Office of The Surgeon General, Department of the Army, and Borden Institute; 1991: 341.

Location

The anatomical location of burns is important in determining burn severity.[45] Burns, even of similar size, to various areas of the body have differing and significant impacts on survival, functional outcome, and cosmesis, especially when depth of injury is factored in (Figure 13-11). Additional considerations for critical care, wound care, and rehabilitation management must be made for specialized anatomical areas, such as the face, hands, feet, and genitalia.[41] Burns that cross skin creases require special rehabilitation to prevent contracture and minimize hypertrophic scarring.[46]

For military casualties, the most frequently burned anatomical areas include the head, face, and hands.[23–25,47] Injuries to these areas are due to several factors, including the need for unimpeded accessibility for vision, breathing, and communications, as well as for activities requiring maximal hand dexterity. Other anatomical locations frequently burned include the upper arm, forearm, thigh, and lower leg.[23–25] New advances in body armor and flame-resistant protective clothing are being examined and fielded to decrease the incidence of burns to these areas.[47] There is no noticeable difference in burn distribution between combat- and noncombat-related burn injuries, except that the face is more likely to be burned in combat operations.[24]

The burn location on the hand is important when determining an appropriate treatment plan. Range-of-motion (ROM) exercises, splinting, or serial casting should be implemented in the direction of tissue tension to provide optimal tissue realignment. For example, a dorsal hand burn needs to be placed in the safe resting position to put mild tension on the involved structures. Exercises should emphasize regaining a composite flexion of the digits. A palmar burn will contract into thumb flexion, thumb adduction, and finger flexion. Splints or casts used for palmar burns should hold the hand in the position of thumb radial abduction and finger metacarpophalangeal (MCP), PIP, and distal interphalangeal (DIP) extension. Caution should be taken to avoid MCP hyperextension of the thumb when positioning into radial abduction. Exercises should emphasize finger extension and radial abduction. Flexion exercises can be performed to prevent joint capsule tightness of the MCP and interphalangeal (IP) joints; however, caution should be taken to avoid digital extension losses.

Associated Illnesses and Injuries

Most military casualties are healthy adults. However, 37% to 52% of combat burn casualties sustain associated injuries (Table 13-3).[23,24,48] Additionally, combat burn casualties are significantly more likely to sustain associated trauma than noncombat burn casualties.[24] Acute injuries, whether due to penetrating or blunt trauma, are given first priority. Inhalation injury affects about 16% of combat and 6% of noncombat burn casualties.[24] An associated injury may complicate care, interfere with surgical treatment, and impede normal rehabilitation.

TABLE 13-2

BURN TERMINOLOGY

Old Classification	New Classification	Description
First degree	Epidermal burn	Involves only the epidermis, is erythematous or deeply tanned in appearance, does not blister
Second degree	Superficial partial thickness burn	Involves both the epidermis and dermis, blisters, is moist and erythematous, reepithelializes in less than 3 weeks
	Deep partial thickness burn	Cream colored or white beneath blisters, takes longer than 3 weeks to heal
Third degree	Full thickness burn	Involves the entire depth of the skin, destroys both the epidermis and dermis, must heal from the wound margins
Fourth degree	Subdermal burn	Occurs when damage is deep to the skin and involves muscle, bone, and other deeper tissues

Data sources: (1) Richard R. Assessment and diagnosis of burn wounds. *Adv Wound Care*. 1999;12(9):468–471. (2) Devgan L, Bhat S, Aylward S, Spence RJ. Modalities for the assessment of burn wound depth. *J Burns Wounds*. 2006;5;e2. (3) Peitzman AB. Burns/inhalation injury. In: Peitzman AB, ed. *The Trauma Manual: Trauma and Acute Care Surgery*. 3rd ed. Philadelphia, PA: Wolters Kluwer Lippincott Williams & Wilkins; 2008: Chapter 45. (4) Johnson RM, Richard R. Partial-thickness burns: identification and management. *Adv Skin Wound Care*. 2003;16(4):178–189.

Clinical Relevance

The severity of a burn has an impact on casualty survival, as well as on nutritional and surgical considerations. Additionally, severity largely influences rehabilitation outcomes.[49] The physical manifestations of burn scar contracture, hypertrophic scarring, and overall long-term functioning are often directly attributable to how severely a casualty is burned.

The development and number of burn scar contractures have been directly related to the extent of TBSA burned (Figure 13-12).[50] If less than 20% TBSA

Figure 13-6. Typical appearance of an epidermal burn.

Figure 13-7. Superficial partial-thickness burn with intact blisters.

Figure 13-8. Deep partial-thickness burn demonstrating mottled appearance.

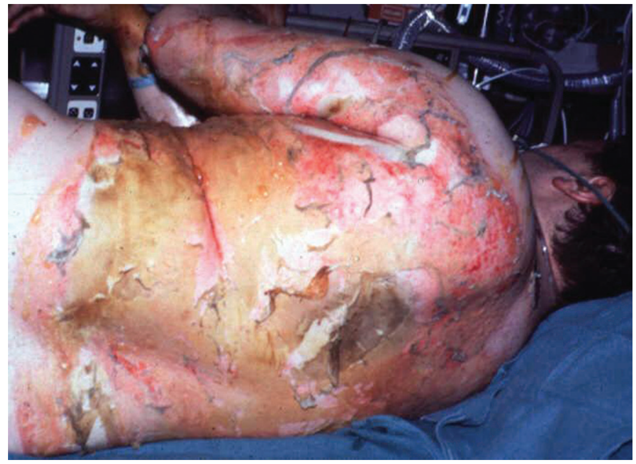


Figure 13-9. Full-thickness burn showing eschar on flank.

is burned, a casualty is expected to do well, unless the hands are heavily involved, in which case the potential for impaired functional outcomes is considerable.[45] If more than 20% TBSA is burned, casualties begin to manifest burn scar contractures during the intermediate and long-term phases of burn rehabilitation. Recently, the incidence of burn scar contracture has been identified to be as high as 50%.[51] Additionally, burn depth has long been implicated in the appearance of burn scar contractures, based on healing either by secondary intent or skin grafting and burn wound location relative to anatomic functional sites.[50,52,53] In recent combat operations, TBSA burned, inhalation injury, associated trauma, and length of hospitalization were found to be the most influential parameters determining whether or not an injured service member would return to duty.[54]

CRITICAL CARE OF BURN CASUALTIES

Skin, the largest organ of the body, is vital for survival. Aside from protecting the body from losing temperature, fluid, electrolytes, and other solutes, skin provides the first line of protection from a hostile microbial world. Severely burned casualties experience a cascade of metabolic and physiologic consequences, including recurrent infections, organ failure, and, in the worst cases, death. Until every open wound can be closed with functional skin, a burn casualty remains at risk for infection and organ failure. Open wounds must be closed with autograft and healing conditions must be optimized before organ failure and death can ensue. Organ support, nutrition, and early rehabilitation should optimize the conditions for successful graft take.

Figure 13-10. Subdermal burn displaying exposed tendon and bone on the dorsum of the hand.

Burns involving critical locations must be identified immediately to be managed appropriately. The head, face, hands, feet, genitalia, perineum, and major joints are considered critical areas by the American Burn Association and must be managed at a burn center.

Early Life Support Evaluation and Management

In most cases, especially during military conflict, it is crucial to remember that burn injury is a traumatic event, often associated with other possibly life-threatening injuries. Isolated burns are rarely immediately life threatening; however, burn casualties must be viewed within the context of a multisystem injury that could reveal varying degrees of life-threatening conditions. Other conditions that may result in immediate

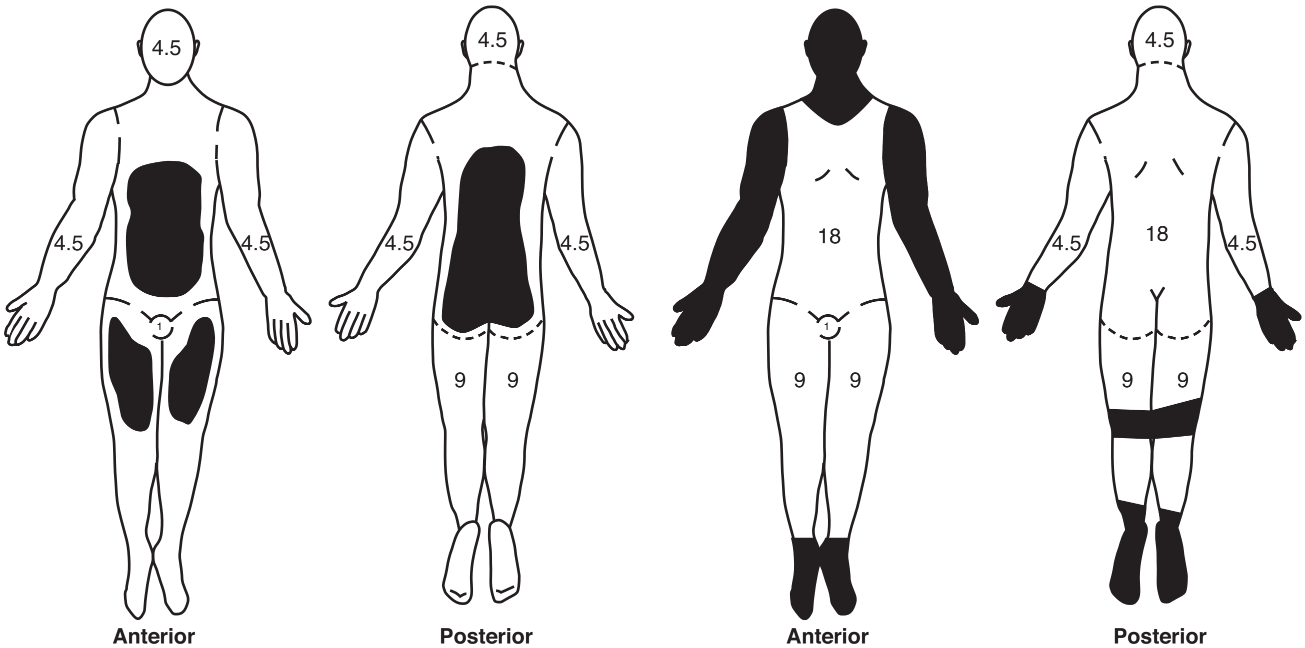


Figure 13-11. Body diagrams of equal size burn depicting the difference that location of burn has on functional areas.

death include a compromised airway and uncontrolled hemorrhage, and should be identified and treated first. A thorough and rapid assessment of the casualty helps prioritize care during the initial critical phase. Primary and secondary surveys are designed to help rescuers identify and treat the most life-threatening conditions.

Service members often initially manage and treat burn casualties. This treatment should follow the three basics of first aid: (1) stop the burning process, (2) evaluate and secure the airway, and (3) treat other life-threatening injuries. If the airway is compromised, ventilation should be maintained by mask and oxygen, or intubation if possible (see "Respiratory Considerations" below). When facial or neck edema is anticipated from fluid administration and prolonged transport times (ie, > 4 hours), intubation is usually necessary prior to transfer. The burn wound should be covered with a clean sheet or simple dry dressing to minimize further contamination and to help conserve body heat. The basics of trauma emergency care apply to initial burn treatment.

Vascular venous access is established peripherally for immediate use, or centrally for when necessary or

TABLE 13-3

INCIDENCE OF ASSOCIATED TRAUMA IN BURN CASUALTIES

Type of Injury	Incidence
Eye injury	8.5%
Skull fracture	7.5%
Neck/Torso fracture	3.5%
Upper limb fracture	10.0%
Lower limb fracture	16.6%
Intracranial injury	2.0%
Internal torso injury	4.2%
Fragment wounds	38.4%
Traumatic amputation	2.3%

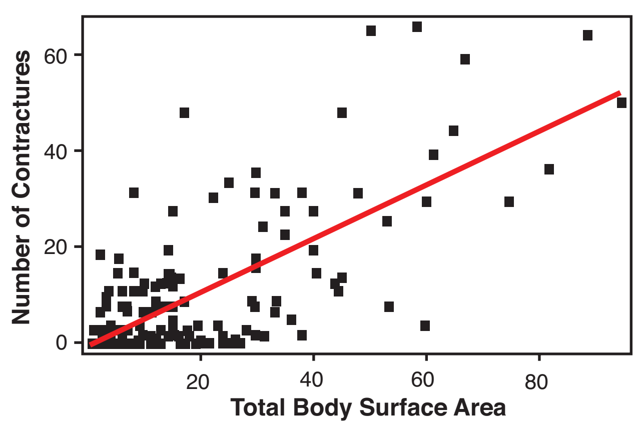


Figure 13-12. Graph displaying the relationship between total body surface area burned and the incidence of burn scar contractures.

when multiple ports are required. Obtaining central venous access is not without risks; however, central venous lines provide a means of monitoring central venous pressure and ease serum sampling. Casualties with cardiovascular instability or inhalation injuries often benefit from arterial lines, which provide hemodynamic values and allow blood to be drawn without repeated arterial punctures.

The secure maintenance of intravascular devices warrants special care as well. Loss of these devices places a casualty at unnecessary risk of additional invasive procedures. Intravascular devices should be securely sutured or stapled in place at multiple anchor points, with care and attention given to these sites during rehabilitation activities.

Fluid Resuscitation

Severe burn injury results in massive fluid shifts from the intravascular space into the interstitium and intracellular space of both burned and unburned tissues.[55] This fluid shift results in intravascular volume depletion and hemoconcentration, with blood hematocrit elevated in the first 24 hours after burn.[56] Several formulas exist to calculate the required amount and rate of volume repletion for burn casualties,[57] such as the modified Brooke formula,[58] in which volume is replenished by providing crystalloids (Ringers lactate, 2 mL/kg/% burn) over the first 24 hours post burn. No colloids are given during the first 24 hours. Over the next 24 hours, colloids are provided in the amount of 0.3 to 0.5 mL/kg/% burn. No crystalloids are given during the second 24 hours. Glucose in water is also provided over the second 24 hours and titrated to maintain good urinary output.

The Starling equation indicates that two forces, capillary hydrostatic pressure and interstitial colloid osmotic pressure, push fluid out of the vasculature into the interstitium (Exhibit 13-1).[6] The remaining two forces, capillary colloid osmotic pressure and interstitial hydrostatic pressure, work to counterbalance this shift by holding fluid in the vasculature. These forces are balanced in a healthy organism.[6] Based on this principle, fluid resuscitation is managed to maintain organ perfusion with minimal physiological cost.[7]

Delayed or inadequate replacement of intravascular volume results in suboptimal tissue perfusion and can lead to end-organ failure and death. The goal of fluid resuscitation after severe burn is to replace lost intravascular volume with intravenous (IV) crystalloid, maintaining adequate tissue perfusion throughout the 48-hour period of increased capillary leak and relative hypovolemia at the lowest physiologic cost.[59]

Casualties with severe burns, extensive soft tissue trauma, inhalation injury, or electrical injury require increased amounts of fluid to prevent burn shock. In certain casualties, burn shock and resuscitation failure occur, despite optimal resuscitation by experienced personnel, because of factors associated with limits in cardiovascular reserve and adverse host responses.[60]

Under resuscitation, which contributes to shock, and acute renal failure must be avoided. On the other hand, the consequences of over resuscitation have been termed "resuscitation morbidity" and have severe, long-ranging effects. Resuscitation morbidity includes complications such as extremity eschar and compartment syndromes and abdominal compartment syndrome (ACS).[61] Extremity eschar and compartment syndromes resulting from over resuscitation have immediate and long-term rehabilitation consequences. Eschar syndrome is characterized by a leathery, noncompressible, circumferential burn that prevents skin expansion as tissues become edematous. This leads to compromised tissue perfusion. Early mobility may be restricted when edema impairs joint motion (Figure 13-13). In addition to

EXHIBIT 13-1

STARLING EQUATION

$J_v = K_f\,([P_c - P_i] - \sigma\,[\pi_c - \pi_i])$

K_f: filtration coefficient
π_c: capillary oncotic pressure
π_i: interstitial oncotic pressure
P_c: capillary hydrostatic pressure
P_i: interstitial hydrostatic pressure
σ: reflection coefficient

Figure 13-13. Example of an escharotomy of the lower extremities.

early escharotomy, early extremity elevation and range-of-motion exercises are encouraged to decrease gravity-dependent edema.

Extremity compartment syndrome differs from eschar syndrome in that it is characterized by tissue expansion occurring specifically within a fascial compartment, resulting in decreased tissue perfusion and cell death. The mainstay of management is early recognition through monitoring of compartment pressures, and release of the involved compartment via fasciotomy if compartment pressures are elevated (Figure 13-14).

Delaying escharotomy or fasciotomy can result in myonecrosis. Acutely, myonecrosis can lead to acute renal failure and lung injury secondary to the systemic release of intracellular contents into the circulation. The long-term consequences of myonecrosis are linked to the muscle groups involved. From a rehabilitation standpoint, loss of significant muscle groups can severely impact a casualty's functional outcome in various ways, ranging from the loss of independence with ambulation or transfers acutely to increased risk for overuse and degenerative processes due to muscle imbalances over the long term.

ACS results in decreased renal blood flow and subsequent renal failure, intestinal ischemia, respiratory failure, and death if not recognized and treated early.[62] A resuscitation volume greater than 237 mL/kg over 12 hours (or 16 liters over a 12-hour period in a 70 kg male) appears to be the threshold for the development of ACS.[63] Treating ACS by placing a drain and performing an abdominal escharotomy (or a decompressive laparotomy as a last resort) may improve survival but is associated with dramatic increases in morbidity. The mortality rate after decompressive laparotomy for ACS in burn casualties is documented to be 60% to 100%.[64] For those few survivors, the added catabolic load of an open abdomen (and all the potential subsequent complications thereof) can significantly increase wound healing times, muscle catabolism, and functional recovery time.

Respiratory Considerations

Intubation entails passing an endotracheal tube from either the nose or the mouth through the pharynx into the trachea. This tube is then connected to a mechanical ventilator to cause inspiration and passive exhalation through the lungs. General indications for intubation in burn casualties are to improve oxygenation and ventilation, or to maintain gas exchange during respiratory distress or clinical conditions expected to compromise the airway. Indications include:

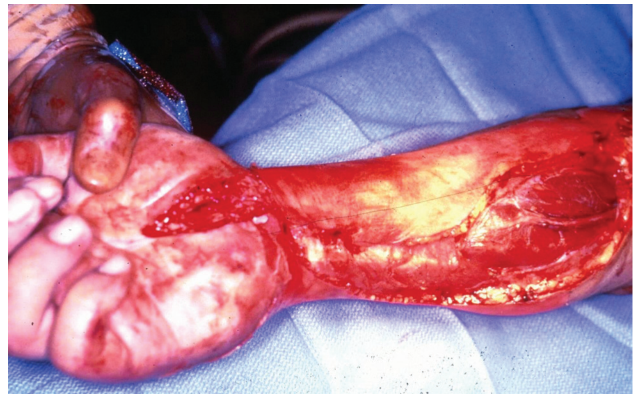


Figure 13-14. Example of a fasciotomy (carpal tunnel release) of the upper extremity.

- tachypnea,
- hypoxia,
- impending need for airway maintenance,
- initial management of smoke inhalation injury, and
- expected massive edema.

The importance of securing an airway device cannot be overemphasized. During rehabilitation activities, caution must be exercised and all efforts should be made to prevent the loss of the airway. The inadvertent displacement or removal of an endotracheal tube is often fraught with difficulties and can (rarely) result in death. Commercially available, function-specific devices are not ideal for burn casualties, especially those with burns of the face and neck. Tape does not adhere to burned tissue, and the edema associated with resuscitation is often marked.

To ensure security of an endotracheal tube, a cotton umbilical tape is tied securely around the tube, then around the head. As facial edema increases and decreases, adjustments in the ties should be made to prevent skin breakdown. Alternatively, stainless steel wire may be routed around a molar tooth and the wire subsequently attached to the endotracheal tube. This technique is sturdy and eliminates the need for constricting materials across the face. The challenge of this technique is routing the wire. Wire cutters should be readily accessible for removing the securing wire if necessary.

Endotracheal intubation and respiratory support treat burn casualties in two general groups: those who need a definitive airway for airway protection, and those who need mechanical ventilation. Casualties needing airway protection may include those whose airways have been compromised by upper airway inhalation injury, airway edema from massive resuscitation, or loss of consciousness from carbon monoxide poisoning. Casualties needing ventilatory support include those with severe smoke inhalation injury, acute lung injury, acute respiratory distress syndrome, or those who require deep sedation for extensive burns.

Endotracheal tubes can be placed either via the nasotracheal or orotracheal route. If orotracheal intubation is used, a bite block should be placed between the teeth to prevent the casualty from biting the tube and obstructing it. The nasotracheal route is preferred because the tube can be better secured, and oral care and rehabilitation can be performed that intubation via the orotracheal route would not allow. The disadvantages of using the nasotracheal route include inability to pass the tube, discomfort, and the potential for sinus infection. Occasionally, severe burns involving the face and neck preclude traditional nasotracheal or orotracheal intubation, and performance of a cricothyroidotomy may be required. The cricothyroidotomy is generally followed by a formal tracheostomy when appropriate surgical support is available.

A tracheostomy may be necessary for some casualties, either acutely due to the inability to access the airway via the orotracheal or nasotracheal route, or long term because of a prolonged need for mechanical ventilation. Tracheostomies often offer the advantage of better comfort, improved oral care, and improved ability to clear pulmonary secretions. However, the risks and benefits of the tracheostomy must be weighed because complications, although uncommon, can be fatal.

The tracheotomy tract usually matures in 5 to 10 days. If the tube is unintentionally pulled out before the stoma and if the tract has matured, replacing the tube can be difficult. It is therefore crucial that careful attention is given to the tracheotomy site during all rehabilitation activities or whenever there is a significant position change. It is recommended that a respiratory therapist be present at all times during any major casualty movement when an endotracheal tube or a fresh tracheotomy is present.

There are various modes of ventilatory support, including:

- **Controlled mechanical ventilation.** The casualty receives a breath from the ventilator at predetermined rates, whether or not the casualty attempts to breathe. This mode is rarely used in the intensive care unit.
- **Assist control (volume or pressure).** The casualty receives a ventilator breath, either volume- or pressure-targeted, whenever an attempt to breathe is made; a minimal rate is provided if no attempt to breathe is made.
- **Synchronized intermittent mandatory ventilation.** Regular predetermined breaths are delivered and casualties are allowed to breathe first at their own tidal volume, later between ventilated breaths. This mode is frequently used for weaning.
- **Pressure support.** The casualty initiates every breath, which is supported with a set amount of pressure.
- **Continuous positive airway pressure.** Continuous positive airway pressure restores the glottic mechanism of intrapulmonary pressure maintenance, which has been eliminated by intubation. This allows the casualty to take full spontaneous negative-pressure breaths. It is the setting most used during spontaneous breathing trials.
- **Other modes.** High-frequency oscillatory ventilation, high-frequency percussive ventilation, airway pressure release ventilation, and bilevel continuous positive airway pressure are alternative modes of ventilation that can be used for ventilatory support.

Ventilation and oxygenation must be monitored in casualties on mechanical ventilation. Adequate ventilation is assessed via arterial carbon dioxide tension. A casualty's minute ventilation (the amount of carbon dioxide exchanged in 60 sec) is the product of the volume of each breath (tidal volume) and respiratory rate over a minute. A minute ventilation requirement can be affected by a variety of conditions, including exercise. Thus, it is possible that simple ROM exercises in a severely burned casualty, already pushed to the limit in terms of catabolic workload at baseline, can result in carbon dioxide accumulation. An acute rise in carbon dioxide (hypercapnea) can result in respiratory acidosis, leading to a variety of systemic effects (eg, coagulopathy, hemodynamic compromise, and mental status changes). A casualty's ventilatory status must be closely monitored during rehabilitative sessions. Arterial carbon dioxide is typically measured via blood gas analysis. After assessing the partial pressure of carbon dioxide, ventilatory settings can be made to adjust minute ventilation.

Oxygenation is determined using the partial pressure of oxygen in arterial blood. In general, 60 mmHg of oxygen has been considered sufficient oxygenation. Another frequently used monitor is pulse oximetry, which is an optical measurement of oxygenated hemoglobin in pulsatile vessels. The percentage of oxygenated hemoglobin in the arteries can be calculated using differences in absorption of red and infrared light. Because of the shape of the oxyhemoglobin dissociation curve, when the saturation of oxygen exceeds 90% and the partial pressure of oxygen in arterial blood is greater than 60 mmHg, the curve is flat, and the latter can change considerably with little change in the former. Regardless, it is assumed that an oxygen saturation value greater than 90% is indicative of adequate oxygenation. Like minute ventilation, the impact of exercise on oxygenation can be significant. This is particularly important in casualties who have a high oxygen requirement (ie, needing > 50% fraction of inspired oxygen [FiO_2]). It may be necessary to closely monitor oxygen saturation to determine the limits of an activity. In general, activity should be curtailed or stopped when oxygen saturation is less than 90%.

Ventilator-associated pneumonia is a common complication in intubated and ventilated casualties and is associated with high morbidity and mortality. Hospital-acquired pneumonia can occur in nonintubated casualties with an equally morbid impact. In burn casualties, especially those with smoke inhalation injury, both ventilator-associated pneumonia and hospital-acquired pneumonia occur at a much higher frequency, and all efforts must be made to minimize this nosocomial complication. Simple interventions, such as frequent handwashing, daily oral care with chlorhexidine oral rinse, and head-of-bed elevation above 30º can decrease the incidence of hospital-acquired pneumonia and ventilator-associated pneumonia.[65]

Early mobilization out of bed to an upright position, either chair or standing frame, can optimize pulmonary function in spontaneously breathing casualties. Compared to the supine position, the upright position allows for easier diaphragmatic excursion with each breath, bibasilar recruitment of atelectatic alveoli, and improved aeration. In casualties with abdominal distension, a standing position may be preferred over a sitting position to allow optimum excursion. In addition to optimal positioning, burn casualties use secretion-clearing devices for aggressive pulmonary toilet.

In general, those casualties who require only airway protection may be good candidates for early mobilization out of bed. Casualties who are cooperative, minimally sedated, and have minimal lung pathology, may even be able to ambulate, with assistance of frequent bagging. Aggressive mobilization out of bed for rehabilitation activities, such as tilting and transfers to sitting position, can be safely performed with—and is recommended for—intubated casualties. Respiratory parameters during mobilization of intubated casualties out of bed include a peak inspiratory pressure equal to or less than 30 cm H_2O and a FiO_2 equal to or less than 40%.

Once airway edema has subsided and it is determined that casualties are able to protect their own airways, extubation may be considered. Typically, those who are placed on a ventilator for pulmonary problems remain on mechanical ventilation until the underlying reason for needing the support has resolved. These casualties are placed on a spontaneous breathing trial when the provider feels they no longer require as much or any ventilator support. Breathing trials can last anywhere from 30 minutes to 2 hours, during which it is important that casualties are not overly stimulated or anxious.

A significant amount of interdisciplinary coordination is necessary in order to perform spontaneous breathing trials around daily wound care and rehabilitation. In some cases, casualties no longer need a ventilator, but may continue to require airway protection. The use of continuous positive airway pressure or a minimal spontaneous mode of ventilation may be appropriate.

Once the casualty is liberated from a ventilator, aggressive pulmonary hygiene is crucial to maintain the airway. Proper casualty care includes frequent deep breathing, coughing, position changes, use of incentive spirometer, nebulizer treatment, and provision of humidified oxygen. Suctioning may be required if a casualty is not able to adequately clear secretions. Continued monitoring of arterial blood gasses or oximetry and serial chest radiographs are required.[66]

Gastrointestinal Considerations

The gastrointestinal response to burn is highlighted by mucosal atrophy, changes in digestive absorption, and increased intestinal permeability.[67] Atrophy of the small bowel mucosa occurs within 12 hours of injury in proportion to the burn size. Given the changes in the gut, it is common to see evidence of gut dysfunction after burn manifested by feeding intolerance and mucosal ulceration and bleeding, particularly in the stomach and duodenum. Enteral feeding is one of the most important means of providing nutrition to burn casualties and has led to a decrease in mortality, but at times the gut will not cooperate.[68] Reduced motility and ileus are common, at times requiring parenteral nutrition to meet caloric needs. At the present time, there is no specific treatment for burn-induced ileus, but it seems that early enteral feeding will prevent some of these potential complications. Gastric distention can be avoided by nasogastric tube decompression of the stomach, accompanied by enteral feeding through a tube placed beyond the ligament of Treitz. Failure to decompress the stomach can result in respiratory complications that need to be considered when deciding optimal positioning of the casualty. Furthermore, the risk of aspiration must be considered, and the head of the bed elevated to greater than 30º as often as possible.

Curling's ulcer, with erosion of the stomach and duodenal mucosa, results in upper gastrointestinal bleeding or perforation. However, its incidence has been largely eliminated by the use of histamine-2 blockers, proton-pump inhibitors, early enteral feeding, and antacids. Burn casualties with significant anemia and resultant hemodynamic instability should be evaluated for stress-induced gastrointestinal bleed.

Occasionally, severe burns involving the face and neck preclude traditional nasotracheal or orotracheal intubation, and performance of a cricothyroidotomy may be required. The cricothyroidotomy is generally followed by a formal tracheostomy when appropriate surgical support is available.

Metabolic Considerations

Over the course of hospitalization, catabolic derangement in burn injury results in a tremendous loss of lean body mass. This occurs over the entire first year after injury, and the impact on the rehabilitative course can be significant, ranging from isolated strength impairments to decreased independence with activities of daily living (ADLs). Time to full functional recovery may also increase.

One of the responses to severe burn is a dramatic increase in catecholamine production. This has been linked to a number of metabolic abnormalities, including increased resting energy expenditure (REE), muscle catabolism, and altered thermoregulation.[69] The effects of this sustained catecholamine surge on the cardiac system are to increase heart rate and, therefore, myocardial work. Propranolol, a nonspecific β-blocker, has been used to decrease heart rate and myocardial work in casualties with severe burns. Propranolol can be given intravenously and orally to equal effect on heart rate and myocardial work without detrimental effect on cardiac output or response to stress. Propranolol administration also decreases peripheral lipolysis and muscle catabolism, which are additional beneficial effects.[70]

Oxandrolone, an anabolic agent that helps decrease lean mass catabolism and improves wound healing, was recently shown to significantly decrease length of hospital stay.[71] Oxandrolone should be considered in all casualties with a burn size greater than 20% TBSA. Liver function tests should be monitored for the potential for hepatotoxicity and stopped if significant elevations in enzymes are detected.

Renal Considerations

Acute renal failure, usually in the form of acute tubular necrosis, is characterized by deterioration of renal function over a period of hours to days, resulting in the failure of the kidney to excrete nitrogenous waste products and to maintain fluid and electrolyte homeostasis.[72] In burn casualties, the causes can generally be narrowed to renal hypoperfusion from volume depletion or sepsis, or nephrotoxic iatrogenic insults (eg, aminoglycosides or IV contrast agents). Acute renal failure may be isolated or may occur in conjunction with other organs (ie, multiple organ dysfunction syndrome).

Generally, a conservative approach is applied in managing acute renal failure. Supportive care, optimization of hemodynamics, and prevention of further insults will result in resolution. In severe cases, renal replacement therapy or extracorporeal renal support is needed to eliminate toxins. Various modalities can be used, including intermittent hemodialysis and continuous renal replacement therapies.[73] To date, trials have not shown any differences in outcomes between continuous modes of renal replacement and traditional intermittent dialysis.[74]

The rehabilitative implications of renal replacement therapy depend on the modality. In hemodynamically stable casualties with renal failure, intermittent hemodialysis is generally well tolerated and, because casualties are off dialysis the majority of the day and are allowed to participate in rehabilitation sessions, it does not hinder rehabilitation. Casualties who are hemodynamically unstable and need vasopressor support are often unable to tolerate intermittent hemodialysis. For these casualties, treatment with continuous renal replacement therapy may be effective. While a casualty receives treatment, rehabilitation is limited to therapeutic bed exercises and positioning because working vascular access must be maintained without bending or kinking the catheter. Casualties typically remain in bed for the duration of treatment.

Cardiac Considerations

Early rehabilitative care in severely burned casualties requires an understanding of cardiovascular physiology in the acute period. There is a direct link between cardiac performance and casualty function. Several factors, including ventricular preload, myocardial contractility, ventricular afterload, and heart rate and rhythm, determine cardiac function, and thus tissue perfusion of blood, at the whole body level. Understanding the effects of each of these components on heart function, as well as the effects of added activity, is necessary for the optimal rehabilitative care of the casualty.

Ventricular Preload

The force that stretches the cardiac muscle prior to contraction is known as "preload." Severe burns reduce preload to the heart through volume loss into the burned and nonburned tissues. Therefore, volumes predicted by resuscitation formulas must be used to maintain blood pressure and hemodynamics. The Frank-Starling relationship describes the increase in cardiac performance via preload augmentation by volume resuscitation.[75] Preload is measured clinically by either central venous pressure or by pulmonary capillary wedge pressure (PCWP) obtained with a pulmonary artery catheter. Of these, the PCWP is the best estimate because it assesses the left side of the heart.

Myocardial Contractility

The force with which the heart contracts is referred to as "cardiac contractility." Severe burns can induce myocardial depression early (characterized by abnormalities in contraction and relaxation),[76] reducing cardiac output. This is followed by a hyperdynamic phase of increased cardiac output that generally persists throughout hospitalization.

Ventricular Afterload

Afterload is the force that impedes or opposes ventricular contraction. Elevated afterload is most evident early in the course of injury; however, shortly thereafter, it is decreased primarily through vasodilation and an increase in heart rate.

Heart Rate and Rhythm

For the heart to function properly, the electrical conduction system must be intact and provide regular contractions sufficient to propel blood through the circulatory system. If heart rate exceeds 160 beats per minute, the heart may not have time to fill completely, thus decreasing myocardial fiber stretch and heart function. The same effect is seen with frequent premature ventricular or irregular beats. Heart rate and rhythm are continuously monitored in critically ill casualties.

Hemodynamic Therapy: Preload Augmentation and Use of Vasopressors

When a patient exhibits hypotension or other signs of inadequate cardiac function (eg, decreased urine output), the usual response is to augment preload by increasing intravascular volume. This sound physiologic approach is based on the Frank-Starling principle, and should be the first therapy for a casualty in shock. Intravascular volume can be increased with either crystalloid or colloid to increase the central venous pressure and PCWP to a value between 10 and 20 mmHg. The effects of this therapy can be monitored by the restoration of arterial blood pressure, a decrease in tachycardia, and a urine output greater than 0.5 mL/kg/h.

If volume replacement is insufficient to improve hemodynamics in burn casualties in shock, vasopressor support may be required. Agents with primary effects on the α-adrenergic receptor can be used to induce vasoconstriction and increase blood pressure. These agents consist of norepinephrine and phenylephrine, and can be used effectively during septic shock or neurogenic shock to increase vascular tone. In burn casualties, it is believed that these agents cause vasoconstriction of the skin and splanchnic circulation to preserve blood flow to major organs, such as the heart and brain. This redistribution in blood flow can convert partial-thickness skin injuries to full-thickness injuries and result in ischemic injury to the gut. The benefits of specific vasoconstrictors must be weighed against these effects. Alternative agents include vasopressin, dopamine, dobutamine, and epinephrine. Vasopressin acts primarily by augmenting the effects of existing catecholamines. Dopamine has a dose-related response at different receptors. Dobutamine, which is considered an inotrope, acts primarily on β-receptors and increases contractility (and thus stroke volume). Epinephrine has both β and α properties.

The cardiac implications of physical activity during rehabilitation are extremely important. Casualties who have inadequate preload, as determined by central venous pressure or PCWP, are likely to exhibit orthostatic symptoms when going from the supine position to an upright chair or standing position. Inadequate preload, when further decreased by gravity via venous pooling in the lower extremities, can lead to tachycardia and hypotension because the casualty cannot maintain or augment sufficient cardiac output. In these instances, intravascular volume loading (with crystalloid, colloid, or blood products) may allow the casualty to tolerate positioning changes more readily.

Contractility and afterload varies in the post-burn period. Early on, physical activity may not be tolerated due to depressed myocardial function. Later, profound tachycardia may prohibit activity and limit rehabilitation potential. A casualty may also be hemodynamically unstable, requiring vasopressor support, and unable to tolerate rehabilitation. Physical activity is not necessarily prohibited when a vasopressor is required. Constant communication between the rehabilitation team and the critical care team is vital to determine a casualty's threshold for any type of activity. An understanding of cardiovascular physiology and its impact in the post-burn period is important in order to optimize rehabilitation and promotion to functional recovery.

Hematological Considerations

Severely burned casualties develop a variety of hematologic conditions that may impact the rehabilitative process.

Anemia

Over the last 10 years, restrictive transfusion practices have led to clinicians being more tolerant of lower hemoglobin and hematocrit levels; studies demonstrated improved outcomes for casualties who tolerated anemia with hemoglobin levels as low as 7 g/dL.[77] Unless anemia is acute, lower hemoglobin levels are not only well tolerated, limiting unnecessary, potentially harmful blood transfusions, but can save lives. Severely burned casualties are generally not transfused blood products unless they are symptomatic from anemia; it has become more common to transfuse blood only when hemoglobin levels fall below 7 g/dL, unless there is active bleeding, shock, or evidence of myocardial ischemia. Thus, rehabilitation occurs routinely in casualties with stable anemia and is, in most cases, well tolerated.

Thromboembolic complications

Thromboembolic complications were thought to be rare in the burn population; however, recent reports have suggested an incidence at an estimated 2.9%.[78] This is much lower than the general trauma population, but remains clinically significant. As a result, on admission, burn casualties are placed on chemoprophylaxis with either low-molecular–weight heparin or unfractionated heparin. Those who are at highest risk (eg, those who are morbidly obese or have sustained spinal cord trauma) may be considered for inferior vena cava filter placement. Development of deep venous thrombosis is not a contraindication for early mobilization out of bed. Generally, after a deep venous clot has been identified, the casualty is fully anticoagulated with IV heparin. Casualties may be as physically active as they can tolerate; there is no evidence that early activity increases risk of clot dislodgement and pulmonary embolism. However, anticoagulation is recommended for at least 24 hours prior to any activity.

Nutritional Considerations

Severe burn injury results in a hypermetabolic and catabolic state. For burn casualties, adequate nutrition is vital for wound management and rehabilitation. Without it, wounds, grafts, and donor sites will not heal, and the casualty will become more susceptible to infection. Additionally, weight loss can be associated with impaired immune function, decreased wound healing, functional impairments, and morbidity.[79] All the members of the interdisciplinary burn team must be familiar with the importance of providing nutrition to burn casualties. Providing adequate nutrition is a difficult task, considering that resting energy can be as high as double normal levels. The needs of casualties with less than 20% TBSA burns can usually be met with a high-calorie, high-protein diet and supplemental multivitamins. Casualties with greater than 20% to 30% TBSA burned often require nutritional support via feeding tubes. Many complications and treatments can inhibit feeding, and careful monitoring is essential. The goals of nutrition support are to avoid malnutrition without overfeeding, to promote wound healing and graft retention, to preserve immune function and gut integrity, and to maximally support functional rehabilitation.

After burn injury, the body goes through ebb and flow phases. The ebb phase is characterized by decreased cardiac output, oxygen consumption, body temperature, blood volume, and insulin levels. The flow phase is characterized by increased cardiac output, oxygen consumption, body temperature, insulin levels, and gluconeogenesis.[80] In 1979 Long et al discussed the ebb and flow phases in subjects with major burns, describing the loss of nitrogen through the urine and the REE by indirect calorimetry.[81] Burn casualties have been shown to have a prolonged flow phase. Pereira et al found that the initial increase in REE can be as high as double, 150% at full healing, 140% at 6 months, 120% at 9 months, and as high as 110% after 12 months.[82] The magnitude and duration of the flow phase can be minimized by placing casualties in a warm environment, providing adequate pain relief, completing early wound closure, applying occlusive wound dressings, and preventing sepsis.

Burn injury results in major changes in metabolism that are believed to be largely hormone-mediated. These changes are likely due to increased catecholamines, glucocorticoids, and glucagon-to-insulin ratios, and they include increased gluconeogenesis, proteolysis, and ureagenesis, and decreased lipolysis and ketone utilization. In addition, skin barrier destruction results in physiologic losses of heat, water, and water-soluble nutrients. These changes result in increased energy expenditure, increased nitrogen losses, and changes in nutrient metabolism. The body's available kilocalorie stores are quickly consumed after a burn injury, and gluconeogenesis must occur to further fuel the body (Table 13-4). This results in the expense of lean body mass.

Nutritional support for burn casualties should be

TABLE 13-4

AVAILABLE ENERGY STORES

Source	Type	Available Kilocalories
Liver	Glucose	300
Muscle	Glucose	600
Liver	Triglyceride	500

initiated early. Studies have shown early feeding after burn injury increases gut size in animals,[83] promotes better nitrogen balance in humans,[84] and can be safely initiated.[83,85] Nutritional support should be monitored closely to ensure that nutritional needs are being met that promote wound healing. Underfeeding can affect wound healing and immunocompetence.[86] Overfeeding can result in hyperglycemia, elevated carbon dioxide, and fatty liver, leading to delayed ventilator weaning and liver dysfunction.

Energy needs can be estimated using equations that are based on factors such as body size, age, activity level, and percentage of burn. A casualty's preburn weight should be used in figuring energy needs because weight is affected by massive edema, as well as bulky dressings and external fixations. Many other factors affect a burn casualty's metabolic rate, such as body composition, body temperature, circadian rhythm, ambient temperature,[87] chemical paralysis,[88] the energy costs of protein synthesis and respiratory stress, evaporative heat loss from wounds, infection,[89] other trauma, pain, the thermogenic effect of food, and surgery. No metabolic rate equation can incorporate this vast range of variables.

The most well-known equation for calculating burn energy needs was developed by Curreri et al, and uses weight and burn size to determine needs.[90] Later studies show that it is likely that this formula overestimates the calorie needs.[91,92] USAISR also developed an equation for determining calorie needs (Exhibit 13-2).[93] Carlson et al noted a linear relationship between burn size and REE,[93] and Milner et al validated this formula during the first month following burn injury.[94] Initial feeding based on the USAISR equation is an appropriate approach until a metabolic cart study can be completed.

Because of the many factors affecting a burn casualty's metabolic rate, the most precise method of measuring energy requirements is by taking serial measurements of REE by indirect calorimetry. Indirect calorimetry uses a portable metabolic cart at the casualty's bedside that can be attached to the ventilator or to a canopy if the casualty is not on a ventilator. The cart measures respiratory gas exchange and calculates REE from this data. This measured energy expenditure includes increased needs because of the injury, but not the energy needed for activity because it is performed when the casualty is at rest. Total calorie needs can be estimated by adding 10% to 40% to the measured expenditure to account for activity.

With the USAISR formula, Carlson et al used an

EXHIBIT 13-2

US ARMY INSTITUTE OF SURGICAL RESEARCH EQUATION FOR DETERMINING CALORIE NEEDS*

$$EER = [BMR^{\dagger} \times (0.89142 + \{.01335 \times TBSA^{\ddagger}\})] \times BSA \times 24 \times AF^{\S}$$

$$\text{Male } BMR = 54.337821 - (1.19961 \times Age) + (0.02548 \times Age^2) - (0.00018 \times Age^3)$$

$$\text{Female } BMR = 54.74942 - (1.54884 \times Age) + (0.03580 \times Age^2) - (0.00026 \times Age^3)$$

$$BSA\ (m^2) = \text{square root of: } \frac{Ht(cm) \times Wt(kg)}{3600} \text{ or } \frac{Ht(in.) \times Wt(lb)}{3131}$$

*This applies to burns ≥ 20% total body surface area; for burns < 20% total body surface area, use 30–35 kcal/kg.
†This is determined using the Fleisch equation.
‡For example, for 30% TBSA burn, use "30."
§Use 1.25 or a value appropriate for the specific patient.
AF: activity factor
BMR: basal metabolic rate
BSA: body surface area
EER: estimated energy requirement
Ht: height
TBSA: total-body surface area burn (eg, for 30% TBSA, use "30")
Wt: weight

estimated activity factor of 1.25.[93] Wall-Alonso et al used the doubly labeled water technique, along with resting metabolic rate, and determined an activity factor of 1.05 to 1.15.[95] Hart et al found that an activity factor of 1.4 can lead to weight maintenance but results in an increase in body fat, while an activity factor of 1.2 can maximize lean body mass retention.[89]

If tube feeds are a patient's only source of calories, a goal rate derived from the REE times 1.4 is appropriate. At least the REE times 1.2 must be provided. Many sources of calories need to be considered in tube-fed patients, including food and beverages taken orally and IV fluids (eg, a solution of 5% dextrose in water contains 170 cal/L; albumin contains 200 cal/L in a 5% solution, 1,000 cal/L in a 25% solution; and propofol contains 1,100 cal/L).

Burn injury results in profound changes in protein metabolism, increasing liver synthesis of acute phase proteins. Energy needs are met by muscle proteolysis. In addition, significant amounts of protein are lost through urine, feces, and open wounds. Losses can lead to as much as 2 to 3 lb of muscle in a day. The protein needs of burn casualties are difficult to determine with available data. It is currently recommended that 20% to 25% of a burn casualty's calories come from protein.[96–98] Protein intake should be adjusted serially, based on nitrogen balance. The Waxman formula is used to determine nitrogen loss from open burn wounds.[99] Total body nitrogen losses are determined by urinary urea nitrogen, insensible losses, and wound losses. The surface area of open wounds is entered into the Waxman formula for the appropriate post-burn day to determine nitrogen lost through the wound. The urinary, wound, and estimated insensible losses are added to determine the current rate of nitrogen loss. The goal is to provide more nitrogen to the casualty than what is being lost, promoting overall anabolism. Increased nutritional protein does not stop catabolism; rather, it serves in anabolism to replace lost tissue.

Recent studies have focused on the role of specific amino acids in nutritional support of the burn casualty. In the past, arginine supplementation was shown to improve cell-mediated immunity and wound healing and decrease morbidity and mortality.[100–102] However, its safety has been called into question, especially in septic casualties. Use of another amino acid, glutamine, is now advocated because it is the primary fuel for enterocytes and immune cells. Its use purportedly preserves gut integrity and decreases translocation and infections.[103] Branched-chain amino acids, leucine, isoleucine, and valine, although once believed to spare endogenous muscle catabolism, have not been proven to improve outcomes in burn casualties.[104–108] More research is needed to determine the utility and proper use of amino acids and to examine safety and efficacy.

Carbohydrate metabolism is altered during the acute post-burn phase. For example, glucose is produced from gluconeogenesis. Carbohydrates are the primary energy substrate during this period, and a high carbohydrate diet (3% fat) may decrease muscle protein degradation.[109] Although this may be convincing evidence to provide high-carbohydrate, low-fat nutritional support, excess carbohydrate use is also likely to lead to increased carbon dioxide production.

The optimal amount and type of lipid to use in nutritional support of the burn casualty is controversial and currently the subject of extensive research. During the acute post-burn phase, lipolysis decreases because protein is the preferred fuel source, and serum free fatty acids and triglycerides increase. Lipids are a concentrated source of calories for burn casualties, but high levels of lipid intake may impair immune function. Because adequate essential fatty acids aid in wound healing (among other things), it is necessary to prevent their deficiency in burn casualties.[96,110,111]

Specific vitamin and mineral requirements for burn casualties have not been established, although it is believed there are increased needs for at least those nutrients involved in wound healing and tissue synthesis (zinc and vitamins C and A). Providing a vitamin-mineral supplement equal to the recommended dietary allowances is commonly recommended. Additional daily supplements of 1 g ascorbic acid and 250 mg zinc sulfate are also recommended.[112–114]

The levels of the trace elements copper, iron, selenium, and zinc are of interest because they decrease plasma levels in the acute phase after thermal injury.[115] A deficiency in iron, which is involved in adenosine triphosphate production, can lead to decreased performance and decreased immunity.[116] Copper is involved in wound healing and collagen production.[117,118] A copper deficiency can lead to decreased synthesis,[117] decreased immune function,[119] heart and lung dysfunction, and bone demineralization.[120] The loss of copper in the first week after thermal injury is as high as 20% to 40% of the body's stores.[121] Selenium is involved in immunity, lipid peroxidation,[122] tissue oxygenation,[123] and the phagocytic activity of neutrophils.[124] Selenium deficiency can cause cardiomyopathy,[125] myalgia,[126] and decreased immunity.[127–129] A deficiency in zinc, which is involved in the function of metalloenzymes[130] and bone metabolism,[118] can lead to decreased wound healing and impaired immunity.[130]

Developing a nutritional care plan involves selecting the appropriate route of nutritional support and the specific formula, diet, or supplement to be used. Early enteral support (within the first 24 hours) is preferred.[131] Nutritional support for burn casualties may include an oral diet, oral supplements, enteral nutrition, or parenteral nutrition.

PAIN MANAGEMENT

Pain is a negative sensory or emotional response to a stimulus that may or may not be associated with actual tissue damage.[132,133] Nociceptive pain results from stimulation of nocioreceptors within the body, neuropathic pain is due to nerve damage, and central pain is associated with central nervous system (CNS) lesions.[134] Purely psychogenic pain, which is secondary to mental illness, is very rare in burn casualties.[135]

Pain impacts interpersonal relationships, as well as a casualty's ability to carry out ADLs and participate in rehabilitation. Poor pain control is associated with increased incidence of posttraumatic stress disorder (PTSD), anxiety, conditioning, and development of avoidance behaviors,[136] as well as a decreased willingness to remain actively engaged in the rehabilitation plan.[137] Casualties frequently cite inadequate pain control as the reason for noncompliance with their medical treatment plans.[138] Pain management can rely on both a multimodal pharmacological approach and an interdisciplinary approach.

The pharmacological management of pain is heavily dependent on opioids.[139] Moderate- to long-acting medications, such as continuous release morphine and methadone, are generally used on a scheduled basis for background pain. Methadone is especially useful for prolonged treatment when casualties become intolerant to morphine.[140] Rescue medications intended for breakthrough pain include short-acting agents, such as oxycodone and acetaminophen/oxycodone. Fentanyl transmucosal lozenges work in minutes and last longer than IV doses because they are absorbed through the stomach and the oral mucosa.[141]

Anxiolytics, such as benzodiazepines, alleviate anxiety in burn casualties.[142] A casualty's level of sedation must be closely monitored because of the synergism anxiolytics have with other drugs. Ketamine, commonly used with midazolam,[143] is often used for burn dressing changes because it provides analgesia with minimal respiratory depression[144]; however, it may cause prolonged sedation, dysphoric reactions, and delusional hallucinations.

Several other classes of drugs also improve pain control and decrease narcotic use. Anticonvulsants, such as gabapentin, pregabalin, and carbamazepine, are especially useful as neuronal membrane stabilizers whenever there is a component of neuropathic pain.[145] Local anesthetics, which act to block sodium channel conductance of the pain signal, can be used as topical analgesics and in regional anesthesia,[146] which will be addressed later in this chapter.

Antidepressants, such as tricyclics, are another class of drugs commonly used to manage chronic pain. Nonsteroidal antiinflammatory drugs (NSAIDs) and acetaminophen relieve minor pain; however, NSAIDs are less commonly prescribed because of concerns over their antiplatelet and nephrotoxic effects. Other medications used or soon to be available may include topical sprays, salves, and creams or iontophoretic and lozenge-based fentanyl. Intranasal applications of ketamine, butorphanol, morphine, and hydromorphone are also being developed.

In addition to a pharmacological approach to pain management, an interdisciplinary approach has also been successful. Clinics with pain management specialists are a staple, but alternative and complementary medicine techniques, including acupressure, music therapy, and massage therapy, are also being welcomed.[141] Additionally, virtual reality and hypnosis are being investigated as pain management techniques.[147] Pain populations that were difficult to manage in the past, including those with phantom limb pain or sensation, have achieved some success with pain psychology professionals.[148] Group therapy and counseling, support groups, psychotherapy, and behavioral modification, such as breathing and relaxation techniques, have all been used to deal with severe and life-altering pain.[149]

Burn pain is unique in many ways. Most pain decreases with time from the original insult and throughout the recovery period; however, burn pain may increase with time, increase with recovery (full-thickness burns are insensate initially) and are more likely to result in chronic pain (> 6 months' duration).[150] Predictors of burn pain include depth and location of burn. Extent, age, gender, ethnicity, educational history, occupation, history of drug or alcohol abuse, and other psychiatric illness do not predict the severity of burn pain.[133] Although many people have lasting impressions of burn injury related to momentarily touching hot stoves or scalding water, few can actually understand the pain associated with a major burn. For example, with superficial partial-thickness burns, even air currents moving over the affected tissue may result in excruciating pain.

Chronic pain—an intense, prolonged pain—is common in burn casualties and is aggravated by the need for frequent wound care, dressing changes, and rehabilitation activities. The repetitive and extensive nature of dressing changes cause anxiety and depression, which can further decrease pain thresholds.[151] The sequelae of poor pain control can affect the psyche, including self-image, motivation, and will to live.[152] Burn injuries cause significant pain during the entire recovery period, and although complete elimination may not be possible without a general anesthetic, thorough assessment and planning can make pain more tolerable.

During the acute phase, burn pain is managed through emergency care. The American Burn Association recommends the use of morphine during this phase, but many other opioids could be titrated to be effective.[153] Burn casualties experience intense pain and usually require large doses of opioids to remain comfortable, even in the absence of movement or surgical procedures. Because airway compromise is an ever-present concern, ketamine may also be considered to decrease opioid requirements.[143] When possible, subcutaneous and intramuscular administration should be avoided in favor of IV delivery because the former result in unpredictable absorption. When IV access is unobtainable, intraosseous placement may be considered by skilled personnel in urgent need of temporary venous access.[23]

Inhalational agents, such as volatile anesthetic gases and IV agents, form the main portion of an intraoperative anesthetic regimen.[154] Casualties may develop opioid tolerance. Regional anesthesia may also be indicated, either alone or combined with general anesthesia, but is often limited to casualties with small burns and for analgesia of donor sites.

Operative intervention often leads to a change in pain focus because donor sites are commonly more painful than excision sites, which may be insensate.[137] Neuraxial techniques, such as epidural or spinal anesthetics, may help with postoperative analgesia in affected areas, especially when more caudad. For example, femoral or iliac fascia compartment nerve block may be used to provide analgesia for the anterior flank donor site. Blood loss may be increased from the resultant sympathectomy after neuraxial techniques, and percutaneous technique risks infection.

Severe burn injuries often present significant perioperative challenges to providers and therapists secondary to reported inadequate pain management.[155] A characteristic hospital course for burn casualties includes frequent operative visits, long hospital stays, and extended rehabilitation, during which casualties are placed on chronic opioid therapy to manage pain.[156] Burn rehabilitation is unique because it is repetitive, painful, and prolonged, increasing the difficulty of achieving goals.

In addition to use of systemic pain medications during potentially painful acute and intermediate rehabilitation sessions, regional anesthesia (in the form of peripheral nerve block) can be added to a multimodal pain management regimen. Historically, regional anesthesia has been used in the form of CNS block or neuraxial techniques to control intraoperative pain and labor-induced pain (eg, epidural and spinal anesthesia). However, advancements in peripheral nerve block techniques, with targeted placement of local anesthetic medications via peripheral nerve stimulation and ultrasound guidance, has created new interest in peripheral nerve blocks to control intraoperative, acute postoperative pain, and chronic pain syndromes during the recovery phase following burn.

In addition to opioids, regional anesthesia of the extremities and of the trunk is useful for burn casualty rehabilitation. Intramuscular, oral, and IV opioid medications have a long history of use as part of acute and chronic pain control regimens. However, based on the known side effects of sedation, respiratory depression, and inadequate pain control, exclusive use of opioids for analgesia has been replaced by multimodal approaches, including regional anesthesia for the extremities. Benefits of regional anesthesia include reducing pain during rehabilitation, avoiding side effects of respiratory depression caused by opioid and sedative medication use, and minimizing limits imposed on therapists secondary to casualties' intolerance to pain, allowing the advancement of rehabilitation goals.

In the extremities, regional anesthesia is given using a needle attached to a low-current electrical impulse generator, which stimulates motor fibers and identifies the targeted nerves.[157] Once the nerve fibers are identified, large volumes (20–40 mL) of local anesthetic are injected to produce nerve block. An alternative technique uses an ultrasound probe to identify targeted nerve bundles and uses direct visualization of the needle during local anesthetic injection.

Peripheral nerve block can be performed by a single injection or continuous catheter technique. Single injection techniques are limited in duration, based on the local anesthetic medication used, but can be extremely useful in immediate rehabilitation.[157] The most commonly used local anesthetic medications for peripheral nerve block can be classified as either amide or ester local anesthetics. The local anesthetic drug class affects onset of action, duration of drug effects, rate of systemic absorption versus elimination, and distribution throughout the body. Commonly used local anesthetics for peripheral nerve block include lidocaine (short duration, 1–2 hrs), mepivacaine (intermediate duration, 2–4 hrs), ropivacaine (long duration, 5–8 hrs), and bupivacaine (long duration, 4–12 hrs).[157]

Continuous catheter techniques can extend the duration of analgesia to the desired length of time. Continuous peripheral nerve catheters have commonly been reserved for the inpatient population, secondary to provider concerns over potential systemic toxicity, potential nerve toxicity, infection at the catheter site, and risk of accidental limb injury as outpatient. In an ambulatory setting, casualty selection is critical. Only casualties who are capable of accepting the additional responsibility of the catheter and infusion pump should be selected. Ambulatory use of continuous nerve block is contraindicated when a casualty is cognitively impaired and without a home caregiver, unable to attend scheduled follow-up catheter care, or is at high risk for systemic toxicity (ie, hepatic or renal insufficiency).[158]

During regional anesthesia procedures, casualties frequently require minimal to moderate sedation to tolerate the pain from placing the peripheral nerve block. Preoperative fasting practices have been established to reduce the risk of pulmonary aspiration from gastric contents during elective procedures, based on American Society of Anesthesiologists Task Force on Preoperative Fasting guidelines.[159] These guidelines do not apply to casualties who undergo procedures without anesthesia or with only local anesthesia, when upper airway protective reflexes are unimpaired, and when there is no apparent risk of pulmonary aspiration. An anesthesiologist should be consulted before discontinuing oral intake for peripheral nerve block.[159] In addition, care must be taken to ensure the daily anticoagulation dose is discontinued prior to regional technique.[160] Therapists, anesthesiologists, and primary team physicians should consult one another before performing regional block and discontinuing scheduled medication.

Complications of peripheral nerve block, although rare, must be considered when weighing the risks and benefits of the procedure. When complications arise, it is imperative that the provider and therapist be aware of the symptoms and take appropriate action. Systemic drug toxicity is caused by excessive absorption or accidental injection of greater-than-recommended blood concentrations of local anesthetic. Signs of generalized CNS toxicity are dependent on plasma concentration. Lower plasma concentrations may cause CNS depression (eg, lightheadedness, tinnitus, numbness of tongue), whereas higher plasma concentrations of local anesthetic may result in CNS excitation (eg, seizures, unconsciousness, coma, respiratory arrest, cardiovascular depression).[157] Additional procedure complications include the following:

- nerve injury during needle placement,
- bleeding from vascular puncture,
- intravascular injection of local anesthetic,
- allergic reaction to local anesthetic,
- lung injury during peripheral nerve block placement in the upper extremities or trunk,
- temporary phrenic nerve paralysis during upper-extremity blocks, and
- high local anesthetic cerebral spinal fluid level, causing respiratory depression.

During the long term, burn pain management relies on controlling both baseline (often chronic) and breakthrough pain. "Pain soup" refers to a group of pain medications that target different receptors to attempt synergistic pain management while minimizing adverse effects related to overuse of any one class of drugs. Chronic use often escalates the requirement for opioids, secondary to the development of drug tolerance. A multireceptor approach helps reduce drowsiness, nausea, vomiting, constipation and addiction potential seen with narcotics by interfacing with receptors other than just the μ-opioid receptor.[150]

Peripheral nerve block techniques can also be effective over the long term. When developing therapeutic plans, anesthesiologists or interventional pain specialists should be consulted. Outpatient follow-up at a pain clinic is often an ideal solution to best tailor a pain management plan for each burn casualty.[161] Nonpharmacological pain control modalities to consider include behavior modification (conditioning),[148] transcutaneous electrical nerve stimulation, acupressure (to the external ear), massage or music therapy, virtual reality,[147] and counseling and group therapy. Enlisting the assistance of professionals, such as psychiatric nurses, psychotherapists, and fellow burn survivors, is also often advantageous.[2]

REHABILITATION OF THE BURN CASUALTY

Rehabilitative interventions are paramount to a casualty's total functional outcome and are required through all phases (acute, intermediate, and long term) of the recovery process (Figure 13-15).[162] On a daily basis, burn therapists treat burn casualties with the goal of achieving maximum physical and functional recovery.[163] Occupational therapy and physical therapy evaluations performed throughout the rehabilitation community initially resemble typical burn rehabilitation evaluations. They include acquiring a baseline of neurocognitive function, ROM, strength, sensation, activity tolerance, and intervention response. These components of the evaluation are performed following an appropriate chart review to understand the expected physiological, psychological, and emotional involvement from the described injury or insult.

Burn Edema

Massive tissue edema develops following thermal injury (Figure 13-16).[6] Current evidence indicates biochemical mediators, released in response to thermal

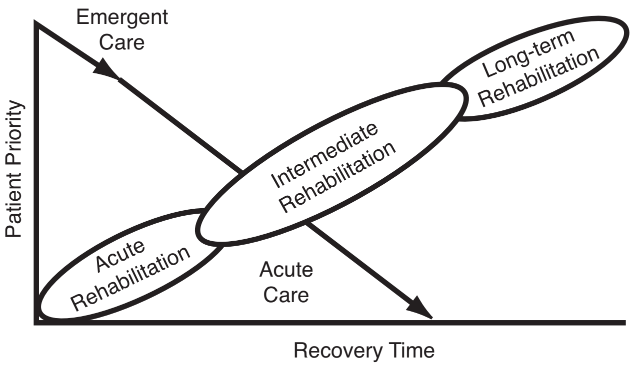


Figure 13-15. Interaction between medical care and rehabilitation of burn casualties.

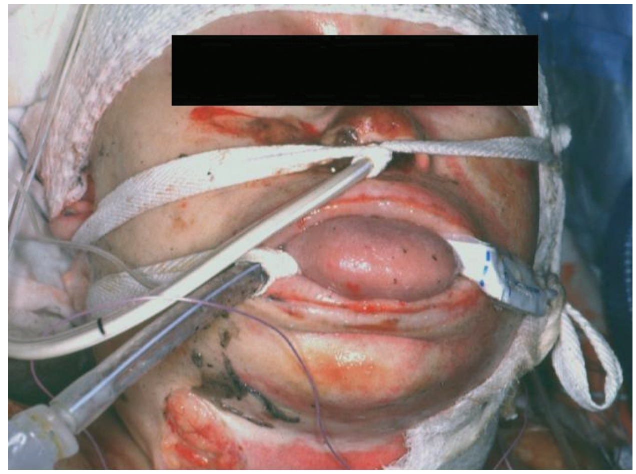


Figure 13-16. Burn casualty displaying massive facial edema.

injury, play a significant role in edema development.[6] The pathogenesis of tissue edema following thermal injury involves changes in the physical forces controlling fluid flux across the capillary, as well as fluid accumulation in the interstitium.[6] Edema forms at the expense of the vascular and extracellular compartments. Electrolyte concentrations can vary considerably, due in part to large potassium intracellular losses, urinary excretion, and large sodium intracellular and extracellular gains.[164]

Although edema is common to most significant burn injuries, no modalities have proven completely effective at managing it in severe burn casualties.[6] To better understand edema formation, one must appreciate the basis of fluid management and its role in resuscitation, both positive and negative (see "Fluid Resuscitation" above).

Edema Evaluation

Measuring edema is an important aspect of a burn casualty's physical examination. Edema can impair joint ROM, slow wound healing, and compromise circulation.[165] All areas of the body can be affected by edema that results from a burn. Hands are commonly affected and are particularly troublesome to rehabilitate.

Typically, edema is first assessed on a subjective scale by a therapist and is rated as minimal, moderate, or severe. If edema persists or progresses, therapists use objective measurement to more accurately assess the quantity of edema and the effectiveness of treatment measures and to document progress.[166] Although traditional methods of objectively assessing edema, especially in burns, are difficult to perform clinically or have limited validity, recent literature demonstrates an objective edema measurement that provides a more valid assessment and can be performed just as expeditiously as a subjective measure.[167]

The most commonly used methods of objective edema assessment include circumferential measurement, water volumetry, and the figure-of-eight measurement. Circumferential measurements give therapists a value to quantify edema at a specified site along an extremity. The therapist identifies a site along an edematous area to be evaluated, and the site is either marked or measured at a set distance from an anatomical landmark, allowing for future reference or measurement. A circumferential measurement is then taken at the designated point to quantify the edema.[168] Circumferential measurements are practical for all body areas, but provide only a point estimate of volume for an area. Depending on the site chosen to measure, the results can be significantly different. This method is best reserved for use on areas of isolated edema, such as the fingers, or where other measurement techniques are not available, such as the trunk. Although they are clinically expedient and more useful for monitoring the effectiveness of treatment and progress than a subjective assessment, the limited reliability and validity of circumferential measurements limits their usefulness.[168]

Volumetry, a measurement based on the principle of water displacement as a measure of volume, is considered the "gold standard" for measuring edema.[169] The volumeter is a standardized tool that allows a therapist to measure edema, most commonly of the hand and foot.[166] Reliability and validity of volumetric measurements is well established[169,170]; however, volumetry has several limitations.[171] For example, it is time consuming, requires expensive specialized equipment, and great care must be taken to ensure a consistent position for each measurement.[168–170,172] Also, whenever possible, open wounds and immature skin grafts should not be immersed in water.

The figure-of-eight technique offers an alternative that is reliable, valid, and clinically expedient (Figure 13-17).[167,173–175] It uses a tape measure and defined anatomical landmarks to quantify edema. Although the reliability and validity of this technique are superior or equal to other forms of objective measurement, its applicability to areas of the body other than the ankle and hand are limited.

Edema Management

Excessive edema can have severe, long-lasting consequences. The complications resulting from severe edema include tissue hypoxia and massive loss of intravascular fluid (which results in hypovolemia). Tissue hypoxia may develop as a result of increased tissue pressures from an impending compartment syndrome, and over-aggressive fluid therapy, often used to correct suspected hypovolemia, catalyzes the edema process.[6] Organ systems, such as the brain, lungs, and heart, do not function well under the stress of severe edema. Circulation to an edematous extremity can also be compromised. Early escharotomy is indicated when massive edema is anticipated or observed to compromise tissue.

Severe edema that does not require escharotomy may also have a profound effect on a burn casualty. Loss of dexterity in edematous hands and digits can further compound a casualty's feelings of helplessness following injury, leading to a cycle of decreased use, joint stiffness, contracture, tendon shortening, and long-term disability (Figure 13-18). It is imperative to provide adequate resuscitation to burn casualties while making every effort to minimize edema formation.

Figure 13-17. Figure-of-eight technique for measuring hand edema.

Acute Phase. Generally, edema peaks within 48 hours following burn.[165] Ongoing burn resuscitation can compound and prolong edema. If left untreated, edema can progress to critical levels, leading to eschar and compartment syndromes that require escharotomy or fasciotomy.[165] During the acute phase, the burn team must regularly examine the casualty for signs of vascular compromise.

Initially, edema is managed by elevating the affected areas. To facilitate edema reduction, the upper and lower extremities should be positioned such that the hand or foot is above the elbow or knee, which is above or at the level of the heart (Figure 13-19). ROM exercises are also an effective edema reduction tool in the acute phase. Passive range-of-motion (PROM) and AROM exercises have been shown to be effective, depending on the responsiveness of the casualty.[176,177] ROM exercise activates the muscle pump and

Figure 13-18. Burn casualty with edematous hands resulting in decreased dexterity.

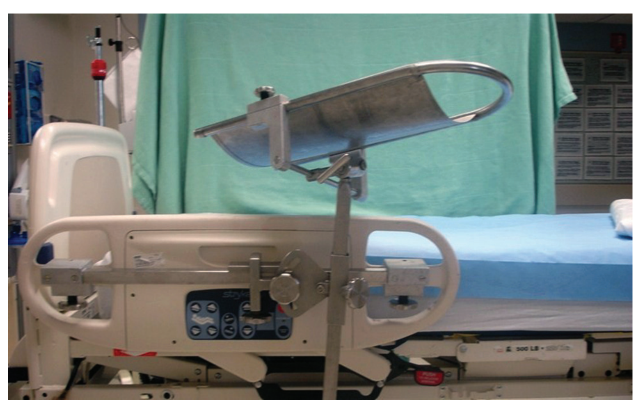


Figure 13-19. Positioning device used to elevate the upper extremity to facilitate edema reduction.

promotes edema reduction through enhanced venous and lymphatic flow.[178] Hand edema should be measured using the figure-of-eight technique.[167] The optimal position to control hand edema is placing the hand above the elbow and elbow above the heart.[168,179,180] AROM exercise of the digits can also help control edema; however, muscle contraction must be sufficient enough to act as a pumping mechanism and help venous and lymph return.[181]

Compression with elastic wraps can reduce edema when combined with elevated positioning and ROM exercises. The wrap should be applied uniformly to prevent a tourniquet effect and must have a greater perpendicular pressure distal to proximal. Elastic wraps are typically applied in a figure eight (Figure 13-20). For compression to be effective, the wrap must remain in place for prolonged periods of time. Generally, wraps are applied daily after completing wound care, and remain in place until wound care is performed the following day. Caution should be exercised when using compression in the acute phase because elastic wraps can contribute to increased compartment pressures or graft loss if applied too early or incorrectly. Therapists should frequently monitor vascular status distally on all areas being compressed. Burn casualties should be positioned with joints opposite the tendency for contracture. The individual's medical history and potential comorbidities should be considered at this stage of developing a positioning plan. Previous arthritis, strokes, brain injury, or residual functional motion deficit may require a modification to the positioning plan. A thorough history, physical examination, and sensory evaluation will reveal accompanying injuries that must be considered when developing plans for prolonged positioning. After sustaining a burn, a casualty's inflammatory response initiates a process by which any position maintained for more than 8 hours without active motion may cause early contracture formation.

During the acute phase, appropriate positioning decreases the potential to develop contractures; assists venous return, minimizing edema and the risk for compartment syndromes; protects the neurovascular bundles from further trauma; assists proper respiratory function; and protects the healing wound. The typical anticontracture bed positioning method during this phase should hold the neck in extension, with the shoulders abducted to 110° and forward flexed 15° or in the position of scaption.[182] Elbows should be extended and in supination, wrists and hands in functional position, hips extended and abducted 20° without external rotation, knees in extension, and ankles neutral. Although described as the anticontracture position, there is no single position that

Figure 13-20. Figure-of-eight application of elastic wraps to the lower extremity.

completely ameliorates contractures. For those at risk for ACS, preventive measures incorporate the reverse Trendelenburg's position used to elevate the head of the bed while keeping the rest of the body straight, reducing intraabdominal pressure.[183]

As the initial, acute resuscitation process resides, the risk of compartment syndrome reduces; however, acute protective position techniques continue to assure optimal effectiveness for combating burn scar contracture, which will be addressed daily until the newly formed tissue matures. The incidence of joint contracture is high in this population and it is indicated that joint contracture has a significant detrimental impact on a burn casualty's quality of life.[51]

Each burned part of the body must be considered independently and in conjunction with other parts when planning positioning. Independent considerations include the various positioning and splinting devices available or required to achieve maximum benefit from the intervention (Table 13-5 and Figure 13-21). The concept of positioning must be well understood for optimal effectiveness in edema management and contracture prevention as well as to avoid adverse affects throughout the course of therapeutic interventions. Casualties with burn injuries are at high risk to develop pressure sores due to the nature of the injury and specifically identified risk factors related to the development of pressure sores. Although the cause of pressure sores is multifactorial, several of the factors listed include shear, friction, and unrelieved pressure.[184] All opportunities must be taken to get casualties out of bed to the highest level of functional position and activity possible.

Requisite repositioning is essential in preventing tissue contracture. Repositioning is recommended, at a minimum, every 2 hours to alleviate pressure from susceptible areas, such as the sacrum, coccyx, and heels. Heels are extremely vulnerable to pressure sores and require additional protection beyond specialty beds.[185] Other areas susceptible to pressure sores are the ankles, buttocks, and occipital area.

TABLE 13-5

POSITIONING AND SPLINTING DEVICES USED TO MANAGE EDEMA

Position	Device/Technique	Indications
Bed Position, Supine		
Head	Gel donut	Alternate flat to round every 2 hrs to avoid pressure sores to occipital region
	Foam pad	Used for custom requirements to maintain neutral alignment and avoid ear pressure
Face	Wide tie tapes	Used to distribute pressure over a larger area
Ears	Pillows are removed	Alleviates pressure and reduces edema
	Gel or foam donut	Used to prevent ear contact with the bed; irritation of ears increases the risk of chondritis
	Ear glock (see Figure 13-21a)	Used to prevent contact to the ear if the risk of chondritis is high
Nose	Foam or gel face support	If the prone position is required, a foam face support with a cutout is used to prevent pressure on the nose; a gel horseshoe pad can also be used
	Wide tie tapes	Used to distribute pressure under the nose for implementation of nasal airway, feeding, or gastrostomy tubes
Mouth	Bite block	Used to position the jaw and oral opening
	Microstomia	Used to extend the oral commissures; uses an expansion screw
Neck	Pillows are removed	Allows for improved neck extension
	Foam wedge	Used if additional neck extension is required
Shoulder	Arm slings	Used to position the shoulder in a supported posture to achieve between 90° and 120° of abduction and 15° forward flexion, or scaption[1]
Elbow	Positioned in extension with the forearm in supination on the sled of the shoulder sling	Supination and scaption remove undue tension from the neurovascular and muscular structures and elevate the upper extremity to improve vascular return
Wrist	Volar-based functional position hand splint	Wrist placed in functional position extended 20° to 25° and without ulnar or radial deviation
Hand	Volar-based functional position hand splint (see Figure 13-21b)	Places the thumb in palmar abduction with the MCP and IP joints in extension; the MCP joints of the index through small fingers is flexed to 70° and all IP joints are extended
Torso	Body wedges or tumble forms	Used to adjust the torso to relieve pressure from side to side and directly from the back
Hip	Positioned in full extension with 20° abduction and no external rotation	Alleviates pressure and reduces edema
	Abduction wedge	Maintains full extension position when the casualty is unable to maintain the position due to concomitant injury
	Elevation of lower extremity	Assists with fluid return, reducing the risk of compartment syndromes; protects the neurovascular bundles from further trauma; protects the healing wound
Knee	Extension	Alleviates pressure and reduces edema

(**Table 13-5** *continues*)

Table 13-5 *continued*

Position	Device/Technique	Indications
Feet, ankles, and legs	Inflatable booties	Used to keep the ankle at 90° and the toes extended; removes pressure from the heel of the foot
	L'nard boot	Used if the foot begins to develop an equines deformity
	Leg net	Made with copper tubing and fittings with surgical netting stretched over the frame (see Figures 13-21c and 13-21d); used to elevate the leg to reduce the risk of compartment syndrome acutely; used to prevent pressure sores from developing on the heels, typically alternated with the inflatable bootie and positioned so that there is a bootie on the contra-lateral lower extremity; reduces the degree of direct pressure on the sacrum, therefore reducing the risk of pressure sores; helps dry donor sites postoperatively, and prevent maceration and further tissue damage[2]
Seated Position		
Head, face, ears, nose, mouth, neck, shoulder, elbow, wrist, and hand	See above	See above
Torso	Body wedges, tumble forms	Used to assure posture is maintained in a midline posture
Hip	Positioned in flexion between 60° and 90° through chair recline; hip abduction is maintained at 20° and external rotation is avoided	Alleviates pressure and reduces edema
Knee	Full extension while seated (can alternate between flexion and extension if not contraindicated)	Alleviates pressure and reduces edema
Feet and ankles	Ankles are maintained at 90° and the toes extended	Alleviates pressure and reduces edema
Miscellaneous	Total lift chair	Used for its versatility in casualty transfer and positioning adaptability
	Roho cushion	Used to protect against pressure sores in the seated posture
	Slings, sandbags, foam blocks, and sponge positioning devices	Used to reduce edema and protect the healing wound

IP: interphalangeal
MCP: metacarpophalangeal
(1) Chapman TT, Hedman TL, Quick CD, Dewey WS, Wolf SE, Holcomb JB. Airplane sling with seven degrees of freedom used to position the burned upper extremity. Poster presented at: Southern Region Burn Conference; November, 2006; Durham, NC. (2) Hedman TL, Chapman TT, Dewey WS, Quick CD, Wolf SE, Holcomb JB. Two simple leg net devices designed to protect lower-extremity skin grafts and donor sites and prevent decubitus ulcer. *J Burn Care Res*. 2007;28(1):115–119.

Techniques used in repositioning for pressure relief include various forms of ROM exercise. AROM, active assisted range-of-motion (AAROM), and PROM exercises allow for changes in body position to remove direct pressure from a susceptible area, therefore reducing the risk of pressure sores. Positioning order sets or turning schedules can be placed on a casualty's order profile so nursing staff will know to reposition the casualty every 2 hours when active intervention is not occurring (eg, at night during a sleep pattern). Mobility training and activity progression help manage pressure relief as well.

Postoperatively, casualties are placed in splinting and positioning devices to prevent disruption of new grafts. Positional splints and devices are used to assist in graft protection, pressure relief, and donor site healing. Most significantly noted are for the torso, elbow, and legs (Table 13-6 and Figure 13-22). Normal therapeutic ROM, mobility, and ADL activities are continued to the areas unaffected by surgery.

a

b

d

c

Figure 13-21. (**a**) Ear glock for protection of ear burns and grafts. (**b**) The Safe Position Burn Splint (Northcoast Medical, Morgan Hill, Calif) is a functional position hand splint that properly positions hands following burn. The (**c**) high profile leg net device and (**d**) low profile leg net device are used to position lower extremities.
Photograph (b): Courtesy of North Coast Medical Inc., Morgan Hill, California.

Intermediate Phase. The majority of edema resolves during the acute phase as the initial physiological response to burn injury, fluid resuscitation, and wound closure are completed. However, residual, chronic edema and the episodes of acute edema associated with ongoing surgical procedures pose the same limitations for casualties in the intermediate phase as they did in the acute phase.

As in the acute phase, during the intermediate phase edema is managed through a combination of elevation, ROM exercises, and compression. A casualty's responsiveness is typically improved and wounds are healed or nearly healed during this phase, allowing for more vigorous AROM and increased compression to mobilize edema. Compression wraps commonly used in this phase include elastic wraps and Isotoner (totesIsotoner Corporation, Cincinnati, Ohio) edema gloves. Dependent positioning of the affected areas must be avoided at night, and elevation at night is recommended to sustain the edema-reducing benefits of activity throughout the day.

Retrograde massage may be beneficial for persistent edema during this phase. During the acute phase, the casualty's wound status, pain tolerance, and risk for skin breakdown do not typically permit the use of retrograde massage. Therapists can use retrograde massage to mobilize persistent, chronic edema that has proven recalcitrant to more conservative edema management strategies.

Long-Term Phase. As casualties progress into the

TABLE 13-6

POSTOPERATIVE SPLINTING AND POSITIONING

Body Area	Device/Position	Indications
Torso	Back net (see Figure 13-22)	Used to air the donor site on the back; alternated on and off every 4 hrs[1]
Elbow	Hyalite low-temperature thermoplastic material is modeled to the elbow	Used to maintain the extended position following initial excision and grafting
Knee, feet, and ankles	Leg splints	Used to maintain the knee in extension, the ankle at 90°, and extend the toes; a heel dropout prevents pressure sores from developing
Miscellaneous	KinAir (Kinetic Concepts Inc, San Antonio, Tex) bed	Minimizes contractures
	The grafted sites are immobilized	Minimizes contractures
	Splints and other positioning devices	Keeps casualty immobile
	Bed rest	Used only when immobility of the graft cannot be achieved through splinting and positioning devices

(1) Salinas RD, Hedman TL, Quick CD, Wolf SE, Holcomb JB. Ventilation back ramp designed to prevent suppurative donor sites and accelerate healing time. *J Burn Care Res*. 2007;28:S109.

long-term rehabilitation phase, the focus of edema management shifts substantially. The persistent, chronic edema associated with this phase generally does not respond to passive elevation. Vigorous ROM exercises and retrograde massage, in conjunction with a comprehensive compression regimen, are the most effective ways to treat chronic edema.

Casualties generally receive custom compression garments during this phase. Casualties should wear compression garments 23 hours a day, removing them only for daily hygiene activities. A strict compression regimen and daily therapeutic activities effectively reduce edema.

Wound and Skin Care

Proper wound assessment and adequate wound care strategies are paramount during all phases of wound healing. Appropriate, timely, and effective wound care techniques can make the difference between successful healing and prolonged, problematic rehabilitation. Rehabilitation providers must be vigilant and aware of how wounds progress in order to recognize adverse changes and avoid setbacks in rehabilitation.

Acute Phase

During the acute phase, strategies are developed to manipulate the wound healing process, minimize wound progression, and avoid involvement of deeper tissue.[186] Goals of therapeutic intervention in this phase focus on reducing the chance or rate of further burn damage to the involved tissue; positioning and splinting devices, in conjunction with fluid mobilization techniques, improve tissue viability.[187] Common rehabilitation goals during the acute phase include:

- educating casualties about the rehabilitation processes and expectations,
- reducing edema,
- facilitating wound healing,
- preventing skin breakdown,
- protecting skin graft and donor sites,
- preserving ROM,
- maximizing ADLs,
- accomplishing mobilization, and
- managing psychological coping and adjustment.

The acute phase of wound healing includes the initial injury assessment and evaluation. Loose tissue must be removed and the injury thoroughly cleansed to properly evaluate the extent of the burns and depth of the injury. IV narcotic medications are usually required to facilitate the initial wound cleansing. Small wounds can initially be cleaned in bed or in the shower. Additional space is often required to inspect larger wounds; shower carts and hand-held showerheads are

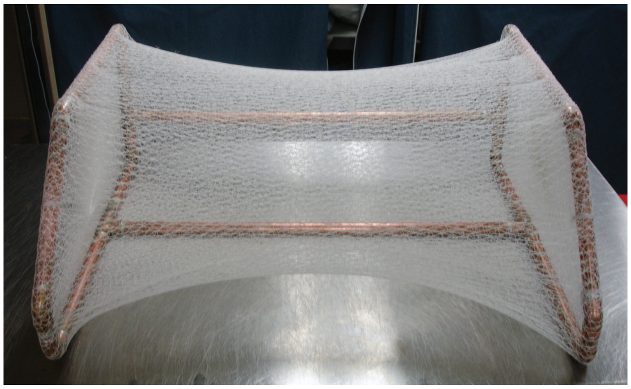


Figure 13-22. Back net device used to provide protection and ventilation for skin grafts and donor sites on the back.

used to adequately cleanse larger areas. Larger carts facilitate quick draining of water spray and provide an area that can be accessed by multiple caregivers. A shower cart basin can be covered in propylene drapes to guard against cross contamination. The use of Hubbard tanks (large full-body immersion tanks) has been largely abandoned due to the risk of cross contamination, space requirements, and difficulty in transferring casualties to and from beds.

Infection related to skin loss can be life threatening for a burn casualty, making meticulous wound care crucial. All areas of the body should be exposed and inspected to determine the extent and depth of the injury on an interval basis. During wound care, plastic aprons, gloves, hats, masks, and protective eye wear should be used. Plastic aprons prevent scrubs from becoming contaminated with body fluids and also prevent cross contamination to other casualties.

Wounds are gently cleaned using a mild cleanser and loose damaged skin is removed and blisters debrided to prevent infection. Thick blisters of the palms or soles of feet may be aspirated instead of unroofed to reduce pain.[188] Shaving body hair adjacent to the wound is beneficial in exposing the burn for evaluation and makes it easier to apply topical agents and dressings. Shaving is repeated as necessary until the wound is closed. Wound touch plate cultures are done on initial wound cleansing and thereafter for bacterial surveillance. Progression of wound healing is documented using the Lund and Browder chart.

After evaluating a burn, a wound dressing is chosen based on the operative plan, if indicated. If a casualty has areas of all partial-thickness burns that have been recently debrided and may be lightly weeping serous fluid, a synthetic skin substitute may be considered (Figure 13-23). After applying the synthetic skin, the wound is wrapped first with dry gauze, then with an elastic bandage to ensure conformity and adherence of the contact dressing. After 24 to 48 hours, the outer dressing is removed and the synthetic skin is exposed to air. Keeping the skin substitute dry appears to aid in its adherence and overall performance. A synthetic skin substitute will spontaneously separate from the reepithelialized wound in 10 to 14 days.

A contact dressing that uses a combination of silver fibers incorporated into nylon can be left in place for an extended period of time. Silver-nylon dressings may be useful when treating burns that are deeper partial-thickness burns that exude large amounts of serous fluid or are dry. Silver-nylon dressings are easy to apply, conform effectively, and, because silver ion is an antimicrobial agent, they can be left in place for up to 72 hours, making them very effective during long-range transport. All of these dressing materials are available in varying sizes, including glove-shaped designs for easier application over burned hands.

Deeper partial-thickness, marginal full-thickness, and full-thickness burns that may require surgery can be treated with dressings that will facilitate daily wound care and evaluation. Most bacteria are found in the burn eschar, so dressings that guard against infection are preferred and topical, rather than systemic, antibiotics are effective.[189] Gauze dressings soaked with antimicrobial agents (eg, mafenide acetate in a 5% solution) and placed in contact with the burn are known as "bolsters." Bolster dressings provide the necessary wound protection and moist environment to improve wound outcome and aid in wound-bed preparation for future excision. Other solutions commonly used include dilute sodium hypochlorite (0.25% Dakin's solution) or silver nitrate. Topical burn ointments and creams are also used for antimicrobial protection include mafenide acetate cream, 1% silver sulfadiazine, polymixin, and bacitracin. Mycostatin can be added to provide additional antifungal protection if indicated.

Burn Wound Excision. Full-thickness burn wounds require excision and subsequent application of donor autograft, or temporary application of homograft (cadaver skin), a bilaminar dermal substitute, or xenograft

Figure 13-23. A synthetic skin substitute applied to partial-thickness burn of the lower extremity.

if the casualty does not have adequate donor skin. Prompt application of split-thickness skin grafts expedites wound closure and decreases risk of infection, scarring, contracture, loss of function, and the time needed for dressing changes (see "Plastic and Reconstructive Surgery" below). A principle goal of burn care is to debride nonviable tissue and provide early and functional wound coverage. Estimation of wound depth determines whether the burn can be managed conservatively or will require surgical intervention. Superficial and full-thickness burns are generally readily determined, and appropriate management can be immediately initiated. Partial-thickness burns are more difficult to evaluate and often require a serial assessment of the burn over several days to determine the actual depth of injury and initiate the appropriate intervention. A partial-thickness burn may also vary in depth within a small area, thus, healing may be patchy or delayed. A burn that fails to heal by 21 days after injury typically requires skin grafting.

For burns that require surgical intervention, expedited wound closure minimizes inflammation, wound contraction, and scar formation. Early excision and grafting are the modern standard of care for full-thickness burns. Early excision is based on the principles of general surgical wound management and has been clinically proven effective in diminishing morbidity in the burn casualty.[190–194]

The estimated depth of the burn wound often determines the choice of excision technique (tangential, sequential tangential, or fascial). Partial-thickness burns are generally excised with either tangential or sequential tangential methods until viable tissue is exposed. Hydrosurgery can provide an alternative to sharp excision. Full-thickness burns deep into subcutaneous fat are excised in segments to the fascia.

Tangential Excision. Dermal burns are excised with either a single pass (tangential) or multiple passes (sequential tangential) with the debridement instrument until viable tissue is reached (Figure 13-24). This method of debridement allows maximum preservation of viable dermis, which ultimately leads to better long-term results in the quality of the healed grafted skin.

There are a number of manual and mechanical instruments available for wound debridement. Debridement involves excising tissue in the range of 0.008 to 0.012 inches for partial-thickness burns, and up to 0.030 inches for full-thickness burns. Areas requiring intricate or delicate work, such as digit web spaces and the dorsum of the hand and fingers, are best approached using small instrumentation with shallow settings in multiple passes.

Areas that have been adequately debrided show brisk punctate bleeding in healthy white dermis (Figure 13-25). Poor bleeding in grayish dermis indicates inadequate debridement and a need for further excision. As debridement progresses deeper into and through the dermis, more fat appears and capillary bleeding gives way to brisker flow from arterioles and veins.

Hemostasis of the debrided wound bed is accomplished using one or more proven methods, including directed electrocautery on larger vessels and dilute, epinephrine-soaked lap pads on the diffuse capillary bleeding bed. Local pressure and temporary elastic wraps can reduce bleeding. Topical epinephrine solutions in concentrations ranging from 1:10,000 to 1:100,000 can be safely used with few systemic effects in acutely burned casualties. Topical thrombin spray has also been used for this purpose.

Figure 13-24. Tangential excision of a burn injury.

Figure 13-25. Punctate bleeding of healthy dermis following adequate burn excision.

It is important for a surgeon to consider a casualty's overall status, the available resources, and the capabilities of the team when formulating the operative plan. Blood loss from a debrided wound bed can be significant and require serial monitoring of hemoglobin and hematocrit levels, platelet counts, levels of coagulation factors, body temperature, blood pressure, and urine output. With adequate planning and preparation, it is safe and practical for an experienced surgical team to rapidly excise and cover very large TBSA burns in a single operation.

Excision to Fascia. Subdermal burns extending well into the subcutaneous tissue are often excised to the fascial plane using a combination of sharp dissection and electrocautery (Figure 13-26). Excision at this level can generally proceed rapidly with minimal to moderate blood loss. On extremity burns, blood loss can be minimized by tourniquets. To use a tourniquet, a surgeon must be confident of the level of injury because punctuate bleeding cannot be used to determine tissue viability until the tourniquet is released and perfusion restored.

Engraftment on fascia is often more effective than placing autograft onto subcutaneous fat. However, this improved graft take can result in inferior cosmetic appearance, increased edema in distal extremities, decreased sensation, and inferior function, especially without early and progressive rehabilitation.

Skin Grafts.

Split-Thickness Skin Grafts. A split-thickness skin graft is usually harvested in a range from 0.007 to 0.012 inches (Figure 13-27). Donor sites for split-thickness skin grafts heal in 7 to 10 days, may be reharvested once healed, and heal with little or no scar formation. Split-thickness skin grafts may be placed as either a sheet or meshed graft.

The typical healing time for a split-thickness skin graft is 3 to 5 days for adherence to the wound bed and up to 7 days for durable engraftment. Rehabilitation of areas that have been grafted should be implemented during the first 3 days after grafting. Mobilization activities, such as ROM exercise and transfers, can be performed during this time if the area of grafting can be protected from shear forces. As the split-thickness skin graft matures, rehabilitation activities may progress, but consideration must be given to the healing graft until approximately 7 days after grafting. Excellent functional outcomes with split-thickness skin graft coverage can be achieved with early and progressive rehabilitation and through the comprehensive development of a safe and effective rehabilitation plan.

Sheet Grafts. Faster wound closure and cosmetic uniformity (without the appearance of a pattern) are some advantages of sheet grafting. Unlike meshed grafts, sheet grafts do not have perforations or incisions and are not expanded. Examples of areas best served by sheet grafting include the hands, face, and neck. The use of sheet grafts is often limited by the availability of adequate donor tissue.

When blood or serum collects under sheet grafts, the grafts may separate from the vascularized bed, resulting in graft loss. Hemostasis is critical to the success of a sheet graft. Large fluid collection can threaten the entire graft and may result in local drainage or aspiration to rescue the graft.

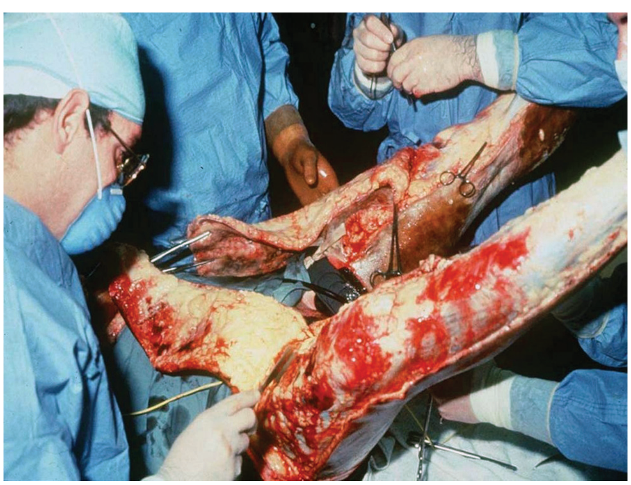


Figure 13-26. Fascial excision of subdermal burns to the lower extremities.

Figure 13-27. Harvesting of a split-thickness skin graft using a dermatome.

Meshed Skin Grafts. The instrumentation to accurately and reproducibly mesh skin (Figure 13-28) revolutionized burn care by providing a method of skin coverage for massively burned casualties. Skin expansion allows for greater graft coverage from limited donor sites. The surgeon has a choice of multiple expansion ratios, ranging from 1:5 to 9:1. One-to-one meshing is essentially uniform perforation without expansion. As the expansion ratio increases, the quality and cosmesis of the skin decreases, and healing time increases for the graft interstices or the perforations made in the skin graft because of the meshing and expansion process (Figure 13-29). As a general rule, most coverage is accomplished with a mesh ratio of 3:1 or less.

Full-Thickness Skin Grafts. The depth of harvest for a full-thickness skin graft depends on the skin thickness of the designated donor site. The technique involves excising slightly into the subcutaneous layer, then preparing the full-thickness skin graft by removing as much of the subcutaneous tissue as possible from the bottom side of the dermis. A full-thickness skin graft provides appropriate wound coverage for small full-thickness and subdermal burns, especially over anatomical areas requiring durability, extensibility, or cosmesis, such as the hands and face (Figure 13-30). Full-thickness skin grafts are associated with less wound contraction and scar formation than split-thickness skin grafts and are placed on the burn wound as a sheet graft only. Donor sites for full-thickness skin grafts may require grafting with a split-thickness skin graft for improved healing, minimizing wound contraction and scar formation.

The typical healing time for a full-thickness skin graft is 10 to 14 days. Rehabilitation of areas with full-thickness skin grafts during this time should focus on graft protection through splinting and positioning. Mobilization activities, such as transfers and ambulation, can be performed during this time, depending on the location of the full-thickness skin graft and if the area of grafting can be safely protected. As the full-thickness skin graft matures, rehabilitation activities may progress, but consideration must be given to the healing graft until day 14 following operation. As with split-thickness skin grafts, functional outcomes are best achieved with early and progressive rehabilitation and through a safe and effective rehabilitation plan.

Skin Graft Adherence. Skin graft adherence is a two-part process. The first phase, known as plasmatic imbibition, lasts for 24 to 48 hours. During this phase, the graft is held in place with fibrin bonding and nourished by direct diffusion. The second phase, inosculation, follows plasmatic imbibition and is marked by neovascularization.[195]

Figure 13-28. Meshed split-thickness skin graft applied to the lower extremity.

Figure 13-29. Interstices (perforations) in a meshed skin graft.

Figure 13-30. Full-thickness skin graft to the face of a burn casualty.

Proper management during the immediate postoperative period can significantly affect the final outcome of a scar graft. Graft movement or shear is generally the first cause of graft failure; infection is the second. Securing the graft to the wound bed is important to avoid shear. Grafts are often secured with staples or sutures. Sutures are typically used in sensitive areas, such as the eyelid. Biological glue is occasionally used to supplement adherence, such as in areas with irregular contours. Splints incorporated into the final dressing help maintain the desired position and prevent graft loss due to motion, especially over joints. Negative-pressure wound dressings, such as vacuum-assisted closure devices, can also prevent shear and have been shown to significantly increase skin graft take when used over freshly grafted wounds (Figure 13-31).[196]

Figure 13-31. Application of a negative-pressure wound dressing following skin grafting to the hand.

Techniques used to cover fresh skin grafts are wide ranging and often depend on surgeon preference. Skin grafts may be treated in either an open or closed fashion, which corresponds to the degree to which the graft is covered. Regardless of the exact type of dressing used, most fresh grafts are protected to prevent desiccation. This necessitates maintaining a moist environment while avoiding a wet wound bed.

Generally, autografts can be left uncovered by the fifth day following grafting, and can be protected with an antimicrobial emollient, such as petrolatum impregnated gauze, to retain moisture in the recently grafted tissue and protect reepithelialization at the grafted site. Grafts can usually withstand gentle cleansing in a shower by day seven.

In contrast to the highly vascular peritendineum, exposed tendons have poor vascular supply and autograft will not "take" over an exposed tendon.[44,197] Granulation tissue is needed to cover exposed tendon and allow the wound to be closed with skin grafting. Negative-pressure wound dressings can be used to promote wound bed granulation. Therapists should pay particular attention to exposed tendons over the PIP joint. If tendon exposure is noted, the PIP joint should be immobilized continuously in full extension to prevent stress on the central slip caused by PIP flexion.

Flap Grafts. Deep subdermal wounds that injure muscle and bone can be covered by flaps. A pedicle flap involves rotating tissue (typically a flexor surface) from an unburned area into the defect (Figure 13-32). When suitable donor tissue is not available directly adjacent to the defect, free tissue transfer may be required. This technique, requiring a surgical microscope, is commonly employed for complex injuries (Figure 13-33). Free flaps are also occasionally needed to cover areas prone to contracture, such as the neck. Some common flaps include the parascapular flap, anterolateral thigh flap, and groin flap.[198]

Figure 13-32. Pedicle flap to the nose of a burn casualty.

Figure 13-33. Free tissue transfer (free flap) on the torso of a burn casualty.

Cultured Autologous Keratinocyte (Epidermal) Grafts. Human epithelial cells can now be grown in cultures with techniques developed by Rheinwald and Green[199] and modified by Pittelkow and Scott.[200] The multistep process starts with the harvesting of a small piece of thin skin from an unburned site. Epithelial cells are enzymatically cleaved and separated, then placed in a serum-free culture medium where, under ideal conditions, they grow rapidly. Thin, fragile keratinocyte sheets are approximately 7 to 10 cell layers thick and have the consistency of wet tissue paper (Figure 13-34).

Figure 13-34. Multiple keratinocyte sheets applied to the lower extremity of a burn casualty.

Before grafting with cultured grafts, the wound bed must be carefully prepared. Most grafts adhere by fibrin adhesion. Casualties grafted with cultured epithelium do not develop hair, sweat or oil glands, or normal sensation in the grafted area. The epidermis remains relatively fragile and requires extra protection from exposure to sun, chemicals, and trauma. Rehabilitation is challenging because the epithelium does not tolerate exercise, splinting, or external supports. Casualties may have the cultured graft replaced with autograft as donor sites become healed enough for reharvesting.

Artificial Dermal Replacement. Another approach to providing more rapid coverage is through the use of an artificial dermis (Figure 13-35). One type of artificial dermis is composed of bovine collagen fibers bonded to chondroitin-6-sulfate, a component of shark cartilage.[201] Thin split-thickness skin grafts are later placed on the neodermis, resulting in a closed wound. A multicenter controlled study of this dermal replacement system showed favorable results, concluding that the healed artificial dermis covered with thin epidermal graft is essentially equivalent to standard skin grafts but with faster healing at the donor sites.[201]

Biological Dressings. The ideal biological dressing would function as natural skin and come prepackaged off the shelf, ready to apply and perform as a complete skin replacement on a permanent basis. Synthetic dressings are laboratory designed to mimic their biological counterpart, skin. Because these act as biological dressings, for the purpose of this discussion, they will be reviewed along with true biologic dressings. Satisfactory biological dressings undergo the same bonding process as skin grafts. Most importantly, when they

Figure 13-35. Artificial dermis applied to the lower extremity following excision.

adhere, the wound gains resistance to infection.

Biological dressings are designed to function in a similar manner as their more expensive natural counterpart, cadaver skin. There are many biological dressings available, but none is a true skin replacement. Biological dressings provide temporary coverage and time for adequate donor sites to become available for repeated graft harvest. This coverage is important in the overall physiological well being of a burn casualty because it provides better wound and pain management, helps decrease metabolic rate, reduces fluid losses through the wound, and suppresses the growth of granulation tissue.

Homograft or Allograft. Human cadaver skin is commonly used for grafting and is the standard against which other biological and synthetic dressings are measured. Banked frozen human skin is becoming more widely available, but is inferior to its fresh counterpart. Improved salvage of major burn casualties is based on early aggressive burn excision and coverage with homograft, followed by sequential replacement with autologous skin.

Fresh homograft adherence and capillary ingrowth is similar to that seen with autografts. Burn casualties with greater than 50% TBSA injury are autoimmunosuppressed. This state of immunosuppression can result in slowing of the natural rejection process, especially when the homograft skin is ABO compatible. Aside from providing excised wound coverage, homografts can also be used as overlay grafts to protect thin, widely expanded autografts or cultured keratinocytes, providing protection to the underlying grafts.

Homograft rejection occurs anywhere from 14 to more than 60 days after grafting, depending on the casualty's immune status. Replacement homografts tend to reject at a faster rate than original grafts, and the rejection process affects the wound bed and may negatively influence further grafting. The wound bed should be completely excised prior to grafting with autograft.

Availability, cost, and the potential risk of viral transmission are the major drawbacks of fresh homograft. Procurement, preparation, and storage costs are relatively high. Despite testing, there remains the possibility of viral transmission, including hepatitis, cytomegalovirus, and human immunodeficiency virus (HIV). There is at least one known case of HIV transmission involving autograft from England in 1987.[202,203] Amnion is used for temporary coverage in underdeveloped countries but not in the United States, and carries the same infectious risks.[204,205]

Because cadaver graft take is expected to be prolonged, the area is protected postoperatively in a method similar to that used with autografts. Rehabilitation of cadaver-grafted areas can commence in 3 to 7 days.

Heterograft and Synthetic Dressings. Porcine skin heterograft (xenograft) is occasionally used in the United States. However, it has limited value for short-term, temporary wound coverage. It has no advantage over homograft, but does have numerous disadvantages. Most importantly, xenograft does not incorporate into the wound, and therefore does not stimulate neovascularization.[206] If used, rehabilitation activities should mirror those following grafting with homograft.

Numerous synthetic dressings are currently available, and many more are expected to be developed in the future. Some dressings have been designed for a specific purpose (eg, use in a combat zone), while others are adapted to a wide variety of clinical applications. The choice of a particular dressing is usually based on a mixture of tradition, art, and science.

Synthetic dressings range from simple transparent polyurethane or polyurethane membranes to a more complicated bilaminate membrane. The former often work well to relieve pain and protect skin donor sites, as well as to decrease pain, protect, and decrease fluid loss in small, isolated, minor burns treated in an outpatient burn clinic. There is no restriction in ROM exercises with these products. A bilaminate membrane dressing is composed of collagen peptides bound to a silicone nylon mesh. To function properly, it must be bound to the tissue by ingrowth into the collagen network. Bilaminate membrane dressings have proven effective on partial-thickness burns and excised wound beds,[207] but they are contraindicated for use over full-thickness burns. To allow for adequate adhesion, ROM exercises are temporarily restricted for 24 hours following application of a bilaminate membrane dressing.

Donor Sites. As burn size increases, the donor site takes on added importance (Figure 13-36). The donor site can be considered analogous to a partial-thickness burn, which heals in the same way. Essentially, donor-site healing involves epithelial regeneration via migration of replicating epithelial cells, which originate from remaining hair follicle shafts and adnexal structures left in the dermis.[208] It is imperative that donor sites heal quickly because numerous repeat harvestings are required to close massive burns. The scalp is an ideal donor site because it heals rapidly and has few associated complications. A scalp donor site covered with an appropriate dressing can be expected to heal in 5 to 7 days for a graft harvested at 0.0008 to 0.010 inches. As a general rule, the further the donor site is from the heart, the longer it will take to heal.

Donor sites are dressed to decrease pain and promote rapid healing. Donor site dressings can consist

Figure 13-36. Donor site on the chest and abdomen of a burn casualty.

of fine mesh gauze with or without antibiotics or ointments (Figure 13-37). An open-to-air technique may also be used, but is not typically tolerated as well by casualties. Donor site dressing should be applied so that it overlaps by several centimeters onto the normal skin surrounding the site. If a donor site exceeds the size of the largest dressing, multiple dressings can be patched together to achieve complete coverage. Elastic or tubular support bandages may be applied over donor site dressings to provide external compression to the site microvasculature, especially in the case of the lower extremities. This technique decreases pain and the potential for tattooing of the donor site when rehabilitation activities force the extremity into various dependent positions.

The donor site dressing becomes problematic when the site is adjacent to or between burns, as it often is in massive burn casualties. If this donor site is covered with a traditional dressing, it may rapidly become infected, so it is preferable to treat the donor site with a nonadherent dressing and a topical antimicrobial, similar to the way the adjacent burned or grafted areas are treated.

Donor sites can also cause problems when the harvested grafts increase in depth, such as in the case of a full-thickness skin graft. The donor site may become as deep as the original burn and often heals slowly, and hypertrophy of the donor site can occur, resulting in a cosmetic appearance that is less favorable than that at the grafted sites. To avoid problems with slow or nonhealing donor sites, a thin split-thickness skin graft can be harvested, expanded at a ratio of 3:1, and regrafted to the donor sites.[209]

Healed donor sites can have problems with blisters and pigmentation changes. To minimize splotchy pigmentation, sun exposure should be avoided for a year or more. Educating casualties on donor site care mitigates these occurrences.

Intermediate Phase

The intermediate phase of rehabilitation, which begins after grafting, can be a trying time for the casualty, family, and staff. Casualties may see it as a setback if they are unable to continue exercising areas that were grafted. Grafting and the period of immobilization should be thoroughly explained to casualties and their families to prepare them emotionally for the postoperative period. Postoperative positioning and splinting should be discussed with the physician, therapist, and nursing staff preoperatively. Whenever possible during preoperative teaching, the nurse should assist the casualty into the position that will be assumed postoperatively; this will help alleviate discomfort issues in advance. Preoperatively, a low-air–loss bed or air-fluidized bed should be considered, not only for comfort reasons, but also for pressure reduction on healed, unhealed, old, or new graft sites, as well as donor sites.

During the intermediate phase, rehabilitation efforts continue to focus on wound healing, managing edema, and restoring ROM; however, increased emphasis is now directed towards strength, endurance, independence with ADLs and mobility, psychological adjustment and initiation of scar management. Common goals during this phase include:

- progressing toward independence with ADLs and mobility;
- preserving and restoring ROM;
- initiating strengthening;

Figure 13-37. Application of petrolatum gauze dressing to a donor site on the anterior thigh.

- developing self-management skills;
- facilitating wound closure with graft adherence;
- modifying edema;
- preventing complications, such as skin breakdown;
- maintaining joint and skin mobility;
- educating the casualty and family about the expected results;
- conducting behavioral interventions; and
- counseling to focus on the positive final outcome, rather than on loss of independence, pain, or inactivity.

During this phase, wounds in nonsurgical areas need to be cared for at least daily. Surgical areas should be observed for signs of increased bleeding and infection, or because of complaints of pain from splints or dressings throughout the period of immobilization.

Negative pressure wound dressings enable casualties to resume limited mobility earlier during the immediate period following grafting. The negative pressure effect of the dressing splints the graft into the wound bed and prevents disturbing the engraftment process. A nonadherent overlay dressing is applied directly over new grafts. Immediately after grafting, a nonadherent dressing can be soaked with bacitracin and used to protect and hold the graft in place. After applying the interface dressing over the graft, an open-cell sponge can be placed to fit slightly larger than the graft. The open-cell sponge must be applied with a nonadherent interface dressing. A thin, adhesive-backed occlusive film is applied over the sponge and adjacent wound area to form an airtight seal. The entire dressing is then negatively pressurized to 125 mmHg. This dressing decreases risk for maceration, improves engraftment, and provides an effective splint. It is usually placed on the casualty in the operating room and is removed after 3 to 5 days at the direction of the physician.[210] Secondary dressings also applied in the operating room include agent-soaked bolsters, tie-down bolsters, or negative pressure wound dressings.

The first postoperative dressing change can be done at the bedside or in the shower area. Thoroughly soaking the gauze outer dressings with water or saline facilitates their removal without disrupting the underlying grafts or overlay dressings that may be used to secure and protect grafts. The contact dressing is usually left in place for 24 hours after the first dressing change. Bending the dressing back 180° as it is pulled away from the wound, rather than lifting it at 90°, is less disruptive to the graft. After this time, graft dressings can be changed daily. If the contact layer adheres to the graft, applying an antibiotic ointment or white petrolatum 1 hour prior to removal decreases sticking and bleeding. Acute pain management with IV narcotics and anesthesia may be necessary for larger, more extensive, or painful dressing changes that require removal of numerous staples, negative pressure dressings, or further debridement. Subsequent dressings are placed considering the location of the graft, facilitation of rehabilitation, and casualty tolerance. In general, moist bolsters are continued until interstices are closed or nearly closed, at which time a topical moisturizer and dry protective dressings may be applied. Splinting, compression, and mobilization facilitate the quickest time to mobility and function.

Postoperative rehabilitation of a hand that has been grafted consists of an immediate protective phase of full-time immobilization. The hand can be immobilized with a splint or a negative-pressure wound dressing, and must be immobilized for 3 to 5 days for split-thickness skin grafts. If the dorsal hand is grafted, it should be immobilized in the resting position full time. A palmar split-thickness or full-thickness skin graft must be immobilized in finger extension and thumb radial abduction. Full-thickness grafts are usually immobilized continuously for 5 to 7 days following operation.

AROM and gentle PROM exercises usually begin 3 to 5 days after operation for split-thickness skin grafts, and 5 to 7 days after full-thickness skin grafting. Dorsal hand ROM exercises following split-thickness skin grafts should emphasize composite flexion of the digits (concurrent MCP, PIP, and DIP flexion), thumb opposition, and thumb palmar abduction. Splinting should be discontinued after the protective phase if the casualty is able to perform adequate ROM. Continued splinting should be considered for nighttime and as needed during the day if adequate ROM is not obtained with ROM exercises and ADLs.

Once the graft is well adhered, interim compression can be applied to the involved areas. Interim compression can be provided using self-adhesive elastic wrap and is usually initiated 7 to 10 days following split-thickness skin grafting. A nonadherent dressing can be used underneath the elastic wrap to prevent adherence of the compression dressing to the skin graft. ROM exercises should be performed as prescribed while wearing the interim compression.

Topical Treatment. Burns are cleansed once or twice daily, followed by application of a topical agent. A soothing ointment can be applied to small wounds (less than 10% TBSA), such as bacitracin, which is relatively inexpensive but does not penetrate well and is ineffective against gram-negative bacteria. Mafenide acetate can be used as a solution in bolsters or in cream form. Bolsters soaked in 5% mafenide acetate are often used to improve marginally full-thickness burns.

Alternating mafenide acetate with silver sulfadiazine and a dry protective dressing over deep burns with leathery eschar has proven effective in helping separate eschar from wound beds, and penetrates more effectively than other topical agents alone. Alternating these agents helps with tolerance because silver sulfadiazine is soothing after the irritating mafenide acetate cream. All previously applied agents must be thoroughly removed before applying subsequent topicals. Meticulous wound care between dressing changes is the hallmark of progressive burn healing. Although mafenide acetate has been shown to cause metabolic acidosis when applied over very large areas, it is the preferred treatment when dealing with burns to the outer ear because it penetrates well into cartilaginous tissues and is the most effective antimicrobial agent for preventing chondritis of the outer ear. Burns that are obviously full-thickness or are potentially infected are treated twice daily with mafenide acetate until the burn is healed or nearly healed,[211] at which time transition is made to topical bacitracin ointment or plain white petrolatum. Silver sulfadiazine does not penetrate well, but has a good spectrum of coverage, is easy to apply, and is the least painful agent, but sensitivity and leukopenia are not uncommon. Silver sulfadiazine is avoided in casualties with sulfa drug allergy.

Topical treatments vary depending on location, extent of injury, and surgical excision and grafting. Wounds that do not appear they will heal within 2 to 3 weeks are usually excised and grafted 1 to 5 days following burn.

Wound care and wound management are large parts of the recovery process for injured casualties. Rehabilitation is also vital in returning the injured to normalcy or optimal function. Discharge criteria include particular levels of independence in ambulation, ADLs, hygiene, transfers, and ability to manage wounds. Pain and pain management must also be considered when determining discharge eligibility. Today, there are numerous wound dressings that require little more care than regular follow-up for progress evaluation. Pain medications traditionally given in IV form can now be given orally.

Long-Term Phase

Rehabilitation focus continues to shift in the long-term phase. By this time, edema, ROM, strength, ADLs, and mobility are typically well managed. Rehabilitation efforts are now more specifically targeted toward reintegration, psychological adjustment, return to duty, and continued scar management. However, if impairments persist from the acute or intermediate rehabilitation phases, continued focus for these will be required. Common goals include:

- societal reintegration;
- improving aerobic capacity;
- preventing hypertrophic scarring;
- remediating scar contracture;
- modifying edema;
- increasing joint and skin mobility;
- increasing strength;
- facilitating casualty and family participation in resumption of family roles;
- learning self-care activities;
- mastering compensation techniques for exposure to friction, trauma, ultraviolet light, chemical irritants, and extremes of weather or temperature;
- developing a profile for active-duty training, return to part-time modified duty, or to full-time active duty; and
- continued counseling to deal with life and psychological stresses regarding permanently changed appearance, altered ability levels, and difficulties with PTSD symptoms.

As a casualty transitions into the long-term rehabilitation phase, the healing burn is very fragile, and if not protected, is prone to shearing, pressure, and subsequent breakdown until matured. It is not uncommon to have small blisters form during this time, because the epidermal layer is not firmly attached to the underlying dermis for several months.[212] All wound areas should be gently cleansed and rinsed well with water. Infection is no longer a significant consideration; therefore, antibiotic ointments are generally discontinued. However, multiple topical agents may be used for cleansing, barrier protection, and antimicrobial control, and may lead to complications of contact and irritant dermatitis, further complicating reepithelialization and wound healing.[213] Blistered areas should have a light, nonadherent dressing applied for protection. The intact blister should not be opened or debrided. If the blister is large and spreads when external vascular support is applied, the blister should be drained and the wound protected with the dry skin. If the dry skin peels away, a protective nonadherent dressing can be applied and changed daily.

During the end stages of wound epithelialization, the wound is assessed to determine whether compression by elastic wraps, interim compression garments, or custom compression garments will be most effective. The integument should be continually inspected for changes resulting from increased activity, exercise, or in response to treatment procedures. External vascular support should be applied to the lower extremities prior to dependent positioning or ambulation.[214] Standing in the shower with legs dependent is permitted only after all open areas are closed and purple color exhibited by dependent wounds in this position decreased.

After a burn, the number of sebaceous and apocrine glands are decreased, leaving healed skin dry and flaky. Casualties may be irritated by pruritus, but vigorous rubbing or scratching results in newly opened areas. Moisturizing lotions should be applied to all healed areas after bathing and routinely as needed. The lotion should not be perfumed, have an alcohol base, or be so viscous that it causes blisters during application. Long-acting oral antipruritic medications should be used[215] in conjunction with lotion to relieve the itch. Fingernails should be kept trimmed, smooth, and clean to prevent excoriation of fragile skin. Desensitization exercises and vibration massage may reduce itching.[216] When exercising outside, a casualty's healed burn or donor areas should be protected from sunlight until all the red color has faded.

The long-term phase emphasizes addressing deficits to allow optimal return of function following a hand burn. Finger amputations, poor autograft take, age, full-thickness TBSA burned, and full-thickness hand burn area are all long-term predictors of hand function following a burn.[217] Management during this phase is primarily dependent on scar maturation; mobility of skin, joint, and soft tissue; and neuropathy.

Chronic Nonhealing Wounds. Occasionally, chronic nonhealing wounds will develop. In these instances, it is important to identify the underlying problem causing the healing delay. Pressure, shear forces, infections, and poor nutrition are common factors that delay healing. Interventions such as pressure relief, properly fitting compression garments, and nutritional counseling may be needed to promote healing. Occasionally hypertrophic granulation tissue may keep wound edges from migrating effectively, resulting in a chronically open wound. Silver nitrate as a cauterizing agent, surgical excision, and regrafting have all proven beneficial in managing chronically open wounds.

Biomechanics of Skin and Scar

A severe burn is both a physical injury to the integumentary system and a physiologic insult to several other organ systems. Skin is unique because one piece of tissue encapsulates the entire body while permitting unrestricted flexibility to the extremities and trunk. When naturally pliable skin is replaced by scar tissue or skin grafts, tissue contractures can develop.

The viscoelastic nature of native skin is derived from the interactive combination of a fibrous matrix of collagen and elastic fibers surrounded by an amorphous gel generically referred to as "ground substance."[218] Collagen fibers lend strength to the skin, while elastic fibers give the skin its extensibility and subsequent retraction after deformation. The ground substance lubricates the fibers and partially absorbs energy applied to the skin during movement.

The collagen network of the dermis in undamaged skin is made up of long, undulating fibers that are somewhat randomly oriented under relaxed conditions.[218,219] Elastic fibers are straighter than individual collagen fibers and are interconnected as well as attached to the collagen strands. As traction is applied to the skin, the elastic fibers elongate, pulling on the collagen fibers to orient them in the direction of applied force.[220] During this action, the viscous ground substance is displaced from between the fibrous network.[218]

The interaction of these three biomechanical components of skin can be described on a stress-strain curve (Figure 13-38). Initially, skin can be significantly elongated with minimal force because mostly the highly pliable elastic fibers are being stretched.[221] As additional tension is added to elongate the skin, more collagen fibers reorient themselves in the direction of the applied stress. As collagen fibers accumulate in the direction of the applied force, a greater force is required to overcome the resistance by the aligning collagen fibers to gain further length. Once all the collagen fibers have aligned parallel to one another in the direction of the force, the slope of the curve becomes linear, with little further elongation attainable despite the input of greater force. At the physical terminus of skin elongation, applying additional force causes the skin to rupture. Cessation of an elongating force allows

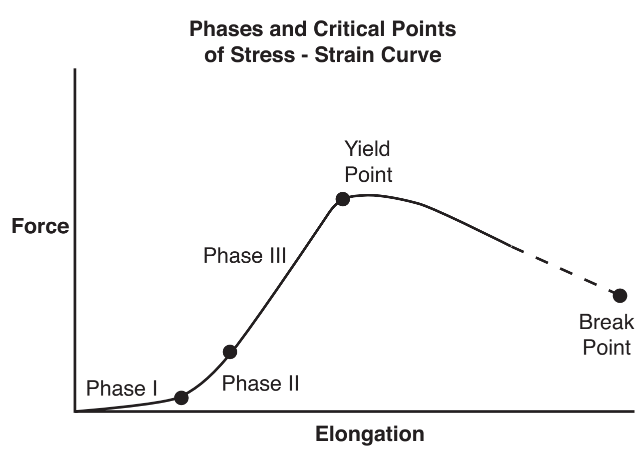


Figure 13-38. Stress-strain curve of tissue.

the fibrous network to revert back to its original resting length by a recoil action of the elastic fiber attached to the straightened collagen fibers (Figure 13-39).[221] Undamaged skin has the capacity to elongate up to 50% to 60% of its original resting length.[222]

The dermis injured by burn is replaced by scar tissue. Scar tissue differs from normal dermis in that elastic fibers do not regenerate,[223] the composition of ground substance changes, and the fibrous portion is only collagen. Morphologically, untreated burn scar develops into a disarray of randomly oriented collagen fibers. Characteristically, nodules form in the extracellular matrix, which may be under the influence of ground substance changes.[224] Biomechanically, burn scar behaves much like tendon, resisting deformation. Immature burn scar is only 16% extensible, which decreases to approximately 4% at maturity.[225]

Acute Phase

Burn scar must be managed while it is being produced. Physical intervention is an imperative part of the early rehabilitation phase. Arem and Madden have shown that stress applied to newly developing scar tissue causes it to orient in the direction of the force.[226] Burn scar begins to form during the proliferative stage of wound healing, which begins approximately 5 to 7 days after injury.

The effect of burn rehabilitation interventions is based on biomechanics principles. Repeated ROM exercise or the use of reciprocal pulleys, for example, harness the principle of successive length induction.[227] With successive length induction, each time the body segment is moved, the tissue further elongates (Figure 13-40). However, tissue length increase from successive length induction is not permanent because as soon as stress is relieved from the tissue, the tissue begins to return to its original resting length. Also, it is important to consistently use ROM measurements from either the beginning of the treatment session or the end to accurately compare improvement between treatment sessions. Improvements in ROM achieved within a given treatment session are misleading because the improved ROM is temporary.

Positioning, static and static-progressive splinting, and serial casting incorporate the biomechanical principle of stress relaxation.[228] With stress relaxation, tissue is elongated to a set point and held at that given length by the selected intervention. The set point should cause slight discomfort for the casualty. As time passes (within an hour), stress on the tissue eases and the tissue relaxes, making the intervention more tolerable (Figure 13-41). Stress relaxation prevents scar tissue from shortening.

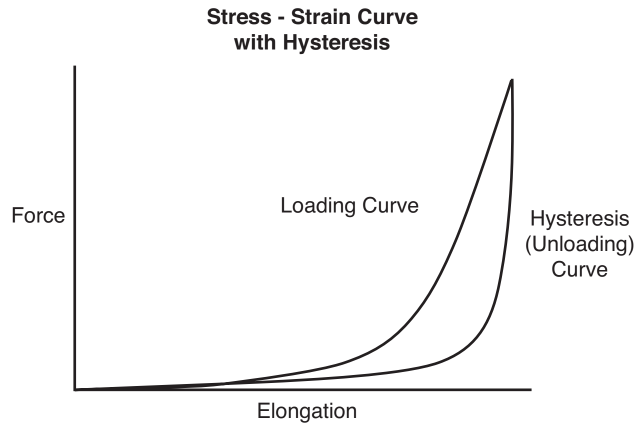


Figure 13-39. Tissue hysteresis.

Another biomechanical principle used in burn rehabilitation is based on tissue creep.[229] When controlled stress is applied to tissue over a prolonged period of time, such as with dynamic splints, the tissue continually undergoes elongation (Figure 13-42).

Strain rate, or how quickly tissue should be elongated, is another biomechanical consideration (Figure 13-43).[230] Tissue responds to stress that is applied either rapidly or over a prolonged period, as long as the force of the stress is at a therapeutic level. However, rapidly elongating tissue causes casualties more pain than if the intervention is performed or applied over a prolonged period of time.

Regardless of the therapeutic approach or biomechanical principle, casualty tolerance of the procedure

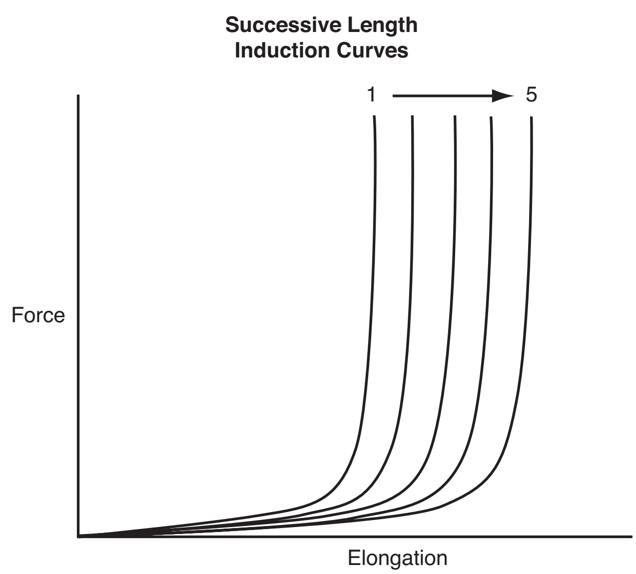


Figure 13-40. Successive length induction.

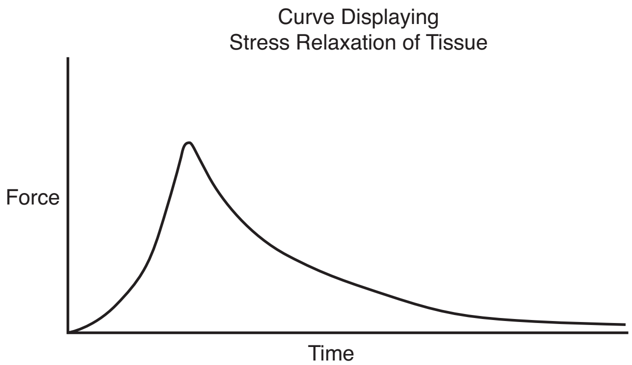


Figure 13-41. Stress relaxation of tissue.

should guide rehabilitation. Furthermore, a sustained-approach treatment minimizes the chance of damaging tissue.

Intermediate Phase

Positioning during the intermediate phase is based on several factors relevant to tissue recruitment and creep. If a body part has a direct burn injury resulting in grafting or healing of native skin, positioning in the intermediate phase continues in the same fashion as it did acutely, so as to place the body part in anticontracture or a maximum wound length position while at rest or between active therapeutic interventions. If a body part has residual healthy native skin and is involved as recruited tissue due to close proximity to the burn wound, positioning in the intermediate phase continues in the same fashion while at rest or between active therapeutic interventions.

Burn casualties increase their daily activity level in the intermediate phase. The primary function of positioning now becomes more focused on stressing the grafted and healing sites beyond what is accomplished in active therapeutic intervention to create tissue creep and increase native skin recruitment. Success in this phase requires creative interventions beyond the standard positioning and splinting devices. The therapist should always consider various interventions to prevent contracture; aside from positioning and repositioning, ROM exercise, strengthening, and ADLs are implemented to reduce contracture risk.

Additional activity integrates postural awareness and dependant posture demands on wounds. A therapist will instruct a casualty in postural adaptations and explain the need to adjust from dependant to nondependent postures throughout the day, allowing the casualty to avoid undue stress to the wounds and preventing acute swelling.

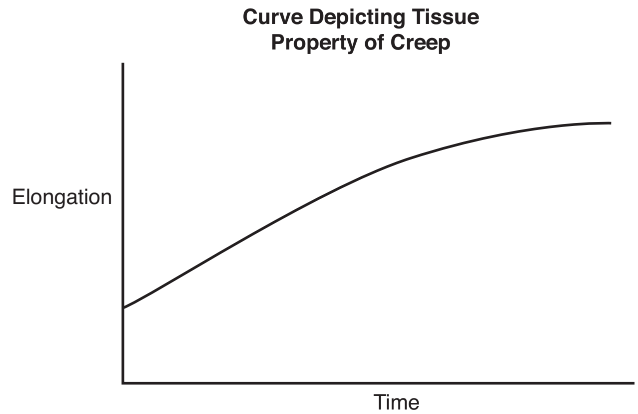


Figure 13-42. Tissue creep.

Long-Term Phase

Many different interventions applying these biomechanical principles have been successfully employed to treat established burn scar contractures. A study investigating approaches to remediating burn scar contracture documented that serial casting and splinting, as well as dynamic splinting, were the most efficacious methods to reverse burn scar contractures.[231] By using one of these three interventions, contracture resolution took approximately half the time than it took using various other methods. These methods were effective on immature scar tissue.

Positioning requirements continue to be a key factor in contracture prevention and burn scar management until the wounds reach maturation. As the casualty

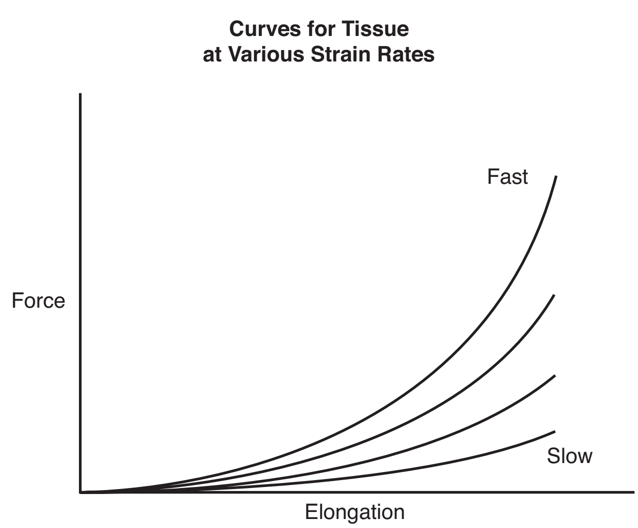


Figure 13-43. Graph displaying the difference in various strain rates of tissue.

reaches the long-term rehabilitation phase, wounds are closed and essentially healed. The casualty then endures the process of wound maturation as the scar tissue gradually slows in formation, flattens, and reestablishes a color presentation more similar to native skin. This process can last as long as 2 to 3 years after injury.

The techniques for positioning during the long-term rehabilitation phase closely resemble those of the intermediate rehabilitation phase. The most significant adjustment in implementing contracture prevention techniques includes increased use of custom splinting and positioning devices. Initially, dependent positioning of the extremities will be painful, which will remind the casualty to elevate the hands or feet. By this time, casualties must take responsibility for varying their own positions while at rest. However, it will still be necessary to apply various splinting devices to critical areas that have lost strength or active motion to produce burn scar contracture.

Splinting

A splint is defined as "an orthopedic device for immobilization, restraint, or support of any part of the body."[232] Splints can also mobilize, position, and protect a joint or specific body part.[233] Different types of splints are used throughout a burn casualty's rehabilitation, depending on the phase the casualty is in.

Acute Phase

There have been 93 splints used for burn rehabilitation described in the English language; *An Atlas and Compendium of Burn Splints*[234] provides a description and summary of each. During the acute phase, the primary goal of splinting is to maintain proper positioning of the burn casualty's extremities in order to reduce edema, prevent soft tissue contracture, and protect skin grafts, all of which minimize burn scar contracture and deformity. Proper positioning is vital because burn casualties may not be alert enough to maintain ROM with active movement. Static splints are used most frequently and may be custom or prefabricated, depending on the burn casualty's specific needs. Splints are generally applied 72 hours after burn. If implemented during the first 72 hours after burn, complications may develop because of the confining nature of splints and the active edema accumulation from fluid resuscitation.

A commonly used, prefabricated hand splint maintains the hand in the intrinsic plus position, also known as "the position of safe immobilization" (Figure 13-44). This position involves 20° to 30° of wrist extension, maximum flexion of the MCP joints, maximum extension of the IP joints, and palmar abduction of the thumb to avoid contracture of the first web space.[235]

Prefabricated burn splints are clinically expedient and generally meet the needs of burn casualties during this phase. Also, they are oversized and can accommodate bulky dressings. These early burn splints are secured with a gauze wrap; straps are contraindicated at this time because they do not accommodate for changing edema, have the potential to compromise circulation, and do not evenly distribute pressure over the edematous extremity.

When using splints, it is essential to constantly assess the burn casualty's skin integrity. Pressure areas can increase the risk for skin breakdown, nerve compression, or burn wound conversion. The safe position can also be achieved with a custom splint, which may be more appropriate for a burn casualty with fluctuating edema, associated orthopaedic conditions, or digit amputations. Custom splints may also be indicated for the hand in the presence of full-thickness burns of the dorsal hand that result in exposed tendons. During the acute phase, static splinting can be used to maintain proper joint alignment and to help prevent contractures.

Dorsal hand edema encourages wrist flexion, MCP joint hyperextension, and IP flexion.[42] Intrinsic muscle edema encourages PIP joint flexion.[236] Therefore, the resting hand splint is the most common splint used during this phase. The resting position maintains 20° of wrist extension and 60° to 70° of MCP flexion, and keeps the thumb in palmar abduction.[42]

The PIP joint can be immobilized with a gutter splint or with surgical placement of Kirschner wires, and the PIP should be immobilized until the tendon is no longer exposed. MCP and DIP joint motion should be maintained as long as there is no tendon exposure in these areas. If the tendon over the PIP joint is ruptured, immobilizing the PIP joint in extension for 6 weeks

Figure 13-44. Hand splint secured with gauze wrap.

may prevent volar migration of the lateral bands that contributes to a boutonnière deformity. The scar over the PIP joint may form a pseudotendon that assists with PIP extension.[237]

A palmar burn will contract into thumb flexion, thumb adduction, and finger flexion. Splints or casts used for palmar burns should hold the hand in the position of thumb radial abduction and finger MCP, PIP, and DIP extension. Caution should be taken to avoid MCP hyperextension of the thumb when positioning into radial abduction. Exercises should emphasize finger extension and radial abduction. Flexion exercises can be performed to prevent joint capsule tightness of the MCP and IP joints; however, caution should be taken to avoid digital extension losses.

Splints are not usually necessary for superficial partial-thickness burns unless there is minimal active motion of the hand and poor exercise participation because of pain. Resting hand splints are more commonly used for deep partial-thickness or full-thickness burns because of the higher risk of joint or skin contracture. Prefabricated resting splints covered with gauze are primarily used during the acute phase.

Intermediate Phase

Although reducing edema and preventing soft tissue contracture remain priorities, the primary goal of splinting is to protect skin grafts during the intermediate phase of rehabilitation. One of the most important responsibilities of the rehabilitation staff is to promote skin graft adherence. The most common type of splint indicated is a static splint, or a splint that does not allow movement. Newly grafted areas are generally immobilized with static splints for 3 to 5 days following operation for split-thickness skin grafts, and 5 to 7 days for full-thickness skin grafts. Preventing burn scar contracture from forming is also important at this point and can be accomplished concurrently with skin graft protection using the appropriate splint.

Ears. An ear-dressing kit can be used to protect ears before and after grafting. A typical kit includes a hard plastic cup to cover the ear and is lined with gauze for wound protection

Mouth. A microstomia prevention appliance[238] or a mouth spacer can maintain the horizontal component of mouth opening after a burn to the commissural region (Figure 13-45).

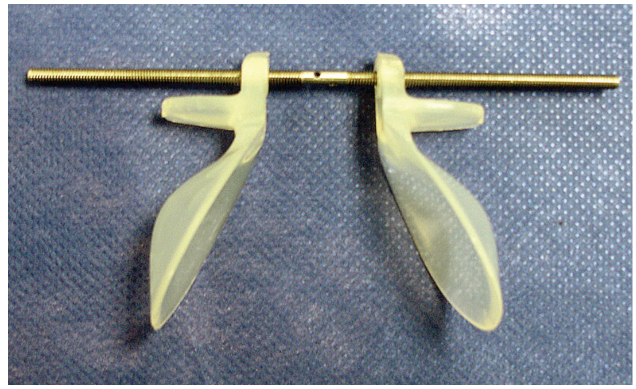


Figure 13-45. Jouglard's mouth spacer (Medical Z, San Antonio, Tex) for the prevention of correction of microstomia. Photograph: Courtesy of Medical Z, San Antonio, Texas.

Neck. There are several options for immobilizing the neck in the intermediate phase of recovery. A soft neck collar, consisting of foam placed circumferentially around the neck, can serve as a positioning device to promote neutral neck positioning (Figure 13-46).[239] Custom thermoplastic splints may be fabricated to protect neck grafts or to provide optimal positioning, most commonly in neutral or slight neck extension. An anterior neck splint is conformed along the anterior neck, the upper chest, chin, and lower mandible.[240] The splint can be secured with hook-and-loop fasteners around the posterior of the neck, and can protect the graft and provide optimal positioning to limit the formation of burn scar contracture.

Both the soft collar and the anterior neck splint can provide contact pressure to help minimize scar hypertrophy while providing neutral or slight cervical extension. Both splints can be used past the immobilization phase to provide prolonged neck positioning. Providers must frequently perform skin integrity checks when using these splints, as both can cause

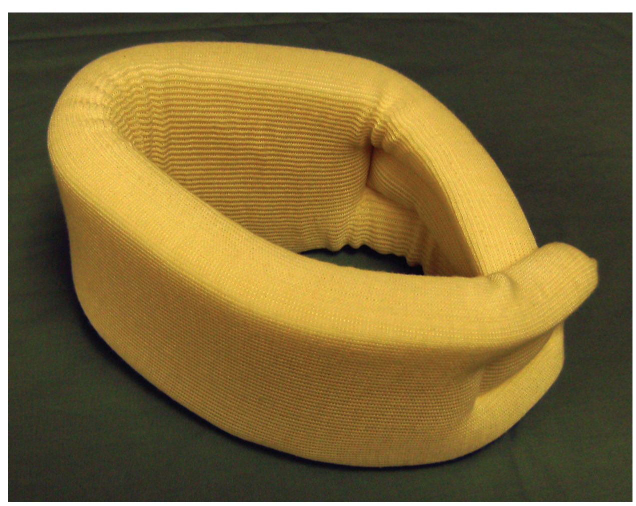


Figure 13-46. A soft neck collar for neutral positioning of the neck.

mechanical shear to skin grafts with any movement or excessive pressure.

A halo neck splint[241]and three-point anterior neck splint[242] are two types of "open" neck splints that can immobilize the neck after grafting (Figure 13-47). These splints do not permit direct wound contact and allow the wounds to ventilate. The halo neck splint consists of a posterior thermoplastic post with a skull cup and a circumferential head strap. These are connected to a thermoplastic base over bilateral anterior and posterior shoulder girdles. The three-point anterior neck splint is similar to the anterior neck splint, but there is an opening over the anterior neck, with three thermoplastic posts connecting the chin and shoulder girdle components.

Axilla. In the event that traditional positioning is not enough to immobilize and protect the axilla area, a thermoplastic splint may be fabricated. An airplane splint with a support rod[243] can be custom fit to the burn casualty in order to keep the axilla positioned in at least 90° of flexion or abduction for optimal positioning after burning or grafting. This splint can also be used to protect lateral trunk grafting.

Figure 13-47. Halo neck splint used to position the head and neck after grafting.

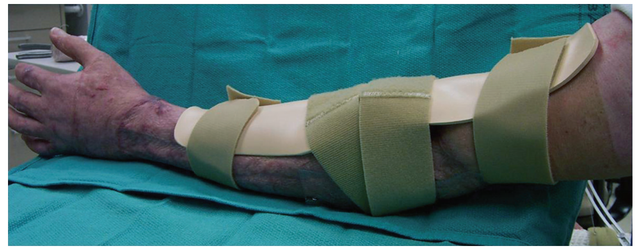


Figure 13-48. Thermoplastic static elbow plank for optimal post-grafting positioning.

Elbow. A static elbow splint, or elbow plank, is commonly used for graft protection or for optimal post-burn positioning (Figure 13-48). This splint can be fabricated out of thermoplastic material and can be placed posterior[244] or anterior.[245] The splint is usually worn until 3 to 5 days after split-thickness skin grafting when used for graft protection.

Wrist and Hand. There are several splints that can immobilize the hand or wrist after skin grafting. A prefabricated splint is the most common type used for protection following grafting (see Figure 13-21b). An advantage of this oversized splint is that it can accommodate the typical bulky postoperative dressings. These splints are usually worn continuously until at least 3 to 5 days after grafting, when ROM exercises are again permitted. A custom resting splint is indicated if a proper fit is not obtained due to anatomical restrictions or dressing limitations.[246] A custom splint is also indicated if specific positioning other than the "safe" position is indicated (Table 13-7 and Figure 13-49**)**. Static or serial static splinting are the primary splint types used during the intermediate rehabilitation phase. Dynamic or static-progressive splints should be implemented if sufficient ROM gains are not achieved with static or serial static splinting. Serial casting is an effective alternative to splinting that provides the low force and long duration positioning needed for optimal tissue elongation.[247] It can protect open wounds, facilitating healing. Antimicrobial wound dressings that remain effective for at least several days should be used underneath the casts on open wounds. ROM gains made in a cast can be maintained with static splinting or improved with static-progressive or dynamic splinting once casting is no longer indicated.

Deep partial and full-thickness burns also require interim compression for scar control during the intermediate rehabilitation phase. Permanent custom compression garments are not appropriate during this phase because of open wounds, edema, and skin fragility. However, interim compression can help with edema control and protect fragile skin from friction.

TABLE 13-7

CUSTOM HAND AND WRIST SPLINTS

Type	Indication
C-bar	Stretches first web space; places the thumb in palmar abduction for optimal dorsal web space positioning, or in radial abduction for optimal palmar or thenar positioning following burn or skin grafting (see Figure 13-49a)[1,2]
Slot-through	Used when combined wrist and palmar extension is indicated following grafting to the palm or for adequate positioning after a palmar burn with or without volar wrist involvement (see Figure 13-49b); a C-bar component can be added to place the thumb into optimal radial abduction if the thenar eminence is involved (see Figure 13-49c)[3]
Volar wrist extension	May be fabricated with thermoplastic material to immobilize the wrist following skin grafting or volar wrist burn; may also be indicated if wrist support is needed due to a neurological deficit, such as a radial neuropathy[4]
Finger gutter or finger tunnel	Fabricated to hold interphalangeal joints in extension, protect exposed tendons, immobilize after skin grafting, or prevent a boutonniere deformity[5,6]

Data sources: (1) Fess EE, Philips CA. *Hand splinting, Principles and Methods.* 2nd ed. Saint Louis, Mo: Mosby; 1987. (2) Walters CJ. *Splinting the Burn Patient*. Laurel, MD: RAMSCO Publishing Company; 1987. (3) Forsyth-Brown E. The slot-through splint. *Physiotherapy*. 1983;69:43–44. (4) Miller H, Posch JL. Acute burns of the hand. *Am J Surg*. 1950;80(6):784–798. (5) Von Prince KMP, Yeakel MH. *The Splinting of Burn Patients*. Springfield, Ill: Thomas; 1974: 60–70. (6) Salisbury RE, Bevin AG. *Atlas of Reconstructive Burn Surgery*. Philadelphia, PA: WB Saunders; 1981: 164.

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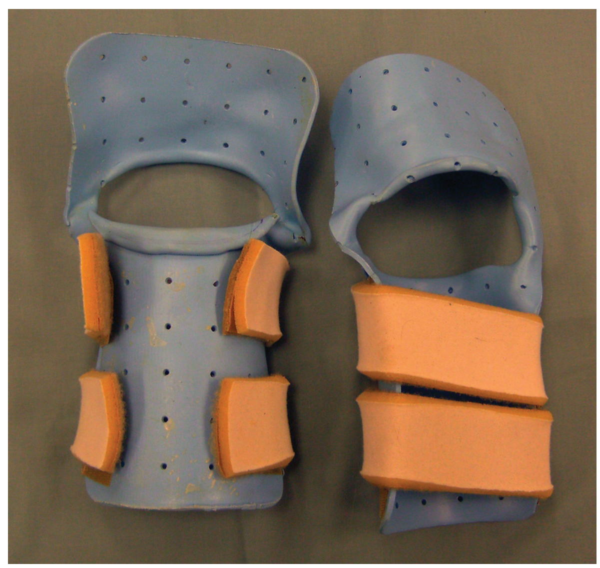
b



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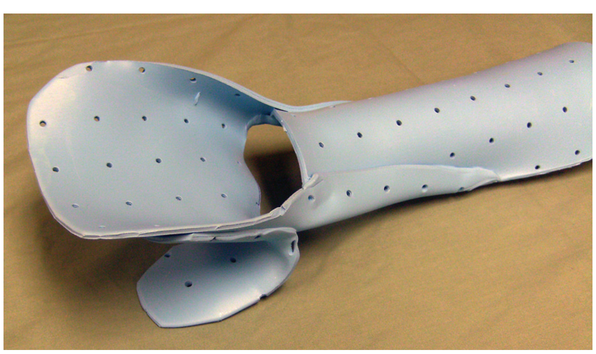

Figure 13-49. (**a**) C-bar splint for preventing and correcting contracture to the first web space (top view).
(**b**) Slot-through splint for combined wrist and palmar extension. (**c**) Slot-through splint with C-bar component for optimal thumb positioning.

Interim compression options for the hands are self-adherent elastic wrap or commercially available nylon gloves. Superficial partial-thickness burns do not require scar compression, but a nylon glove can reduce edema or protect the involved hand from friction.

Knee and Ankle. There are several options available to immobilize the knee and ankle after grafting or for proper positioning. A long leg splint—a static, prefabricated, metal-based splint lined with foam inserts, cast padding, and gauze dressing—may be indicated when it is necessary to simultaneously immobilize the knee and ankle (Figure 13-50). A long leg splint immobilizes the ankle in a neutral position and the knee in full extension. It extends posteriorly from the plantar surface of the foot to the posterior thigh and is typically applied to the burn casualty using gauze. When it is necessary to isolate either the knee or the ankle, a custom thermoplastic splint can be fabricated.[244,246] Ankles can be isolated and immobilized or held in a neutral position with a prefabricated boot (Figure 13-51).

Figure 13-50. A long leg splint used for simultaneous knee extension and ankle dorsiflexion positioning.

Long-Term Phase

The primary goal of splinting during the long-term rehabilitation phase is to prevent skin or joint contractures. Because collagen fibers are aligned along lines of stress,[189] splinting is an important component of rehabilitation. The three types of splints used during this period are static, dynamic, and static progressive. Static splints are indicated if an achieved position needs to be maintained during the scar maturation phase. Static splints can also be serially fabricated. Serial static splints get remolded progressively at the maximum tolerable end ROM to increase tissue length.[247]

A dynamic splint allows for or provides movement. A dynamic splint can be used correctively or functionally. A corrective splint is indicated to correct burn scar or joint contracture. The movement provided should include a low-load force in the direction of tension.[248] The most common dynamic force used for dynamic splinting is rubber band or elastic tension. If the goal for this splint is to gain motion, a period of 6 to 8 hours of cumulative wear time, with wear intervals lasting at least 30 minutes, is recommended. The key to successful dynamic splinting and tissue elongation is to provide a low-load force for a long duration.[248]

Corrective dynamic splints are most frequently used for the elbow, wrist, and hand, and the involved area must be frequently inspected for skin breakdown. A 90º angle of pull is required to provide optimal dynamic force.[249] Dynamic splints for the elbow, wrist, forearm, hand, knee, and ankle are also commercially available, providing many options depending on the targeted movement or joint. However, commercially available splints may not adequately fit a casualty; therefore custom fabricated dynamic splints are sometimes indicated. A dynamic supination splint can be effective for increasing ROM if limited by burn scar or joint contracture.[250] A thermoplastic wrist extension splint has also been used to address burn scar and joint limitations (Figure 13-52).[251]

Dynamic splints are also useful during this phase to substitute for loss of function from concomitant nerve injuries or amputations. The most commonly used

Figure 13-51. Commercial ankle-foot orthosis for ankle positioning.

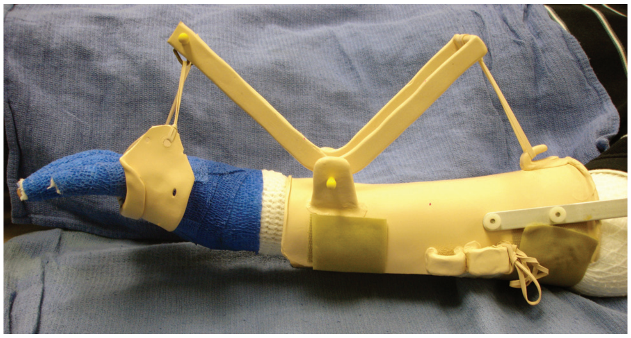

Figure 13-52. Fulcrum wrist extension splint.

adaptive splint for burn casualties is the mobilization splint for radial nerve palsy, originally designed at the Hand Rehabilitation Center in Chapel Hills, North Carolina, in 1978 (Figure 13-53).[252] This mobilization splint reestablishes the tenodesis pattern of the hand[253] and includes a dorsal base splint with a low-profile outrigger that spans from the wrist to each proximal phalanx.[233]

Another type of corrective splint, a static progressive splint, uses inelastic components to apply torque to a joint at end range to increase available ROM.[254] Unlike the dynamic splint, the static progressive splint does not permit active-resisted ROM against the line of pull.[255] Flowers states that static progressive splints are indicated when the targeted tissue is stiff and requires the most aggressive intervention.[256] The principle of a low-load force for long duration should be implemented with static progressive splints. Wearing schedules and precautions are similar to those observed with dynamic splints. A variety of static progressive splints for the upper and lower extremities are also commercially available.

There are several different types of static progressive splints used to correct contractures of the upper extremity. An elbow extension turnbuckle splint or elbow flexion splint may be used when joint or burn scar limitation results in elbow flexion or extension contractures.[257] Wrist and hand splints can also be fabricated to address burn scar or joint limitations, and various other static progressive splints can be fabricated for the upper extremities, depending on the target joint or tissue.[255] A common static progressive splint used to regain hand ROM following burn or skin grafting is a composite flexion splint, which includes combined flexion of the MCP, PIP, and DIP joints (Figure 13-54).

Casting

Serial casting is typically recommended for managing burn scar contracture when the involved structures are resistant to traditional methods of treatment, such as AROM exercises, paraffin baths, massage, progressive resistive exercise, and splinting (**Figure 13-55**).[258,259] Casting can help throughout the various phases of burn recovery.

Acute Phase

In the acute phase, casting can be used for immobilization, edema reduction, and tissue protection.[260] Burn casualties often present with a significant soft tissue defect that leaves underlying structures exposed. Some of the qualities of Plaster of Paris make it the perfect material to intercede, including unparalleled conformity, decreased pressure (which is due to the conforming quality of the material), and reduced shear force compared to alternative materials.[260,261] Plaster of Paris is also porous and retains heat well, which is important for individuals with friable tissue. These qualities decrease the likelihood of maceration

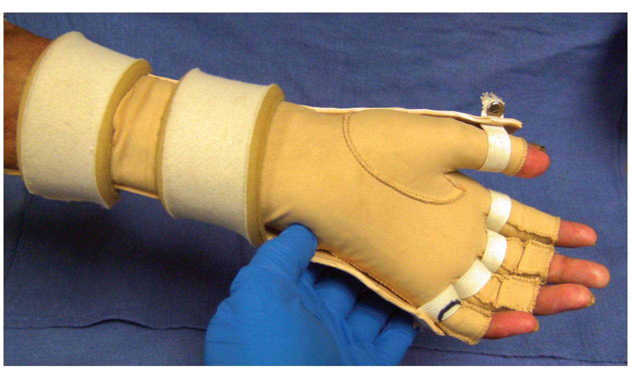

Figure 13-53. Volar view of radial nerve palsy mobilization splint, displaying elastic straps around first phalanx that assist with metacarpophalangeal extension.

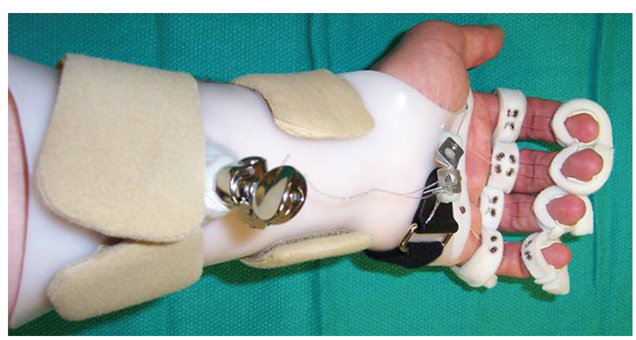

Figure 13-54. Static progressive finger composite flexion splint.

Figure 13-55. Elbow cast used to serially correct burn scar contracture.

and create neutral warmth, required because casualties with large burns have difficulty regulating their temperature.[260]

Intermediate Phase

The clinical focus in the intermediate phase moves from tissue protection toward mobilization while maintaining emphasis on reducing and managing edema. The indication for casting as an intervention during the intermediate phase is based on the same factors as in splinting: tissue recruitment and creep. If a body part has healthy, native skin and is involved as recruited tissue because of close proximity to the burn wound, aggressive total active motion is sought throughout each intervention. All active components of ROM progression, such as AROM, sustained stretch, strengthening exercises, and daily functional activities, should precede casting. Keeping in mind that the chosen modality should help restore ROM, serial or dropout casting may be considered to stimulate tissue creep or native tissue recruitment. Skin and joint tightness suggest serial or dropout casting will be effective.[260] The extended gentle stress of serial casting results in the repose of links between collagen fibers and realignment of collagen into a parallel and lengthened state. The realignment of collagen structures around the affected joint is also protected.[262]

Guidelines to Serial Casting

Serial casting is indicated for the following:

- casualties who have scar contractures for less than 18 months,
- casualties with contractures that are not responding to traditional methods of therapy,
- casualties with exposed tendons,
- casualties who do not comply with traditional therapy,
- casualties willing to comply with inconveniences of wearing a cast,
- casualties with multiple joint involvement,
- casualties with increased muscle tone, and
- when extra contour or compression must be applied for scar management.

Serial casting is contraindicated when a casualty exhibits heterotopic ossification (HO), excessive edema, or agitation, or does not comply with follow-up appointments.

A thorough chart review, followed by a complete physical examination, will help determine if serial casting will be therapeutically beneficial. The assessment must include radiographs to rule out HO in the affected joint. ROM and the functional components of the affected joint should be assessed to acquire joint feel and mobility while using proper alignment. The end range test should be concluded just beyond the point of resistance to achieve an appropriate end feel.[262] Fragile or friable skin, open wounds, an insensate extremity, and cognitive or emotional impairments should be taken into account when considering serial casting. These considerations are weighed against the advantages of a noninvasive procedure. Serial casting allows for continuous intervention with total contact in addition to continuous stretch, which allows for more concentrated intervention on other affected areas.[260,262]

Long-Term Phase

Casting techniques during the long-term rehabilitation phase closely resemble the interventions of the intermediate rehabilitation phase, but with a focus on mobilization and edema management. Casting is key in reducing and preventing contracture until the wounds reach maturation and full active ROM can be achieved and sustained. A variety of casting techniques are available to help burn casualties recover ROM. Any design that can be made with splinting material can also be made with casting material.[260]

Range-of-Motion Exercise

Acute Phase

Burns heal naturally by contraction, and shortened connective tissue responds to the stress imparted by ROM exercise. A thorough history is required to determine the type of ROM exercises that will meet the casualty's, physician's, and therapist's goals. Additionally, service members who sustain battlefront burns often incur accompanying injuries, such as penetrating wounds or fractures, which require consideration when selecting appropriate ROM exercise.

Acutely burned service members must move gently through full ROM each day to improve peripheral circulation, keep joints nourished, and prevent contractures or decubitus ulcers. All areas injured, including the face, neck, bilateral upper extremities, hands, bilateral lower extremities, feet, and trunk, require attention. Contractures of the flexor surfaces of joints are noted most frequently. However, exercise in all planes of motion must take place. Therapists and casualties collaborate to form the ROM exercise plan most appropriate to the individual injury (Exhibit 13-3). The progression of ROM differs based on the casualty and injury characteristics. All types of ROM exercise apply to all casualties at some point in the recovery and rehabilitation process.

Casualties with larger burns (> 30% TBSA burned) are typically intubated, sedated, and admitted to the intensive care unit, rendering AROM impossible. In these cases, PROM is the mainstay of daily ROM treatment. In the case of smaller burns, casualties are capable of beginning with AAROM or AROM in the acute phase. Casualties admitted with acute hand burns should be evaluated by a therapist within 24 hours of admission.

Although PROM may be the least desirable type of ROM exercise, it can be useful when treating a comatose casualty, and it helps maintain joint mobility and integrity.[263] PROM should be performed gently, slowly and cautiously by a therapist, and precautions should be taken to avoid overstretching joint structures.[177] PROM should be performed in the appropriate planes of motion for each joint while stabilizing the joints above and below. Some clinicians believe that PROM may cause tissue damage that leads to increased scarring, but this theory has not been substantiated.[263–265] Scar tissue responds well to passive force when applied in a steady, controlled manner (Exhibit 13-4).[177] Special instances where PROM is called for include after an escharotomy or fasciotomy, or when it is necessary to preserve tendon gliding and the casualty is unable to perform AAROM or AROM exercises.[177,263] Caution should be exercised when tendons are exposed, especially at the PIP joint of the finger. PROM exercise should be restricted to the amount of force required for an observable tendon excursion to occur.[177] Additional force provides no increased benefit and places exposed tendons at risk for rupture, leading to joint deformities. Once hemostasis has been achieved, any type of ROM exercise is permissible to obtain full ROM and preserve joint integrity.[177]

Continuous passive motion (CPM) devices reduce edema[266] and preserve motion. The deleterious effects

EXHIBIT 13-3

RANGE-OF-MOTION EXERCISE CATEGORIES

- Passive range of motion (PROM) is movement of the joint through the range of movement, which is produced entirely by an external force.[1] The prime mover muscle for the joint does not voluntarily contract to complete the range of movement. Movement performed without assistance on the part of the casualty is considered passive exercise.
- Active assistive range of motion (AAROM) is movement in which AROM by the casualty is supplemented with assistance by an external force.[1] The prime mover muscle for the joint needs assistance to complete the range of movement. AROM with terminal stretch means the casualty vigorously moves the joint through available motion, then the therapist gently stretches the joint in its proper plane of motion, toward the extremes of full motion.
- Active range of motion (AROM) is movement within the range of movement, which is produced by voluntary active contraction of the muscles crossing that joint by the casualty.[1] The prime mover muscle for the joint voluntarily contracts to complete the range of movement.
- Low-load prolonged stretch is a relatively long-term stretch, applied in a controlled manner at a tolerable load.[2] Typically achieved through positioning, splinting, casting or with the use of equipment, this type of stretch is used for a prolonged time and therefore must be tolerable for the long-term benefit to be realized. As it is characterized by length of time rather than number of repetitions, it is different from all other range-of-motion definitions.

Data sources: (1) Kisner C, Colby LA. *Therapeutic Exercise: Foundations and Techniques*. 3rd ed. Philadelphia, Pa: FA Davis; 1996. (2) Humphrey C, Richard RL, Staley MJ. Soft tissue management and exercise. In: Richard R, Staley MJ, eds. *Burn Care and Rehabilitation: Principles and Practice*. Philadelphia, Pa: FA Davis; 1994: 334.

EXHIBIT 13-4

CONSIDERATIONS FOR USE OF PASSIVE RANGE-OF-MOTION EXERCISE

- Level of consciousness
- Level of medication
- Severity of condition
- Decreased range of motion
- Scar contractures
- Peripheral nerve injury
- Preservation of joint mobility
- Anesthesia
- Area of escharatomy
- Preservation of tendon glide

of prolonged immobilization of the synovial joints, demonstrated by numerous orthopaedists,[267] inspired the development of CPM machines. There are two basic CPM designs. One is an anatomical design that moves the joint in an arc of motion as similar to actual anatomical movement as is possible. The other design is free linkage, which moves body parts adjacent to the involved joint. For example, it can move the forearm while allowing the casualty to move an elbow or shoulder if possible.

The anatomical motion machine is probably the more comfortable of the two devices. Most of the machines can be set to pause at the end range and resemble slow, prolonged stretch. Machines may be portable, free-standing, or attached to a bed or chair. Those who are most likely to benefit from use of CPM in addition to customary physical and occupational therapy include individuals who have burns involving multiple joints; comatose casualties; and casualties who refuse to perform active motion because of pain, swelling, or anxiety. The specific protocol of use for CPM machines depends on a casualty's tolerance and limitations.

The hand CPM device restores hand ROM. It does not damage skin grafts or newly healed tissue, and the pain experienced is the same as that with conventional hand stretching and exercise therapy.[266] Adaptations can be made to block MCP or PIP motion, and some splints can be used over the dorsum of the hand to achieve improved composite MCP and IP flexion. AROM exercise of the involved hand joints should be measured daily to assess for skin tightness and to evaluate joint mobility. If the casualty is able, hourly AROM exercise and ADL participation should be encouraged at home to maximize ROM. If the casualty is unable to participate in sufficient AROM exercise, then PROM exercise should be performed at least three times a day on the involved joints. Dressings should be applied with digits individually wrapped to permit participation in ROM exercises. To maximize tissue elongation, PROM activities should include low-load force with a long duration of hold.[249]

Shoulder CPM machines, which attach to a bed or chair and move the shoulder through 180° of flexion or abduction, help prevent axillary scar bands and nourish shoulder joint cartilage. Additional models move the shoulder in other planes, including a figure-eight pattern. Some models incorporate the elbow, providing ROM for both joints simultaneously.

The elbow CPM can be set for low-load stretching and auto reverse, so there is little risk of overloading the joint or surrounding tissues (Figure 13-56). The degree of elbow flexion, extension, pronation, and supination can be adjusted to the casualty's tolerance. When set for gentle motion, this device provides thorough ROM while minimizing the risk of HO.

Knee CPM machines should be used when the casualty is not participating in active therapy (Figure 13-57). They provide improved motion at the knee and can be set up to address the ankle and hip joints, as well. These CPMs are useful until ambulation is possible, or longer if joints continue to exhibit ROM limitations.

Showering and dressing changes are good opportunities to perform ROM exercises. During these procedures, bandages and wraps that typically inhibit ROM are removed, allowing for more thorough treat-

Figure 13-56. Continuous passive motion device for the elbow.

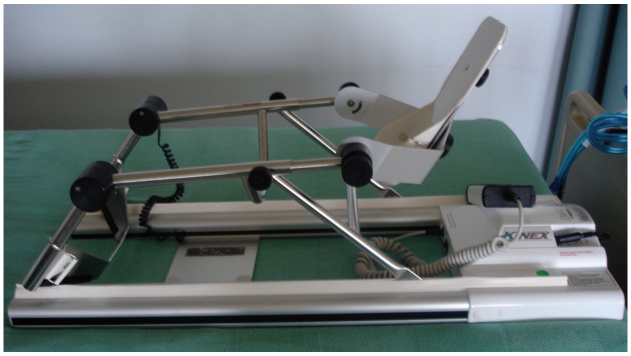

Figure 13-57. Continuous passive motion device for the knee.

ment. Therapists can see the affects of ROM exercise on the tissue and can ensure enough force is being exerted to elongate the tissue. Additionally, because the casualties' pain will already be managed for the wound care procedure, ROM exercises will be better tolerated (however, casualties must not be overloaded with pain from both wound care and ROM exercises).

When casualties are under anesthesia for skin grafting or debridement, ROM exercises can be used to evaluate range and determine the cause of limitations. ROM may be limited because of soft tissue contracture or pain; anesthetizing the casualty can help distinguish the cause. If the primary cause of the limitation is pain, the pain management plan can be adjusted to improve the casualty's tolerance. If the primary cause is determined to be soft tissue contracture, the casualty should be encouraged to increase the frequency and vigor of rehabilitation. A gentle, slow, controlled force in the correct orientation is the key to safe ROM exercise, particularly when the casualty is anesthetized.

Intermediate Phase

Casualties generally regain responsiveness in the intermediate phase, and PROM exercise should be replaced with AAROM exercise if full ROM has not been achieved. AROM exercises should be initiated when the casualty has full ROM. Alert casualties must learn to move past the painful range to the extremes of joint motion; this can be accomplished with gentle terminal stretching. AAROM exercises with terminal stretching teach casualties how to move the affected body part and achieve the extremes of motion that are not used spontaneously during activity (Exhibit 13-5).[177]

For AAROM exercises, healing and healed tissue should be stretched to the point of tissue blanching and maintained until the tissue becomes more pliable or tissue color returns.[177] A casualty's tolerance to the force applied must also be considered. Typically, 1 to 2 lb of force is required to cause blanching.[177] Several preliminary repetitions must be performed to ensure tissue is at its optimal length prior to sustaining the force applied.[177] Best results are achieved when a casualty performs AROM exercises to the limits of pain or tissue restriction, and then the therapist applies the required slow and controlled overpressure to complete the ROM exercise.

Additional AAROM exercises can be performed with various devices, such as pulleys, finger and dowel ladders, and weights. These activities use the casualty's unaffected limbs as the source of overpressure to achieve full ROM at the affected joint. A stationary bike or upper-body ergometer can also be used for AAROM exercise, as can the casualty's body weight. These AAROM techniques allow casualties some control, improving tolerance and promoting compliance and independence.

AROM is the most desirable form of ROM exercise.[265] It tends to be less painful and activates the muscle pump, enhancing venous and lymphatic return and reducing edema.[178] However, AROM should only be used with casualties who can achieve full ROM within a reasonable amount of time (Exhibit 13-6).[177] AROM is also the safest form of ROM exercise and is recommended for joints with exposed tendons or immature skin grafts, or those at risk for HO, where PROM exercise and AAROM exercise must be used sparingly and cautiously. Casualties generally self-limit voluntary muscle contractions because of pain and will not produce the force required to rupture a tendon or disrupt skin grafts.[265] Active motion decreases the risk of HO at the elbow joint.[268,269] Occasionally, casualties need encouragement and relaxation reminders in order to tolerate ROM exercises. If casualties are still unable to tolerate the force required to achieve scar tissue blanching, their pain management plan must

EXHIBIT 13-5

CONSIDERATIONS FOR USE OF ACTIVE ASSISTED RANGE-OF-MOTION EXERCISE

- Limited range of motion
- Scar contractures
- Area of escharotomy
- Skin graft adherence
- Increased physiological demands
- Decreased cardiac reserve
- Poor ventilation and respiratory status
- Decreased strength secondary to prolonged hospitalization

EXHIBIT 13-6

CONSIDERATIONS FOR USE OF ACTIVE RANGE-OF-MOTION EXERCISE

- Edema reduction from muscle pumping
- Increased circulation
- Initiation of exercise first week after skin grafting
- Conditioning of uninvolved areas
- Exposed tendons (except the proximal interphalangeal joint)
- Prevention of soft tissue shortening
- Prevention of muscle atrophy

be reviewed and modified to improve tolerance of ROM exercise.

Full ROM returns most quickly when inflammation is minimal, wound healing is complete, and a casualty complies with rehabilitation. Applying heat prior to ROM exercises may also be beneficial.[263,265,270–272] Joint mobilization and distraction of joint surfaces, in conjunction with stretching, may decrease pain and muscle spasm and increase the effectiveness of stretching.[273]

Casualties must invest a significant amount of mental concentration and vigorous physical energy for ROM exercises to be effective. Distractions, such as visitors, should be minimized to allow casualties to concentrate on restoring greater function.

A clock that announces time intervals, such as one that rings every 15 minutes, can help a casualty remember to stretch eyelids or other important contractures throughout the day without the verbal cues that may come to seem like nagging from a therapist. A casualty may also be able to relax and benefit more from ROM exercises when the therapist uses another activity, such as conversation, to distract the casualty from the pain at the treatment site. During the latter phases of recovery, casualties wear external vascular supports, which may need to be removed for 10-minute periods for ROM exercises but donned immediately after.

Post-burn management of a superficial partial-thickness burn differs from management of a deep partial-thickness or full-thickness burn. Superficial partial-thickness burns are at minimal risk for contracture.[274] Full ROM is usually restored with AROM exercises performed in a home program, and AROM exercises are initiated as soon as possible. Adequate pain control is imperative to allow participation in a home program. Splinting is only necessary if poor exercise participation is noted over a prolonged period of time and ROM gains are not being made.

Deep partial-thickness and full-thickness burns are at a high risk for contracture.[274] AROM and PROM exercises should be consistently performed throughout the intermediate rehabilitation phase. Home exercises and supervised therapy should include low-load force and long duration PROM exercises and should place the involved tissue at its greatest length. Isolated joints should be stretched, with the involved skin in a shortened position prior to elongation. For example, isolated MCP, PIP, and DIP PROM exercises should precede a composite stretch involving combined MCP, PIP, and DIP flexion stretching. AROM exercises in the same movement pattern should immediately follow passive exercises.

Long-Term Phase

During the long-term rehabilitation phase, as with the early phases, low-load, prolonged stress is recommended for minimizing and preventing burn scar and joint contractures.[275] Gentle, graded, and prolonged ROM stretching, preferably achieved actively by the casualty, will help collagen fiber realign into a longer, less tightly convoluted, mat-like configuration. At this point, if burn scar contractures are present, they are usually so severe that they will not resolve with prolonged ROM stretching alone. Additional interventions, such as positioning, splinting, casting, strengthening exercises, and functional activities will be required. However, the burn therapist must reserve adequate time for prolonged individual joint and composite ROM stretching because casualties will need encouragement, supervision, and hands-on treatment during this phase of rehabilitation.

Low-load, prolonged ROM stretching has the additional benefit of gently, slowly overcoming muscular cocontraction in casualties who fear pain. With prompting, casualties who have had adequate analgesia during the first two phases will put forth maximum effort to move through the extremes of motion, preventing joint motion from becoming painful, nourishing joint cartilage, and elongating surrounding burn scar and soft tissue. Low-load, prolonged ROM stretching may also be combined with work-equivalent activities. All other types of ROM exercise should be applied and incorporated into written home programs during the long-term rehabilitation phase.

Strengthening and Conditioning

Acute Phase

Casualties recovering from burn injuries will require strength training and cardiovascular reconditioning. These treatments can begin as soon as the casualty is admitted to the hospital, and may continue throughout several years. Although each burn casualty is unique, all will experience some form of deconditioning. When designing a rehabilitation program, therapists should consider the casualty's phase of recovery, the percentage of TBSA burned, the etiology of the burn, comorbitities (including inhalation injuries), postsurgical skin grafting precautions, and prior level of function.[276] Depending on the casualty's status, strength and conditioning programs can commence on the same day as admission.

In the sitting position, casualties experience reduced pulmonary congestion, facilitated diaphragmatic expansion and ventilation, and ease of dyspnea. If possible, a casualty can be transferred to a bedside chair, with or without assistance, and remain sitting for as long as tolerated. When a casualty is sedated or otherwise unable to assist with the transfer, a total lift chair may be used (Figure 13-58). A casualty can be transferred laterally from a bed to a chair in a flattened position. From there, a therapist can manipulate the chair into an upright sitting position, where the casualty may remain for as long as tolerated to receive the benefits of upright sitting. Some hospital beds may also have specific settings that move the bed from a supine position to an upright sitting position if the casualty is unable to be laterally transferred to the total lift chair.

When a casualty is medically cleared for lower-extremity weight bearing but is unable to stand without great assistance, a therapist may use a tilt table. With a tilt table, the casualty is secured to the plinth with a series of straps while in the supine position. A therapist can mechanically tilt the table into the upright position and can pause the tilt at any interval to allow a casualty to slowly become acclimatized to the upright standing position. The casualty's response to the activity will dictate the progress of the tilt. Because the straps restrict casualty movement, the motion is generally passive and recruits mainly postural muscles. The primary benefit of a tilt table is its ability to decrease orthostatic hypotension through gradual retraining of the cardiovascular system to the upright position.[277] It also allows gradual weight bearing through the lower extremities.

If a casualty is able to tolerate the standing position of the tilt table but does not have the endurance to stand for any great length of time, the standing frame may be appropriate. The standing frame uses a system of levers to raise a casualty from the sitting position to the standing position with a solid support, allowing the casualty to receive the cardiovascular benefits of an upright position while experiencing weight bearing to increase lower-extremity and trunk strength.

If a casualty is cleared for lower-extremity weight bearing but still unable to stand without great effort, a therapist may use a modified tilt table (Figure 13-59). The modified tilt table has a system of pins and locks that allow the plinth to slide so the casualty may

Figure 13-58. Total lift chair used for early out-of-bed transfers.

Figure 13-59. Modified tilt table.

perform an inclined squat unilaterally or bilaterally in an environment of decreased gravity resistance. This permits the casualty to increase lower-extremity strength in preparation for ambulation.[277]

Early ambulation is vital to the success of all casualties. Ambulation may begin while a casualty is still intubated if deemed safe. If the casualty is recovering from lower-extremity skin grafting over a joint, ambulation may begin as early as the third day following operation. Casualties that ambulate within this timeframe experience increased ROM, cardiopulmonary function, and muscular strength compared to those that remain immobilized for a longer period of time.[278,279]

ROM exercise also promotes cardiovascular reconditioning. PROM of all extremities requires the casualty to exert 1 metabolic equivalent (MET), AROM exercise of all extremities requires 1 to 1.5 METs, and AROM with moderate resistance requires 1.5 to 2 METs. ROM exercises not only increase joint mobility and integumentary movement, but promote proper cardiovascular reconditioning and increase muscular strength.[280]

Intermediate Phase

When burn casualties have 50% to 100% wound closure, they transition to an outpatient program. Prior to discharge from the hospital, the casualty should be able to transfer and complete ADLs with little to no assistance. Practicing these activities is a functional method of increasing strength and cardiovascular endurance. When casualties are preparing for discharge, strengthening and conditioning therapy sessions should focus on increasing independence with ADLs.

Resisted ROM exercises can be provided by the therapist, resistance bands, or weight-lifting equipment, and should progress in accordance with the casualty's treatment plan. Circuit training programs increase muscular strength and cardiovascular endurance while providing variety in the casualty's program. Pilates exercises, on a mat or with equipment, increase strength, promote proper body alignment, and improve ROM.[281]

Casualties can use gym equipment to increase cardiovascular conditioning and muscle strength. Recumbent bicycles and elliptical machines increase cardiovascular strength without increasing weight bearing. The NuStep machine (NuStep Inc, Ann Arbor, Michigan), a recumbent cross-training machine, promotes lower-extremity strength and ROM without increasing weight bearing in the hip and knee joints. The American College of Sports Medicine recommends that adults exercise at moderate intensity for at least 30 minutes on most, if not all, days of the week.[282] Casualties with burns are no exception to this recommendation. Casualties should begin their reconditioning slowly, with the long-term goal of meeting the American College of Sports Medicine standard.

Long-Term Phase

Once a casualty transitions to the long-term rehabilitation phase, high-level functional activities should be encouraged. In the rehabilitation gym, isokinetic exercises can be used to improve strength and power, in addition to maintaining ROM.[283] When participating in outdoor activities, casualties should be aware of their own limitations concerning thermoregulation. Many areas of healed burn scar or skin grafts are unable to produce sweat to cool the body; therefore, the casualty is at a greater risk for overheating and should take the necessary precautions.[284] Casualties should also keep water close at hand and remain in the shade when possible if outside.

Burn casualties have a higher resting metabolic rate than individuals without burns. Despite having an elevated resting metabolic rate, the stress on the casualty's cardiopulmonary system resulting from activity increases resting metabolic rate proportional to that of an individual without burns.[285] The Karvonen method should be used to determine the appropriate heart rate range because it takes into consideration the casualty's resting heart rate (Exhibit 13-7).[276] Ultimately, proper rehabilitation for burn casualties should consist of a cardiovascular reconditioning and muscle strengthening program that maximizes functional outcome and return to duty.

EXHIBIT 13-7

THE KARVONEN METHOD FOR DETERMINING HEART RATE RANGE

Target heart rate = ([maximum heart rate − resting heart rate] • percent intensity) + resting heart rate

Activities of Daily Living

Acute Phase

Functional activities should be practiced around the clock when possible. Not only should the burn team be aware of what a casualty is capable of doing in areas of self-care, but the casualty's family should know as well. Frequently, the burn team and family perform activities that a casualty is capable of performing independently. This is detrimental because casualties gain self-esteem and self-confidence by being as independent as possible. Families can be directed to participate with casualties in activities such as applying lotion, organizing get-well cards, answering mail, or playing games, rather than assisting with essential tasks, such as feeding, that a casualty must learn to perform independently.

ADLs, such as independent phone use, self-feeding, shaving, brushing teeth, and self-toileting, are beneficial exercises for the upper extremities. Repetitive calisthenics may be boring; however, casualties understand the importance of practicing daily living skills and are often motivated by the desire to regain independence. It is helpful for casualties to be reminded of the goals of regaining maximum independence with the fewest possible scar bands and with the least possible disfigurement while struggling with self-care or uncomfortable exercises.

Participation in functional ADLs is important in the rehabilitation of the burn casualty.[286] The major ADL classifications are:

- Mobility: including movement in bed, wheelchair mobility and transfers, indoor ambulation with special equipment, outdoor ambulation with special equipment, and management of public or private transportation.
- Self-care: including feeding, bathing, toileting, grooming, and dressing.
- Managing environmental hardware and devices: including the ability to use telephones, doors, faucets, light switches, scissors, keys, windows, and street control signals.
- Communication skills: including the ability to write, operate a personal computer, read, type, and use the telephone, a tape recorder, or a special communications device.
- Home management activities: including shopping, meal planning and preparation, cleaning, doing laundry, caring for children, and operating household appliances.[287]

There are numerous benefits gained from independently performing functional tasks and activities. Physical benefits include improving ROM, fine motor dexterity, and overall endurance. The psychological benefits include increased self-reliance, improved self-esteem, and positive feelings about the future. Involving casualties in planning and implementing functional activities early on allows them to more easily resume social roles and decreases posttraumatic disability later. Independent performance of ADLs also hastens hospital discharge to home or a less-supervised setting.

Several factors can influence the overall outcome of a functional activity program, including medical status (percent of TBSA burned, degree, and location of burns); age; degree of cooperation and motivation; premorbid physical, psychological, educational, intellectual, economic, and functional status; and social resources. Additional factors that impact independent living include memory loss from medication, pain or severity of illness, cognitive changes due to anoxia or accompanying head injury, preburn or medication-induced impaired judgment, depression, and pain. Successful programs involve the casualty and family in prioritization, goal setting, and problem solving for accomplishing functional activities.

Functional activity performance can be analyzed in terms of independence, speed of performance, and safety when considering how a casualty accomplishes tasks. Independence in ADLs can be achieved in a number of ways. Burned soldiers need to perform ADLs without adaptive equipment, using repetitions to improve strength and endurance. When adaptive equipment is used in the earliest phase of rehabilitation, it should be discontinued as soon as possible. Occupational therapists can make recommendations concerning adaptive equipment, task alteration, adaptive techniques, and environmental modifications.

Burn casualties are encouraged to self-feed, despite hand burns. Conventional silverware with handles enlarged by elastic rolls and an elevated table are often adequate to encourage self-feeding. Adaptations for self-care are discontinued as soon as possible to avoid dependence and to increase hand and upper-extremity ROM. Adaptive feeding devices include long-handled silverware, utensils with built-up handles, and universal cuffs (Figure 13-60). Universal cuffs with hook-and-loop fasteners or D-ring attachments allow casualties to don them without assistance. Expanded universal cuffs can be fabricated for bulky dressings, casts, or splints. Additional devices, such as bent-angled silverware or bendable, foam-handled spoons, are available if wrist radial deviation is permanently limited (Figure 13-61).

Figure 13-60. Adaptive eating utensils with built-up handles.

Figure 13-61. Bendable foam-handled eating utensils.

Utensils with extensions can be helpful when there is limited mobility in decreased shoulder or elbow flexion. Utensils with swivel attachments or horizontal handles replace forearm supination. Vertical handles can be used when the forearm is fixed for midposition. Long straws held in place by straw clips, adaptive mugs and glasses, easy-grip mugs with protruding handles, glasses with a cutout area for the nose, and bilateral glass holders can aid in drinking. Sealed mugs are also helpful when a casualty lacks hand control. Weighted mugs can be used when a casualty exhibits a tremor. When inhalation injuries result in swallowing difficulties, vacuum flow suction mugs can prevent choking by controlling the rate at which liquid is released.

There are several types of adaptive equipment that provide stabilization when a casualty has use of only one hand. Nonskid mats can be placed on counters or tabletops to prevent plates and bowls from slipping. Scoop dishes and plate guards provide stability for utensils (**Figure 13-62**). A rocker knife can be used for cutting when a casualty is permanently unable to use one hand. Pan and bowl holders also provide stability. Adaptive cutting boards have a nail to stabilize items for cutting, and built-up corners to hold bread while buttering. Special openers for jars, cans, or bottles are helpful for casualties with only one functional hand or decreased hand strength or control.

Grooming is another self-care activity that can be performed early. Oral care and hair brushing and combing are initiated when bathroom privileges begin. Although rarely needed, a built-up handle or universal cuff can compensate for the inability to grasp a toothbrush, hairbrush, or comb. A temporary extended handle can make teeth brushing easier while ROM improves. Toothpaste tube squeezers are available if fine motor dexterity is limited. Denture brushes with suction cups are also useful when only one hand is functional. Adding extended handles (straight or bent-angled) to hairbrushes and combs is useful when shoulder flexion, shoulder external rotation, or both are lacking.

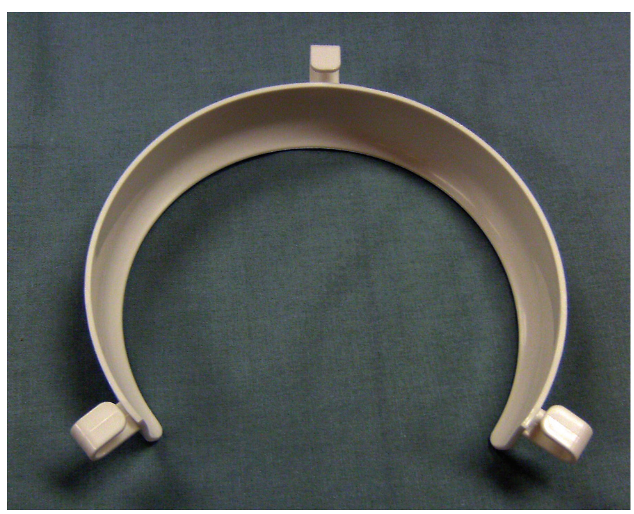

Figure 13-62. Plate guard used to assist with self-feeding.

During the acute phase, toileting skills vary according to the extent of the burn. Casualties with larger TBSA burns may be unable to participate in self-toileting because of sedation, intubation, catheterization, and limited upper-extremity use. Less-involved casualties can use a variety of large-handled urinals and spill-proof containers at the bedside, and can transfer to and from the bedside commode for bowel activities (which will help advance mobility as well as toileting skills). As casualties progress, they may be left with some level of deficit requiring use of a toileting aid to manipulate toilet paper, or they need to incorporate assistive technology such as a bidet, autoflush commodes, or a raised commode seat to assist with sit–stand transfers.

Communication is a functional activity that is very important in all phases of rehabilitation. This is a broad category that includes expression, reading, use of environmental controls, writing, and telephone and typewriter or computer use. Large button, programmable phones can be adapted with speakers, allowing early independent telephone use. Because telephones keep burn casualties in touch with their support systems, adaptations are requested early. An adjustable gooseneck phone holder allows a casualty to speak and hear without holding the telephone. The gooseneck holder affords more privacy than the speakerphone. There are also special phone holders for casualties with weak grasps. A phone flipper lever can be added to the base of a telephone to activate the connection button if a casualty cannot press it. A flipper can be operated by hand or by mouth stick. Another type of phone adaptation is a touchtone adapter, which enlarges regular push buttons and can be operated by a very light touch.

Expression is important because it allows casualties to interact with others in the environment and decreases fear and frustration. A casualty with a severe burn may be intubated, ventilator-dependent, and unable to speak. Prolonged exposure to smoke can result in vocal cord injuries, leaving speech unintelligible or contraindicated. Communication boards composed of letters, pictures, body maps, words, or complete sentences are commonly used to convey thoughts if the casualty can point to them. There are also sophisticated communication devices with voice outputs that can be operated by touch or by a light-activated beam. However, because casualties are often medicated or too ill, complicated communication devices are best used in the later stages of recovery.

As a casualty progresses, a number of environmental controls can be adapted for independent use. Environmental controls are available in a wide variety of switching systems with specific mounting devices. The basic plate, light touch plate, air cushion, rocker, foot, wobble, sip-and-puff control, and joystick are common switch options. The same switch and input device method can also be used to operate a communication device, computer, or electric wheelchair in other phases of rehabilitation. Switches can be specially ordered or can be purchased from electronics retail stores.

Reading can be a very important functional exercise when a casualty is confined to bed. There are several types of book and magazine stands that can assist with reading. Bed readers, positioned slightly overhead, are useful when an alert casualty must stay supine. A prone casualty can use a floor stand or music stand with pages stabilized by clothespins. Height- and angle-adjustable bookstands can be clamped to a bedside table or headboard. Bookstands with automatic page turners can be used if a casualty is unable to turn pages independently. A mouthstick can also be used to turn pages. Mouthstick devices have increased friction at the end and can be adapted to fit universal cuffs. Prism glasses allow a casualty to look down at pages to read while the head is positioned forward. In cases of preexisting visual acuity deficits, a variety of magnifiers can be used, in addition to large-print books.

Writing is another important self-care activity that can be performed in early stages of burn rehabilitation. Pen and pencil holders are useful temporary adaptations when a casualty's ability to grasp or pinch is decreased. Built-up foam handles or plastic easy-grip adapters facilitate holding a pen. Special splints or adaptive writing utensils can be fabricated out of thermoplastic materials, or commercially available splints can be obtained to customize writing devices. A clipboard can be used to stabilize paper when the nondominant hand is unable to hold it steady for writing. A writing device can be attached to a mouth stick if neither hand can write.

Intermediate Phase

As a casualty becomes more independent in the hospital, it is important to identify home management responsibilities, including general maneuvering, operating home appliances, cooking, and cleaning. It is important for casualties and their families to identify the tasks that the individual wants or needs to perform. Ideally, a survey of home needs is accomplished with the casualty, family, and a staff member, but it can also be performed by just the casualty and family. A home evaluation focusing on independence and safety can identify functional or environmental limitations, and casualties can use mobility aids and adaptive equipment in the home to determine the level of assistance that will be required after hospital discharge.

It is important to avoid trauma or shearing the skin surface while practicing ADLs during the intermediate phase. Functional activities, such as feeding, grooming, and communication, should be performed, and adaptive equipment can continue to be used. Applying lotion to healed or unburned areas increases sensory input and decreases hallucinations from sensory deprivation.

Casualties usually view hospital discharge as a welcome termination of burn care, exercise, and pain, and they often eagerly anticipate what they believe is a well-deserved rest. Recalcitrant casualties who endure exercise and scar control devices at the hospital may abandon custom-made elastic stockings, traction, total contact splints, and activity once they feel safe at home. Many casualties believe returning home will restore their previous physical and emotional status. However, it quickly becomes obvious that achieving adequate epithelial healing at home is only the beginning of rehabilitation and return to active duty.[288] Work-hardening programs—graded work activities that simulate a casualty's work requirements— are appropriate for severely burned casualties. The activities are adapted to assure success in the simulated activity and are designed to lead to progress in work performance. Acitivities can be sequentially redesigned to require less adaptation until adaptation is minimized. Work hardening also reinforces protective measures for friction, trauma, chemical irritants, and extremes of weather or temperature.

The best outcomes result when the casualty, therapist, and physician formulate an appropriate active-duty limitation outline with each clinic visit. It can be helpful for casualties to return part time to as many active-duty tasks as possible, even if their ability to perform tasks is limited. Jobs done by habit eliminate the need for casualties to constantly think about the discomfort of exercising.

Long-Term Phase

In the long-term rehabilitation phase, casualties continue to actively participate in functional activities that are consistent with life roles and return to active duty. As they become medically stable and burn scars and skin grafts become more durable, casualties can pursue a variety of activities; however, caution is required because maturing burn scars and skin grafts remain fragile in this phase. Casualties must learn proper interventions to compensate for sensory, pigmentation, and circulatory changes while performing ADLs. At this time, casualties must begin to wean off adaptive equipment used in the initial phases of rehabilitation. However, casualties with electrical injuries, amputations, or burns greater than 70% TBSA may continue to use adaptive equipment if residual impairments exist. For severely impaired casualties, sophisticated orthoses and adaptive equipment should be used to reduce disability.

Adaptive silverware, drinking aids, and stabilization devices are rarely used in the long-term rehabilitation phase. If decreased shoulder ROM and proximal weakness are permanent, suspension slings or mobile arm supports can be used when a casualty is seated. These devices support the entire arm, assist shoulder flexion, and allow the elbow to move in a gravity-eliminated plane. The mobile arm support is available in standard, elevating, and table-mounted models. Battery-powered or electric feeding machines operated by microswitch control are available for casualties in which severe burn has resulted in upper-extremity amputations. The switches can be operated by various body parts that can predictably and consistently control the machine.

Casualties can participate in additional grooming tasks, such as shaving with special holders for electric or regular razors (Figure 13-63). Casualties should regularly care for nails to prevent excoriation of skin during scratching. Mounted nail clippers (Figure 13-64) or files are available to assist with such activities.

At this stage, casualties should begin to assume responsibility for the condition of their skin, burn scars, and skin grafts, inspecting them regularly to identify any areas of concern. Flexible inspection mirrors are available to assist with this task. Casualties can also assume responsibility for wound care and should demonstrate the ability to safely cleanse and apply medication and dressings to any remaining wounds. Casualties should also massage scars and apply moisturizer as indicated.

Figure 13-63. Adaptive holding device for a shaving razor.

Figure 13-64. Commercially available adaptive mounted nail clippers and file.

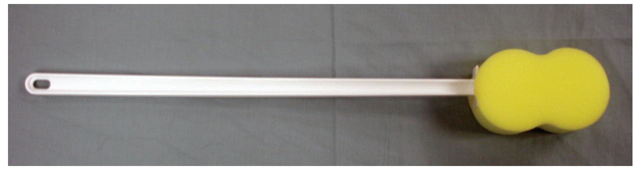

Figure 13-65. Adaptive long-handled sponge for self-bathing.

As casualties progress, they will want to perform toileting tasks independently. A variety of adaptive equipment is available to ensure safety and independence. Safety rails can be mounted on either side of the toilet to increase transfer stability. Use of a raised toilet seat is usually discouraged, but it can be helpful when a casualty permanently lacks strength or control in the lower extremities and cannot perform transfers with a standard seat. A bedside commode is necessary in the hospital or at home only when ambulation to the bathroom is not possible. Toilet aids are also helpful if a casualty lacks the necessary upper-extremity ROM for hygiene.

A number of adaptive safety aids also allow independent bathing. It is often safer for casualties to bathe in a seated position if endurance is low. Edema can be minimized by keeping burned legs elevated until bathing is finished and external vascular supports are reapplied. Shower seats, with or without backs, provide stability in walk-in showers. Extended tub benches allow casualties to bathe independently on a seat if they are unable to step over the tub safely. Grab bars can be mounted on the tub or wall to further increase stability with transfers. A flexible shower hose permits casualties to bathe independently in a seated position if they are unable to stand for a prolonged period of time. Long-handled sponges compensate for decreased trunk or upper-extremity ROM and allow a casualty to wash feet and back independently (Figure 13-65). A bath mitt can stabilize a bar of soap if the casualty's grasp is weak. Safety features, such as nonskid surfaces or bath mats, can be applied to the bottom of the tub to prevent slipping.

Casualties assume total responsibility for donning external vascular support garments, orthoses, and clothing during the long-term rehabilitation phase. Casualties must be cautioned against pulling too rigorously on garments while donning them, which could injure fragile skin. A nylon stocking contact layer worn over wound dressings secures them and facilitates donning external vascular supports. Casualties must demonstrate donning facemasks, microstomia splints, hand splints, and lower extremity orthoses independently in front of a mirror to ensure proper fit.

There are a number of adaptive aids that assist with donning pressure garments and regular clothing. It is often more effective to use practice time donning items without adaptations when a casualty is expected to achieve enough ROM in a short period of time to make adaptations unnecessary. Long-handled aids are helpful in cases where there is decreased trunk, hip, and knee flexion, and hip external rotation. Many different "reachers" can be used to don pants; they are available in a standard size, extended length, and a self-closing model for decreased hand grasp (Figure 13-66). Long-handled shoehorns and stocking aids help with donning shoes and socks (Figure 13-67). A dressing stick can be used for donning pants and shirts if upper-extremity ROM is limited.

Other adaptive aids are useful if finger dexterity is limited or if a casualty has use of only one hand. Elastic shoelaces and button and zipper aids are available in

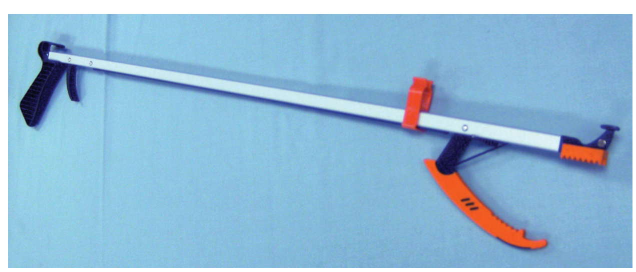

Figure 13-66. Adaptive reaching device used for a variety of self-care activities.

Figure 13-67. Long-handled shoehorn for donning shoes.

standard and easy-grasp varieties (Figures 13-68 and 13-69**)**. Hook-and-loop fasteners can replace buttons and zippers, and large loops can be sewn onto pants to help casualties with donning. In general, some types of clothing are relatively easy to put on, such as large shirts, gym pants, and hook-and-loop closure tennis shoes, and many varieties of easy-to-don clothing are available through special-order catalogues.

A number of home accessibility aids can also facilitate independence. Wheelchair ramps are important modifications for some casualties. Stair glides are often used within a house to allow movement from one floor to another. High-rise furniture leg extenders make independent transfers to chairs and couches easier, and lamp and light switch extensions are helpful if a casualty has decreased finger dexterity or is functioning from a wheelchair. A variety of turning adaptations can help a casualty operate doors, faucets, stoves, and radiators when grasp is limited or weak (Figure 13-70).

As burn casualties continue in the rehabilitation process, they will generally resume kitchen activities. In addition to the adaptive kitchen and feeding tools already mentioned, home kitchen modifications can be made to make cooking safe and efficient. For example, special devices can be used to safely operate an oven. Push/pull devices can be used to manipulate hot oven racks when a casualty has limited finger dexterity or sensory impairments. Long oven mitts made of flame-retardant fabric protect sensitive skin. Kitchen roll carts can move hot or heavy pans and dishes; if the cart is sturdy, it may also be used like a wheeled walker for stability. A positioning mirror placed over the stove allows wheelchair-bound casualties to better see the stovetop and cook safely.

Figure 13-68. Elastic shoelaces.

As with many of the other functional activities, adaptive housekeeping aids compensate for a decreased ability to reach or grasp. Examples include extended dustpans and brushes, long-reach sponge mops, extended dusters, and housekeeping cuffs with hook-and-loop attachments that permit casualties with weak grasps to hold a broom or mop handle.

During the long-term rehabilitation phase, some of the communication devices used in earlier phases are unnecessary, although others will still be required. Casualties who are able to be out of bed in a seated position can practice typing and computer activities. Typing aids that fit over the hand and depress keys are commercially available or can be custom made. These aids are useful when fine motor dexterity is lacking and a casualty is unable to access the keyboard in a traditional way. If a casualty has limited ROM in the shoulders or elbows, a keyboard can be mounted on a special device to allow access. Detachable keyboards are also available for casualties unable to access the keys in the usual location. Key guards that separate keys are useful for casualties who have impaired coordination. One-handed users can use a key lock to simultaneously press multiple keys, and there are a variety of special switches casualties can use to operate environmental controls or activate computers.

Mobility

Acute Phase

Early initiation and aggressive progression of mobility activities are critical during the acute rehabilitation phase. ADLs orient casualties to the upright position,

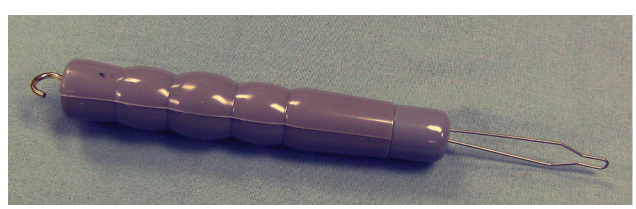

Figure 13-69. Button aid for self-dressing.

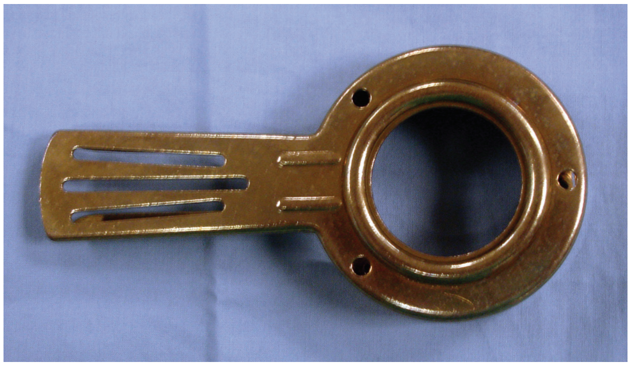

Figure 13-70. Door knob extension.

decreasing risk for pulmonary infection and complications, improving cardiovascular function, preventing orthostatic hypotension, preventing skin breakdown and decubitus ulcers, and restoring strength and independent functional mobility.[289] Exercise has also been shown to increase energy and decrease depression[290] as well as facilitate wound healing and pain reduction by more rapidly decreasing edema and inflammation.[289]

Mobility activities are commonly divided into three categories: (1) bed mobilities, (2) transfers and pregait activities, and (3) gait or ambulation activities. Bed mobilities include rolling, scooting, bridging, bed chair positioning, bed tilts, and supine-to-sitting transfers. Pregait activities include transfers (sit-to-stand, squat pivot, stand pivot, and stand step), and out-of-bed activities, such as sitting upright in a chair and standing frame or tilt table sessions. Trees et al described a novel therapeutic device that allows casualties to be challenged orthostatically while simultaneously performing body-weight–resisted squatting exercises for lower extremity strengthening.[277] This device has recently become commercially available (see Figure 13-59). Gait activities, or ambulation, complete the casualty's progression of mobility activities. Casualties may require assistive devices, such as canes, crutches, or walkers, depending on medical status and associated injuries. Close communication and coordination of the interdisciplinary burn team is critical to developing a mobility plan that safely enhances the casualty's recovery.

During the acute rehabilitation phase, several factors must be taken into consideration when determining the appropriate mobility activities. Factors to consider include the following:

- the casualty's level of alertness and orientation,
- the casualty's ability to follow commands,
- the casualty's baseline vital signs,
- the presence of new (< 1–3 days old) skin grafts that require immobilization or protection,
- the casualty's respiratory status (ie, on a ventilator, undergone a tracheostomy with oxygen support, or spontaneously breathing room air),
- the casualty's mobility activities, which may be precluded by certain treatments or procedures (eg, blood transfusion, dialysis, or respiratory treatments),
- the presence of orthopaedic issues that require accommodations,
- the need for vascular support wraps to the dependant extremities, and
- the physician's expectations for mobility activities.

Generally, some type of mobility activity along the continuum of activities may be safely performed after close coordination with the interdisciplinary burn team (Figure 13-71).

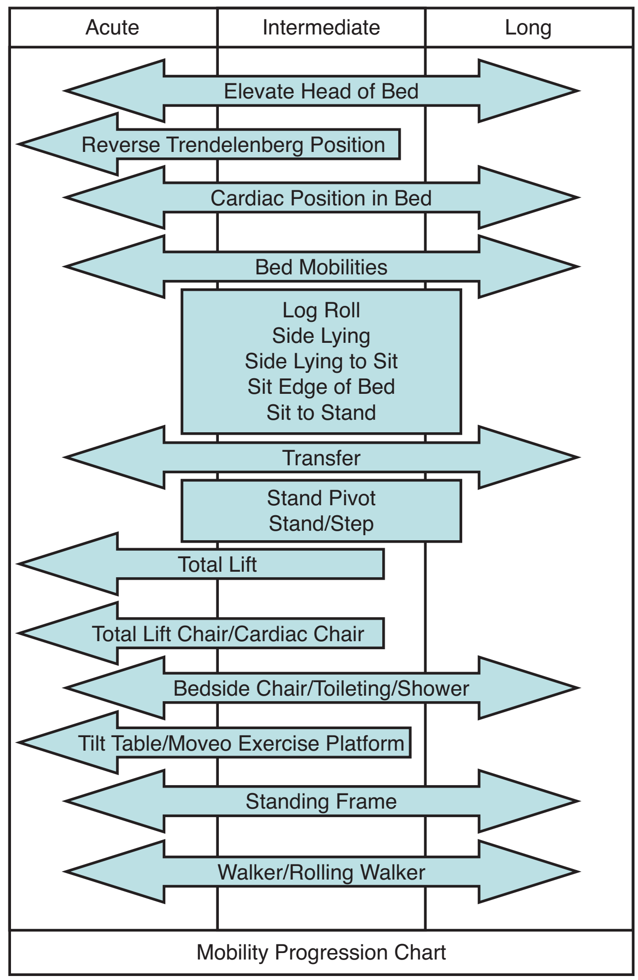

Figure 13-71. Continuum of mobility activities throughout the phases of burn rehabilitation.

Depending on the severity of injury and the casualty's status, a casualty may begin mobility activities anywhere along the continuum and progress as appropriate. For severely injured burn casualties (TBSA burned > 30%), the casualty is usually initially positioned in a bed chair position or bed tilt and alternated every 2 hours, or as indicated by a physician. As the casualty's status improves, bed mobilities and lateral transfers to a chair are implemented. Casualties are encouraged to spend several hours (> 4 hrs) sitting in a chair each day. ROM, strengthening, and other functional activities are performed while in the chair and on the tilt table, and distract casualties enough to improve tolerance of the activity. When a casualty can tolerate 30 minutes of tilting to 70° for 3 consecutive days, more advanced pregait or gait activities can begin.

It is not unusual for a casualty in the acute rehabilitation phase to require several IV lines, chest and feeding tubes, or a Foley catheter. In these cases, it is imperative that all lines and tubes are properly secured before, during, and after mobility activities. Chair positioning, tilting, standing frame activities, and ambulation all require use of gait belts at the torso, waist, buttocks, and thighs for safety. Gait belts may need to be placed in such a way as to protect skin graft sites and prevent shearing.

Intermediate Phase

During the intermediate rehabilitation phase, the emphasis of mobility activities shifts from reorientation and improving tolerance to the upright position to improving endurance and functional independence. In this phase, casualties are typically more medically stable and are capable of tolerating more aggressive mobility activities. However, some mobility activities may carry over from the acute rehabilitation phase and should continue until the casualty demonstrates the strength and endurance to progress to more advanced functional activities.

The primary focus of this phase is independence with transfers, ambulation, and ADL training, such as bathing and toileting. Casualties are introduced to equipment in the rehabilitation gym, such as stationary bikes, upper-body ergometers, treadmills, parallel bars, and stair trainers to improve strength, endurance, and independence. An ADL room is also useful at this point in the casualty's recovery. Casualties must be encouraged and motivated to participate in mobility activities on a daily basis. Maximum participation will result in the expeditious return of function and prepare the casualty for discharge from the burn center and return home.

Long-Term Phase

Advanced mobility activities are the mainstay of the long-term rehabilitation phase. By this time, casualties have already met the functional mobility requirements for discharge from the burn center and are ready to begin mobility activities that will prepare them to return to duty. Advanced mobility activities focus on transitioning back to duty through advanced physical training and simulated work activities. Mobility training, such as jogging, running, swimming, weight lifting, sports, driving, and firearm training simulation, is implemented to improve a casualty's strength, cardiovascular endurance, and capacity to return to duty. At this time, it may be appropriate to refer a casualty to an advanced rehabilitation center, such as the Center for the Intrepid at Brooke Army Medical Center, Fort Sam Houston, Texas.

Psychosocial Aspects

Acute Phase

The psychological characteristics of the acute phase of rehabilitation include dealing with stressors of the intensive care environment, uncertainty about outcome, and the struggle for survival. Tremendous stress affects burn casualties' mental abilities, including their alertness, attention to detail, perception, reasoning, comprehension, memory, motor responses, communication, self-control, and interpersonal relations. Shock, numbness, and detachment, which protect casualties while they collect emotional coping resources, are commonly noted at the time of injury. Reorientation helps increase trust and lower anxiety, and reassurance can help casualties feel optimistic and lower anxiety. Families are encouraged to learn deep breathing relaxation techniques, and humor is often used throughout rehabilitation to lower a casualty's anxiety. Giving the casualty control and choices can also prevent serious psychological issues and can lead to a strong working relationship.

Casualties with minor burns who will return to duty as soon as their wounds heal need to be treated using the principles of proximity, immediacy, and expectancy. The mental health section at the unit level can provide support that focuses on mild and moderate battle fatigue and burns. Keeping casualties as close as possible to their units makes it easier for them to return to normal duty. Expectancy refers to the understanding that casualties will return to normal duty when they are healed. Treatment using the principle of expectancy is appropriate not only for casualties returning to duty within a short recuperation time, but also for casualties who will require extensive rehabilitation.

For casualties with severe enough burns to be evacuated, early psychological intervention and support help with motivation and encourage cooperation with treatment. Burn casualties separated from their units do not have ready access to family or friends for psychological support; therefore, an important role of the treatment team at all echelons is to provide emotional support and reassurance to reduce casualties' anxieties and fears. The evacuation team provides ongoing orientation information, including calling casualties by name. Part of the chaplain's mission is to provide comfort, assurance, and encouragement. Positive affirmations and encouragement, even during initial delirium, reinforce a casualty's motivation.[291]

The speed of physical recovery may be affected by the early emotional adjustment to an acute burn.[292] It is important to continually provide preparatory information before performing procedures and to encourage simple relaxation techniques during treatments. It is also important to frequently repeat instructions, provide orientation, and allow verbalization of fears.

The immediate reaction of a massive burn casualty includes psychological shock. This reaction usually lasts a short time and may involve disorientation delirium, emotional instability and liability, and sleeping problems with nightmares of being burned.[293] Fear and anxiety also accompany the initial part of the acute phase of burn recovery. Casualties should be allowed to express fears regarding death. These fears should be met with a realistic response regarding the chance of survival.[294] Behavioral manifestations, such as increased startle response, difficulty concentrating or following instructions, withdrawal, resistance to treatment, overt hostility, or other inappropriate behavior, are often noted immediately after burn.[295] Burn casualties may perceive a major threat to their survival. Information regarding the seriousness of the burn should be given, if possible, before pain medications cloud awareness.

Following resolution of the initial shock of the burn incident, casualties become more aware of the impact of their injuries. Orientation improves and survival anxiety diminishes. Thoughts are more focused on concerns about self, including the effects of changed appearance and altered function or lifestyle. The casualty's preburn physical, emotional, intellectual, social, and spiritual characteristics provide the basis for initial coping skills. Rehabilitation counselors, psychologists, social workers, and chaplains help casualties focus on regaining as much control as possible and on redefining the meaning of the accident, desensitizing the reminders of the injury, dealing with stress in a positive way,[296] and gradually accepting loss and trauma.

Adequate pain control, correction of sleep disturbances, decreasing the fear of long-term consequences, and cooperation with the burn team are crucial for optimal outcome.[293] Numerous interventions are appropriate and may include providing the casualty with as much physical comfort as possible; providing ongoing orientation information, including calling the casualty by name; mentioning the date and time of day; providing explanations about the procedures that are being used, even if the casualty is comatose; providing relaxation training after orientation is established; providing routine for bathing time, exercise, and meal times to decrease unexpected procedures; encouraging family involvement as soon as possible; and emphasizing individual control over as many situations as possible.

Losses and changes related to the burn injury affect each casualty differently. Casualties grow, find new strengths and coping mechanisms, recover from grief, and develop renewed goals sometime after realizing the impact and disruption they will experience from the injury. When casualties determine that there is potential for survival, their focus may turn to the perceived pain and its alleviation. This focus frequently results in increased reports of pain, as well as requests for analgesia. When adequate pain control is not provided, casualties begin to believe that pain will be associated with each treatment, which may result in poor compliance. The anticipation of pain may be complicated when painful procedures occur at different times, increasing a casualty's anxiety level. Medication dosage for pain, anxiety, and sleep is increased because of the hypermetabolic state of the casualty. When IV lines are in place, patient-controlled analgesia is allowed during the day, interspersed with comfortable rest periods. This improves cooperation with antigravity positioning and elevated exercise that ultimately also results in diminished pain. Relaxation training, counseling, and behavioral management are effective, nonpharmacological ways to deal with pain. However, they cannot replace analgesic, hypnotic, or tranquilizing medications. The goals of pain management are to maximize comfort, minimize disruptive behavior, and increase cooperation and productivity.[293]

When casualties complain of dysesthesias and pain as medications are being tapered, short continuance of narcotics combined with desensitization techniques reduces the problem. Most neuropathies resolve slowly. However, in addition to being taught desensitization and compensation techniques, casualties will appreciate assistance with reintegrating sensory information. Relaxation techniques (eg, Benson's relaxation technique, which involves slow breathing and repetition of a single, meaningless word[296]), practiced daily, can help casualties tune out sensations they would not have been aware of before the accident. For some casualties, dysesthesias from the healed tissue become a central, compelling part of their awareness. Individual counseling and reassurance by the physicians and therapists help casualties accept the return of sensation as a positive sign, even if it is temporarily distorted and therefore painful. Casualties slowly come to realize that the burn emergency has passed and, by using vision and tactile sensation from the burned and unburned parts, sensory information will be more quickly reintegrated.

As orientation improves, additional behavioral methods of relaxation may be implemented. These include Benson's relaxation response, autogenic training, biofeedback, imagery, and distraction. Deep breathing exercises may also be used, though they may alter sensation in a negative way, especially if a casualty hyperventilates when attempting deep breathing. Progressive muscle relaxation is another option, though it can be painful if the overlying skin is burned. Combining familiar techniques with nonpharmacological techniques can provide the casualty with greater control of the situation.

Intermediate Phase

During the intermediate phase, burn casualties are able to communicate with others, including staff members, family, and friends. Behavioral health providers and other medical staff provide support and information related to their specialty. Pain control may remain an issue. Rehabilitation remains aggressive to maximize function. The surgeon and rehabilitation team help casualties see grafting operations positively and allay fears related to loss of control during anesthesia.

Casualties are unable to exercise the grafted area or perform many activities because of potential skin shearing from movement. The resultant lack of movement and sensory deprivation create the potential for confusion and hallucinations, but this is reduced by sensory stimulation, provided by staff or family.[297] Rubbing lotion on closed areas controls itching and provides reassurance through therapeutic touch. Auditory and visual input may be emphasized through the use of television, radio, music, and frequent family and staff interaction.

Explaining procedures before they are performed can reassure casualties. Adequate analgesia and sedation, as well as the use of familiar relaxation exercises, help casualties tolerate discomfort during this phase. Avoiding repeated, unexpected, painful, and frightening treatments reduces the potential for developing PTSD. Staff should provide casualties as many choices as possible, and casualties should be invited to participate in procedures, such as staple removal, wound cleansing, and antigravity positioning, to reinforce the sense of control and responsibility in the healing process.

During this phase, burn casualties may come to terms with their injuries and prepare to leave the safe environment of the burn unit and reenter society. Reentry may be accomplished in steps, including excursions outside the burn unit, day passes for outings with family or friends, passes to restaurants, or trips home. These outings help casualties adjust to the rude reactions they may receive from the public. It can also help determine what adaptive equipment will be needed at home. At this stage, casualties can benefit from talking to other burn casualties, rehabilitation counselors, psychologists, psychiatrists, and social workers, and from viewing videos about other burn casualties and their families to learn how they coped. Along with physical and emotional recovery, ongoing social support is necessary. Nurses provide psychological support and encouragement to burn casualties as they prepare to leave acute care and return to society. Nurses also refer casualties to appropriate services, such as alcohol and drug treatment facilities (studies have confirmed that burn victims who abused drugs or alcohol before the accident are likely to do so again[298]) or chronic pain programs. Outpatient treatment may be indicated in these situations.

Long-Term Phase

Research on lifelong psychological issues as a result of combat-related burn injuries is limited. The Department of Defense and the Department of Veterans Affairs are taking proactive steps to identify and treat combat-related psychosocial issues stemming from Operation Iraqi Freedom and Operation Enduring Freedom.[299]

Normal responses to a major burn injury often include crying, degrees of fear, depression,[300] grief, loss of hope, and other reactions unfamiliar to the casualty. Discharged casualties report it takes about 6 to 7 months of being at home before they can cope, as they did before the injury, with emotions and activities that require concentration; however, distractibility gradually subsides. Impatience, irritability, and frustration are common. Casualties must learn to accept gradually improving function instead of perfection in activities. Family members can often help sort out the realistic reactions from overreactions.

Casualties at home or in the rehabilitation center must learn how to safely return to duty and routine life despite their injuries. Physical changes are often bothersome, and physical fitness is now a prolonged, daily struggle. Reconditioning may take place at a much slower pace than before the burn.[301]

Another factor to consider is psychological adjustment when a casualty returns to work in the area where the injury occurred. Few casualties return to the injury site easily. Referring a casualty to a psychologist is appropriate at this time. Return to duty at the earliest possible time provides casualties with the benefits of buddy support as well as routine and work. Strength and coordination improve much sooner from work than from therapy. Ego strength and social interaction are also improved with return to duty. Feelings of anger, fear, loneliness, or helplessness make casualties acutely aware of pain.[302] Casualties benefit from sharing personal experiences of pain relief. Former burned casualties report being helped by participating in trauma survivors' groups. With leadership from social workers and psychologists (or both), trauma survivors' groups are able to deal positively with symptoms, including the following:

- disturbing dreams,
- appetite disturbances,
- difficulty with sleep,
- feelings of estrangement or detachment,
- recurrent intrusive memories of the event,
- memory impairment,
- difficulty concentrating,
- reluctance to accept a changed body image,
- decreased interest in sex,
- sensitivity to loud noises or other cues related to the accident,
- irritability, and
- fear of returning to field duty or other work.

Return to active duty improves the casualty's self-concept. Burn physicians must consider the duty tasks and the progress of the healing burn scars and skin grafts when recommending return to active duty. Food handlers must remain off-duty until open areas are closed and wound cultures reveal no pathogens. Heavy laborers may need job modifications when they first return to duty. Often casualties need a transition period of half-day work, progressing slowly to full-time work. Rehabilitation counselors, nurses, or occupational therapists can help with changes in the work setting when these are encountered. The adaptations are often inexpensive. For example, a footstool may be placed near a bench or counter, and casualties may alternately place their feet on it for half-hour periods. Similarly, items can be arranged so casualties avoid reaching beyond their center of balance when first returning to duty.

Appraising the extent of burn injury and objectively estimating residuals that affect performance are most accurate when based on objective criteria[303] and experienced prediction. Rating permanent impairment is a physician's function. Disability is related to performance loss, preinjury age, education, economic and social situations, sex, and the burn casualty's attitude toward recovery. The physician has the final responsibility in determining when it is medically safe for casualties to return to active duty.

Community Reintegration

Acute Phase

The ultimate goal of burn casualty rehabilitation is reintegration into casualties' previous roles in their homes, schools, workplaces, and communities. Until recently, the goal for burn casualties was simply survival, with little emphasis focused on the quality of life after a severe burn injury. Advances in the medical care of casualties with major burn injuries have led to increased focus and need for rehabilitation services, as well as the need to improve intervention programs at acute, intermediate, and long-term phases of burn recovery. For a more successful and complete reintegration into society, research has indicated the need for a multidisciplinary team approach to ensure all areas of reintegration are addressed appropriately.

Sheridan describes three things needed for burn casualties to successfully reintegrate into their previous roles: rehabilitation, reconstruction, and reintegration, with the emphasis placed on long-term rehabilitation.[304] Sheridan further divided burn care into four general phases: initial resuscitation; initial excision and grafting; definitive wound closure; and the rehabilitation, reconstruction, and reintegration phase.[304] Rehabilitation and reintegration begins at the acute stages and can continue up to 2 years after the casualty is discharged from inpatient care.

In the acute stage, basic goals for rehabilitation and reintegration include positioning and splinting, reducing edema, and completing ROM exercises. This enables more functional mobility as the burn casualty continues to recover. These rehabilitation goals are important in the acute stage because they address the needs of the burn casualty and maximize the long-term functional outcome of reintegration into society. Educating families on positioning, splinting, and exercises to help maintain a burn casualty's functional mobility is crucial to the casualty's recovery and reintegration into society.

Intermediate Phase

In the intermediate rehabilitation phase, burn casualties begin to further comprehend the extent of their deficits secondary to their injuries and the potential impact on their previous functional roles. During this time, limited reintegration into society is accomplished with day passes and excursions outside the burn unit. Family education is another key element of successful reintegration. Proper training and information of assistance programs has led to family members and burn casualties reporting more successful reintegration into society and higher satisfaction with quality of life.[305] Burn casualties should be put in contact with veterans' service organizations as they reintegrate into their communities and seek to return to work.

Long-Term Phase

Once discharged from the hospital, many burn casualties report feelings of self-consciousness, anxiety, sadness, and anger about their physical appearance as well as in everyday social interactions with other individuals.[305] In the past, burn casualties reported receiving little assistance from burn care professionals beyond discharge from the hospital. Others, however, expressed empowerment from burn casualty organizations, such as the Phoenix Society, that provide support for burn casualties and their families in the challenges they face during reintegration into society.[305] Most research on community reintegration has focused on the "psychological adjustment" versus the physical or social adjustments burn casualties face.

A community reintegration program must be designed to support the needs of burn casualties and their family members as they transition back into society or past performance roles. The purpose of such a program is to assist in the development of appropriate psychosocial skills, peer-to-peer interactions, executive functions, motor planning, and physical components. The program must also provide a real-world environment in which casualties can develop the skills required to handle social interactions and environmental challenges. Casualties should be screened by the interdisciplinary team to ensure that they are ready to participate in community outings and that the outings will be therapeutic. The goal of a community reintegration program is for the burn casualty to achieve complete reintegration into the community. In order for the casualty to complete a community reintegration program, the casualty must meet all short-term and long-term goals. Some common goals include interacting appropriately and independently with peers, the general public, and burn team members. Casualties have successfully completed a community reintegration program once they have developed effective coping skills or adaptive techniques to interact appropriately with the environment.

Casualties with associated injuries, such as traumatic brain injury or spinal cord injury, may require transfer to a Department of Veterans Affairs rehabilitation center. Casualties being transferred should be medically stable and able to tolerate and benefit from a minimum of 3 hours of therapy a day.

The decision for a burn casualty to transition to an outpatient burn clinic should be made by the interdisciplinary burn team, casualty, and family. However, this may be challenging when the casualty has unrealistic expectations or when there is a lack of family presence or involvement. The success of outpatient treatment involves proper wound care, pain management, and rehabilitation by experienced burn team members. A patient should be followed up with at least weekly for the first 30 days after discharge, then monthly for 3 months, and finally every 3 months until the casualty's outcome has been maximized. Casualties are evaluated and treated by several members of the burn team at each follow-up visit, including a surgeon, physician assistant, nurse, therapist, mental health professional, and case manager.

In addition to a burn clinic, all outpatient casualties requiring continuing rehabilitative services are evaluated and treated by an outpatient rehabilitation service. These casualties must remain engaged in goal-oriented and outcome-based rehabilitation programs supervised by therapists.

Sexuality

Resuming sexual activity and relationships is an important part of recovery after a burn injury.[306] A casualty's partner should to be included in discussions about changes that take place during recovery and the expected final outcome. Most partners appreciate participating in an open discussion prior to resuming sexual activity. Casualties often worry about rejection; counseling to encourage trusting, honest communication can become the basis of a loving, caring, and exciting relationship. Understanding, communication, imagination, and experimentation can expand opportunities for a fulfilling relationship.[306] Potential problems related to sexual activity and birth control should be addressed by the physician. Friction or trauma to healed burns during sexual activity may cause blisters that are slow to heal. As burn scars and skin grafts mature and become more durable, blisters will be less likely to occur. Lubricants may help reduce friction and blister formation.

The areas least affected by the burn can often be used to enhance sexual activity. Because the lips and tongue are rarely burned, patients and their partners should be encouraged to use their mouths as a means of sexual expression. The lips and tongue are also more sensitive to touch and temperature than other body parts. Any part of the body that can be made clean enough for oral contact should be explored. Pregnancy may cause hypertrophy of burn scars and should be avoided until scars are mature. Stretching the tissue away from the direction of contracture and frequent erections assist with burn scar and skin graft maturity. Vigorous exercise and stretching of these areas results in the best outcome. Contracture releases are possible if required to improve function.[307]

COMPLICATIONS ASSOCIATED WITH REHABILITATION

Orthopaedic Complications

Bone and joint changes are common complications of burns, especially following thermal and electrical injuries.[308] Common changes include internal changes in bone, such as osteoporosis; bone necrosis; bone growth disorders in children; and periosteal bone formation. Early mobilization and weight bearing is thought to diminish the risk and severity of osteoporosis. Periarticular changes can include HO and calcific tendonitis. Generally, periarticular ossification is noted in the area of deep burn, although it has been noted in areas distant from the burn, as well.[309]

Joint changes, such as septic arthritis and ankylosis, occur when the injury is deep into the joint or when bacteremia seeds the joint. When a joint is thought to be infected, in addition to appropriate medical management, the joint should be positioned and rested using a static orthotic device in a functional position. If ankylosis does occur secondary to the septic process, the joint will then be at a maximal position of function.

Dislocation can occur from improper positioning of an injured joint or, more commonly, by scar contracture. If a joint is subluxed by a contracture, orthotic management, such as an IP extension serial cast, should be instituted immediately. If the orthosis cannot adequately control the deformity, internal fixation or release of the contracture (or both) should be considered.[310]

Heterotopic Ossification

HO is the ectopic deposition of bone around joints and tendons.[170] Incidence is variable in the literature, and ranges from 4% to 23%.[268,310] When it occurs in muscle body, it is more appropriately termed "myositis ossificans." It most frequently occurs at the elbow, hip, and shoulder, and to a lesser degree at the temporal mandibular joint, wrist, hand, knee, and ankle.[268,310] Usually the amount and location of the extra bone is clinically insignificant, but it can be severe enough to completely lock a joint in place.

Occurrence seems most likely to be related to the extent of the burn, size of open areas, and bed rest.[311] Inflammation may also contribute to HO or fibrosis.[269] The exact etiology has yet to be determined. HO should be suspected if there is a sudden onset of joint pain, swelling, or redness. When the diagnosis is confirmed by plain radiograph or bone scan, rehabilitation consists of AROM exercises without passive stretching and orthotic positioning in the maximal functional position.

There is currently no prophylactic treatment available for HO. Etidronate disodium has been used to prevent HO in the treatment of spinal cord injury.[309,312] However, a recent retrospective review found that it was ineffective in preventing HO in burn casualties.[313] Prospective studies need to be performed. Etidronate disodium has been used after early resection of HO, with significant improvement in functional ROM and without recurrence after periods of 6 months to 2 years. Early resection has been supported in the literature.[314]

Other techniques to prevent recurrence include irradiation and the use of NSAIDs, both of which may have significant complications in the burn population.[310] There is also controversy regarding thermo exercise. Some data suggest that vigorous AROM exercise can cause HO.[315] Splinting, combined with AROM exercise and PROM exercise, is appropriate unless HO occurs, in which case, ROM exercise should be limited to AROM activity only within the casualty's pain-free range.[315,316]

Amputations

Amputation can occur as a separate injury concurrent with a burn, particularly with explosive mechanisms of injury. The use of improvised explosive devices in Operations Enduring Freedom and Iraqi Freedom has resulted in a high rate of amputations associated with burn injury.[23,24]

Amputation can also occur as the direct result of an electrical injury, or as the sequela of a full-thickness or subdermal burn. The rate of occurrence varies with the etiology. Amputations from burn injury usually occur in 2 to 4 weeks and are related to infection.[317,318] Amputations are treated concurrently with the burn.

Electrical burns are associated with a 10% to 50% incidence of amputation.[317,319–323] An electrical current may result in an explosive loss of all or part of a limb. Because the current follows the path of least resistance, damage tends to follow the nerves, arteries, veins, and muscle tissue, with the potential for deep tissue necrosis. Generally, it takes 4 to 5 days for an electrical burn to completely declare itself and for the need for amputation to become apparent. The need for amputation may also arise later in the course of care, such as when neurologic function or sensation does not recover, leaving an extremity that appears healthy without function or sense of temperature, pressure, or pain.

When considering amputation, preserving length is important; however, it should not result in a functional disadvantage or problematic prosthetic care, such as occurs with a knee or elbow disarticulation. Burn injury can often delay fitting and application of a prosthesis because of the healing status of the skin. Grafted and healed areas of burned skin may require a prolonged course of treatment before they are able to tolerate the shear and pressure requirements of prosthetic use. Applying compression to the residual limb with stump shrinkers or elasticized tubular, self-adhesive, or compression bandages is important in preventing complications and may offset the delay in actual prosthetic fitting if done early.

Fitting a prosthesis to an extremity with healed burns is problematic because of various factors, including irregular length and shape, inability to tolerate pressure and shear, inadequate tissue for suspension, and limited ROM and strength to power myoelectric devices. Fitting must be approached with patience and innovation. Skin must be diligently monitored because breakdown can occur even after months of seemingly normal wear.

Another significant problem after amputation is phantom pain. It is normal for amputees to sense that an amputated limb is still attached, and the phantom limb may even seem to be in an odd position. Phantom sensation may last for many years and does not require any treatment other than education. However, if the sensation is painful, it should be aggressively treated using gabapentium or pregabalin and amitriptyline at night.[324] Desensitization techniques, such as rubbing, tapping, and contrasting temperatures and textures, are also helpful. Compression wraps and prostheses may help or exacerbate the pain. Treatment can include a single modality or combinations of the above. Narcotics have not proven beneficial in treating phantom pain.[324]

Neurological Considerations

Neurologic problems result from various etiologies. Although there may not be direct CNS damage from a burn, most burn casualties notice changes in reflexes and their perception of tactile and visual information. It is important to understand the etiologies of these deficits so precautions can be taken for prevention. Peripheral neuropathies may occur, resulting in decreased motor, sensory, and proprioceptive input. Early recognition and treatment may help prevent permanent deformity. The itching and pain sensations associated with burns subside gradually and may benefit tremendously from desensitization techniques.

A desensitization program can enhance the neurological recovery of a burn casualty and allows the casualty to control the level, frequency, duration, and pressure of differing external stimuli applied to a healed wound.[325] As the casualty's tolerance increases, the ability to withstand unexpected stimuli improves. Sensations from the healed wound, such as pain and itching, decrease and return to preinjury sensation. This occurs more rapidly when a desensitization program, including massage, vibration, and exposure to varying textures and temperatures, is practiced regularly.[325]

Texture desensitization involves introducing various textures to the healing tissues. Desensitization through texture contrast is commonly accomplished using cloth-covered wooden dowels to produce differing stimuli over the affected area (Figure 13-72). The repeated use of graded contact increases the sensory

Figure 13-72. Wooden dowels with varying textures used for desensitization.

tolerance of the affected area. A hand or foot may be immersed in a basin that contains various objects, such as cotton, rice, plastic squares, or beans. The use of fluidotherapy may also be beneficial for desensitizing the hands.

Temperature desensitization is performed through controlled exposure to warm and cool water. The affected area is maintained at heart level if possible, and water is allowed to run over the healed wound—first cool water for 20 seconds, then warm water for 5 seconds—repeated for up to 10 minutes. Contrast baths of warm, followed by cool, water may be used for dipping hands or feet.

Peripheral neuropathies are relatively common among burn survivors, yet the diagnosis is often delayed or missed. Clinical weakness or atrophy is attributed to disuse after prolonged hospitalization with periods of forced immobility. The incidence of peripheral neuropathy has been reported to be as high as 30%. There is a greater incidence of peripheral neuropathies as the burn size increases above 20% TBSA. Casualties with electrical burns develop neuropathies at an even higher rate. Predisposing factors, such as alcohol abuse and diabetes, also increase casualties' susceptibility to neuropathies.[15]

The most frequently diagnosed neuromuscular abnormality observed in a burn casualty is generalized peripheral neuropathy, which commonly presents as distal weakness in the upper and lower extremities. The casualty's complaint, however, is usually lack of endurance and easy fatigability, not weakness. When weakness is noted, it occurs in the burned as well as unburned extremity. The cause of generalized neuropathies is not entirely understood but is probably multifactorial, related to toxic, nutritional, management, and metabolic factors.

Local peripheral neuropathies are also concerning because they are probably related to preventable causes, such as compression or stretch injuries of a peripheral nerve or damage from intramuscular injections.[326] The ulnar, radial, and median nerves are the most commonly affected peripheral nerves. However, neuropathies of the peroneal (fibularis) nerve and brachial plexus have also been observed. For example, the ulnar nerve is at risk of compression as it passes through the cubital tunnel at the elbow. When a burn casualty is positioned, for purposes of edema reduction, with the elbow elevated on pillows or arm troughs, flexed at approximately 90° and pronated, the cubital tunnel is narrowed. In this position, the ulnar nerve receives both external and internal compression and can be damaged, resulting in weakness of the ulnar intrinsic muscles of the hand and a claw hand deformity with loss of sensation to the ulnar side of the hand. Neuropathies are best prevented with frequent position changes and positioning that limits external pressure and avoids positions that impose internal compression. Thorough initial and logitudinal neuromuscular examinations are essential to properly manage burn casualties.

Manual muscle testing should be performed to evaluate for the presence of upper-extremity peripheral neuropathy, especially in the presence of circumferential, full-thickness burns. The resting position of the hand can be indicative of neuropathy. For example, radial nerve involvement should be suspected if the wrist is held in flexion and the casualty is unable to actively extend the wrist, MCP joints of the fingers, and the thumb. Signs of ulnar neuropathy are clawing of the fingers and the inability to adduct the thumb. A median neuropathy should be suspected if the casualty is unable to oppose or abduct the thumb.

Median, ulnar, and radial neuropathy also influence positioning needs. The loss of active palmar thumb abduction associated with a median neuropathy increases the risk for adduction contracture. Splinting should include a resting splint or a C-bar splint, positioning the thumb in palmar abduction.

Emphasis should be placed on avoiding MCP joint extension and IP flexion contractures, which can result from an ulnar neuropathy and manifest with the fingers (especially the ring and small) maintaining a clawing position. When the skin is durable enough, an "anticlaw" splint can place the involved MCP joints into flexion and block hyperextension.

The absence of wrist extension, finger MCP extension, and thumb radial abduction is indicative of a radial neuropathy. Positioning and exercise should prevent wrist flexion contracture or contracture of the flexor compartment in the volar forearm. Splinting should hold the wrist and fingers in extension and thumb in radial abduction. MCP joint extension contractures must be avoided if dorsal hand burns are present; thus splinting the casualty into a resting position of 70° of MCP flexion may be indicated. In this case, the therapist needs to modify the splinting program, which may include alternating each type of splint indicated for day or night use.

Burn casualties often experience symptoms of pruritus.[2] In some cases, these symptoms can be worse than other pain a casualty experiences. Histamine release was previously thought to be the cause of the itching, but this has been proven incorrect. The exact mechanism remains unknown. It may be that pruritus, in some cases, is a manifestation of neuropathic pain. Nevertheless, initial treatment of pruritus is antihistamines, which do clinically benefit the casualty by managing symptoms. Diphenhydramine hydrochloride or hydroxizine, taken alone or in combination, are reasonable choices. Neuropathic pain medication (gabapentium or pregabalin) may be reasonable for resistant cases. Massage and transcutaneous electrical nerve stimulation may also be helpful.[216,327] Pruritus will improve over time, frequently in conjunction with scar maturation.

Psychological Considerations

The psychological effects of being burned in combat are complicated and challenging to identify and treat. While grief, bereavement, and sadness are understandable and natural feelings, when not managed appropriately, combat-related burn injuries can result in more serious reactions and lead to more debilitating mental illness.[328] Significant psychological distress occurs in over a third of casualties. Psychological management must be initiated early on, because evidence shows there is little clinically significant, reliable change in symptom severity when casualties are followed as outpatients.[329] Operations Iraqi Freedom and Enduring Freedom have presented a unique opportunity to study the psychological effects of burns because the number of individuals affected by the same event permit comparison not possible in individual trauma.[330]

The following principles and presented guidelines, consolidated by Faber et al,[331] should be implemented when managing burn casualties:

- **Routine care**. Psychological screening and support should be routine from the start for the casualty and family and continue well into the completion of physical care.
- **Promotion of a casualty- and family-centered approach**. In light of the complexity and cultural considerations, a holistic approach based on the casualty's psychosocial needs should be addressed in conjunction with the requisite medical model.
- **Staff should be sensitive, trained, and fully integrated members of the burn care team**. Psychosocial support is critical to the degree that casualties' long-term psychosocial adaptation is largely dependent on their successful community reintegration.[305]
- **The survivor is assumed to be a "normal" person and is expected to fully recover**. The burn casualty's sense of well-being is contingent on the ease with which they relate with the nonburned community.[305]
- **Difficulties are normal experiences**. It is natural for a casualty to struggle to develop a new life, new body image, and new ways of feeling good. The entire process has been described as achieving a "new normal." The burn center team plays a vital role in this process.
- **The family is critical to success**. Next to the casualty's desire to reintegrate into societal roles, family support is the most important component to healthful recovery.[331]

Appropriate pain management is also important when providing psychological and emotional support. Special attention should be made to address pain, especially as it relates to wound care, patient activity, therapies, and patient expectations. Anxiety often amplifies pain and therefore must also be addressed. Providers should be aware that acute pain may become chronic if not treated early and aggressively. Both background and breakthrough pain need to be aggressively monitored and appropriately managed. In addition to medical interventions, modalities such as hypnosis, acupuncture, deep breathing relaxation exercises, and distractions (eg, music and positive imagery) may ameliorate pain and its deleterious emotional effects.[332]

Agitation is frequently observed in sedated and intubated casualties and must be assessed for cause (eg, pain, anxiety, or sleep deprivation). Sleep deprivation can cause various other conditions, such as stress, pessimism, and anger.[333] Sleep deprivation and restriction diminish vigilance (which can negatively impact performance), alter neuroendocrine control, and negatively impact immune function.[334] This deficit can be the difference between a successful outcome and one that is less than adequate. A sleep hygiene protocol that allows for uninterrupted sleep and reduced environmental stimuli can augment restorative sleep. Relaxing music or a cool dark room may also help a casualty fall asleep.

Nightmares are common in burn casualties,[335] which may explain agitation in sedated and intubated casualties. Atypical antipsychotic medication may prevent nightmares. Antihypertensive medications and β-blockers can block the adrenergic response to nightmares. One way casualties may confront the fears and issues in their nightmares is by recording them in a journal and changing their endings.[335]

Delirium is a common and usually reversible disorder that occurs during a period of illness and must be aggressively assessed and treated.[336] Possible causes of delirium include pain, pain medications, sleep deprivation, and witnessing loss of life, limbs, and horrific trauma. Recognizing these triggers is crucial when assessing work in war-injured casualties. Reorientation, restorative sleep, reassurance, and relaxation techniques can be effective in preventing and minimizing delirium symptoms.[334] Atypical antipsychotic medication can also be extremely effective.[337] Benzodiazepines are not recommended because casualties may have sustained traumatic brain injury, resulting disinhibition and respiratory depression.[336]

Armed conflicts have a long-lasting impact on the mental health of those affected.[338] PTSD, acute stress disorder, and their associated anxiety disorders are common psychological problems secondary to combat-related burns.[338] PTSD is the most common and predictable mental health problem that results from exposure to war and terrorism.[339] Most casualties will have symptoms of PTSD weeks to months following the event. A high incidence of PTSD among burn casualties has been noted from current conflicts.[328]

A burn casualty's response to a recognizable stressor signals PTSD if it evokes distress symptoms. Casualties also often experience vivid, intrusive dreams or recollections of the traumatic incident. Other frequently noted characteristics of PTSD are an exaggerated startle response, impaired memory, concentration problems, avoidance of cues of the accident, and withdrawal from normal social interaction, chores at home, tasks at work, or participation in active duty.[340] Treatment is aimed at giving casualties as many choices as possible during recovery, thereby relieving a sense of helplessness. Stress reduction strategies and goal-directed individual counseling can also be beneficial. Short-term pharmacological intervention may also be appropriate. It is helpful for casualties returning to active duty to know that PTSD may be exacerbated by distant yet significant events, such as the dedication of a war memorial or reunion event.[330] Reading about an individual who sustained a similar burn may also revive PTSD symptoms.

Losing fellow service members during combat is a significant source of distress.[341] Grief and depression are common concurrent with combat-related burns.[341] A number of medical interventions are effective in treating combat-related grief and depression, including antidepressant medications and grief counseling. Combat casualties have experienced numerous losses and changes that may take time to resolve, and they should be allowed to express their feelings and concerns.[341]

It is important to provide behavioral health support to casualties and their families from the earliest phases of hospitalization throughout the hospital course.[342] The Red Cross may relay information between casualties and their families while separated, and can help families secure quarters near the medical treatment facilities where their loved ones will be treated. Intact and supportive families have been influential in the successful long-term psychosocial adjustment of casualties of severe burn injury.[343] Family members may be interviewed by social workers, nurse specialists, psychologists, psychiatrists, and chaplains to get an accurate history of the casualty's preburn personality, coping styles, and reactions. This facilitates the development of rehabilitation strategies.

It is important to involve casualties' families in support groups and to provide them with educational classes to inform them about burn injuries and treatment. Families' reactions to burn injuries and their ability to support casualties through recovery and reintegration into society is critical to casualties' successful life adjustment.[342] Support groups may help family members deal with the stress and uncertainty of caring for a combat-injured casualty.

Family members are often responsible for immediate communication with loved ones, extended family, colleagues, and community groups or churches. Family and friends at home can provide significant support and focus toward the future by letter writing and maintaining positive contacts with burn casualties. Evidence shows psychosocial adjustment is a function of both coping responses and social resources.[340]

Alcohol and substance abuse or dependence research over the past decade has demonstrated a strong association between PTSD and substance abuse and dependence.[344] The assessment and treatment of alcohol withdrawal is challenging in burn casualties because hyperthermia, tachycardia, and narcotic medications may mask these symptoms. Some of these signs, symptoms, and behaviors may not reveal themselves until long after the casualty is discharged from the service.

Combat casualties who have sustained burns are neither exempt from, nor more prone to report, suicidal or homicidal ideations than other casualties who have experienced severe trauma. Risk assessment should be performed during the course of the behavior health assessment. Concerns for suicidal or homicidal ideations should be assessed and interventions provided by mental health professionals.

SCAR MANAGEMENT

Scar management is an essential component in burn casualty rehabilitation. Appropriately managing burn wounds can minimize the resultant functional limitations. As burn wounds heal, scar tissue, comprised of collagen fibers, forms over all affected areas. The impetus of the healing process is to achieve closure as quickly as possible to achieve tissue contraction.[345] Tissue contracture protects a casualty's survival, but also creates a setting for joint contracture and restrictive scarring that interferes with functional independence.

Tissue Contracture

When considering the rehabilitation of burn casualties, most clinicians think about the deleterious physical effects of burn wound healing in the form of scar tissue contractures that appear after wound closure. However, burn scar contractures develop during the acute rehabilitation phase, making early therapist intervention important. Additionally, it is important to differentiate between burn scar contracture and burn scar hypertrophy. It is likewise important for clinicians to be able to differentiate between burn scar contracture, which occurs early, and contracture from muscle or joint capsule, which occurs following prolonged immobilization.[346]

During the inflammatory phase of wound healing, edema can cause body parts to become malaligned, positioning body segments to develop scar contractures.[6] In the proliferative phase of wound healing, granulation tissue, which contains the elements that can ultimately lead to scar tissue contracture, forms.[347] Simultaneously, wounds naturally undergo contraction, which, by action of myofibroblasts, pulls the edges of the surrounding tissue centripetally, reducing the pliability of the surrounding tissue.[348] All areas of the body do not contract to the same extent. Areas where skin is loose, such as over the abdomen or buttock, can contract further than areas where skin is tighter, such as around the leg. Because of these biological processes, casualties will develop burn scar contractures if proper interventions are not instituted, especially during the intermediate phase of burn rehabilitation.[53]

Because of known poor outcomes associated with the formation of granulation tissue, early excision of burn wound and skin grafting is a common practice.[348] Nonetheless, burn wounds that are skin grafted still undergo contraction. Partial-thickness skin grafts contract more than full-thickness skin grafts.[349] More important than the overall thickness of the skin graft is the makeup of the skin graft. Partial-thickness skin grafts from an area where skin is thin, but that transplant a large portion of the reticular layer of the dermis, contract less than skin grafts taken more superficially. Therefore, even if casualties are skin grafted, they will need rehabilitation beyond the intermediate phase of burn rehabilitation and well into the long term, until the tissue no longer demonstrates a tendency to contract.

Hypertrophic Scarring

Hypertrophic scarring is the most common and debilitating complication of burn injury and occurs when burns extending into the dermis of the skin heal through scar formation (Figure 13-73).[350] Hypertrophic scarring is defined as an overgrowth of dermal elements that remains within the boundaries of the original wound, a distinguishing characteristic from keloid scarring (see below).[350] Hypertrophic scarring frequently occurs in cases of burns extending into the deep layer of the dermis (the reticular layer) or if there is a delay in wound healing longer than 3 weeks.[351,352] It also tends to occur in areas of full-thickness burns or where donor sites have been harvested too deeply, reharvested several times, or in which healing has been delayed because of infection or trauma.[350]

Hypertrophic scarring may be painful, limit range of motion, impair sensation, and result in loss of function. Compression garments, scar massage, dynamic splinting, serial casting, and other conservative therapies may prevent or minimize hypertrophic scarring. Some burn casualties may need to undergo reconstructive surgery to deal with these scars.

Keloid Scarring

Another complication of scar formation in burn healing is keloid scarring. Keloid scarring occurs when an overgrowth of dermal elements extends beyond the boundaries of the original wound.[189,350] According to Linares, keloid scarring is the most severe degree of hypertrophic scarring, with the differentiating factor being quantity.[351]

Keloid scarring is not as commonly observed as

Figure 13-73. Severe hypertrophic scarring of the hands.

hypertrophic scarring, but depending on the location of development it can be, by its progressive and proliferative nature, more debilitating. Keloid scars go beyond limiting function because they are also disfiguring. Intradermal steroid injections, excision, and compression are often used to manage keloids. There is currently no preferred therapeutic modality to treat keloids. Location, size, disfigurement, debilitation, and depth of the scar are all considerations when deciding on a particular therapy.[353]

Hyperpigmentation

As a scar matures, it may become hyperpigmented (Figure 13-74). This occurs because newly formed epithelial cells eventually contain a relatively greater number of melanocytes than surrounding unburned tissue.[354] The amount of color contrast varies from one individual to another. Exposure to sun must be gradual; avoiding sun exposure for about 1 year after injury is the best way to prevent permanent hyperpigmentation, and healed skin will tolerate graded sun exposure 3 to 18 months following injury. Damaged, thinned skin will turn very dark brown with even brief sun exposure. If sunscreen is being used, it is important to prescribe the type appropriate for the casualty's natural skin condition. A commercially available, waterproof sunscreen with a sun protection factor rating of 15 or more should be applied to all burned areas. A wide-brimmed hat can protect the ears and nose during exercise in the sun. It is common for areas underneath custom-fitted, elastic, external vascular support garments to burn in the sun.

Figure 13-74. Hyperpigmentation of burn scar on the lower extremities.

Once a scar has matured, steps can be taken to modify its appearance. The simplest modification is applying camouflage or makeup. When combined with prosthetic facial components, makeup can significantly change appearance. Skin may be lightened over a period of months with daily topical application of hydroquinone, which can be purchased over the counter in strengths up to 4%, or prescribed in strengths up to 10%. Ruby laser may also lighten the skin. Hydroquinone and ruby laser are most effective in lighter skinned casualties because of the greater contrast between the affected and nonaffected areas.

Burn scar contractures can lead to decreased ROM and decreased mobility, resulting in a functional deficit in ADL performance as well as an altered aesthetic appearance and ending in a dysfunctional outcome. Various modalities can reduce the severity of burn scar contracture and the extent of surgical reconstruction required to preserve function. Appropriate burn scar control can effectively decrease the adverse affects of burn scar contractures and hypertrophic scarring.[345]

From the rehabilitation perspective, burn scar management includes using external vascular support to avoid excessive edema and compartment syndromes, positioning to create an environment for tissue elongation, and AROM and PROM exercises to retain joint motion and functional capacity as the healing tissue initiates typical contraction behavior.[355] As the wound area heals and scar is formed, the immature scar tissue will receive heat treatment and massage to enhance tissue pliability. Rehabilitation will also include additional compression interventions, occlusive dressings for hydration, custom splinting devices for tissue elongation and flattening, more aggressive AROM exercise, and reintroduction of ADLs.

Characteristics of Burn Scars

An increased healing time can result in hypertrophic scarring. In such a case, the wound-healing process begins like it does with normal scarring, but the additional healing time results in a protracted course of repair matrix accumulation, increasing morphologic and biochemical abnormality.[345] According to Burd and Huang, "although the hypertrophic scar follows the same cycle as the normal scar, time to heal is considerably prolonged and the adverse effects of the scar on form and function, particularly caused by contraction, are significantly worse than those of normal scars."[345] Hypertrophic scars also have an increased microcirculation compared to normal skin and mature scar tissue. Clinically, active lesions are firm and erythematous, resulting in maturation related to microvascular regeneration.[345] As scar tissue forms, the early, immature presentation is often described by appearance using the "3 Rs": red, raised, and rigid (see Figure 13-73).

Burn scar management begins at the time of insult. Following a dermal injury, a cascade of events results in the formation of a collagen-rich repair matrix; in normal scar tissue it presents clinically with increased height, firmness, and redness, indicating increased vascularity.[345] At this time the interdisciplinary staff is focused on wound management and closure. Reepithelialization, or wound healing, following a split-thickness skin graft, can take from 2 days to several months; however, most wounds heal within a few weeks.[356] Graft loss, hypergranulation tissue, and malnutrition can all result in lengthy healing of a split-thickness skin graft.[356]

Compression

Pressure therapy helps restore the extracellular matrix organization identified in normal scar.[357] External vascular support, begun early in the acute phase, uses a thin, moist contact layer to prevent the appliance from sticking to the epithelium at the wound edge. The initial purpose of external vascular support is to protect fragile, newly healed skin from blistering; improve venous and lymphatic return; decrease extremity pain; decrease itching; prevent sunburn or frostbite; moisturize the epithelium; modify overly bulky, thick, hard, scars; and elongate maturing contracture bands. Complete baseline descriptions of the healed wound, open areas, and areas of early scar symptoms or contractures are documented. Pressure must be adequate to decrease capillary circulation and must be continued until the scar matures. Pressure adequate to decrease edema and compress scar tissue cannot be applied to the middle of an extremity without impairing lymphatic return. Therefore, the principle of gradient pressure (the greatest support at the distal limb and the least at the proximal limb) must be observed.

For external vascular support of the hand, the fingers can be individually wrapped in a supportive, self-adherent elastic wrap (Figure 13-75). Several compression companies provide elastic digi-sleeves, also called edema sleeves. Isotoner gloves are an economical, off-the-shelf support glove manufactured in three sizes for hands that are not extraordinarily large or small. The most universally used early external vascular support is the elastic bandage wrap applied in a gradient figure eight, distal to proximal. Because early excision and grafting have become the norm, external vascular support is provided in the acute phase of healing primarily for the upper and lower extremities.[358]

Burned legs have generally been supported with figure-eight elastic bandage wraps from the acute phase through discharge from the hospital. This method of support facilitates ambulation and prevents pain and lower extremity edema or hemorrhage.[214] Elastic wraps are applied while the casualty is recumbent to avoid edema and poor venous return when standing. The most distal part of the extremity (ie, the hand or foot) must be properly managed first; then the support can be worked proximally.

Wound exudate may cause elastic wraps or garments to stick, so they should be soaked off during bathing to prevent denuding skin. Unless worn only for protection, the external vascular support appliance must apply continuous pressure in a gradient manner.

Massage and Vibration

Massage may break up bands of scar tissue that can cause contracture and decrease sensitivity and pain in the healed scar.[355] Massage therapy often helps desensitize the skin and scar and assists with venous return. It involves manipulating the soft tissues with the hands

Figure 13-75. Self-adherent elastic wrap of the hand and fingers for vascular support.

to produce effects on the neuromuscular and circulatory systems. The massage should generally work in the direction of the venous and lymphatic circulation. Massage should be a slow, repetitive motion, moving distal to proximal, with the affected area elevated above the heart, if possible. However, applying too much pressure can cause pain or blisters.

Massage with lotion or mineral oil softens and increases the pliability of scar tissue. Nongreasy sunscreen and adequate medication to decrease pruritus help individuals avoid damaging newly healed tissue. In addition to increased pliability, massage with lotion lubricates dry scar tissue and skin grafts, which may prevent dehiscence of the less mature scar tissue.[355] Topical silicone gel is effective in both preventing and managing hypertrophic scar.[358,359] Silicone gel sheeting has been used for decades to effectively manage scars. Silicone therapy's mechanism of action has not been completely determined, but is likely to involve occlusion and hydration of the stratum corneum.[360] Applying self-adhesive silicone gel sheeting to a scar allows for a comfortable, reusable silicone product that implements the occlusion and hydration necessary to manage and prevent hypertrophic scarring. Silicone sheeting is also easy to apply under vascular support garments.

Vibration is a controlled method of massage that stimulates nerve endings and may lessen pain or irritation. An electric or battery-operated vibrator can be used to massage around affected areas. As tolerance increases, the vibrator can be placed directly over the healed wound, first with a stocking covering the skin and then directly against the healed skin. Vibration is used to decrease pruritus associated with healing scar tissue. It is also indicated for flattening scar tissue.[361] Casualties and their families are typically taught vibration therapy in clinic instruction.

Range of Motion

ROM and stretching exercises increase joint movement and lengthen scar tissue to reduce the restrictions of joint ROM. Preparing the tissue with massage allows for less restrictive scar tissue while performing ROM and functional activities. Goal-directed progress in ROM is required daily throughout all phases of recovery to prevent contracture and deformity and to increase function.[355,361]

Splinting and Positioning

Splints and casts are used to manage scar tissue. Compressive forces flatten scars and positional forces create a stretch by imposing a constant tension on the scar.[355,361] These modalities are used from day of admission on all casualties and modified or advanced depending on a casualty's needs.

For casualties who have sustained facial burns, preventing and managing microstomia contracture is essential for maintaining premorbid quality of life. Mouth opening is imperative for speaking, eating, performing dental hygiene, interacting, and restoring psychosocial well-being. Opposing horizontal, vertical, and circumferential forces are necessary for effective scar management.[362]

Heat

Initially heat packs, and later paraffin, are used to increase pliability and tissue flexibility and to prepare the tissue for elongation stresses prior to progressive ROM exercise programs.[355,361] Heat should not be applied to insensate areas.

Compression

Casualties wearing external vascular supports or orthoses for the face and neck must be closely observed for complications such as sleep apnea,[363] changed bone growth,[364] and posterior migration of the teeth. A separate nose orthosis may be fitted under the clear facial orthosis to maintain patent nostril openings. Custom-fitted inserts may be made of soft silicone or hard acrylic. If the ear meatus is scarring closed, it can be maintained with a silicone elastomer or acrylic insert or hard plastic.

It is difficult to properly fit a neck orthosis because there are no bony landmarks on the anterior neck, the larynx must be able to move during speech or swallowing, and the sternocleidomastoid muscles change as they contract and relax for neck movement. However, with practice, a neck orthosis may be fitted that reduces edema and supports the tissue between the sternal notch and the chin at the maximum possible length. Wearing an orthosis should never replace AROM exercises to improve the quality and length of the healing epithelium and underlying connective tissue.

When the extremity is healed, it is usually durable enough for tubular external vascular support on a foot and leg, or Isotoner gloves on a hand. The prefabricated garments are made of a variety of materials, including unidirectional, stretchable rubber; elasticized cotton; elasticized nylon; nylon/spandex; spandex; and rayon.[365] Many casualties tolerate prefabricated cotton and rubber garments well; scars recede and no other support is needed.[366] In addition, fabrics with varying elasticity are available from most custom garment manufacturers. Multiple types of custom-fitted orthoses are available for external vascular support and scar compression. Once wound closure is complete, a wide variety of commercially available support designs are available, as well.[348]

Transparent Facemasks

Casualties with extensive facial burns can use custom-made, silicone-lined, transparent facemasks (Figure 13-76). Facial skin is loosely connected to underlying structures, and permanent distortion of the nose, eyelids, mouth, ears, and neck may result if this connective tissue is allowed to contract around the face or neck. Face-scanning technology, which digitizes the complex surfaces of a burn casualty's face, and rapid prototyping on a computer-controlled milling machine can create a transparent facemask that provides compression.[367]

Body Garments

Weight gain and loss should be stabilized before measuring for custom garments. Custom garments are usually measured circumferentially for the extremities and at the waist, hips, and chest for the trunk. Joints are marked on a circumferences record and measured on a pictorial form. Each garment company has its own forms, tapes, and measuring style. Measurements are usually taken by a company representative. Tape measure designs include longitudinal paper tape with cross-sections taped on an extremity, and lightly adhesive measuring devices placed directly on the body. Knowledge of the casualty's injury and course of recovery helps in planning the proper design and individual options.[368] Climate, employment conditions, physical limitations, and psychological status also influence the garment type. Casualties should be measured as early in the morning as possible, when extremities are the least edematous. Measurements are taken in direct contact with the casualty's skin, not over clothing or dressings. The tape measure should be placed firmly but not tightly. When there are two adjacent garments—for example, a glove and an arm sleeve—measurements should be overlapped so the garments themselves overlap and do not gap or pinch. A tracing should be done with a thin marking pen. The garments are produced and mailed, and the casualty usually tries the garments on in the therapy department of a burn center.

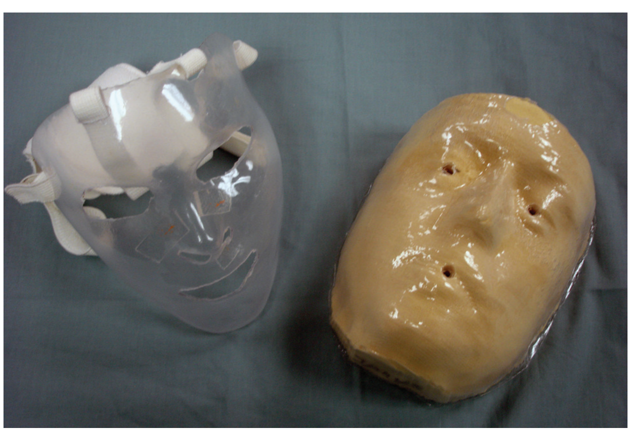

Figure 13-76. Transparent facemask providing compression for scar management.

Burn site, casualty age, burn depth, the presence of split-thickness skin grafts, and wound healing time influence garment design. Of primary importance is predicting whether a wound will scar and the location and size of the potential scar area. The garment should completely cover the potential scar area with a 2- to 3-inch overlap at each end so that when the casualty moves, the garment will still be in contact with the area being treated. Because edema and deep vein thrombosis are always concerning, the garment design must include tissue distal to the burn. Fingertips and feet can be either open or closed, depending on the casualty's needs. Liners can be placed around joints with bony prominences.

Garments need firm attachment points so they do not roll, slide down, or ride up. Attachment points could be at the waist, forearm, shoulders, or hips. Ending the garment on the muscle belly should be avoided because the edge may constrict when the muscle is flexed. Ending the garment directly on a joint can decrease circulation.

The initial, custom-measured, full glove with closed or open fingertips is appropriate for the hands. This glove should also have slanted interdigital seams and a thumb design that allows radial and palmar abduction without losing fit over the dorsum of the hand. The initial glove is often made of soft fabric; the density of the fabric is increased to heavy duty when the skin can tolerate it.

For the thorax and limbs, basic designs can be varied to create several options. A thorax garment can be a basic sleeveless vest, or a full suit with long arms and thighs with a crotch that is opened, closed, or has a hook-and-loop fastener, zipper, or snap flap. If the vest rides up and a body brief is not desired, the vest can be made several inches longer, or a heavy-duty snap or hook-and-loop fastener crotch strap can be added. Hook-and-loop fasteners allow for some adjustment in tightness. For females, breast cups are measured and front closures are used in vests. Unburned arms can have short sleeves, which are useful because the open armholes put little pressure on the chest and upper back. Vests with only one arm pull the neck opening away from the open side, take away chest and back pressure, and exaggerate poor posture. Various arm sleeve lengths are feasible. However, if the shoulder requires compression, a vest style is most effective. The axillary area may be made larger if no compression is needed there. Pants can be waist high, and wide clip-on suspenders or elastic bands may keep the waist from rolling down. If a vest is also required, overlapping hook-and-loop fastener tabs or heavy-duty snaps can be used. Garter belts can be used to secure bilateral thigh-high stockings. A garter belt will not work on a unilateral thigh-high stocking. If the skin is durable enough, some skin adhesive or foam tape can be used.

Anklets and knee-length stockings usually stay up well, especially if the skin is well moisturized before donning the stocking. Zippers can be placed on any of the extremities to assist initial donning and doffing when the skin is still fragile; however, zippers decrease the uniform compression of the garment and at times need to be padded, so it is best to avoid them if possible. Other options to add to compression garments are inserts, gussets, pads, and darts.

The initial fitting of a garment should always be done in the clinic to assure an accurate measurement and fit. To be therapeutic, the correct level of compression should slightly blanch the hypertrophic scar areas. There should not be any restrictions in motion, circulation, or skin integrity. Color, motion, and sensation should be checked before the casualty leaves the clinic. Fingers and toes should be observed for swelling, coolness, and dusking, as well as numbness or tingling. Casualties should be instructed to discontinue the garment, reapply elastic wraps, and call the therapist if problems occur at home.

Applying the new garment for the first time is challenging. It should fit tightly, like a wet suit, and should take several minutes to don. The fit can be checked by how the garment feels to the casualty and how the scars feel through the garment. The garment should be tight enough that it is not possible to grab hold of it easily and pull it away from the skin, and should not wrinkle. Shoulders, elbows, and knees should have adequate relief for full AROM without allowing open areas. Often the first garment does not fit correctly and alterations or new measurements may be required. Most commercial companies will replace a problematic garment.

The body garment is worn 23 hours a day throughout the duration of the skin maturation process. The garment must be removed for bathing, and occasionally it is necessary to remove it during vigorous exercise sessions when it causes blisters. It should be washed daily to remove perspiration, body oils, and dirt. Meticulous hygiene is essential for the skin, as well. Garments should be cared for according to the manufacturer's recommendations.

A light dusting with cornstarch or powder may help with garment donning; however, casualties should be reminded to wash the powder away each day to avoid plugging pores. Wearing nylon under the body garment can decrease the shear on skin and increase the ease of donning. Foam pads at the joint creases of the knee and ankle can prevent garments from cutting into underlying skin. A protective hydrocolloid patch on the olecranon, the antecubital area, or both, can prevent scrapes in these vulnerable spots.

Initially, reassessment is best done weekly to ensure wearing tolerance and to watch for complications and changes in weight or muscle mass. If an aggressive therapy program is not required, the scars are becoming soft and light in color, and the casualty is doing well, visits can be decreased to biweekly, monthly, and bimonthly through the maturation process. Generally, prefabricated garments last only 1 to 2 months, depending on the casualty's activity level. A weight change of 10 lb or more may require new measurements be taken. A new garment should be issued at each clinic visit until the casualty has five garments that fit well. Custom garments generally last 2 to 3 months. Some casualties may require more than two sets, depending on their work or leisure situations. It may be necessary to set aside one set of garments for dress and use stained ones for daily activities.

Bothersome open areas should be checked for infection. If they interfere with motion or cause excessive pain, garments can be removed for exercise. It may be necessary to wear elastic bandages for a few days before reapplying the garments.

Skin covered with support garments may develop offensive odors. Daily bathing, washing open areas and body wrinkles thoroughly, drying skin meticulously, and applying a lotion every day improves wound hygiene. Heavy petrolatum or oil-based lotions should be avoided because they liquefy natural sebum, and it is then washed away. Deodorant is appropriate if it does not cause contact dermatitis. If blisters form or open areas increase in size, the casualty should discontinue wearing the support garment, resume elastic wrapping of the extremity, and explore the causes of blistering. If excoriation has resulted from scratching, antihistamine medications can be increased or changed. Ambulation and exercise should be continued.

Inserts

A mature scar will never return to a high degree of organization of normal dermal architecture.[345] However, an insert can accelerate hypertrophic scar maturation process.[369] Inserts that fill in concave areas that a custom-measured garment cannot reach are usually placed between the skin and the compression garment over a thick hypertrophic scar, tight skin, contracture, or a concavity where a bridging area has begun. Some inserts have been used successfully alone, for small areas, without compression. Overlays are placed over the custom-measured garment with an elastic wrap or another garment to press the garment into concavities between bony prominences or anatomical structures that compression garments "tent" over. The overlay or insert fills in the negative spaces for a smooth, total-contact compression from the external vascular support garment. Inserts are also used to help flatten and soften the taut, rope-like contractures that are often noted over joints.

As tissues eventually become longer, blanching decreases when the skin is stretched, and contractures decrease. Inserts add extra pressure over thick, nodular, hyperemic scars. When used in this manner, tapering the edges of the inserts assures total contact by preventing tenting from the elevated ridges. Inserts can be used as padding for protection over bony prominences, under zippers, and at the inner angle of flexor creases, such as the ankles or elbows, to prevent garments from cutting into the skin. Closed-cell inserts may need to be worn with an open-cell, fabric, or disposable gauze, or paper liner to absorb perspiration.

Wounds must be healed before inserts can be used. Inserts can be fabricated prophylactically for areas of anatomical vulnerability, such as the thumb web space, or for concave areas, such as between the breasts. When the skin begins to shrink and before contracture can form, properly placed inserts can prevent more difficult problems later. As dynamic scars change, inserts can be serially made for increasingly larger anatomical spaces. As the scar flattens, impressions can be filled in until the insert is flush with the surface and the scar impression is no longer seen in the insert.

There are a wide variety of materials to use for inserts or overlays to increase pressure over a hard scar. The creativity of both therapists and casualties has resulted in many successful scar modifications. Fabric, open-cell or closed-cell foam, rubber or plastic pieces, and silicones are all appropriate inserts or overlays (Figure 13-77). Silicone can be placed between two Isotoner gloves or between two tubular compression stockings to increase the pressure on the scar and prolong the life of the insert. When the insert causes contact dermatitis, it must be discontinued and, after the area is healed, a different insert material can be tried.

The insert and support must be applied to maintain gradient pressure. As with the vascular support garment, they cannot be applied like a tourniquet in the middle of an extremity, which would impair venous return and cause edema in the distal hand or foot. Even if edema is not severe enough to be seen with the naked eye, the distal circulation will change. Therefore, the insert must be placed under or over a support that is donned from the hand or foot to the shoulder, knee, or hip. Certain prefabricated, commercially available fabrics and foams can be used. Lamb's wool, in coil form, is a very soft, natural fiber that absorbs moisture in interdigital web spaces and protects fragile areas. Fibers adhere and incorporate into open wounds, so wool should be covered if applied where open areas or drainage is present. Cushioned strapping materials made of thin foam work well as finger inserts. They are loose fabric compatible with hook-and-loop fasteners.

Silicones and elastomers can also be useful, such as a protective skin care pad with a solid, gelatinous consistency (described as artificial fat). These pads are lightly adherent and can be cut into any shape to provide cooling comfort. Thicker pads eliminate friction and absorb pressure. Thinner flexible pads are effective on mobile joints, such as the elbow. Both increase compression. The pad's surface is oily, and

Figure 13-77. Variety of insert materials for scar management.

the scar must be protected or observed for maceration. Using these pads for periods of 8 to 12 hours, then leaving them off for 12 to 16 hours, may relieve skin over-moisturization.

Silicone gel sheeting is another compression insert option. This clear, soft, slightly adherent, semiocclusive, flexible insert is made from medical-grade silicone polymers without fillers (Figure 13-78).[242,370] One version is very tacky and stays in place well, but crumbles fairly easily. Another type has a netted back woven through and is advertised to modify a scar with or without pressure. It is effective when worn a minimum of 12 hours per day (rather than the usual 23 hours).[359,371]

Putty-based, white silicone elastomers can also be used for compression. In this case, the elastomer is mixed with a red tube catalyst, resulting in a firm, pink, rubbery, closed-cell insert. It does not run, sets in 5 minutes, is odorless, and is semirigid but flexible. It is easy to work with in small quantities, and works well for interdigital web spacers and as a shock absorber, decreasing contractures and filling in cavities.

A closed-cell, gray-liquid–based, taffy-like elastomer mixed with a clear catalyst can also be used. It cures to a rubbery texture, and the setting rate depends on the amount of catalyst used. Handling it can be challenging and requires a tongue depressor. It sticks to hair, so a protective layer of lotion or plastic wrap should be used. It stains before the catalyst is added, and it requires refrigeration or storage and has a 1-year shelf life. It picks up very fine detail and works well on large areas. Serial inserts can be made by filling in the scar impression with medical adhesive as it improves. Repetitive fabrications can be made on a revised scar until the insert is flush. On large body areas, a pattern can be made and the insert fabricated on old radiographic material; this works well on flatter surfaces with less mobility, such as the trunk, lateral ankle, or palmar arch. This elastomer can be mixed with prosthetic foam.

Hot and cold gel pads can be used under compression garments. They have a cloth covering on the back that protects the garment from oils. The pads are occlusive, can be used on open wounds, and can be cut to size, but should extend 1 to 2 inches beyond the wound or be 25% larger than the wound. They can be worn over topical medication and made waterproof by applying a film dressing over the top. They can be secured with tape, gauze, or elastic compression.

If both compression and silicone gel sheeting are used, they should only be worn together 12 hours a day. For the other 11 hours that compression garments should be worn, one or the other can be used separately; otherwise, skin irritation may develop and the gel sheet will disintegrate from too much wear.

Although scar tissue usually looks shiny and is lighter in color than surrounding tissue, the optimal final healed wound should appear flat, soft, mobile, durable, supple, of proper color, and have minimal thinning and wrinkling. The wound is mature when the skin texture is soft and the scar is flat and thin. There may be some loose, excess skin folds that appear to be wrinkled, but overall the skin should be more flexible and exhibit some extensibility. Erythema will have faded or lightened from purple to red, then pink, then dark brown or white. The skin will return closer to its normal pigmentation in darker-skinned individuals than in fairer-skinned individuals. Often a graft site that required mesh continues to present the mesh pattern. Even with optimal results, there is usually some change in color tone. External vascular supports decrease the amount of hyperpigmentation deposited in the wounds of casualties with darker skin.

When a scar appears to be mature, external vascular support is discontinued for a trial period lasting at least 1 to 3 days, but not longer than 1 to 2 weeks. If the symptoms or signs of active scar formation do not recur, the ultimate outcome has been achieved.

For burned hands, compression should continue on burned or grafted areas until the scar is mature.[192] Custom compression gloves should be introduced approximately 6 weeks following the burn for deep partial-thickness burns and full-thickness burns or after skin graft. All burn wounds should be closed and there should be minimal or no edema present. ROM exercises should continue during the long-term phase to emphasize tissue elongation. If adequate skin length is not obtained, the risk for joint capsular tightness

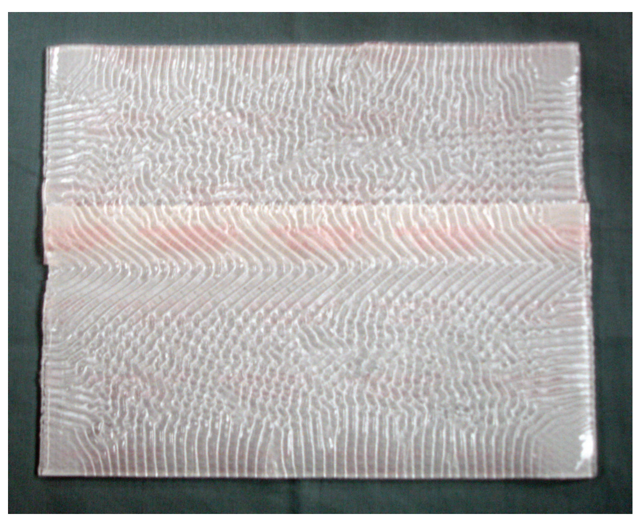

Figure 13-78. Silicone gel sheeting for scar management.

increases. Therapists should continually assess for joint capsular tightness, skin tightness, tendon adherence, or intrinsic muscle tightness. ROM exercises should address the appropriate deficits.

If adequate ROM gains are not achieved with exercise alone, splinting or serial casting should be considered. Dynamic or static-progressive splints are the most common splints used during the long-term rehabilitation phase, when the goal is to increase ROM. Static splints are usually sufficient if the goal is to maintain what was achieved with exercises. Static-progressive or dynamic splints should be worn for at least 6 to 8 hours a day, for intervals of at least 30 minutes, to provide the optimal duration for tissue elongation.

PLASTIC AND RECONSTRUCTIVE SURGERY

Reconstructive surgery and subsequent rehabilitation must be appropriately timed for the casualty to improve functionally, cosmetically, and psychologically. Otherwise, when inaccurately timed, the inverse is probable, resulting in loss of function, wasted valuable donor areas, and failure to benefit from the procedure.

Burn surgery is reconstructive rather than cosmetic. The American Society of Plastic Surgery defines reconstructive surgery as a surgical intervention "performed on abnormal structures of the body, caused by birth defects, developmental abnormalities, trauma or injury, infection, tumors, or disease. It is generally performed to improve function, but may also be done to approximate a normal appearance."[372] In addition to reconstructive surgery, plastic surgeons recommend makeup to enhance appearance and self-confidence for both male and female casualties.

The phases of recovery addressed by plastic surgeons include the acute phase, during which the wounds are closing, and the long-term phase, during which the scars are maturing. The ideal time to undertake reconstructive surgery is after scars have matured; however, there are a few specific situations in which reconstruction must begin earlier. In many cases, casualties want reconstruction early, and they must be made aware of the disadvantages of increased inflammatory scar deposition during the early scar maturation phase. As time progresses and the scars mature, casualties often become more satisfied with the appearance of their scars.[373] Additionally, as casualties become involved in former activities, they are less interested in prolonged interruptions for operations or in-hospital care.

The reconstructive process requires communication between members of the interdisciplinary team, including the surgeon and therapy staff, and the casualty. The process requires clinical evaluation, assessment, and planning to select the most troubling functional deficits or disfiguring scars. Casualties take an active part in the planning process. After considering multiple ways of correcting significant problems, the reconstruction surgeon chooses the optimal method for a particular casualty, as well as a backup procedure in case of postoperative complications or tissue loss.

Surgical teams frequently perform multiple operations under the same anesthetic so procedure time is used efficiently and recovery time is minimal. For instance, a fifth finger flexion contracture is often released the same time a web space contracture is corrected with a Z-plasty (see "Flaps" below) on the same hand. Only one hand is operated on at a time, and early motion cases are not mixed with procedures that require immobilization. In most cases, external vascular support garments are not worn and compression is usually not helpful after reconstructive operations. If hypertrophic scarring becomes difficult after reconstruction, the rehabilitation team uses pressure, gel sheets, or intralesional steroids.

Flaps

Skin flaps are frequently used in burn reconstruction when vital structures need coverage. They may be used in any phase of the reconstruction, and various flaps are used for different purposes. Musculocutaneous flaps, or muscle flaps, are often used acutely to cover bone, vascular grafts, or vital organs exposed by the burn. Musculocutaneous flaps are also used during reconstructive procedures. Muscle provides excellent blood supply, new lymphatics, and thick composite coverage. In some cases, the initial reconstructions are bulky and do not shrink adequately, so volume must be reduced at a later procedure.

Free flaps are used to provide blood supply to large avascular areas, such as the scalp, following electrical injury. These flaps require microvascular anastomosis and a specialized and individualized donor site. For example, a free flap of omentum may be used to cover a complete scalp defect. An overlying skin graft is then required. If abdominal burns or gastrointestinal pathology make this choice unwise, a latissimus dorsi flap may be used.[374,375]

A thin, free flap including skin, such as a dorsalis pedis flap, may be better than a muscle flap reconstruction, which requires an additional overlying skin graft. Free flaps are useful in all phases of burn healing and provide sufficient options for the plastic surgeon.

Axial flaps are long, cutaneous flaps that contain an anatomically recognized artery and vein. The flap is turned, rotated, or moved into position. Axial flaps are usually used for hand procedures, such as a pollicization or island pedicle finger pulp reconstruction.

Random, or local flaps, were the earliest flaps used. They do not contain a recognized artery and are used almost anywhere on the body surface. The skin flap survives on the subdermal plexus of vessels. A delay procedure may be needed to enlarge these flaps. Tissue expansion may expand the size of available tissue.

Z-plasty is a procedure using multiple small flaps to lengthen a contracture. Z-plasties may set multiple flaps around a specific joint or along a contraction line. These flaps are occasionally mixed with small skin grafts.

Timing a reconstruction may depend on the type of burn. Chemical and thermal burns may not need reconstruction because they slowly improve. In contrast, radiation burns tend to be chronic and gradually worsen. These injuries require late debridement and flap coverage years after the initial trauma. Skin grafts in these cases are ineffective; musculocutaneous flap coverage ideally provides a new blood supply.

Electrical burns often require reconstruction during the acute phase of burn rehabilitation because they usually expose vital structures, such as tendons, bones, or viscera. Split-thickness skin grafts rarely provide the quality of coverage needed, and flaps are vital to introducing new blood supply during the first few weeks following injury. Musculocutaneous flaps and free flaps are the most adaptable methods for coverage of electrical wounds.

In the face, reconstruction and function begin to merge. Functionally, facial skin identifies an individual, transmits emotion in communication, protects the corneas, and forms the mouth and nose. Eyelids, vital to the protection of the eye, may require reconstruction at a very early stage in the acute phase of burn recovery. To correct eyelid eversion or contraction, full-thickness donor skin must be obtained in sufficient quantity to replace the eyelid skin. If hair-bearing skin or scarred skin is used, the results may give an unacceptable appearance and rapid reoccurrence of ectropion. Reconstructing aesthetic units of the face during the acute phase provides an optimal appearance that may not be matched by another procedure until the casualty's burn wounds have matured. In the interim, facial orthoses (eg, transparent facemasks) are the primary option for improving the appearance.[376] Facial features are not reconstructed until scar tissue has become inactive, supple, and mature. In many cases spontaneous healing, with the use of a microstomia appliance, produces such favorable results that no further reconstruction is necessary.

Timing of functional hand burn surgery is fairly independent of reconstruction considerations for appearance. After initial wound closure, finger motion is vital and surgery assumes a secondary role until the wound has become mature. Once the skin starts to feel supple, reconstruction can begin. Skin grafts to the hand require immobilization for 10 to 14 days, followed by aggressive remobilization using prolonged stretch and AAROM, AROM, and CPM equipment as necessary. Extensor tenolysis is undertaken only when skin coverage is good. Casualties must start ROM exercises within 24 to 48 hours of extensor tenolysis surgery. Web space reconstruction using Z-plasties is managed like skin grafts, with 10 to 14 days of immobilization and 6 to 8 weeks of spacers at night. It is not unusual to need an unexpected skin graft during a web space release because, as the scars are incised and defects are opened, the need for additional skin coverage becomes obvious. Functional problems with hands, eyelids, mouth, axillae, elbows, and neck are the most important to the well-being of the casualty. Because muscles, tendons, and nerves shorten when the skin over a joint is contracted, reconstruction takes precedence, even if the maturation phase has not been completed.

It is important for all team members to understand the objectives and timing of reconstructive surgical interventions in the burn casualty. Proper postoperative rehabilitation is best directed by communication between the plastic surgeon, who knows the surgical intervention and proper timing to resume therapy, and the rehabilitation team, who understands splinting needs and a casualty's independent activity.

SPECIAL CONSIDERATIONS

Special Senses

Casualties injured from burns and explosives can sustain a variety of trauma and complications. For example, blast trauma can leave a casualty with a ruptured tympanic membrane as well as external injury to the ear, resulting in profound hearing loss. If a casualty is burned during the trauma, there may also be injuries to facial skin affecting the ears, eyes, nose, and throat, impairing the casualty's ability to see, smell, taste, eat, or speak. Other types of exposure or idiopathic injury, such as chemical splashes or toxic epidural necrolysis, may result in a number of conditions (eg, purulent conjunctivitis, corneal abrasions, epithelial defects, and retinal detachments), leaving the casualty with temporary vision loss or a residual deficit. Rehabilitation professionals must be prepared to address these issues because they can affect the casualty's ability to participate in rehabilitation and to recover critical independence with ADLs.

During the acute care phase, all deficits must be defined and addressed in the casualty's care plan. Rehabilitation professionals must be familiar with the many types of equipment a casualty may present with (eg, protective ear coverings, moisture chambers or eye coverings that help protect the exposed cornea from drying injury, eye bolsters, a variety of lubricating and antibacterial creams for the injured eye, and eye patches).

Casualties with reduced sensorium require increased safety measures as a daily part of their care. Clear and concise verbal cues enable casualties to follow commands and directions. Written signage above a casualty's bed and daily rounds reports alert staff and family to the casualty's needs. Casualties with significant speech and hearing loss must have alternative types of communication, including writing or pictures on a board to allow them to point and make their needs known. Manual expressions or demonstration of directions can also be used to perform ROM exercises.

As rehabilitation continues from acute care to intermediate care, the casualty's ability to perform basic mobility tasks may improve, but some deficits will continue to be problematic, such as diminished vision or hearing. Rehabilitation goals must shift to accommodate this and advance a casualty's mobility and ability to perform ADLs despite the continued deficits. Rehabilitation specialists should be proficient in adaptive technologies, techniques for low vision training, and assistive devices that may be introduced to continue towards rehabilitation goals.

In the long-term recovery stage, it is hoped that casualties will have regained many of the lost sensory deficits; however, many casualties continue to have additional procedures that prolong visual and hearing deficits. Technologies for coping with permanent vision and hearing loss, and education to protect extremities with decreased protective sensation remain important throughout the rehabilitation process.

Thermoregulation

Full-thickness burns damage dermal appendages, including sweat glands, leading to a decreased ability to sweat in areas of deep burns.[2] Skin grafting of these wounds does not replace the dermal appendages, and the density of sweat glands decreases in areas used for donor sites.[284] Areas of superficial and partial-thickness burns will regenerate lost glands.

As perspiratory function returns, it is common to see an increase in perspiration and sebum in both burned and nonburned tissue because of the body's continued need for thermoregulation within the environment. The loss of glands in the deeper portion of the burn requires the remaining and regenerating sweat glands to work harder to maintain homeostasis.

Austin et al reported no significant difference in the rise of body temperature of subjects with burns after 1 hour of cycle ergometer exercise in a 35°C environment.[284] These subjects were able to maintain heat tolerance through increased sweat rates in areas of healthy skin, and whole body sweat rates were comparable to those of normal subjects.[284] Other studies, however, have shown thermoregulation problems do exist, especially when exercising in warmer environments.[377–379] These studies demonstrated that subjects with greater than 40% TBSA burned had increased sweat rates but were unable to adequately maintain thermoregulation after exercise in a 40°C environment,[377,379] resulting in a significant increase in core temperature and heart rate.

If a casualty has sustained burns equal to or greater than 40% TBSA, there is potential for hyperthermia during exercise, especially in environments with high ambient temperatures. Prolonged exposure to temperatures above 35°C should be avoided. A fan or air conditioner may be needed to help body cooling by evaporation. Casualties must remove garments and orthoses and must shower and cool down after vigorous exercise or work-related activities. Clinical experience shows that the ability to maintain temperature homeostasis at rest and with minimal to extreme exertion is an individual response. Work and exercise tolerance has to be evaluated on a case-by-case basis and requires careful, supervised therapy to maximize a casualty's potential.

Medical Evaluation Boards

An injured service member may remain on temporary physical profile for up to 1 year. During this time, the rehabilitation team makes every attempt to maximize the casualty's recovery potential. Casualties are referred to the Physical Disability Evaluation System if they are unable to meet medical retention standards after ample time or if they are unable to return to duty.

The US Army Physical Disability Agency, under the operational control of the commander of the Human Resources Command, is responsible for operating the Physical Disability Evaluation System.[380] According to Army Regulation 635-40, Physical Evaluation for Retention, Retirement, or Separation, the system's goals are to:

- maintain an effective and fit military organization with maximum use of available labor,
- provide benefits for eligible soldiers whose military service is terminated because of service-connected disability, and
- provide prompt disability processing while ensuring that the rights and interests of the government and the soldier are protected.[381]

The medical evaluation board process begins when optimal medical recovery has been reached, when the service member's ability to perform further duties can be determined, when the service member has been on temporary profile exceeding 1 year, or when the service member has been given a permanent profile of a three (3) or a four (4), indicating a permanent functional deficit exists for which functional recovery is unlikely. The medical evaluation board is comprised of at least two physicians whose job is to assess and evaluate the medical history of a soldier and determine how the injury or disease will respond to treatment protocols.[382]

SUMMARY

Treatment of combat-related burn injuries includes recovering optimal function to maximize participation in societal, psychological, and physical roles. Increased rates of survival have led to greater concern for potential morbidity. Surgical and medical technology has improved to such an extent that now, in most cases, burn care providers must assume that burn casualties will survive. Even during the initial or acute phases of care, the burn team must be aware of what will be important to the casualties they treat in the long term. Burn casualties experience a series of traumatic assaults to the body and mind that present extraordinary challenges to their psychological resilience. Contrary to what might be expected, empirical data regarding the long-term sequelae of burn indicate that many burn casualties do achieve a satisfying quality of life and that most are judged to be well-adjusted individuals. Outcomes studies not only report status of burn casualties following treatment, but can also indicate those factors that seem necessary to good outcomes. These studies have also found that the extent of the injury, the depth of the burn, the area of the body burned, and even amputations are not determining factors of good psychosocial recovery. The two most important factors that have consistently been found to be related to psychological and social adjustment are the quality of family and social support received by the casualty and the willingness of the casualty to take social risks.[383]

Burn casualties must be reassured that confusion, mistrust, anger, guilt, sorrow, and other issues are normal when they consider that their experiences are part of a very abnormal situation. Casualties should be prepared to handle stares and insensitive comments. Casualties must focus on what they can still do and on what functionality they still have, and should be encouraged to keep a sense of humor and nourish their spirits by whatever means possible. Successful reintegration into the community is the ultimate goal for the remainder of their lives. Every individual who interacts with a casualty impacts the psychosocial world of that casualty.

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