Management of Burns and Anesthetic Implications

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Initial Management of Burns

All patients who present with burn injuries should be thoroughly evaluated using the Advanced Trauma Life Support (ATLS) protocol. Approximately 10 % of patients with burn injuries also present with concomitant traumatic injuries, so a head to toe evaluation is imperative. An ABCDEF primary survey should be performed: airway, breathing, circulation, disability, exposure, and fluid resuscitation. If the heat source is not yet removed at initial point of contact, it must be immediately removed. Even after flames have been extinguished, clothing can still retain heat and must be removed as quickly as possible. The exception to this is material that is adherent to the skin such as tar or nylon, which should be left in place to prevent further skin injury. The burn area should first be irrigated with tepid water (approximately 15 °C). Ice water should be avoided due to its vasoconstrictive effects and because of the risk of hypothermia in patients with extensive burns who lose copious amounts of heat due to evaporative losses from disrupted skin barrier. Tepid irrigation for at least 20 min cools the burned area, removes any noxious agents, and also helps to stabilize mast cells and temper histamine release [1–3].

If the patient has not yet arrived to a care facility, the burned area should be covered after generous irrigation in order to prevent heat loss and to serve as a barrier against further evaporative losses and pathogens. Polyvinyl chloride film, otherwise known as common household plastic wrap, is ideal as it is non-adherent, transparent so that the burn area can be visually inspected, and impermeable. This should be gently laid onto the wound rather than wrapped so that in case the area swells, a tight wrap does not create ischemia or compartment syndrome. If plastic wrap is not available, a clean cotton sheet may be used instead, though it is less ideal. Wet dressings should be avoided due to the risk of rapid heat loss. Any topical creams should be avoided at this stage.

Chemical burns must be irrigated with particular care, as the deleterious effects of the offending agent only subside upon complete removal of the agent. If a chemical burn is suspected, a prompt search for the causative agent must be conducted, as simply irrigating with tepid water may not be adequate (Table 14.1). After rinsing with water and removing all contaminated clothing, the agent can be tested with litmus paper to determine whether it was acidic or alkaline. Certain chemical agents are neutralized with specific treatments. Hydrofluoric acid, for instance, which is commonly used for glass etching and can cause industrial burns, must be neutralized with topical calcium gluconate. Any eye injuries must also be irrigated copiously and examined promptly by an ophthalmologist.

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Table 14.1 Specific chemical burns and treatments

Specific chemical burns and treatments
Chromic acid—Rinse with dilute sodium hyposulphite
Dichromate salts—Rinse with dilute sodium hyposulphite
Hydrofluoric acid—10 % calcium gluconate applied topically as a gel or injected

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Approximately 60–70 % of burns seen in the emergency department are minor. If the burn is minor, it may be suitable for treatment in an outpatient setting. Generally, these are small (less than 10 % BSA), superficial burns that do not affect critical areas. The victim of the burn should also be relatively healthy with few or no significant comorbidities. If treated in an outpatient setting, maintenance of sterility is of utmost importance. The wound may be washed with soap and water or cleaned with a very dilute chlorhexidine solution. There is some controversy over how to manage blisters from burns in the outpatient setting; however, if the blister is large, it should be unroofed and the dead skin should be removed in a sterile fashion. The burned area should be securely dressed with sterile gauze and covered with a cotton wool dressing. The area should be inspected every 24 h. After the first 48 h, the dressing should be changed. After the first dressing change, subsequent dressing changes should be done every 3–5 days. If a minor burn has not healed within 2 weeks, it should be referred to a specialist. As the burn area heals, the skin becomes dry, scaly, and may itch. Changes in pigmentation may also occur as healing progresses. Sun exposure to the burned area should be minimized for 6–12 months after the initial injury [4, 5].

Burns that involve more than 10 % BSA or extend beyond the superficial layer of skin merit further evaluation and treatment, possibly in an inpatient setting. Patients who have evidence of electrical burns mandate a detailed evaluation given their tendencies to develop compartment syndrome, cardiac dysrhythmias, and muscle necrosis. Those who fail outpatient therapy or require supplemental nutritional support may also require continuing treatment at an inpatient facility. Patients at extremes of age, with large burns, or with burns involving critical areas should be transferred to a specialized burn center [6, 7].

Management of Airway and Inhalational Injuries

While the treatment for cutaneous burns has improved dramatically in the last few decades, mortality rates for patients with inhalational injuries have not changed significantly. Airway assessment is extremely important after a burn injury as inhalational injury can be present even in the absence of cutaneous burn injuries. Any closed space burn injuries involving steam, hot gases, combustibles, or explosions should raise suspicion for airway involvement and/or inhalational injuries. The oropharynx should be inspected carefully for soot. Carbonaceous sputum, singed facial or nasal hairs, or any burn injuries to the face or neck region may also be clues to inhalation injury. The patient should be observed over time for any signs of respiratory distress such as wheezing, stridor, tachypnea, or hoarseness, which may not be immediately apparent. These symptoms can develop as the airway becomes more edematous over the course of many hours (up to 18 h or more). Confusion, agitation, obtundation, or altered mental status may be indicators of carbon monoxide or cyanide poisoning. Pulse oximetry can often be deceptively normal in patients with burn injury, as it does not reflect abnormal hemoglobin species, nor does it reflect the metabolic ramifications of toxic gaseous byproducts. Arterial blood gas may be a somewhat better indicator for the presence of inhalational injury. A $PaO_2:FiO_2$ ratio of <300 has been shown to be an indicator of poor outcomes in patients with burn injuries. Chest radiographs and computed tomography are generally not useful. Fiberoptic bronchoscopy, however, can be used to directly inspect the supra- and infra-glottic airway for edema and for carbonaceous material. Fiberoptic bronchoscopy also aides in safely placing endotracheal tubes as well

as in removing mucous plugs, exudate, and foreign irritants [6, 8].

All patients who are suspected to have suffered from inhalational injuries should receive 100 % O_2 as soon as possible. As was previously discussed, carbon monoxide poisoning is common in patients with burn and/or inhalational injuries. The half-life of carbon monoxide is normally 240–320 min. However, with the administration of normobaric 100 % O_2, this half-life decreases to 40–80 min. One hundred percent O_2 should be administered for as long as it is necessary, or at least until the carbon monoxide concentration reaches 10 % or below. Hyperbaric oxygen therapy may also be considered for carbon monoxide poisoning. However, there is little evidence to suggest that it improves outcomes, and there is no consensus regarding the duration and intensity of treatment. Hyperbaric oxygen therapy also increases the risk of barotrauma in this patient population.

Obstruction, critical hypoxia, and death can quickly ensue after inhalational injuries, even if the airway is patent upon initial assessment, so establishment of a secure airway in a timely manner is crucial. Delay can result in a difficult intubation. Patients with facial trauma or burns may also be difficult to mask ventilate. Even if intubation is performed promptly, administration of an induction agent can result in obstruction due to relaxation of the upper airways, especially in the presence of upper respiratory tract injuries. Patients with inhalational injuries may also have very swollen tongues, making visualization of the airway cumbersome. Depending on the degree of airway involvement in the burn injury, an awake intubation with a fiberoptic bronchoscope may be the most suitable method of establishing an airway. If the patient is intubated, the endotracheal tube must be very carefully secured as accidental dislodgment of the tube can be fatal. If there is evidence or suspicion of vocal cord damage, a tracheostomy may be the preferred method of establishing an airway in order to prevent any exacerbation of vocal cord injury from an endotracheal tube. However, whether or not an airway is established with an endotracheal tube or a tracheostomy, resources and personnel able to establish a surgical airway should always be available given the dynamic changes to the airway in burn patients over time. Following intubation, the head of the bed should be kept elevated in order to minimize facial and airway edema. Over the long term, as the patient heals, scars and contractures in the head and neck area can limit mouth opening and neck mobility, creating difficulties in establishing an airway for subsequent surgical procedures [6, 9–13].

Patients with inhalational injury may require unconventional ventilation modes in the intensive care unit. Volumetric diffusive respiratory mode (VDR) is a ventilation mode in which high frequency, sub-tidal volume breaths are progressively accumulated until a certain airway pressure is met. At this point, passive exhalation is permitted to occur. The goal of VDR is to reduce mean airway pressures and increase overall PaO_2 and PaO_2:FiO_2 ratios without adversely affecting hemodynamics. It has also been shown to help mobilize secretions more effectively than conventional modes of ventilation. Additionally, studies have suggested that the incidence of pneumonia is decreased in patients who are ventilated with VDR modes versus conventional ventilation modes. Airway pressure release ventilation mode (APRV) is another alternative mode of ventilation that may be beneficial in patients with burn injuries. APRV uses high and low PEEP in order to recruit closed alveoli and therefore improve oxygenation. Essentially, it is a continuous positive airway pressure mode that is interrupted by an intermittent release phase. This mode of ventilation results in improved oxygenation due to improved V:Q matching, and decreased sedation and paralysis requirements. It has also been shown to improve blood flow not only to the lung and muscles of respiration, but also the gastrointestinal system and the kidneys [14–16].

Adjunctive therapies such as the use of bronchodilators, nitric oxide, nebulized heparin, N-acetylcysteine, and aggressive pulmonary toilet are also important in decreasing the incidence of respiratory morbidity and mortality. When inhaled, nitric oxide selectively dilates capillaries that supply ventilated lung regions, improving V:

Q ratios. Although some patients exhibit dramatic improvement in PaO_2:FiO_2 ratios with the use of nitric oxide, studies have suggested that if there is no response to nitric oxide within 60 min of therapy using concentrations between 5 and 20 ppm, nitric oxide is unlikely to be of benefit, and it should be abandoned as a therapeutic option. In patients who are responders to inhaled nitric oxide, however, the drug has been shown to have an overall survival benefit. Nebulized heparin and TPA have also been shown to be of benefit in some studies. These agents are thought to improve ventilation by breaking down fibrin deposits that form as a result of inhalational injury. This in turn improves alveolar oxygenation and ventilation by reducing obstruction. N-acetylcysteine, otherwise known as Mucomyst, has not been shown to confer any survival benefit on patients with burn injuries. However, it has been shown to decrease leukocyte numbers in bronchoalveolar lavage. One particular study that reviewed the benefits of inhaled heparin and N-acetylcysteine in patients with inhalational injury revealed that the combination of the two agents resulted in a statistically significant survival benefit by attenuating the progression of acute respiratory distress syndrome. Inhaled β-agonist agents can also produce bronchodilation and reduce lung inflammation without systemic hemodynamic effects. Aerosolized corticosteroids, though often used to treat chronic pulmonary diseases, have not been shown to be of benefit in patients with inhalational injury. Though some have suggested that corticosteroids confer a limited benefit in patients with late stage ARDS, this conclusion is not definitive [17–21].

In patients in whom conventional or unconventional ventilation modes fail to provide adequate oxygenation and ventilation, veno-venous extracorporeal membrane oxygenation (ECMO) may be considered. ECMO may help to maintain oxygenation while minimizing barotrauma to already injured lung parenchyma. There have been isolated case reports of patients who have successfully survived severe respiratory failure due to the use of extracorporeal life support. However, one retrospective study of patients who failed conventional ventilation and were placed on ECMO revealed low survival rates amongst trauma and burn victims. Other predictors of poor survival on ECMO included older age, prolonged mechanical ventilation prior to initiation of ECMO, multiple organ failure, and long ECMO runs [22, 23].

Burn Resuscitation

Patients with burn injuries must be resuscitated promptly; any delay can significantly increase mortality. The greatest fluid loss in patients who have suffered from burns occurs within the first 24 h. For those with small burns, peripheral intravenous access is generally adequate. However, for patients with burns involving more than 20 % BSA, central line placement for intravenous access is more appropriate.

Several formulas have been developed in order to help guide fluid resuscitation. Generally, these formulas provide guidelines for aggressive but steady fluid resuscitation. Boluses of fluid typically are ineffective and sometimes even deleterious for burn patients, as the rapid rise in intravascular hydrostatic pressure simply drives more fluid out of the circulation. One of the most popular formulas for guiding resuscitation is the Parkland formula, otherwise known as the Baxter formula. It was developed in 1970 by Dr. Charles R. Baxter at Parkland Memorial Hospital who discovered that more aggressive volume resuscitation within the first 8 h after an injury improved cardiac output. The Parkland formula calls for the administration of 4 mL/kg/% TBSA burned for the first 24 h. The Parkland formula does not apply to superficial burn areas. One-half of the calculated fluid need is administered within the first 8 h, and the remaining half is given over the next 16 h. The modified Brooke formula calls for 2 mL/kg for each percentage of TBSA burned over 24 h. Some have suggested that using the Parkland formula more frequently results in over-resuscitation, which can be a risk factor for increased mortality. However, other studies have shown no differences in mortality between the two formulas. Children require maintenance fluid in addition to the calculated resuscitation volumes. The Galveston formula has been used to determine appropriate

resuscitation and maintenance volumes for children with burn injuries. It calls for 5 L/m^2 burned for resuscitation with an additional 2 L/m^2 per day for maintenance. Like both the Parkland and Brooke formulas, half of the resuscitation and maintenance is administered over the first 8 h, and the remaining half is given over the next 16 h. Of note, high tension electrical injuries require more fluid, up to 9 mL/kg/%TBSA in the first 24 h. Patients with concomitant inhalational injuries may also have higher fluid requirements [24–30].

Despite the formulas and guidelines for fluid resuscitation, there is no consensus on a standardized formula or protocol for burn patients. In fact, empiric experience suggests that these formulas often underestimate the fluid requirements in burn patients. Because of these observations, some have advocated that resuscitation be tailored to clinical endpoints. These include urine output of 0.5 mL to 1 mL/kg/h in adults and children with guidance from hemodynamic parameters. Hemodynamic monitoring not only includes the use of invasive or non-invasive blood pressure monitoring, but also cardiac output monitoring. Swan-Ganz catheters are used less and less in burn patients and replaced by monitoring devices that measure the cardiac output using non-invasive methods, such as the end-tidal carbon dioxide tracing, esophageal Doppler and pulse contour cardiac output, which uses the shape of the arterial pulse tracing to determine the stroke volume and cardiac output [6, 24, 31–33].

Usually, for initial resuscitation, crystalloid solution is preferred. There is no consensus on the ideal solution, but generally, 0.9 % normal saline is avoided due to the risk of developing hyperchloremic metabolic acidosis with large resuscitation volumes. Isotonic solutions such as lactated Ringer's, Plasmalyte, or Hartmann's solution that contain more physiologic concentrations of electrolytes are preferred. Historically, albumin was routinely administered as part of the initial resuscitation within the first 24 h. In theory, colloid administration should be beneficial since serum protein levels decrease after burn injuries. Some have shown that those receiving colloid receive less crystalloid and less fluid overall during the resuscitative period.

However, recent evidence has suggested that colloid resuscitation does not reduce mortality and adds to the overall cost of care. For children weighing less than 20 kg, 5 % dextrose should be added to the resuscitation fluid in order to prevent hypoglycemia. After the first 24 h, some centers begin administering colloid at 0.5 mL/kg/%TBSA along with crystalloid at 1.5 mL/kg/%TBSA, titrating resuscitation to urine output [6, 30, 34–36].

Although delayed resuscitation can result in poor perfusion to both vital organs and otherwise viable tissue, over-resuscitation is also risky and can lead to its own set of complications. Compartment syndrome has been reported in cases involving circumferential, deep, full-thickness burns and has been linked to the amount of fluid infused. In addition, the systemic inflammatory response results in microvascular leak, vasodilation, and decreased cardiac output and contractility, all of which can confound fluid management goals in burn patients while contributing to the development of compartment syndrome. The development of abdominal compartment syndrome may be suspected if the patient develops abdominal distension, oliguria, and if he or she becomes increasingly difficult to mechanically ventilate. Abdominal compartment syndrome is particularly concerning as it decreases perfusion to many vital organs, including the bowel, liver, and kidneys, and leads to multiorgan compromise or failure. Serial bladder pressure measurements may provide insight into the development of abdominal compartment syndrome and help determine whether a decompressive laparotomy is necessary in order to prevent organ damage. Another treatment option is percutaneous drainage of fluid with a peritoneal dialysis catheter. For suspected compartment syndrome in other parts of the body, such as the extremities, compartment pressures may be measured by inserting an 18G needle under the eschar into the subfascial tissue and transducing pressure measurements. Pressures greater than 30 mmHg are considered to be diagnostic of compartment syndrome, and measures should be taken to decompress the area. This is usually accomplished by performing an escharotomy or fasciotomy. An escharotomy can be performed at bedside

with light sedation and involves making an incision along the entire length of the eschar with extension of the incision to viable tissue. Only burnt tissue is divided, sparing the fascia.

A fasciotomy must be performed in the operating room as it involves opening the full length of fascial compartments. The pressure within the affected area can be monitored after decompression with a bedside manometry device [6, 37–39].

Wound Management

Wounds must be carefully managed, as inadequately treated wound sites may convert to deeper wounds that mandate surgical intervention. The wound can be cleaned with simply soap and water or chlorhexidine and normal saline washes. Most recommend that blisters greater than 0.5 cm in size be debrided in order to reduce the risk of bacterial colonization. Wounds should be cultured upon admission and recultured at intervals in order to monitor for colonization. Most often, wounds are colonized within a few hours with gram-positive organisms such as *Staphylococcus aureus* and *Staphylococcus epidermis*, or with intestinal flora within a few days such as *Pseudomonas aeruginosa*, *Enterobacter cloacae*, and *Escherichia coli*. Bacterial colonization does not always dictate the need for systemic antibiotics; however, early debridement and topical and/or biological dressings may prevent further spread of infection. Furthermore, healthcare workers must be vigilant in maintaining hand hygiene and a clean environment in order to minimize the chances of cross contamination. Following cleaning of the wound, a topical antimicrobial agent is applied and the wound should be covered with several layers of absorptive gauze and Kerlix in order to minimize evaporative fluid losses [6, 40].

Several types of topical agents can be used, including silver sulfadiazine (Silvadene), mafenide acetate (Sulfamylon), and silver nitrate. Silver sulfadiazine has proven over time to be inexpensive, easy to apply, and to effectively control wound colonization. However, eschar penetration with Silvadene is minimal, and some have linked leukopenia and hemolysis with Silvadene use. Furthermore, it has been shown to have a direct toxic effect on keratinocytes, which in turn delays wound healing. Mafenide acetate, or Sulfamylon cream, is easy to apply but can be painful when applied to superficial partial thickness burns. Nevertheless, Sulfamylon provides good eschar penetration and is therefore useful in cases when eschar excision is not expected to be performed immediately or when control of *Pseudomonas aeruginosa* infection is needed. Sulfamylon is also a carbonic anhydrase inhibitor, and its use can lead to the development of metabolic acidosis. Silver nitrate solution has become less popular over time due to its poor tissue penetration and association with electrolyte abnormalities. However, it is still a good agent for the prevention or treatment of gram-negative bacterial colonization or fungal infection. In other parts of the world, Granulflex, a hydrocolloid dressing with a thin polyurethane foam sheet bonded onto a semipermeable film that is adhesive and waterproof, is sometimes used. Granulflex is particularly useful in areas that are difficult to cover with normal dressings. Another option is Mepitel, a nonadhesive dressing that consists of a flexible polyamide net coated with soft silicone [5, 6, 41, 42].

Generally, purely epidermal burns, though painful, only require supportive therapy and heal in about a week via regeneration of undamaged keratinocytes within skin adnexae. Burns that involve layers beyond just the epidermis, however, require more attention. Superficial partial thickness burns must be treated in order to prevent wound progression. These wounds rarely progress to deeper burns, but this can happen if the wound becomes dry or if the patient is hypotensive for prolonged periods of time. This is accomplished with antimicrobial creams and occlusive dressings, creating a moist environment that promotes epithelialization. Healing occurs usually within 2 weeks as the epidermis regenerates from keratinocytes within sweat glands and hair follicles. Because of the source of epithelialization, regeneration depends heavily on the density of skin adnexae. In other words, thin, hairless skin tends to heal more slowly than thick, hairy skin. Deep partial thickness burns are perhaps some of

the most difficult to address, primarily because they may be unrecognized as deep burns at initial assessment. There are fewer skin adnexae at deeper levels, and therefore, healing occurs at a much slower rate and is more frequently associated with contraction. There are few deep partial thickness burns that can heal without surgical excision by keeping the wound area warm, moist, and free of infection. However, most deep partial thickness burns are best managed by excising the burnt tissue and grafting skin. In full-thickness burns, all regenerative elements of skin are lost, and healing only occurs from the edges of skin. Significant contraction occurs. All full-thickness burns should be excised and grafted unless they involve an area of less than 1 cm in a part of the body that does not affect function (Fig. 14.1) [43].

Grafts used following surgical excision include xenograft, allograft, autograft, or cultured skin substitute. Most burn surgeons recommend that surgical wound excision occur within the first 1–7 days after injury in order to attenuate the systemic inflammatory response to burns and to reduce the risk of sepsis. Aggressive early excision, however, has not been universally supported. One particular study involving adults over 30 years of age with more than 30 % TBSA injured suggests that there is no difference in outcomes between those who are treated conservatively versus those who receive surgical attention within 72 h after the burn. The same study, however, also suggested that in pediatric patients and those between the ages of 17 and 30, early excision led to decreased mortality rates when compared to patients who were managed conservatively. On the whole, many factors including the patient's age, comorbidities, and extent of injury should be taken into account when deciding when the wound should be excised. For the most part, deep burn wounds must be excised early, before it triggers the development of multiple organ failure or becomes infected. When the decision to proceed with surgery is made, some centers stage the excision and grafting process, performing the excision on one day and grafting skin the next in order to shorten operating times, optimize hemostasis, and minimize hypothermia. Post surgical topical antibiotic treatment of the grafted area is crucial for graft survival and prevention of wound infection [6, 44–47].

The ideal graft material is split thickness skin autograft from neighboring, unburnt areas. The depth of excision of the burnt areas determines the thickness of the skin harvested. It is important to note when grafting skin that thinner grafts generally contract more. Usually, the donor harvest site is adjacent to the burned area, as this improves color matching. Sometimes, if donor sites are sparse, the graft can be perforated with a mesher to allow for expansion. This, however, produces cosmetically undesirable results as the mesh pattern is permanent. Because of this, meshed graft is rarely used on the face and hands.

Other options to consider when donor sites are sparse is to rotate donor sites and use grafts from several areas of unburned skin in sequence, or to wait until donor sites have regenerated and may be reharvested. In either case, the wound can be covered in antimicrobial creams or covered with a temporary covering until skin can be harvested. Examples of temporary coverings include cadaveric allograft, synthetic products, xenograft (such as pigskin), or cultured epithelial autograft. Cultured epithelial autografts help to extend available donor sites. It can be cultured into sheets, which take three weeks to develop, or in suspension, which are available after just 1 week [43].

Nutritional Supplementation in Burn Patients

After a burn injury, patients enter a hypermetabolic state that can persist for up to 12 months. Because of the hypercatabolism and loss of lean body mass in the immediate post-burn phase, a negative nitrogen balance is seen during the first 1 to 2 weeks post injury. Although indirect calorimetry remains the gold standard for measuring resting energy expenditure (REE), the energy requirements of patients are usually overestimated. It is also important to keep in mind that indirect calorimetry measurements only provide insight into energy expenditures during a discreet moment in the post-injury period. Energy expenditure and requirements may vary
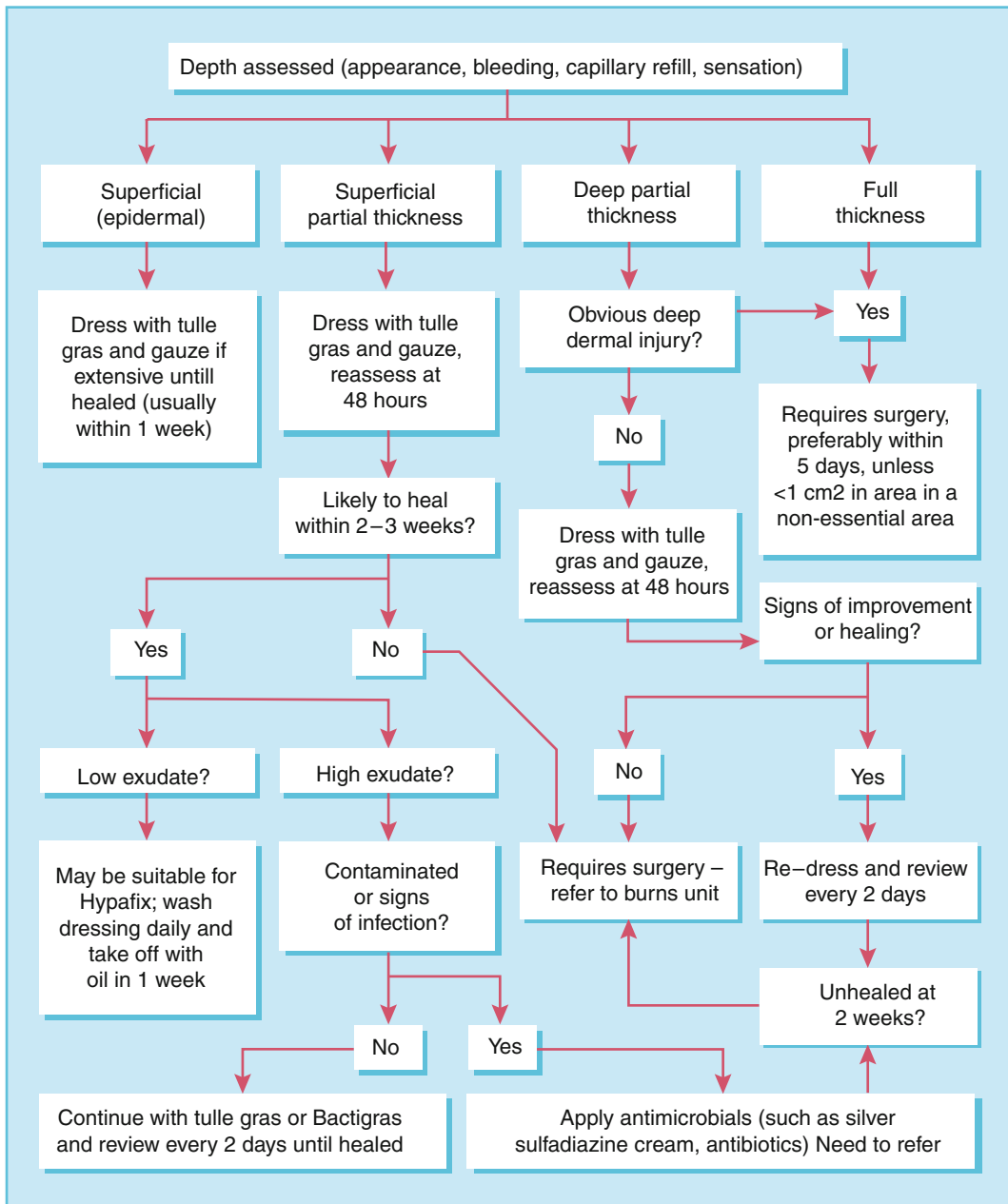
Fig. 14.1 Algorithm for approach to wound assessment and care. Reproduced from British Medical Journal, Ref. [43], copyright 2004 with permission from BMJ Publishing Group Ltd

substantially over the course of the healing process. Care providers must also keep in mind that clinically controlled variables and environmental factors, such as management of heat loss, sedation, and mechanical ventilation may alter energy needs, making nutritional requirements a dynamic issue (Table 14.2). Therefore, performing indirect calorimetry measurements at several points in time in the post-burn period may provide more accurate insight into actual energy requirements.

Overestimating energy requirements can be just as deleterious as underestimating energy

Table 14.2 Factors affecting energy expenditure in burn patients

	Increase	Decrease	No effect
Physiologic effects			
Age		√	
Malnutrition		√	
Wound size	√		
Sepsis			√
Protein catabolism	√		
Pancreatitis	√		
Pain	√		
Fever	√		
Treatment effects			
Mechanical ventilation	√		
Wound closure			√
Warm environment		√	
Surgical procedure			√
Initiation of nutrition support			√
Physical therapy	√		
Medication effects			
Growth hormone			√
Corticosteroids	√		
Vasoactive agents	√		
Neuromuscular blockade		√	

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needs, as overfeeding can be detrimental to burn patients. Excess carbohydrate intake increases CO_2 production, fat stores, hepatic dysfunction, hyperglycemia, and prolongs the wound healing process. Severe burns result in the efflux of amino acids from skeletal muscle, presumably in order to accommodate for the amino acid needs mandated by tissue injury and repair. Furthermore, increased cortisol levels result in increased proteolysis, protein breakdown, and protein oxidation. Inadequate protein intake after burn injury compromises wound healing, muscle function, and the immune system. However, excess protein supplementation may also exacerbate the catabolic process. The goal for protein supplementation should be to slow the efflux of amino acids from skeletal muscle and to maximize protein synthesis needed for maintenance of immune function and wound healing. For adults, protein intake of 1.5 g/kg/day

is associated with a net balance between protein synthesis and breakdown. Lipolysis also occurs in burn patients. However, supplementing with exogenous fat usually exacerbates this process or contributes to increased storage of fatty tissue, making it unnecessary and ineffective. Underfeeding has been demonstrated by some to have positive results in critically ill patients who have not suffered from burns. However, it can be dangerous in the patient with burn injuries. An appropriate nutritional strategy is essential for adequate wound healing, mediation of the inflammatory response, control of the hypermetabolic response, and reduction of sepsis-related morbidity and mortality. Although serum albumin levels are often used to assess the nutritional status in critically ill patients, albumin levels in burn patients are poorly reflective of overall nutritional status since albumin levels fall rapidly after the initial burn injury. Replacement or resuscitation with albumin has not been shown to produce positive clinical outcomes. Other nutritional markers, such as transferrin, carotene, iron, and calcium are also unreliable as markers for nutritional status. Over the long term care of burn patients, prealbumin levels may be an indicator of nutritional status, as it is a marker of protein synthesis. In the acute phase, however, prealbumin levels have less of a role [6, 48–56].

Glucose monitoring is perhaps the most central chemical marker for nutritional status in the burn patient. Hyperglycemia occurs in most patients with burn injury regardless of the degree of injury due to increased glucose production and impaired glucose extraction by tissue. The liver and peripheral tissue are also much less responsive to insulin, making it difficult to achieve normoglycemia, even with very high doses of insulin supplementation. Tight glucose control along with modulation of the inflammatory response has been shown to increase survival, improve wound healing, and decrease the incidence of sepsis. Interestingly, beta blockers have been used to modulate glucose levels, enhance the immune response to sepsis, and mediate catecholamine release after severe injury. Some have shown that burn patients who were taking beta blockers prior to the injury exhibited decreased mortality and improved healing times

when compared to those who were administered beta blockade therapy in the hospital after the injury. Others have observed that patients who are administered beta blocker therapy benefit from decreased hospital stays. In children, beta blocker therapy has been shown to be associated with decreased cardiac work, attenuation of the inflammatory response without an increase in the incidence or severity of sepsis, and reversal of catabolism [6, 57–67].

In patients who have suffered from a burn injury, enteral feeding is the preferred route for nutritional supplementation. Maintaining gut integrity is thought to decrease the chances of bacterial translocation and reduce the incidence of sepsis. If it is anticipated that oral nutritional intake will be inadequate within 5–7 days after the injury, a feeding tube should be placed. Timing of enteral nutrition is not universally agreed upon, though many advocate initiating feeds within hours after the burn injury. This, however, may be logistically very difficult to manage and potentially dangerous. There is a risk of developing complications, including misplacement of the feeding tube, aspiration, and intestinal necrosis. In fact, some have demonstrated that the incidence of intestinal necrosis was much higher in those who received early feedings. This may be related to altered intestinal perfusion and hypotension during the early burn resuscitation phase in conjunction with the need for increased blood flow to the gut during feeding. It is unclear whether or not initiation of feeding within several hours of injury confers any noticeable benefit when compared to initiation of feeding at a later stage (i.e., 72 h or more following the injury). There is also debate regarding the route of enteral feeding and whether there is a significant difference between small bowel and gastric feeds. Those who are in favor of small bowel feeds maintain that burn patients exhibit delayed gastric emptying, and that, as a result, small bowel feeds decrease the risk of aspiration. Post-pyloric feeds also enable patients to continue feeds throughout surgery. However, placement of small bowel feeding tubes in post-burn injury patients can be tricky and is not without complications. Small bowel feeds are also associated with a high incidence of diarrhea.

Gastric tube feeds not only prevent gastric ulcer formation, but also are associated with a much lower rate of diarrhea. Gastric feeds are also much more simple to administer. For patients who require repeated trips to the operating room, however, gastric tube feeds must be stopped prior to going to the OR in order to prevent aspiration. Frequent interruptions to gastric feeds may necessitate alternatives for providing nutrition, such as supplemental parenteral nutrition. Parenteral nutrition is mainly reserved for those patients who are absolutely unable to tolerate enteral feeds due to gastrointestinal diseases or complications. It remains the second line method of feeding and carries with it an increased risk of sepsis due to central line infection. It is important to note that problems with gut barrier failure and infection are associated with the lack of enteral feeding rather than the provision of parenteral feeding. Thus, in cases in which patients are unable to tolerate enteral feeds, parenteral nutrition must be initiated without delay in order to ensure that nutritional needs are adequately met. In many cases, a combination of enteral and parenteral feeding may be used to achieve this. Intravenous lipids are generally avoided unless parenteral nutrition is required in excess of 3 weeks. This is due to the association of lipid supplementation with platelet dysfunction, poor immune function, and worsened lung function [6, 51, 54, 56, 68, 69].

Vitamin supplementation is also a crucial part of the nutritional regimen in the post-burn patient. Vitamin A has been shown to help in wound healing, and supplementation with vitamin A is recommended in patients with greater than 20 % TBSA burn involvement. Vitamin C should also be administered, as it plays a significant role in collagen synthesis and wound healing. Trace elements are often lost through wound exudates. This, in conjunction with decreased gastrointestinal absorption, increased urinary losses, and altered distribution of nutrients, necessitates more careful assessment and supplementation than in critically ill patients who are not victims of burn injury. Zinc, for instance, is crucial in the wound healing process. Studies have suggested that zinc deficiencies in septic patients are associated with poor outcomes. Despite this, it is consistently difficult to

accurately measure levels of micronutrients, partly because trace elements exist in pools that are in a constant state of flux. Many of these micronutrients are bound to protein carriers, and concomitant hypoproteinemia can impair the nutrient's ability to be transported from its storage form to tissues. Thus, isolated measurements of micronutrient concentrations of micronutrients may not reflect actual functional deficiencies. Given the highly catabolic physiology following a burn injury, some have suggested that anabolic steroids may confer some benefit. However, the administration of anabolic steroids in burn patients remains controversial, and there have not been any clear indication that it confers any clinically significant benefit. Other anabolic agents, such as oxandrolone, have also been used in order to restore lean body mass, improve wound healing, and improve overall nutritional status. However, as is the case with steroids, the benefit is observational and supported with little evidence [6, 56, 70–73].

Anesthetic Management for the Burn Patient

Anesthetic management for patients with burn injuries can be challenging. In addition to the airway and resuscitation challenges described above, these patients present unique considerations in the operating room that often require some degree of creativity on the anesthesiologist's part. For one, monitoring can be extremely difficult in these patients for whom access to the chest (for ECG monitoring), arms (blood pressure monitoring), and digits (pulse oximetry) may be limited. For ECG monitoring, skin staples or subcutaneous needles attached to crocodile clips can be used if the thorax has suffered from extensive burns. Even if digits are available for pulse oximetry monitoring, values may be inaccurate due to hypothermia, hypoperfusion, or both. Alternative sites for pulse oximetry such as the nose, lip, or tongue may be necessary. If there is no suitable location for placement of a non-invasive blood pressure cuff, an arterial line may be necessary. Invasive central venous monitoring and monitoring of urine output may also be helpful, but information may be limited if the patient is exhibiting signs of renal insufficiency or failure or if the patient has developed intra-abdominal compartment syndrome. The hypermetabolic state that ensues post-burn injury along with physiology consistent with a systemic inflammatory response may make hemodynamic parameters difficult to interpret.

Induction may be achieved via intravenous or inhalational technique. Maintenance of anesthesia can also be done via inhalational, nitrous-narcotic, intravenous technique, or a combination of techniques. There is no evidence to suggest that one method is superior to the other. Ketamine may be used to augment the anesthetic while adding analgesic effects, particularly in patients who may not be hemodynamically stable. Regional blocks may be considered as a supplement to the anesthetic or, in rare cases, as the primary anesthetic. However, its use is limited by the risk of infection and the area of injury, which may not be isolated to a specific nerve distribution. Extra junctional nicotinic acetylcholine receptors are upregulated 24–48 h after the initial injury. Therefore, succinylcholine must be avoided, as it may result in fatal hyperkalemia. If needed, it may only be used within the first 24 h after injury. The risk of hyperkalemia may persist up to years after the burn injury. A general rule regarding the use of succinylcholine is that once wounds are healed and the patient is mobile, the patient should no longer be susceptible to fatal hyperkalemia from succinylcholine administration. The upregulation of receptors, increased volume of distribution, and increase in metabolic rate also render the patient relatively resistant to the effects of non-depolarizing neuromuscular blockers, mandating much higher doses than usual. Higher doses of induction agents such as thiopental are also required. These physiological changes in addition to increased tolerance with multiple administration also mandate higher doses of opioids. Blood loss can be significant and at times, insidious. Though average predicted blood loss can be variable from center to center, the anesthesiologist should be prepared for at least 50–100 mL of blood loss per percent of body surface area excised. This amount can also vary depending on the age of the wound and

the presence of infection. As the wound becomes more hyperemic with time, bleeding during excision can worsen. Infection also exacerbates bleeding. Achieving hemostasis can also be complicated by the presence of thrombocytopenia and by abnormal levels of clotting factors. The best way to manage blood loss is to frequently check hemoglobin and hematocrit levels. In efforts to conserve blood and reduce blood loss, surgeons may employ measures such as infiltration with vasoconstrictors, limb tourniquets, compressive dressings, and performing excisions as early as possible. Blood loss can be minimized by performing excisions within 24 h of injury or after 16 days from the time of initial injury. Infiltration with vasoconstrictors may reduce blood loss; however, there is potential for systemic absorption of tumescent solution, resulting in hemodynamic fluctuations and fluid overload.

Depending on the area being operated on, careful consideration must be given to patient positioning. Pressure points must be carefully padded and excessive pressure should be avoided on burned areas. Due to the physiological changes and areas of burned, exposed, tissue, temperature monitoring is mandatory, as are measures to prevent hypothermia, including administering warmed fluids, maintaining higher ambient temperatures, and forced air warming. Other measures that may be taken include using heat lamps, placing reflective barriers over the patient, and humidifying anesthetic gases. Given that these patients often require multiple anesthetics, the best approach is to carefully review prior anesthetic encounters while keeping in mind that analgesic requirements will likely be increased. Anxiolysis is usually mandatory for these patients. Over time, if face or neck contractures are present, airway anatomy may become distorted due to flexion abnormalities or limited mouth opening. In extreme cases, surgical neck release may be required prior to induction of anesthesia. Alternatively, in the presence of dramatic craniofacial deformities, ECMO has been used in some cases as a bridge to securing the airway until neck release can be performed. This however, should be reserved as a last resort and rescue strategy. As more time progresses and wounds heal, heat loss becomes less of a concern.

Procedures later in the healing process are generally superficial and should require less aggressive pain control [74, 75].

Sepsis and Multiorgan Failure in the Burn Patient

Although great strides have been made in burn resuscitation, thereby reducing the morbidity and mortality from burn shock, the risk of infection and sepsis remains high. Protective skin barriers are compromised in burn injury, and this is the primary point of entry for life threatening infections. Necrotic tissue and serosanguinous exudate from wound beds is an ideal medium for pathogenesis. A depressed immune system following burn injury further increases the risk of infection. Wound care is especially important, as is frequent culturing of open wound beds. This may help in detecting infection in early stages before it has spread into the blood stream. It is important to remember, however, that extensive microbial colonization of the wound surface can make wound cultures very difficult to interpret and treat. Wound biopsy with histological examination and quantitative culture is perhaps the most definitive way of diagnosing infection in the wound bed. This process, however, is time consuming and expensive, making it impractical. Gram-positive bacteria populate the wound within 48 h of injury. Gram-negative organisms appear anywhere from 3 to 21 days after the injury. Fungal infection is seen even later. The most common infectious agents tend to vary from center to center, but in general, the source of infection in many centers has shifted away from β-hemolytic *Streptococci* to resistant gram-negative organisms such as *Pseudomonas*, resistant gram-positive organisms, and fungi (Table 14.3). It is prudent to note that the longer the wound stays open, the greater the risk of fatal infection, particularly in the case of fungal infections, which are also prone to spreading to the lung. Viral infections, most commonly from CMV or HSV, are less likely to spread systemically and appear to have less of an effect than bacteria on overall morbidity and mortality. However, the diagnosis of viral infections can

Table 14.3 Causative agents of wound infection [76]

Pathogen	Examples	Clinical manifestations
β-hemolytic streptococci	*Strepotococcus pyogenes*	Acute cellulitis, occasionally toxic shock syndrome
Staphylococci	Methicillin-resistant *Staphylococcus aureus*	Abcesses, subeschar pus
Gram-negative bacteria	*Pseudomonas aeruginosa* *Acinetobacter baumanii* *Proteus* species	Common in specialized burn units
Fungi	*Candida*	Most common fungal infection; colonizes the surface but has low potential for disseminated invasion
Filamentous fungi	*Aspergillus* *Fusarium* Phycomycetes	Can aggressively invade subcutaneous tissue; must be treated with surgical debridement
Virus	*Herpes simplex*	Causes vesicular lesions

be challenging in the burn patient; therefore, the true effect of viral infections on morbidity and mortality may be underestimated.

Pneumonia is also a leading cause of sepsis in patients who have suffered from burn injury, though it is not nearly as common as wound infection. Patients who are intubated and on mechanical ventilation are at higher risk, as are patients who have suffered inhalational injuries, those with circumferential chest wall burns, and those who remain immobile for long periods of time after injury. For patients in whom early pneumonia is suspected, aggressive bronchoscopy and bronchoalveolar lavage may prevent dissemination of infection, help tailor antibiotic therapy, and decrease needs for mechanical ventilation and length of overall hospital stays. Catheter based infections from indwelling lines are also a significant source of infection. Prompt removal of unnecessary catheters is perhaps one of the best preventative strategies. For lines and catheters that still remain clinically relevant, frequent evaluation and maintenance of the line, followed by catheter exchange (when possible) may help decrease the incidence of line-related infections. Some have advocated the use of silver impregnated, chlorhexidine/silver sulfadiazine coated, or antibiotic coated catheters to reduce the incidence of line-related infections. However, there is little evidence to suggest that the use of these catheters results in outcomes that are any better than vigilant maintenance and routine line care. Urinary tract infections are seen not

only in patients with indwelling urinary catheters, but also in those who have suffered burns to the perineum. Sinus and middle ear infections may arise in patients who are fed through nasogastric tubes for prolonged periods of time. Corneal burns may result in secondary infections in the eye. Other less common sites of infection include infective endocarditis—most commonly a result of disseminated bloodstream infections from wound beds or indwelling catheters—as well as intra-abdominal infections, which are quite rare [76–80].

Sepsis is an independent predictor of mortality following a burn injury, particularly in the presence of multiorgan failure. After the initial resuscitation, up to 75 % of mortality in burn patients can be attributed to infection. Often the diagnosis of sepsis may be delayed, as its symptoms of tachycardia, tachypnea, fever, and leukocytosis may be attributed to the burn injury itself rather than to a brewing infection. Although laboratory markers may be used to predict the development of infection, white blood cell counts, neutrophil percentages, and body temperature are poor predictors of bloodstream infection in the burn patient. Some have advocated the use of other markers, such as procalcitonin and C-reactive protein; however, the correlation of these markers with the development of sepsis is poorly agreed upon and inconclusive. The American Burn Association has developed a consensus criteria for the definition of sepsis in patients who have suffered from

burns. It includes at least three of the following parameters:

- Temperature >102.2 °F (39 °C) or <97.7 °F (36.5 °C)
- Progressive tachycardia (adults >90 bpm; children >2 standard deviations above age specific normal values)
- Progressive tachypnea (adults >30 breathes per minute; children >2 standard deviations above age specific normal values)
- Refractory hypotension (adults SBP <90 mmHg or a decrease of >40 mmHg or mean arterial BP <70 mmHg; children <2 SD below normal)
- Leukocytosis (adults WBC >12,000/µL; children >2SD above normal) or leukocytopenia (<4,000/µL)
- Thrombocytopenia that occurs 3 days after resuscitation (adults plt <100,000/µL; children <2 SD below age specific normal values)
- Hyperglycemia >110 mg/dL in the absence of pre-existing diabetes mellitus
- Inability to tolerate enteral feeds for more than 24 h based upon:
  - Abdominal distension
  - Residual volumes (two times the feeding rate in adults and >150 mL/h in children)
  - Uncontrollable diarrhea (>2,500 mL/day for adults and >400 mL/day for children)

Additionally, the ABA definition requires that the infection be documented by one of the following modalities:

- Infection is confirmed on culture (wound, blood, urine) OR
- Pathologic tissue source is identified ($<10^5$ bacteria on quantitative wound biopsy or microbial invasion on biopsy) OR
- A clinical response to antimicrobial administration is documented.

Signs of burn wound infection include conversion of a previously partial thickness wound to full-thickness wound and/or infection that develops at a site that was previously epithelialized. Invasive burn wound characteristics include the following:

- Rapid change in appearance of the wound

- Appearance of focal, multifocal, or generalized dark brown, black, or violaceous discoloration of the wound
- Separation or discoloration of the eschar
- Hemorrhagic discoloration of subeschar tissue
- Presence of green pigment (pyocyanin) in subcutaneous fat (i.e., *Pseudomonas* infection)
- Erythema, edema, pain, warmth of surrounding skin
- Edema and/or violaceous discoloration at the margin between burned and unburned skin
- Presence of initially erythematous and later black necrotic nodular lesions (ecthyma gangrenosa) in adjacent unburned skin
- Exophthalmos may be the first sign of mucormycosis in midface burns (retrobulbar space involvement)

The approach to treatment of infection in burn patients can also be tricky. Excessive and overly aggressive administration of antibiotics may only perpetuate colonization with resistant microorganisms. Because of this, prophylactic systemic antibiotics are generally not recommended. Broad-spectrum antibiotics in order to cover wound manipulation are also not recommended unless the burn involves greater than 40 % of TBSA. A better strategy might involve using shorter courses of narrow spectrum antibiotics in an attempt to deliver more targeted therapy. Careful wound care, including the use of topical antibiotic agents, is an important retardant to wound and bloodstream infections. Early surgical closure of the burn wound also helps to minimize entry points for infection [6, 76, 81–84].

The American Burn Association's registry of causes of burn mortalities reveals that nearly 50 % of patients who did not survive burn injuries died as a result of organ failure. Both multiorgan failure and sepsis in burn patients are associated with burn size, age, male gender, length of stay in intensive care, and duration of mechanical ventilation. The gut hypothesis behind multiple organ failure has gone through many changes over time. Initially, it was thought that loss of gut barrier integrity led to

bacterial translocation, bloodstream infection, and systemic inflammation that subsequently resulted in multiorgan failure. This has evolved to the idea that loss of gut barrier function leads to the production of endogenous pro-inflammatory factors and tissue factors that lead to organ injury and eventually, failure. In fact, some have noted that multiple organ failure occurs in burn patients despite the clinical absence of uncontrolled infection, suggesting that the etiology of organ failure is multifactorial and complex in this patient population and may not be solely attributable to sepsis. In fact, in one particular review of burn patients in a specialized facility over the course of 6 years, researchers observed that in most cases of multiorgan failure, patients were actually clinically uninfected at the time of death, even if they had suffered from multiple isolated infectious events over the course of their care. The theory behind this phenomenon is that although the infections and soft tissue injuries that incite the inflammatory process are successfully treated, the systemic inflammatory process persists [85, 86].

It is much more effective to prevent the development of multiorgan failure rather than to treat it after it has begun its course. Minimizing the incidence of sepsis and inflammation through early wound excision and closure, hemodynamic support in order to ensure adequate oxygen delivery to tissues, and early enteral nutrition in order to support the gut and minimize bacterial translocation across the bowel wall are measures that should be taken to prevent the onset of organ failure. Attenuation of the hypermetabolic response—therefore dampening the acute rise in catecholamine, glucagon, and cortisol levels—can also decrease the incidence of multiorgan failure and overall morbidity and mortality. Although there are cases in which multiorgan failure develops in the absence of sepsis, disseminated infection is still a leading cause of multiorgan failure. This is particularly true now with the abundance of multi-drug resistant organisms. Between 1989 and 1999, only 42 % of patients died from sepsis from multi-drug resistant organisms. Twenty-five percent of those patients who died were infected with *Pseudomonas*. Other common offending organisms include *Staphylococcus aureus*,

Escherichia coli, and *Klebsiella pneumonia*. Between 1999 and 2009, the number of patients who died from sepsis and multiorgan failure as a result of infection with multi-drug resistant organisms increased to 86 %, with *Pseudomonas* being present in 64 % of those patients. The incidence of *Acinetobacter* has also risen precipitously over the last few years, whereas prior to 2000, it was seldom in burn patients with sepsis and multiorgan failure. Colistin has emerged as an effective treatment for multi-drug resistant *Pseudomonas* and *Acinetobacter* infections; however, some studies have suggested that there is no difference in mortality between patients who receive colistin versus piperacillin/tazobactam and vancomycin. Clindamycin and vancomycin are perhaps the most popular and effective treatments for methicillin-resistant *Staphylococcus aureus* infection. Although advancements in fungal treatments have improved dramatically over the last two decades, there are still drug-resistant fungi that may not respond to traditional therapies. *Aspergillus terreus*, for instance, is innately resistant to amphotericin B. Alternative, newer, agents, such as azoles (voriconazole, posaconazole) and echinocandins (caspofungin, micofungin) may be used to treat resistant fungi, but each agent's limitations and side effect profile must be carefully considered prior to selecting a drug. Ultimately, given the complex etiology of wound infection and sepsis in this patient population, infectious disease specialist consultation is often helpful [79, 85, 87, 88].

Rehabilitation After Burns

Even with aggressive fluid resuscitation, wound and infection management, and surgical rehabilitation, burn patients are at extremely high risk of developing long-term limitations to mobility. They must be engaged early and aggressively in physical activity to help maintain range of motion. Immobilization should only be allowed if it is medically necessary. Generally, immobilization is only mandated if there is concomitant injury to tendon and/or bone, or after tissue repair such as

skin reconstruction. It was once thought that immobilization time after a grafting procedure should be about 5–7 days. However, the trend has been to decrease the immobilization time after grafting to 3–5 days, promoting passive range of motion exercises as soon as the graft takes and advancing to monitored active range of motion exercises. If a body part must be immobilized, it should be splinted or fixed in an anti-deformity position for as little time as possible. Otherwise, studies have suggested that range of motion exercises be performed anywhere from 2 to 4 times a day with independent activity by the patient in between therapy sessions. Overall, there has been a trend in burn centers toward early ambulation, preferably by postoperative day 5. However, the ability to ambulate by postoperative day 5 is at times limited by the location of the injury and may be more difficult in patients whose injuries involved the lower extremities, particularly below the knees. Patients who are able to ambulate within 24 h after surgery have been shown in some studies to have shorter lengths of stay. Early ambulation also decreases the risk of deep vein thrombosis and pulmonary emboli.

Splinting, though sometimes used to intentionally limit mobility, has also been used to prevent loss of range of motion. There are generally two schools of thought when it comes to splinting: it can be instituted early and used as a preventative measure or initiated therapeutically when the patient begins to show signs of contracture. Generally, the frequency with which this modality is employed is dependent on the depth of burn. Patients with full-thickness burns are more frequently placed in splints than those with more superficial burns. Early splinting is most commonly performed when the injury involves the hand, followed by the ankle, elbow, and axilla. Delayed splinting most often occurs when the injury involves the neck, elbow, perioral region, and knee. Tendon exposure may also mandate splinting in order to preserve range of motion. If the burn involves the hand, particular attention should be paid to rehabilitation efforts as hand function has been found to be a strong predictor of physical quality of life. If the burn has involved the extensor mechanism in the hand, flexion at the proximal interphalangeal joint can result in the development of a boutonniere deformity, in which the proximal interphalangeal joint is permanently flexed while the distal interphalangeal joint is extended. Early splinting is encouraged in hand burns to prevent boutonniere deformities. Exposed tendons are splinted in the slack position to prevent tendon rupture. Alternatives to splinting the hand in the case of exposed tendons include the use of Kirschner wires or direct contact casts. Others have resorted to pinning the joint in a straightened position. If pinned, care must be taken to remove the pins early unless the intention is to fuse the joint. If the joint becomes fused, the patient may lose his ability to grip, a function which remains preserved in patients with boutonniere deformities. Achilles tendon injury and exposure is another type of injury in which splinting is employed. Some have advocated splinting the foot and ankle in the neutral position, while others support splinting in slight plantar flexion. Exercise and motion of the foot and ankle must be done very gingerly in order to minimize the risk of rupturing the Achilles tendon [89, 90].

Scar formation can be one of the factors that contribute to loss of range of motion. Scarring can vary depending on a number of external factors, such as fluid resuscitation, positioning in the hospital, surgical intervention, and wound dressing and management. However, it can also be influenced by patient specific factors such as age, pregnancy, skin pigmentation, and degree of motivation and compliance with rehabilitation programs. There are two primary types of scars that can develop. Hypertrophic scarring results from the buildup of excess collagen fibers during wound healing and the reorientation of fibers in non-uniform patterns. Keloid scarring extends beyond the boundary of the initial injury and tends to be more common in patients with pigmented skin. Scar formation can be minimized if the wound is well managed from an early stage. Pressure garments are the primary intervention in scar management and should be used immediately after the skin has healed. Pressure is thought to reduce scarring by potentiating

scar maturation and encouraging collagen fibers to reorient into uniform, parallel patterns as opposed to the whorled pattern that is seen in untreated scars. Pressure garments need to be tailored to each individual patient, and it is best if they are reassessed and refitted every few months to accommodate the changing contours of the healing wound. For patients with burns that involve the face and/or neck area, an acrylic mask that helps provide conforming pressure over the burned areas may be worn. Masks made of fabric may also be made for patients to wear overnight while sleeping.

Alternatives to pressure garments include pressure devices or non-custom wraps. Although they may not conform to the wound as well as customized garments, they still help to minimize trauma to fragile, healing wound grafts. For areas of scar tissue that have not responded well to pressure garments, other techniques such as massage, creams, and contact media may be considered. Massage helps to soften restrictive bands of scar tissue, making the scar area more pliable. Moisturizing creams prevent the skin from drying and cracking, creating ports of entry for secondary wound infection and skin breakdown. Moisturizing is beneficial to burn patients even if the scar has healed well. There are several different types of contact media that have been used to promote healthy scar formation. Silicone gel sheets are thought to limit the degree of scar contraction through hydration and occlusion. In areas of the body where it is logistically difficult to place silicone sheets such as digits or the web spaces between digits, elastomer molds can be used to help flatten the scar. Hydrocolloid sheets can also be used in lieu of silicone gel sheets. They are also thought to limit scar contraction. Unlike silicone gel sheets, they can be left on the skin for up to 7 days and are very thin, so massage can be given through the thin sheets. Another tool thought to aide in healthy scar formation is ultrasound, which is postulated to help the inflammatory process progress more quickly. Adequate sun protection is mandatory in patients who have suffered from burn injuries for up to 2 years after the initial injury [91, 92].

Heterotopic ossification (HO), which is the extra-articular formation of lamellar bone in connective tissue, is not frequently seen in burn injury, but when it is present, it can lead to serious functional limitations. When HO does occur, the elbow joint tends to be the most common site. The incidence of heterotopic ossification is increased when 25 % or more TBSA is involved in the burn injury. If it develops, it can result in significant pain, loss of range of motion, and even nerve injury for patients. There is little known about what can be done to prevent the development of HO, though early wound closure may play a role. The treatment of HO remains unclear. Active assistive range of motion exercises, gentle terminal stretch, and terminal resistance training are recommended to minimize the development of heterotopic ossification. However, it is probably best to limit the extent of stretching and exercise. Animal models have suggested that aggressive stretching exercises may in fact contribute to the formation of HO and some have suggested that aggressive stretching after development of HO can exacerbate the condition. One particular study demonstrated that forced manipulation during a time of immobilization provoked the development of HO, and remobilization actually increased the density in areas of calcification. Another group showed that passive stretching beyond the pain free range of motion led to progression of HO to complete ankylosis. Thus, once HO has developed, some recommend that exercise should be limited to active range of motion exercises within a pain free range. This issue is particularly tricky in burn patients since stretching plays a critical role in preventing soft tissue contracture in the wound healing process. In severe cases of heterotopic ossification, surgical intervention may be required, followed by a period of aggressive physical therapy. If surgical excision is required to treat HO, it is typically performed a year or more after the initial injury. Local radiation therapy has also produced positive results in some patients. Other treatments, such as the use of non-steroidal anti-inflammatory agents and bisphosphonates, have also been described, but the outcomes have been inconsistent at best. Furthermore, the use of these medications in burn patients may be limited due to

concerns for renal toxicity and coagulopathy [93–95].

Another practice that was once common but has become less popular over time is burn hydrotherapy. Hydrotherapy is thought to promote healing by softening and removing dead tissue, therefore enabling new tissue to form. Other theoretical benefits include preventing excessive loss of moisture through burned tissue, removing pus, minimizing scar tissue formation, providing comfort, and in some cases, aiding in physical therapy. There are several different modes of hydrotherapy. Immersion hydrotherapy occurs when the patient is completely submerged in a disinfected pool of sterile water, regardless of the location of the burn. Shower hydrotherapy is directed toward a specific area of injury and is thought to be just as effective as immersion hydrotherapy. The primary risk with either type of hydrotherapy, however, is infection. Hydrotherapy equipment has been shown in some centers to be contaminated with *Pseudomonas* despite meticulous sterilization procedures. In the early 1990s, as many as 90 % of burn centers in North America reported regularly employing hydrotherapy as an integral part of rehabilitation for burn patients. However, due to the risk of infection, only 10 % of burn centers now report regular use of hydrotherapy [96, 97].
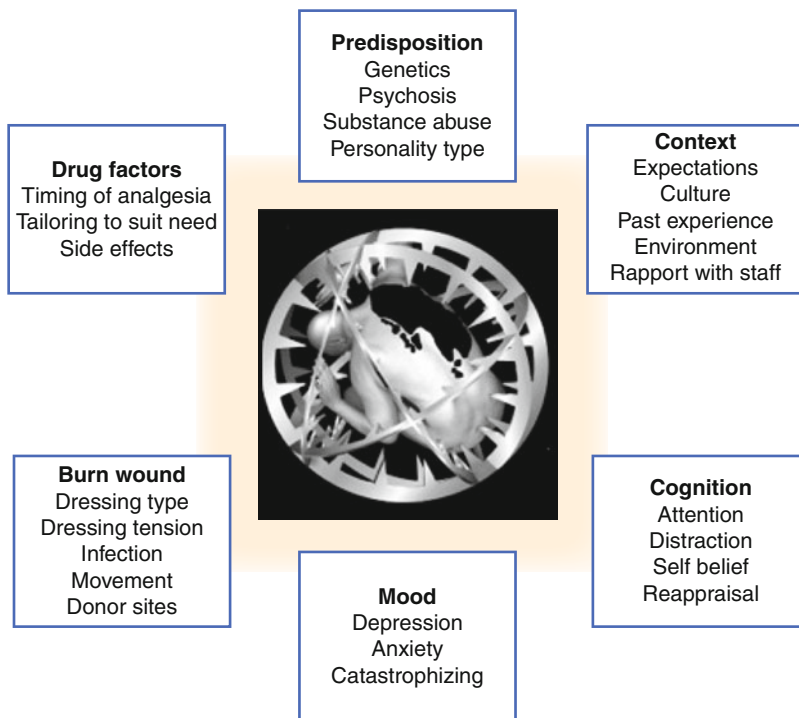
Pain Control in Burn Patients

Pain control in burn patients is a particularly challenging issue. Despite efforts to improve the quality of pain management in burn victims, patients continue to report unrelieved moderate to severe levels of pain. There are many reasons that burn pain remains a challenge for caregivers. For one, burn pain can vary drastically from patient to patient, and it can also fluctuate significantly over the course of the recovery period. As the wound heals and scar tissue forms, pain often begins to de-escalate, though this is not to say that burn patients do not experience pain at all once healing has completed. Even after healing, burn patients may have to return frequently to the operating room for reconstructive procedures

that may become a significant source of anxiety and pain. Over time, chronic neuropathic pain and neuropathies may ensue as damaged neurons regenerate. The inflammatory response from nerve and tissue injury can often result in allodynia and primary hyperalgesia in the injured area and secondary hyperalgesia in the surrounding area. Repetitive painful stimuli can cause neuroplastic adaptations throughout the central nervous system whereby afferent pain sensory impulses undergo facilitation and amplification to a given stimulus, contributing to the generation of chronic pain. Associated pathologies such as depression, anxiety, and posttraumatic stress disorder also exacerbate pain symptoms. The degree and nature of pain can also vary depending on the depth of the burn. Superficial burns generally result in hyperalgesia and mild to moderate levels of pain. Superficial partial thickness burns are associated with marked hyperalgesia and moderate to severe pain as sensory receptors at the level of the dermis are damaged. Deep partial thickness to full-thickness burns are often associated with the absence of pain, and hyperalgesia tends to be uncommon. This is primarily due to the fact that the dermis, along with its sensory and vascular structures, is completely destroyed. Acute pain from dressing changes and surgery can be minimal, though there is usually pain in the transition zone between burned and unburned layers of skin. However, this does not mean that patients with deep burns do not experience pain. These patients often describe a deep aching pain that is likely related to the inflammatory response. There are also a number of psychosocial issues and comorbidities that may affect the patient's experience of pain (Fig. 14.2) [98–100].

There are three types of pain that must be addressed in burn patients. Not only do burn patients have a chronic, underlying background pain for which there is no end in sight, patients must deal with the acute pain associated with bedside and surgical procedures (procedural pain). Furthermore, burn patients can also experience significant breakthrough pain that is frequently associated with movement. This mechanical hyperalgesia is especially common

Fig. 14.2 Factors affecting patient's perception of burn pain. Reprinted from Burns: Journal of the International Society for Burn Injuries, Ref. [100], Copyright 2009, with permission from Elsevier

Predisposition
Genetics
Psychosis
Substance abuse
Personality type

Context
Expectations
Culture
Past experience
Environment
Rapport with staff

Drug factors
Timing of analgesia
Tailoring to suit need
Side effects

Burn wound
Dressing type
Dressing tension
Infection
Movement
Donor sites

Cognition
Attention
Distraction
Self belief
Reappraisal

Mood
Depression
Anxiety
Catastrophizing

in patients who remain immobilized for extended periods of time. At times, however, breakthrough pain may also occur spontaneously with no apparent inciting event. Background pain, though generally less intense than procedural or breakthrough pain, can worsen significantly before epithelialization is complete.

Adequate assessment of pain levels is extremely important. Assessment tools must be practical and reliable and must address the three facets of pain: pain intensity, behavioral reactions, and physiologic reactions. Although there is no single assessment technique that is universally agreed upon, it is important to select an approach and use it consistently. For adults, assessment of pain is done with adjective scales, such as "none, mild, moderate, and severe." Alternatively, some prefer the numeric scale, using 0 as an indicator of no pain and 10 to reflect the worst, most excruciating pain a patient has ever experienced. The caveat to using these methods is that it may be impossible to elicit a meaningful response in a patient who is sedated and on mechanical ventilation, or in a patient

who is demented. The assessment of pain in children can be much more difficult than it is in adults, particularly for children who are pre-verbal. Physiological indicators such as heart rate, blood pressure, and respiratory rate, which are often used to assess pain in children, are unreliable indicators as they are affected by processes related to the burn injury itself. Instead, scales that assess pain based on behaviors are thought to be more specific. For instance, facial expressions and length of cry have been used to assess pain in children. The FLACC scale (Faces Legs Activity Cry Consolability scale) is perhaps one of the most widely employed observer based pain scales used in children. For children that are pre-school age and older, self-reported verbal scales may be used instead. The Wong-Baker FACES pain scale is designed for children 3 years or older and uses a pictogram of faces displaying varying degrees of pain and discomfort. The child is then asked to choose the face that most closely corresponds with their own level of pain. The OUCHER scale uses a picture

scale for very young children and a numerical scale for children 5 years or older [99, 101–105].

The approach to pain management in burn patients must be multimodal, using a combination of pharmacological and non-pharmacological treatment modalities. Pharmacologic agents used for treating pain include opioids, non-opioids, anxiolytics, and anesthetics. Opioid agonists are amongst the more popular pharmacologic analgesics. However, high dose opioids can be associated with short-term adverse side effects such as respiratory depression and constipation, as well as the development of long-term consequences such as tolerance and, in severe cases, addiction. As pain subsides, opioid analgesics cannot simply be abruptly discontinued. For patients who have been on high dose opioids for extended periods of time, abrupt discontinuation may lead to severe withdrawal symptoms. Thus, just as it is important to have a protocol for administering and escalating pain medications, it is important to systematically wean patients who have been on opioids in order to avoid withdrawal symptoms. Of note, there is no evidence that the use of opioids during the management of acute burn pain increases the likelihood of opioid dependency, so opioid analgesics should not be withheld for fear of its adverse side effects. Generally, long-acting opioids such as oral morphine are used to treat chronic, background pain while shorter acting opioids such as fentanyl are given for brief, painful stimuli such as wound care and surgical procedures. When addressing background pain, medication must be administered regularly in order to ensure a steady state of analgesic. Establishing a protocol for medication escalation and administration is crucial to ensure that doses of pain medication are not missed, creating an iatrogenic episode of breakthrough pain. Though opioids can be administered intravenously or orally, the optimal route of administration is intravenous due to its rapid onset of action and titratability. Patient controlled analgesia (PCA) with IV opioids gives patients the flexibility to titrate medication based on patient needs. Oral and gastrointestinal administration of opioids through a feeding tube is also an option and provides equally good pain relief. Though this route of administration is less titratable, it requires minimal monitoring as the risk of fatal overdose is somewhat less.

Oral transmucosal administration of opioids is also useful, particularly in the pediatric population. Intramuscular administration of opioids is not recommended for burn patients. The injections need to be administered frequently, they are painful, and the drug absorption can be extremely variable due to compartment shifts.

Morphine is the standard analgesic against which other analgesics are compared. Morphine tends to be somewhat less effective for short, acute episodes of pain given that its onset and peak effect are somewhat more delayed than other opioids. It is generally reserved for the treatment of chronic, background pain. Oxycodone is an effective alternative to morphine, and some patients exhibit a better response to one versus the other. However, there is no evidence that oxycodone is superior to morphine or vice versa. Fentanyl has a quicker onset and time to peak effect, making it suitable for use in acute pain settings. It is easy to administer intravenously, transmucosally through the buccal or nasal mucosa, and transdermally. Remifentanil is an ultra-short acting opioid that is useful for acute, procedural pain. Given its short half-life and easy titratability, it achieves maximum analgesic effect with a lower risk of delayed side effects. It is, however, extremely potent and should only be administered by trained personnel since it can cause sudden respiratory depression and apnea during administration. Alfentanil is also a short-acting opioid but has a longer half-life than remifentanil. It is also used primarily to treat procedural pain, but given its pharmacokinetics, it provides a greater degree of post-procedural pain relief than remifentanil. Tramadol acts on mu receptors and enhances the reuptake of norepinephrine as well as the release of serotonin. It is generally well tolerated and has an analgesic effect similar to that of morphine. When considering analgesic options for chronic pain, methadone is often used to treat or prevent chronic hyperalgesia related to central sensitization and neuropathic pain [100, 106].

Non-opioid analgesics are also an integral part of the treatment regimen in the burn patient. Dexmedetomidine, a central alpha-2 agonist, provides sedation, anxiolysis, and analgesia with minimal risk for respiratory depression, particularly in children. It is useful for limited

stimuli from debridements and dressing changes. Clonidine, like dexmedetomidine, is also a central alpha-2 agonist that augments descending inhibitory spinal cord pathways. It can be effective as an adjunctive analgesic when administered in doses of 1–3 µg/kg/day in adults and children alike. Ketamine is frequently used for the treatment of acute procedural pain. Case reports have suggested that ketamine, when used in conjunction with clonidine, is an extremely effective analgesic and sedative in children who experience severe burn pain, especially during dressing changes. The NMDA antagonizing effects of ketamine also make it useful in treating chronic pain, since it is thought that NMDA receptors play a role in central sensitization after burn injury. Acetaminophen and non-steroidal anti-inflammatory medications (NSAIDs) can also be added to the pharmacological regimen for pain control in burn patients. Both acetaminophen and NSAIDs exhibit a ceiling effect in their dose response relationship. Therefore, their use is usually limited to treating minor burn pain in the outpatient setting. If used for treating severe burn pain, they are usually used as adjuncts to other agents. For procedures and dressing changes, topical analgesics such as lidocaine may also help augment pain control. The data for topical local anesthetics, however, does not show that it produces a significant reduction in procedural pain. There have been some studies that suggest there may be a role for intravenous lidocaine, particularly for acute increases in painful stimuli caused by dressing changes and surgical procedures. Intravenous lidocaine may help improve analgesic efficiency, alleviate some of the deleterious effects of opioid administration, and minimize the necessity of escalating opioid doses in patients with burn injuries. Systemic lidocaine is thought to achieve this by depressing conduction in afferent nerves, inhibiting dorsal horn neural transmission and modifying the cerebral perception of pain. Lidocaine is also thought to possess anti-inflammatory properties that may play a significant role in the suppression of pain in burns, which stem in part from inflammatory processes. However, many studies have failed to demonstrate a decrease in opioid requirements when intravenous lidocaine was used as an adjunctive analgesic. Consultation with pain specialists may be helpful in achieving satisfactory pain control by helping to develop and adhere to protocols as well as for monitoring the evolution and improvement of pain [107–112].

Anxiolytics play an important role in pain control in the burn patient, whose anxiety levels can contribute significantly to their perception of pain. Anxiety is prevalent in the post-burn population given the needs for aggressive surgical treatment and frequent wound debridements, and patients who report high levels of background pain tend to also exhibit higher anxiety levels. Anxiolytics are a particularly effective premedication prior to wound care in order to address the anticipatory anxiety experienced by patients. In fact, benzodiazepines have been shown to improve post-procedure pain scores in patients. Antipsychotic medications are another option for the treatment of anxiety and agitation associated with burn treatments. First generation antipsychotics such as haloperidol are often used for the treatment or even prevention of delirium in critically ill patients. Second generation antipsychotics, such as quetiapine, are used for the treatment of anxiety disorders and are often administered in conjunction with benzodiazepines in burn patients in order to help with sleep. Other centrally acting agents such as antidepressants (amitriptyline) and anticonvulsants (gabapentin) may help to modulate central neuropathic pain. Amitriptyline modulates pain by inhibiting descending spinal cord pain pathways. It can cause sedation, which may be beneficial in helping the patient sleep at night. Patients on amitriptyline may also experience anticholinergic side effects such as dry mouth and blurred vision. Gabapentin binds to pre-synaptic calcium channel receptors that are involved in pain hypersensitivity and indirectly inhibits NMDA receptors [99, 100, 113–115].

Anesthetics, whether general, neuraxial, targeted non-neuraxial, or regional, are also useful in managing burn pain. General anesthesia or deep sedation is reserved for the relatively brief, intense pain associated with procedures. For moderately painful procedures, inhaled nitrous oxide can be administered to provide analgesia without loss of

consciousness. Usually, this is delivered through a face mask in a mixture of 50 % nitrous oxide and 50 % oxygen. Regional anesthesia can be useful for procedures, particularly when the burned area involves extremities. The most common nerve groups involved include the brachial plexus (interscalene block, infraclavicular and supraclavicular blocks, and axillary block), the sciatic nerve, and the femoral nerve. Interestingly, patients who undergo skin grafting procedures often experience more pain at the donor graft site than the grafted area. Thus, regional anesthetic blocks are often used to treat donor graft site pain. Most commonly, bupivacaine and lidocaine are used for these blocks, though other local anesthetics may be selected depending on the nature and length of stimulus. Neuraxial techniques, which involve the administration of local anesthetic into the intrathecal or epidural space have also been used. Prior to catheter placement, coagulation studies must be done to ensure that the risk of hematoma formation is minimal. Care must be taken in the case of indwelling epidural or spinal catheters to monitor for infection, as burn patients may be at higher risk of developing infectious complications such as meningitis and epidural abscess. Targeted non-neuraxial blocks are another option for pain control. For example, a fascia iliaca compartment block can be performed to provide analgesia to the lower extremity following skin graft harvesting. The risks associated with these blocks are minimal as long as the procedures are performed by experienced practitioners [116–118].

Non-pharmacological pain control techniques should complement pharmacologic agents. Choosing a technique should be based on how the patient has responded to the stress of the burn injury. Some patients exhibit signs of avoidance in which they give up control of all medical decision making to health care professionals. These patients typically respond well to distraction techniques that help them avoid focusing on painful stimuli. Avoidance techniques are those that are designed to psychologically distract or distance the patient from the painful stimulus. Diverting attention toward a nonpainful stimulus may lessen the intensity of perceived pain. Avoidance interventions include distraction, guided imagery, hypnosis, and virtual reality. Distraction is perhaps the most effective in children, whose attention is easily diverted with activities such as story-telling, singing songs, or counting. In adults, distraction might require somewhat more creativity and effort. Guided imagery involves the use of imagined pictures, sounds, or sensations to draw attention away from the stimulus. The imagery in this technique is simply one that the patient creates in his mind and can revisit anytime. Hypnosis is an altered state of consciousness characterized by an increased receptivity to suggestion, the ability to alter perceptions, and an increased capacity for dissociation. The dramatic shift in consciousness that occurs with hypnosis is thought to be the mechanism by which attention is shifted away from the perception of pain. Hypnosis is a very involved process and depends heavily on the clinician–patient relationship. It also involves several stages, including deep breathing, suggestions for enhancing the hypnotic state, narrowing the patient's attention, providing posthypnotic suggestions, and finally, reaching the alert stage. If planned well, hypnosis sessions can be scheduled prior to scheduled surgical procedures. Hypnosis is particularly powerful in burn patients because patients with burn injuries often experience a dissociative response that may render them more hypnotizable. Furthermore, many burn patients demonstrate behavioral regression, making them more willing to be taken care of by others and to relinquish control. Studies have suggested that patients with higher baseline pain levels experience a greater decrease in pain after hypnosis than those with lower baseline pain levels. It is important to realize, however, that many of these studies only involve very small cohorts of burn patients and use inconsistent methodologies to assess pain and the effectiveness of treatment with hypnosis. Virtual reality is another method that has been utilized to treat pain. Since attentional focus is limited and the person cannot attend to more than one stimulus at a time, virtual reality creates an environment in which patients can be absorbed by a controlled, alternative stimulus during painful procedures, thus taking the focus away from the procedure being performed. Hypnosis and virtual reality, often used concomitantly, are perhaps the most effective distraction techniques. They have been shown to significantly reduce pain for

patients undergoing procedures or dressing changes when used in conjunction with pharmacologic agents. Another subset of patients tend to seek information, actively participate in care, and are reluctant to relinquish control throughout the treatment process. These patients may find distraction techniques stressful as they feel a sense of loss of control in the situation. For patients who demonstrate a desire to be deeply involved in care, the best approach is to keep the patient as informed as possible. Helping the patient understand each issue, alternative, and solution puts the patient at ease by building a sense of trust and mutual understanding.

Other techniques include relaxation techniques that help to lower arousal, thus shifting focus away from the source of pain. Deep breathing, otherwise known as diaphragmatic breathing, is a simple and effective measure that can help the patient relax. Often, pain or anxiety lead to rapid, shallow breathing, also known as thoracic breathing, which can exacerbate muscle tension and contribute to a heightened sense of pain. Deep breathing techniques help the patient avert this phenomenon. Cognitive behavioral techniques (CBT) are also popular non-pharmacologic tools used for addressing pain and anxiety in burn patients. CBT helps to change the way patients think and respond to pain and the anticipation of pain. With cognitive behavioral therapy, patients are given the tools to recognize that certain stimuli will cause pain, mentally block the anticipation of pain, and distract themselves from the pain by diverting their thoughts toward something else. Other non-pharmacological techniques such as massage, progressive muscle relaxation, and acupressure/acupuncture can also be considered in patients who continue to experience severe pain despite best efforts [99, 114, 119–124].

In addition to the treatment of burn pain, burn associated pruritus is also an important symptom that affects patient rehabilitation. The pathophysiology of itching in burn patients is not completely understood. Although histamine is thought to be a contributing factor, the central nervous system has also been implicated in the development and maintenance of these symptoms (Fig. 14.3). It appears that after a burn injury, factors such as female sex, number of surgical procedures, and the presence of posttraumatic stress disorder are associated with a higher incidence of pruritus. Although pruritus can be pervasive throughout the healing process, it is thought that pruritus in the "acute" phase (i.e., within 3 months of injury) is related to the transition from wound closure to early remodeling. Chronic pruritus, or itching that persists 12–24 months after injury, tends to be more commonly seen in patients with deep burns who require multiple surgical procedures and who suffer from psychological sequelae from the burn and its aftermath.

Burn pruritus is a multifactorial phenomenon and can be classified into several different categories:

1. Pruritoceptive, originating in the skin as exemplified in urticarial conditions
2. Neuropathic, arising from anatomical dysfunction in the afferent pathway (e.g., postherpetic pruritus and brain tumors)
3. Neurogenic, resulting from CNS dysfunction without evidence of anatomical pathology, indicating abnormal neurochemical activity (e.g., the action of opioid peptides in liver disease)
4. Psychogenic, associated with psychiatric conditions

Antihistamines have been the mainstay therapy for burn pruritus. When given in the early stages after burn injury, they can be effective. However, studies have suggested that the use of a central agent such as gabapentin in conjunction with two antihistamines achieves superior relief than when using three antihistamines. When antihistamines are administered for the treatment of itching in the late proliferative and remodeling stages of the burn, significantly fewer patients report achieving good symptomatic relief. For patients in the later stages of healing, gabapentin in addition to antihistamine therapy again achieved better symptomatic relief than antihistamines alone. Ondansetron, a 5HT3 receptor antagonist, has been used to treat cholestatic pruritus. The ability of serotonin antagonists to inhibit the excitatory CNS pathways that contribute to itching may make ondansetron a useful agent in treating burn pruritus. Transcutaneous electrical nerve stimulation (TENS) is a therapeutic modality that involves the use of controlled,
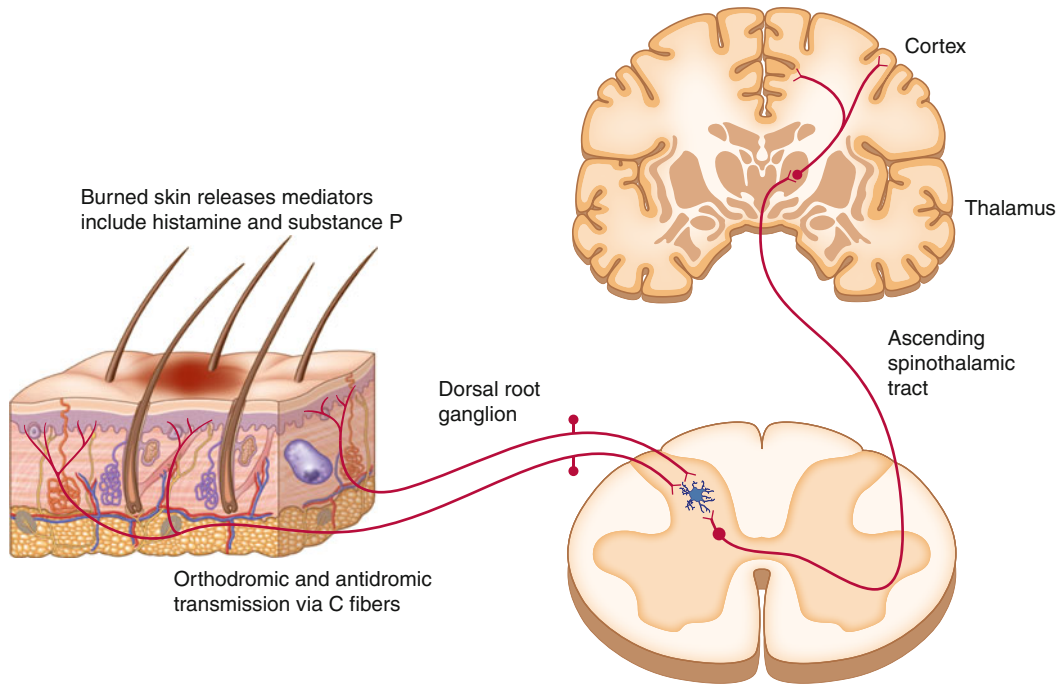
Fig. 14.3 Schematic diagram of the pruritic pathway. Healing/healed burned skin releases a wide variety of pruritic mediators including histamine and neuroinflammatory transmitters like substance P (SP). A subset of C fibers transmits impulses in an orthodromic manner to the spinal cord via the dorsal root ganglion. In addition, impulses spread from afferents in the injured area to neighboring nerve fibers via the antidromic axon reflex (*arrow*); this involves the release of SP from neurons and mast cells (depicted in the skin), which enhances the input to the CNS. Impulses are carried via the ascending spinothalamic tract and the thalamus to higher CNS areas (including the contralateral somatosensory cortex, ipsilateral, contralateral motor areas, and the prefrontal cortex and cingulated gyrus) for sensory registration. Reprinted from Ref. [125], with permission

low-voltage electrical impulses to the nervous system via electrodes that are placed on the skin. This is thought to trigger a release of endogenous opioids that inhibit descending excitatory CNS pathways, thereby alleviating the sensation of pruritus [125].

Conclusion

The effective treatment of burns involves a coordinated, multidisciplinary team. Knowledge of the pathophysiology of burns and management of the multitude of complex physiological changes associated with burns is the key to the successful management of a potentially very complicated injury.

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