CLINICAL THERAPEUTICS

Excision and Skin Grafting of Thermal Burns

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This Journal feature begins with a case vignette that includes a therapeutic recommendation. A discussion of the clinical problem and the mechanism of benefit of this form of therapy follows. Major clinical studies, the clinical use of this therapy, and potential adverse effects are reviewed. Relevant formal guidelines, if they exist, are presented. The article ends with the author's clinical recommendations.

A 45-year-old man was rescued from his burning house. Firefighters removed his smoldering clothes and initiated intravenous access, pulse oximetry, and electrocardiographic monitoring. An endotracheal tube was inserted, and ventilation with 100% oxygen was initiated for presumed airway instability and inhalation injury. He was taken to a local emergency department with both superficial and deep dermal burns involving his torso and arms; the burns covered 42% of his total body-surface area. Intravenous fluid resuscitation was initiated. He was then transferred to a burn center for definitive treatment. Tube feeding was initiated through a nasogastric tube. The burns were cleansed and a slow-release silver dressing was applied. On day 3 after the injury, he is clinically stable. The clinicians are now deciding whether to excise the burns and how to cover the open wounds.

THE CLINICAL PROBLEM

Burn injuries requiring treatment occur in 500,000 patients per year in the United States.[1] Of these injuries, 46% are flame burns. The number of serious burns is decreasing in the United States because of increased prevention (smoke detectors, water-temperature regulations, and decreased smoking), but there are still about 3500 deaths from residential fires yearly. Approximately 75% of such deaths occur at the scene of the accident or during initial transport.[1] Mortality associated with burn injuries is related to the age of the patient, the percentage of the body surface that is burned, and the presence or absence of smoke-inhalation injury. According to this model, the patient described in the vignette, with burns covering more than 40% of his body-surface area and smoke-inhalational injury, would have a predicted risk of death of 33%.[2]

Among patients surviving large burns, morbidity always includes scarring and frequently includes infections, loss of bone and muscle mass, poor wound healing, hormonal imbalance, and pulmonary, hepatic, or renal failure.[3] Loss of skin appendages makes heat regulation and skin care more difficult. Even small burns can cause significant morbidity, such as loss of hand function or facial deformity. There are often psychological sequelae in burned patients, including post-traumatic stress disorder and depression.[4]

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PATHOPHYSIOLOGY AND THE EFFECT OF THERAPY

The pathophysiology of thermal injury is related to the initial distribution of heat within the skin. Hot temperatures for a short period or lower temperatures for a longer period can cause similar injuries.[5] For example, a blistering injury can occur after 5 minutes of exposure to water at 48.9°C (120°F) or after just 1 second of exposure to water at 68°C (155°F). Because skin is a good insulator, most burns generally involve only the epidermis (first-degree burns) or portions of the dermis (second-degree burns). Only with prolonged exposure do burns encompass the entire dermis (third-degree burns) or extend beneath the dermis into fat, muscle, and bone (fourth-degree burns).

Jackson[6] has described three zones of histopathological injury (Fig. 1). The zone of coagulation (eschar or necrosis) is the area closest to the heat source. Tissue in this zone either is entirely necrotic or undergoes severe denaturation of proteins and is believed to have sustained irreversible injury. Just below the zone of coagulation is a zone of stasis and edema, where there is only modest denaturation of macromolecules but slow blood flow. The edema and stasis in this zone have been attributed to capillary leak and cell-membrane disruption.[7,8] Beneath the zone of stasis is an area of hyperemia, where blood flow gradually increases, becoming particularly prominent by about 7 days after the injury. A burn that appears superficial may become deeper over a period of 48 to 72 hours, with the zone of stasis becoming necrotic. This is especially likely to happen if the wound becomes infected or there is poor perfusion of the affected area.[9]

The surface area of a burn can be estimated by using the Rule of Nines (Fig. 2A).[10] In this approach, each arm accounts for 9% of the body-surface area, each leg accounts for 18%, the anterior and posterior trunk account for 18% each, the head and neck account for 9%, and the perineum accounts for 1%. The Rule of Nines is a useful and rapid method for estimating the extent of burns in adults but may lead to either underestimation or overestimation in children. In addition, some centers use the Lund–Browder system, in which values for the legs and head vary according to a patient's age[11] (Fig. 2B). Computer-assisted methods provide improved estimates for burn percentages and are being used with increasing frequency.[12]

Burn injury induces a systemic hypermetabolic response, resulting in inflammation, immune compromise, endocrine dysfunction, and catabolism.[13] In addition, protein coagulation and the avascularity of burn eschar combine to result in a high risk of infection.[14] Infection is the leading cause of complications and death in patients with burns.[15]

The preferred treatment of deep dermal burns includes early excision and grafting. This approach removes necrotic and inflamed tissues and rapidly promotes physiologic wound closure. Excision of burn eschar removes a principal nidus for bacterial infection and exposes a viable bed for skin grafting. Grafting minimizes fluid loss, reduces metabolic demand, and protects the wound from exposure to infectious organisms. Early excision and grafting have been shown to reduce inflammation, as well as the risks of infection, wound sepsis, and multiorgan failure.[16]

CLINICAL EVIDENCE

Cope et al.[17] popularized the concept of early excision and autografting of burn wounds after treating patients from the Cocoanut Grove fire in Boston in 1942. With the advent of antibiotics and topical burn dressings, surgical intervention for burn wounds fell out of favor. Instead, wounds were dressed until the eschar lifted and then were repaired with skin grafts. Janzekovic[18] renewed interest in early excision in 1970, when she reintroduced the concept of tangential excision of the necrotic tissue and immediate closure with split-thickness skin grafts.

Ong et al.[16] performed a meta-analysis of data from six randomized, controlled trials, published from 1966 through 2004, that compared early excision of burns with wound dressing and grafting after eschar separation. They found a trend toward a reduction in mortality with early excision: 39 of 146 patients (27%) treated with excision died, as compared with 52 of 144 (36%) treated with wound dressing and early grafting (hazard ratio for early excision, 0.73; 95% confidence interval [CI], 0.52 to 1.01). However, the difference in the rate of death between the two procedures was significant only among patients without inhalation injury: 10 of 45 patients (22%) treated with excision died, as compared with 28 of 45 patients (62%) treated with wound dressing and delayed grafting (hazard ratio, 0.36; 95% CI, 0.20 to 0.65). Among patients who underwent early excision, blood-transfusion requirements were increased, and the length of hospitalization was reduced. There was no consistent evidence of reduced sepsis or a better cosmetic or functional outcome with early excision.

In a retrospective study, Xiao-Wu et al.[19] exam-

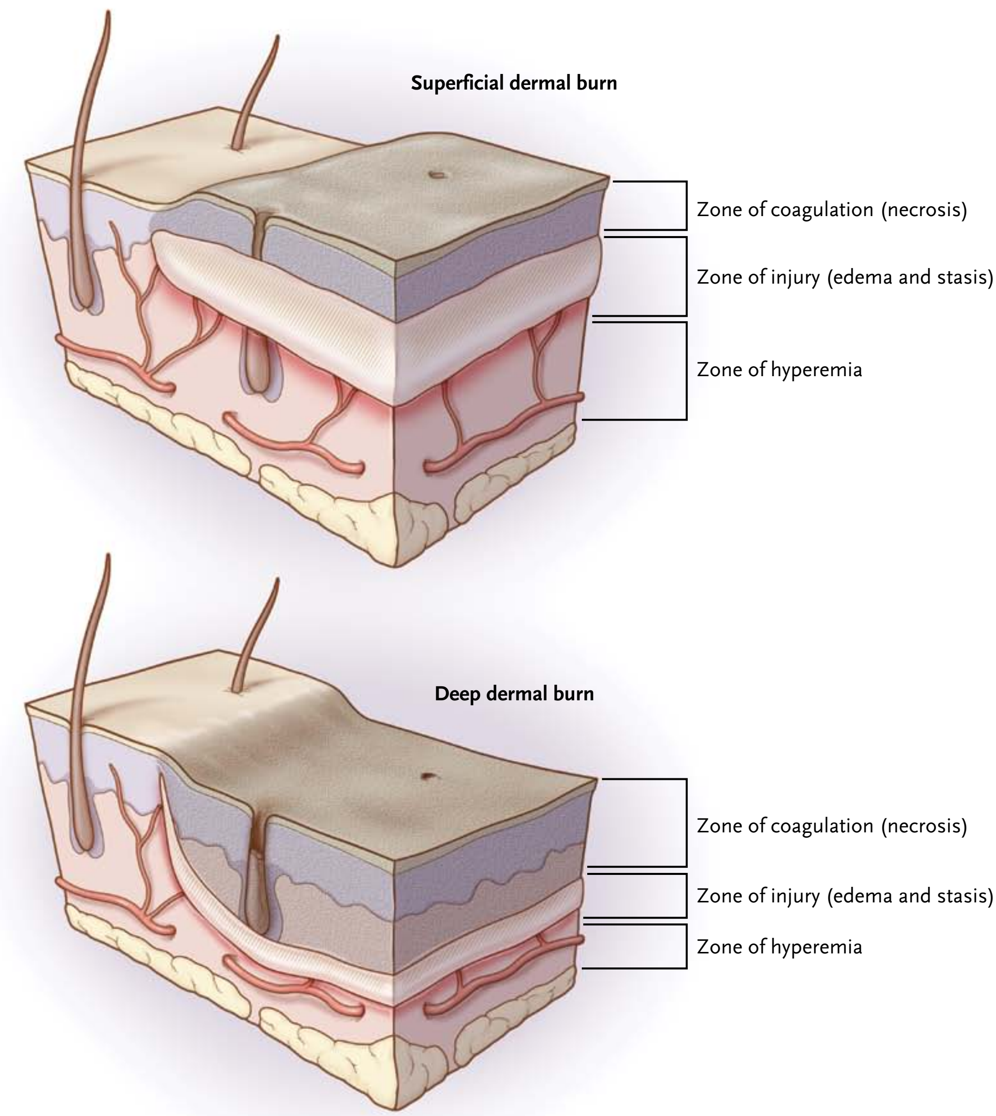


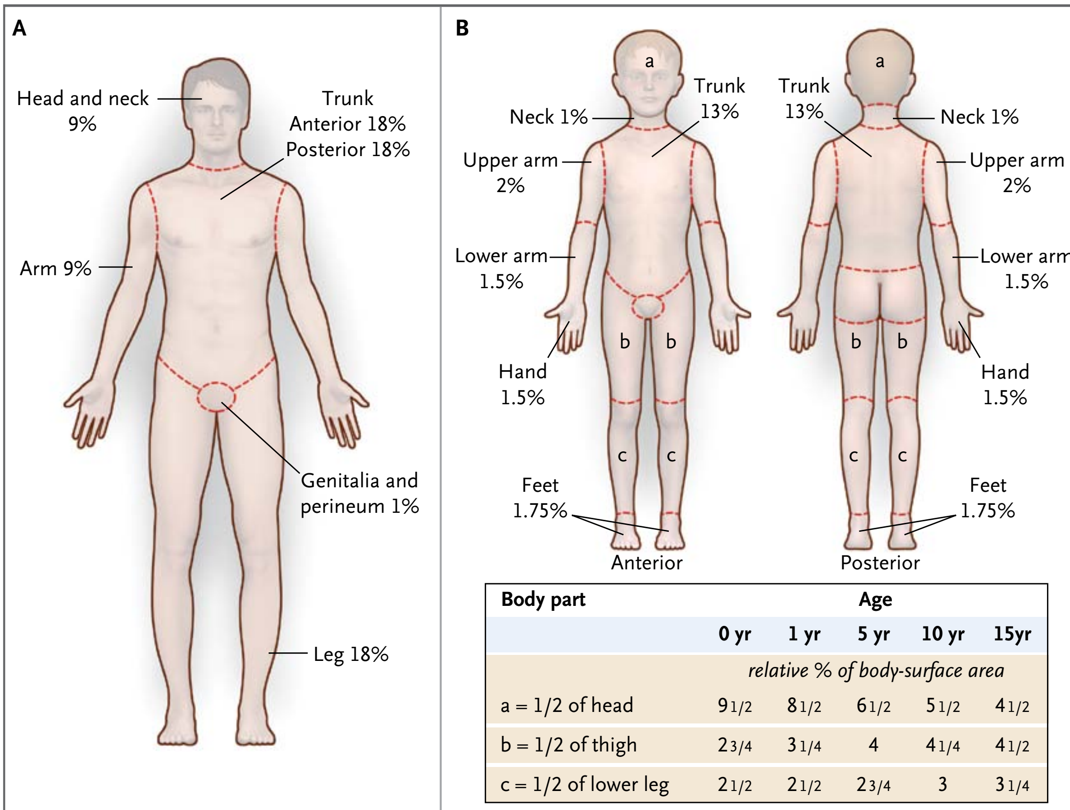
Figure 1. Zones of Injury in Superficial and Deep Dermal Burns.

A burn can result in three distinct zones of injury. The uppermost zone (necrosis) is necrotic from protein denaturation. The intermediate zone (stasis) has edema and slow blood flow. If stasis persists, this zone will progress to necrosis. Beneath the zone of stasis is a zone of hyperemia. In superficial dermal burns, the zone of necrosis occupies only the upper (papillary) dermis, with a normal underlying reticular dermis. In deep dermal burns, the zone of coagulation extends into the reticular dermis. Full-thickness burns extend through the entire dermis.

ined 157 children with burns involving 40% or more of the body-surface area who were stratified according to the number of days between the injury and the first operation (0 to 2, 3 to 6, or 7 to 14 days). Delayed excision and grafting were associated with longer hospitalization and increased rates of invasive wound infection and sepsis in the group undergoing surgery 7 to 14 days after injury.

CLINICAL USE

Patients with deep thermal injuries of more than 20% of the body-surface area should be admitted



Body part	Age				
	0 yr	1 yr	5 yr	10 yr	15yr
	relative % of body-surface area				
a = 1/2 of head	9 1/2	8 1/2	6 1/2	5 1/2	4 1/2
b = 1/2 of thigh	2 3/4	3 1/4	4	4 1/4	4 1/2
c = 1/2 of lower leg	2 1/2	2 1/2	2 3/4	3	3 1/4

Figure 2. The Rule of Nines and Lund–Browder Charts.

The Rule of Nines (Panel A) is often used to estimate the surface area of a burn in adults. However, this approach is less accurate in children. Lund–Browder charts (Panel B) use values for the legs and head that vary according to a patient's age.

to an intensive care unit with continuous electrocardiographic monitoring, pulse oximetry, and frequent monitoring of vital signs, fluid intake, and urine output. Lactated Ringer's solution is infused to maintain a urine output of 0.3 ml per kilogram of body weight per hour and a mean blood pressure of more than 80 mm Hg. Excision and grafting are delayed until hemodynamic measures, body temperature, and organ function are all within normal limits.

Clinicians find it useful to subclassify second-degree (dermal) burns as superficial or deep dermal burns. In superficial dermal burns, the layer of necrosis occupies only the upper (papillary) dermis, with normal underlying reticular dermis (Fig. 1A). Clinically, such burns are pink or red, may have blistering, are painful, and have a good blood supply. These burns are usually managed conservatively (without excision and grafting).

In contrast, in deep dermal burns, the layer of necrosis extends into the reticular dermis, with the zone of stasis extending deep into the dermis (Fig. 1B). Clinically, these burns tend to be less red with poor blood flow. Deep dermal burns are generally best treated with excision and grafting, which can reduce the risk of long-term complications (hypertrophic scarring and burn contractures). Ideally, surgery should be performed within the first week after injury if the patient's clinical condition is stable.[20] Full-thickness (third-degree) burns involve the entire dermis and are most often treated with excision and grafting.

The goal of early excision is to remove all devitalized tissue and prepare the wound for skin grafting (Fig. 3A). All necrotic tissue needs to be removed in order for the applied skin graft to engraft successfully. Tangential excisions are performed with large guarded knives to control the thickness of the excision. Layers of burned tissue are excised until a viable wound bed is reached, as evidenced by capillary bleeding.

An alternative is to excise the burned tissue with underlying subcutaneous fat down to fascia, most commonly with the use of cautery. This approach is faster, requires less skin grafting, and results in less bleeding but can result in severe cosmetic deformity and reduced sensation because of the excision of cutaneous nerves. In the case of deeply burned cartilage or bone, all devitalized tissue should be removed as soon as the patient's condition is hemodynamically stable and the wound covered with skin, muscle, or myocutaneous flaps, as indicated. If the depth of the burn is unclear, the eschar will occasionally be left to lift off by itself, such as in the case of the ear or digits.

For large wounds, once hemostasis has been achieved, a split-thickness skin graft can be applied. Thin pieces of skin, consisting of epidermis and superficial (papillary) dermis, are harvested from a nonaffected area, often the anterior thigh or abdomen, with the use of a powered dermatome at a thickness of 0.20 to 0.51 mm (0.008 to 0.020 in.) (Fig. 3B). These split-thickness skin grafts are placed over the débrided area and attached with sutures or staples (Fig. 3C). Some surgeons also use fibrin glue to assist in fixation.[21] Simple dressings with petroleum gauze or nonadherent dressings (often impregnated with silver or antibiotic ointment to reduce bacterial proliferation) are placed over the skin graft. Outer dressings that are designed to apply mild pressure to the wound are used to promote apposition of the graft and prevent shear forces from shifting the graft on the wound bed.

The donor site heals spontaneously over a period of 1 to 2 weeks, depending on the age of the patient and the size of the donor site. Wound dressings for skin donor sites, which vary among centers, include petroleum gauze, alginate, and silver foam. Reduction in the size of the skin-graft donor site can be accomplished by making the split-thickness skin graft into a "mesh graft." This is achieved by placing multiple small slits in the graft, allowing it to expand by up to six times the original area (Fig. 3D). When a mesh graft is used, the healed recipient site will have a corrugated appearance. Donor sites can often be reharvested after about 2 weeks.

If the burn is so extensive that there are minimal viable areas of donor skin, cadaver skin (allograft) or a dermal substitute may be used. Skin substitutes have a higher propensity for infection than autologous skin grafts. However, they can be useful when there is insufficient donor skin available, and they are associated with a lower risk of complications than autologous grafts.

Patients with large burns are kept in the intensive care unit until respiratory function and renal function are within normal limits and pain is well controlled with analgesics. Grafted areas are monitored for hematoma, seroma, and infection. Any fluid collection underneath the graft should be evacuated immediately to promote adherence of the graft to the recipient site. Any necrotic areas are sharply débrided. Infected grafts are aggressively treated with topical antibiotics. Areas of graft loss are débrided and either regrafted or allowed to heal by secondary intention (without surgical intervention).

Burn care is costly, with the greatest expenses related to hospitalization in an intensive care unit and surgical intervention. According to data from the American Burn Association, from 1998 through 2007, average inpatient charges at a burn center ranged from approximately $18,000 for burns covering less than 10% of the body-surface area to more than $300,000 for burns covering 70 to 80% of the body-surface area.[22]

ADVERSE EFFECTS

One of the most important complications of excision and grafting is bleeding, which can be substantial (100 to 200 ml of blood for every 1% of body-surface area that is excised, according to one study).[23] To reduce the severity of bleeding during excision, the fatty tissue under the burned areas can be infiltrated with a solution of dilute epinephrine in saline until the tissue is distended and has a smooth, firm texture ("tumescent technique").[24] For burn wounds on a limb, a tourniquet can be placed to further limit bleeding during excision. Other hemostatic methods — such as the use of spray or sponge-soaked thrombin, topical epinephrine,[23,25,26] vasopressin,[27] fibrin sealant,[28] and intravenous recombinant factor VII[29] — can also reduce bleeding. Even with such precautions, excisions can result in substantial blood loss. Timely transfusions are often neces-

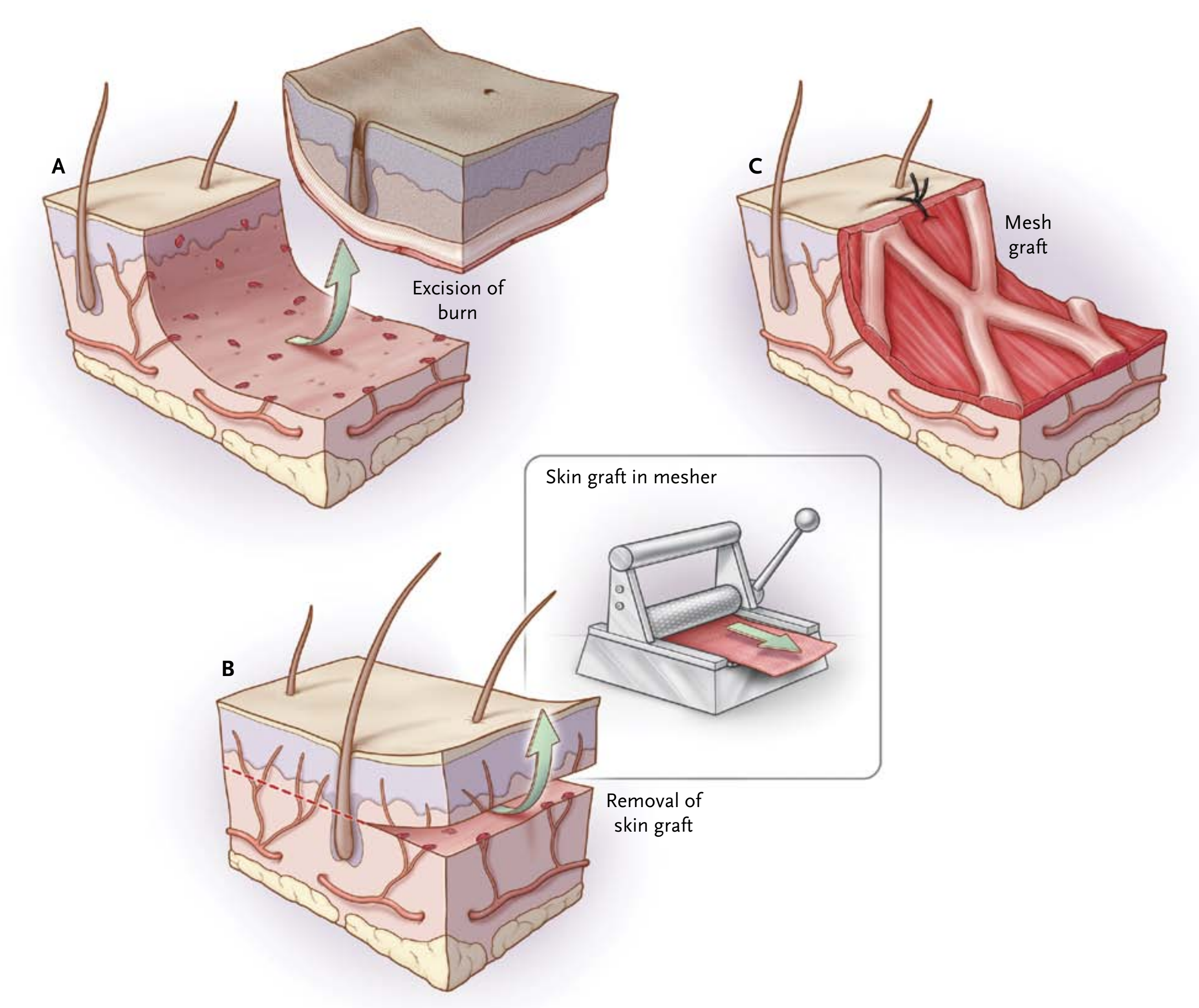


Figure 3. Excision and Grafting.

A combination of excision and grafting is the preferred approach for the treatment of deep dermal burns. The burn is excised (Panel A) until a viable wound bed is reached, as evidenced by capillary bleeding. The graft (Panel B) is a thin layer of skin, consisting of epidermis and partial-thickness dermis, which is harvested from a nonaffected area, often the anterior thigh or abdomen. The skin graft is placed over the excised area (Panel C) and attached with sutures or staples. Reduction of the size of skin-graft donor sites can be accomplished by making the split-thickness skin graft into a "mesh graft" by placing multiple small slits in the graft, allowing it to expand by up to six times the original area.

sary, with the attendant complications, most commonly sepsis.[25]

Infection, both systemic and localized to the burn wounds, is common in patients with large burns and can complicate the healing of skin grafts. *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Acinetobacter baumannii* pose significant risks to patients with burns because of antibiotic resistance.[30] Topical antibiotics and occasionally systemic antibiotics are used to prevent and manage infection. The optimal choice of an antibiotic, timing of its administration, and duration of its use have not been clearly defined.[30]

Pain can occur in association with dressing changes, débridement, and physical therapy, as well as at donor and recipient sites of skin grafting. Pain associated with burns is difficult to manage because it is complex and constantly changing as the patient undergoes different treatments.[31] Pain management guidelines are based on established guidelines from the Society of Critical Care Medicine.[32]

Late effects of deep burns and associated scarring include disfigurement, hyperesthesia, itching, tenderness, and contractures.[33] No known method is completely effective for the prevention or treatment of scar-related complications. Efforts to prevent contractures include frequent use of moisturizing agents and consistent exercising to prevent loss of range of motion due to contracture. Surgical release may be necessary if scar contractures become severe. Dissatisfaction with the cosmetic appearance of scars and graft tissue may also lead patients to undergo subsequent reconstructive surgery. Compression garments are commonly used to prevent hypertrophic scarring, although clinical evidence of their efficacy is lacking.

Table 1. Criteria for Referral to a Burn Center.*

Partial-thickness burns of more than 10% of the total body-surface area
Burns that involve the face, hands, feet, genitalia, perineum, or major joints
Third-degree burns in any age group
Electrical burns, including lightning injury
Chemical burns
Inhalation injury
Burns in patients with a preexisting medical disorder that could complicate treatment, prolong recovery, or increase the risk of death
Burns and concomitant trauma (e.g., fractures) in which the burn injury poses the greater risk of complications or death†
Burns in children treated in a hospital without qualified personnel or equipment for the care of children
Burns in patients who will require special social, emotional, or rehabilitative intervention

* Data are from the American Burn Association's Burn Center Referral Criteria.
† In such cases, if the trauma poses a more immediate risk than the burn, the patient's condition may be stabilized initially in a trauma center before transfer to a burn center. The physician's judgment will be necessary in such situations and should be in concert with the regional medical control plan and triage protocols.

AREAS OF UNCERTAINTY

When patients with burns are evaluated immediately after the injury, it is often difficult to determine the depth of the burn and thus the extent of the need for excision and grafting. This is particularly true for burns of intermediate depth. Although bedside evaluation is the most common method of assessing burns, a number of methods have been proposed to better predict the depth of the wound. Tissue-perfusion measurements are often used, including thermography, videography with the use of indocyanine green with laser fluorescence, and laser Doppler perfusion imaging. Imaging with laser Doppler, although expensive, appears to provide the most accurate objective clinical measurement of burn depth but is somewhat difficult to interpret and is not routinely used in most burn centers.[34] Biopsy with histologic evaluation has also been shown to be useful, but this approach has limited value because of the invasive nature of the biopsy procedure, the subjective nature of histologic interpretation, and the risk of sampling error.

Dermal replacements have been developed as an alternative to autologous grafts. Clinically available substitutes include a semisynthetic matrix composed of collagen and glycosaminoglycan,[35] cadaver skin, and lyophilized (freeze-dried) cadaver dermis.[36] Such materials have been used most commonly to treat large burn injuries. The use of dermal replacements is limited by rates of infection that are higher than those for traditional skin grafts, the time required for preparation, and cost. There is a theoretical concern with collagen-based dermal-replacement therapies with respect to the transmission of prions[37]; however, there are no reported cases of prior transmission in the literature.

Another limitation of dermal replacements is the requirement for a second operation to restore the epidermis. Epidermal-replacement techniques, including cultured epidermal autografts[38] and epidermal sprays (in Europe and Australia), are available for clinical use.[39] Cultured skin substitutes consist of a tissue-engineered combination of dermis and epidermis; so far, these products have not been approved by the Food and Drug Administration.[38] Although skin substitutes show great promise, there is no consensus among practitioners about the optimal use of these products.

GUIDELINES

In 2001, the American Burn Association (ABA) issued a series of guidelines, which are available on the association's Web site (www.ameriburn.org). These guidelines are currently being updated and presented as referenced manuscripts for publication over the next 1 to 2 years.[22] The ABA recommends treating large burns or burns in critical areas of the body in designated burn centers[1]

(Table 1). Burn centers provide not only expertise in the surgical treatment of burns but also a multidisciplinary team (including nutritionists, physical and occupational therapists, and social workers) to help patients recover. A combination of early excision and skin grafting of deep burn wounds continues to be the accepted treatment in most burn centers.

RECOMMENDATIONS

The 45-year-old patient described in the vignette is an excellent candidate for early excision and grafting. Ideally, this procedure should be performed within the first week after injury in a center specializing in burn care. He should be taken to the operating room for excision under tourniquet control of the forearms and hands and for excision of the burn eschar from the anterior chest with the use of a tumescent-injection technique to minimize blood loss. A tangential excision technique is preferred for an optimal cosmetic result. Split-thickness skin grafts can be harvested from the thighs and lower legs. Sheet grafts can be used to cover the dorsum of the hands, with the hands splinted in flexion to avoid subsequent contracture. If there is a sufficient quantity of donor graft tissue, sheet grafts can also be used on the forearms. Meshed grafts can be used on the anterior chest to reduce the quantity of graft tissue that must be harvested from the donor sites. The donor sites and superficial burns should heal without surgery. Once all the burn wounds requiring surgery have been excised and grafted and the patient's condition is stable, he should be transferred to a rehabilitation hospital specializing in burn care and should then receive follow-up care at an outpatient burn clinic.

No potential conflict of interest relevant to this article was reported.

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