Advances in Perioperative and Critical Care of the Burn Patient
Anesthesia Management of Major Thermal Burn Injuries in Adults

Heather E. Kaiser, MD, MPH, Cindy Meerim Kim, MD, Sam R. Sharar, MD, Hernando P. Olivar, MD

Keywords
- Burn injury
- Trauma anesthesia
- Smoke-inhalation injury
- Pathophysiology of burn injury
- Anesthetic management of burns

Key points
- Patients with burn injury can and will present to any hospital.
- Many of those hospitalized for burn injury will require surgical treatment of their injuries.
- Patients undergoing surgical treatment for major thermal burn injury often exhibit preexisting medical issues and/or burn-related pathophysiology that must be considered in the anesthetic plan.
- Performing a focused preoperative assessment of a patient with burn injury is paramount, particularly with respect to airway abnormalities, gas exchange, and hemodynamic status.
- Smoke-inhalation injury largely influences the clinical course of patients with major burn injury.
- Recognizing and managing intraoperative blood loss and volume replacement is critical.

Continued

No financial disclosures or conflict of interest are declared by any author.

*Corresponding author. E-mail address: hkaiser6@jhmi.edu

0737-6146/13/$ – see front matter http://dx.doi.org/10.1016/j.aan.2013.08.007 © 2013 Elsevier Inc. All rights reserved.
INTRODUCTION
In 2012 approximately 450,000 people with burn injury sought medical treatment in the United States [1]. Of these, 40,000 people required hospitalization and, presumably, many of these patients underwent surgical treatment of their injuries [1]. Given the high incidence of burn injury managed at both designated burn centers and other hospitals, the authors have sought to review the literature on major thermal burn injury as it pertains to anesthesia management. Information in this article may be extrapolated to include adult patients with a lesser severity of burn classification.

PREOPERATIVE PERIOD
The early treatment of patients with burn injury begins at the injury scene and continues on arrival to the emergency department with a complete trauma assessment based on the Advanced Trauma Life Support (ATLS) guidelines [2]. Once life-threatening ATLS priorities have been addressed, a secondary survey of the burn injuries should ensue. After hospital admission, burn-injured patients can undergo a wide range of surgical procedures at various phases of the burn care continuum, including the postdischarge rehabilitation phase. Unique physiologic conditions at these various phases of burn care present a variety of anesthetic challenges and require comprehensive preanesthetic assessment.

Patient history and physical assessment
Burn injury is classified by the percentage of total body surface area (TBSA) burned based on the Lund-Browder chart, the depth of the burn, and whether an inhalation injury has occurred (Box 1, Fig. 1) [2,3]. As defined by the American Burn Association (ABA), major burn injury is a partial-thickness burn greater than 25% TBSA in adults or greater than 20% TBSA in children younger than 10 years or adults older than 40 years [4]. Major burn injury is also defined as full-thickness burns involving more than 10% TBSA [4]. Major burn injuries also occur when the patient has sustained a high-voltage burn; a known smoke-inhalation injury; burns to the face, eyes, ears, hands, feet, or perineum that are likely to result in function or cosmetic impairment; or concomitant traumatic injury [4]. Specific criteria for referral to a designated burn center are given by the American Burn Association [5].
Airway and pulmonary system
Airway and ventilatory management of patients with burn injury is of utmost importance. Indications for immediate tracheal intubation of burn-injured patients are listed in Box 2. Whether or not intubation occurs immediately after injury, frequent reevaluation of the airway and respiratory status is critical because of the dynamic evolution of maximal airway edema and complications that may develop as a result of superimposed smoke inhalation. Both of these situations may impair ventilation and oxygenation [6].

Airway obstruction and symptoms of smoke-inhalation injury may not yet be evident on initial assessment; however, they can occur on a rapid and unpredictable time course after the initial injury [7,8]. Impending airway obstruction frequently occurs in the presence of moderate to severe facial burns, full-thickness nasolabial burns, or oropharyngeal burns. Stridor, hoarseness, and dysphagia are classic signs of impending airway obstruction [3]. Owing to the likelihood of worsening airway edema in the 24 hours after injury, the clinical axiom is to have a low threshold for early tracheal intubation, before increasing edema of upper airway structures makes the procedure more difficult.

Smoke-inhalation injury has a direct impact on the anesthetic management of burn-injured patients. Smoke inhalation is suspected if the injury has been sustained from fire in a closed space. Singeing of facial or nasal hair, evidence of oropharyngeal carbonaceous deposits, and carboxyhemoglobin (COHb) levels greater than 10% are highly predictive of subsequent positive bronchoscopic confirmation of inhalation injury [9]. In studies comparing isolated
burn injury with concomitant smoke inhalation, the latter combination is associated with increased fluid-resuscitation requirements, pulmonary complications, and mortality [10–13]. Moreover, in one study the incidence of respiratory failure increased from 5% to 73% in burn-injured patients with concomitant smoke inhalation injury [14]. Thus, inhalation injury significantly influences the clinical course of patients with major burn injury.

**Box 2: Indications for immediate tracheal intubation of patients with major burn injury**

- Total body surface area burns of greater than 40%
- Signs of impending airway obstruction
- Evidence of smoke-inhalation injury
- Prolonged transport time

Furthermore, mortality rates of patients with smoke inhalation injury have largely remained unchanged in the past 20 years in the United States [15]. Smoke inhalation may cause injury by 3 different mechanisms: direct thermal injury, chemical irritation/inflammation, and systemic toxicity [7]. Upper airway injury is typically caused by direct thermal insult, whereas tracheobronchial injury is usually caused by inflammatory responses to chemicals in smoke [7]. The inflammatory process may induce bronchospasm, impairment of ciliary function, distal airway obstruction from viscous secretions, and atelectasis [7,8,16]. Increases in transvascular fluid flux and bronchial blood flow may promote edema in the tracheobronchial system [7,17]. Smoke-induced bronchial epithelial necrosis results in a profuse transudate that can consolidate over time and cause obstruction of the lower airways [7]. These pathophysiologic changes cause hypoventilation and loss of hypoxic pulmonary vasoconstriction, with increased pulmonary shunting and ventilation-perfusion mismatch (Fig. 2) [7,8].

Systemic effects of carbon monoxide (CO) and cyanide toxicity are frequent complications of smoke inhalation. CO has 250 times more affinity for hemoglobin than oxygen, forming COHb and reduced hemoglobin oxygen-carrying capacity, while simultaneously shifting the oxygen dissociation curve to the left [3]. Symptoms of CO toxicity include headache, nausea, and confusion [8]. Severe neurologic dysfunction and coma may occur with COHb levels greater than 2-4%.

![Fig. 2. Pathophysiologic response to smoke inhalation.](image-url)
than 40% [18]. Cardiac dysrhythmias and brain injury may become prominent at levels greater than 55% [18]. A COHb level greater than 90% may lead to immediate cardiac arrest (Fig. 3) [7]. In the presence of COHb, conventional pulse oximeters are inaccurate and provide falsely elevated oxygen saturation readings. Thus, a CO-oximeter is necessary to obtain accurate measurements of arterial oxygen saturation [3].

Cyanide toxicity interferes with the intracellular cytochrome cascade, and disrupts mitochondrial oxygen consumption and aerobic energy production, resulting in lactic acidosis. At a cyanide concentration of 50 parts per million (ppm), the patients may present with headache, dizziness, tachycardia, and tachypnea [19]. Above 100 ppm, lethargy, seizures, and respiratory failure may ensue [19]. An anion gap metabolic acidosis that fails to improve with oxygen administration should be concerning for cyanide toxicity [3]. Plasma lactate levels will correlate with cyanide levels and mixed venous oxygen saturation will appear elevated [3].

In addition to direct inhalation injury, the burn-induced systemic inflammatory process can lead to pulmonary hypertension and disruption of the pulmonary vascular endothelial barrier. In combination with burn-induced hypoproteinemia and decreased plasma oncotic pressure, this increases extravascular lung water and impairs gas exchange [3,6]. Moreover, decreased lung and chest-wall compliance may develop in the first 24 to 36 hours after the burn injury, particularly in patients with circumferential thorax burns that create a restrictive lung defect (and may necessitate emergent escharotomy) [3,6].

Cardiovascular system

Important cardiovascular changes occur in the presence of major burn injury. Patients with major burn injury are initially hypovolemic, owing to extensive
plasma loss into burned tissues and increased systemic vascular permeability [20,21]; thus, fluid resuscitation is one of the pillars of treatment of this patient population [22,23]. Baxter and Shires [24] developed the well-known Parkland Formula (PF) for initial postburn fluid resuscitation with isotonic crystalloid based on body weight and burn size (4 mL/kg/%TBSA burn). One-half of the calculated volume should be infused during the first 8 hours, followed by one-half in the subsequent 16 hours. After this initial crystalloid resuscitation, the PF recommends maintenance volumes of isotonic crystalloid and the addition of colloid boluses in the second 24 hours, as needed, to meet treatment end points such as urine output of at least 0.5 to 1 mL/kg/h.

However, studies addressing hemodynamic monitoring have suggested that urine output, blood pressure, heart rate, and laboratory examination may provide insufficient information to guide adequate resuscitation in patients with major burns [3,25–27]. Although the best end points of resuscitation in major burn injury have not been conclusively determined, the current recommendation is that urinary output be maintained between 30 mL/h and 50 mL/h, or 0.5 mL/kg/h [26,28]. In 2001, the ABA introduced a guideline that invasive hemodynamic monitoring should be restricted to patients with burn injury who have refractory shock or limited cardiopulmonary reserve [2].

Growing evidence suggests that burn patients often receive far more fluid-resuscitation volumes than calculated by the PF [29–32]. This phenomenon of resuscitation volume that exceeds the PF has been termed fluid creep [33]. Fluid creep is associated with complications such as pulmonary edema and abdominal compartment syndrome. Thus, although providers frequently use the PF for burn resuscitation, alternative resuscitation formulas and adjunctive techniques (eg, hemofiltration) are emerging, which are described elsewhere in detail [34–36].

In addition to hypovolemia caused by increased permeability of the microcirculation [3,27,28], the first 24 to 48 hours after burn injury are characterized by a reduced cardiac output as low as 60% of the normal resting value [6]. This reduction in the cardiac output has been attributed to systemic humoral factors, diminution in catecholamine response, and decreased contractility from reduced coronary blood flow [3]. Concomitantly, systemic vascular resistance increases. After 48 hours the recovery phase commences, and cardiovascular changes evolve into a hyperdynamic state with increased cardiac output, tachycardia, and decreased systemic vascular resistance, all of which must be accounted for during subsequent intraoperative anesthetic management, because operative burn care typically occurs during this phase.

INTRAOPERATIVE PERIOD

Airway management
If the patient is not already tracheally intubated before arrival in the operating room, the method for tracheal intubation should be determined according to clinical judgment. Patients with major burn injuries frequently present to the
operating room with a combination of respiratory and anatomic characteristics that accentuate the risk for hypoxemia during induction and tracheal intubation. These characteristics vary depending on the stage of the burn injury. During the acute postinjury phase oxygen demand is elevated, and generalized edema involving the face and upper airway is often present. During the recovery and reconstructive phases, postburn face and neck contractures represent the most common challenges during airway management.

In patients with burns to the face, the presence of burn dressings can make bag-mask ventilation challenging because of difficulty in achieving a good seal around the mask, such that 2-person mask ventilation may be needed. If this proves to be ineffective, removal of the dressings is imperative. Neck mobility and mouth opening may be impaired by pain, edema, and burn injuries, and in later stages of care by wound contractures. Thus, one key assessment that the anesthesiologist should make before managing the airway of a burn victim is to determine the patency and soft-tissue compliance of the airway. Palpation of the neck and submandibular space may reveal tightness that will limit displacement of the tongue and soft tissues into the submandibular area, making laryngoscopy challenging. Both tongue edema and pharyngeal edema are frequent findings in patients with major burns. A tongue depressor or laryngoscope can be helpful in assessing tongue mobility and in visualizing the pharynx. If patency of the hypopharynx is in question, a flexible fiberoptic scope can be gently advanced to assess the epiglottis and surrounding tissues.

If the preoperative examination reveals concern for upper airway patency, mobility, or mask ventilation, and the patient is cooperative, an awake fiberoptic tracheal intubation is warranted. If the patient is uncooperative, a gentle intravenous or inhalational induction preserving spontaneous ventilation (with or without bag-mask assistance) may permit the advancement of the fiberoptic scope. If the examination reveals less concerning airway anatomy, a gentle post-induction test of mask ventilation is nonetheless indicated before injection of a neuromuscular blocker. In these scenarios, a video laryngoscope can also be used not only as an intubating tool but also as a diagnostic tool, permitting assessment of hypopharyngeal and glottic anatomy. A potential algorithm that summarizes these issues is shown in Fig. 4.

For patients with fresh facial burns or those undergoing debridement and skin grafting in the region of the nasal or oral cavity, securing the endotracheal tube or supraglottic device with adhesive tape may not prove feasible or ideal. Placement of a nasogastric tube through the nostril into the oropharynx and retrieved from the mouth can form a taut loop around the hard palate, to which an oral endotracheal tube can be secured [37]. Other techniques to secure endotracheal tubes in patients with facial burns include attachment with interdental wires or a surgical suture to the teeth [38,39], and use of circummandibular, transcartilagenous septal, or nasomaxillary sutures [40,41]. After securing the endotracheal tube, suspending the ventilatory circuit from the ceiling maintains a sterile field and provides adequate surgical exposure for facial debridement.
Tracheostomy
Severely burned patients may require tracheostomies for long-term mechanical ventilation because of the potential complications of prolonged endotracheal tube placement [42,43]. In a retrospective review by Aggarwal and colleagues [43], the indications for early tracheostomy (defined as <10 days after admission) included the presence of facial burns or injuries, and expected prolonged mechanical ventilation as determined by factors such as presence of inhalation injury, advanced age, chronic pulmonary disease, other significant comorbidities, and large burn size. The indications for tracheostomy placement more than 10 days after admission included failure to wean, failed extubation, or expected prolonged mechanical ventilation (Box 3) [43]. A randomized controlled trial by Saffle and colleagues [44], by contrast, showed that early tracheostomy does not improve outcome in burn patients. Regardless, the decision to place a tracheostomy should involve weighing the benefits of placement based on clinical judgment with the risks of long-term morbidity including tracheal stenosis and tracheoesophageal fistula, which has been found to occur in nearly one-third of patients requiring tracheostomy [45].

Ventilation strategies
Intraoperative ventilation of patients with burns and/or inhalation injury can be difficult because of increased airway reactivity, retained secretions, acute lung injury, and adult respiratory distress syndrome (ARDS), with the latter occurring in as many as 54% of mechanically ventilated patients with burn injury [7,46]. Both hyperinflation and collapse of aerated lung regions have been proposed to cause barotrauma by overextension and shearing forces, respectively [47]. Conventional mechanical ventilation involves maintaining airway plateau pressure at lower than 35 cm H2O while using sufficient positive
end-expiratory pressure to maintain alveolar and airway patency [47]. At present, standard of care utilizes low tidal volume ventilation with associated permissive hypercapnia as described by the ARDS Network Study [48], despite this study having excluded patients with burns of more than 30% TBSA [7]. In severe cases, special ventilatory strategies can be implemented to provide adequate oxygenation and ventilation, while preventing further respiratory compromise resulting from barotrauma caused by increased alveolar distention and shearing forces [47,48].

Bronchospasm is frequently present in burn-injured patients, and aggressive bronchodilator therapy with β2-agonists is warranted. Albuterol has been associated with improvement in the PaO₂/FiO₂ ratio (ratio of partial pressure of arterial oxygen and fraction of inspired oxygen) and a reduction in pulmonary edema, pulmonary vascular permeability, and airway pressures [49,50]. Another useful strategy to prevent respiratory dysfunction during the intraoperative period is to minimize retained secretions and cellular debris by attention to body positioning and frequent suctioning [47].

As mentioned earlier, the fluid-creep phenomenon associated with burn resuscitation can put severely burned patients at risk for intra-abdominal hypertension [51]. Intra-abdominal hypertension and abdominal compartment syndrome alter respiratory mechanics (restrictive lung defect) and prevent adequate ventilation [52,53]. Additional restrictive lung defects can be imposed if the patient is positioned prone for surgical debridement of posterior body burns or donor skin harvesting. Thus, measurement of intra-abdominal pressure (eg, transducing urinary catheter) can help guide safe prone positioning in such patients.

Monitoring
Standard intraoperative monitoring is often challenging in patients with major burn injury (Table 1). Electrocardiogram adhesive lead placement may be

---

**Box 3: Indications for tracheostomy**

Presence of facial burns or injuries
- Expected prolonged mechanical ventilation
- Inhalational injury
- Advanced age
- Chronic pulmonary disease
- Significant comorbidities
- Large burn size
- Indications for tracheotomy placement more than 10 days after admission
- Failure to wean
- Failed extubation
- Expected prolonged mechanical ventilation
problematic in those with extensive burns, particularly on the torso and upper extremities. Needle electrodes or surgically stapling the electrodes may be necessary [3]. Significant edema or widespread extremity burns may preclude placement of noninvasive blood pressure cuffs, and peripheral vasospasm during a high catecholamine state may alter arterial-line pressure waveforms [28]. Similarly, pulse oximetry may be unreliable in clinical scenarios of hypothermia, hypovolemia, and the early postburn stage of decreased cardiac output and vasoconstriction [54]. In combination with limited anatomic locations to apply the pulse oximeter probe in patients with extensive extremity burns, this can make monitoring of arterial oxygen saturation challenging. Moreover, conventional pulse oximetry is inaccurate (ie, falsely elevated readings) in the presence of COHb, as already noted.

A review by Lavrentieva and Palmieri [25] examined arterial pressure waveform analysis techniques in burn-injured patients. Although arterial pressure waveform analysis did not affect outcomes in critically ill patients with burn injuries, the technique is less invasive and less costly than pulmonary artery catheter placement, and may play a valuable role in these patients. However, no large, prospective randomized trials have assessed this technique to validate the findings of these smaller studies.

Esophageal echo-Doppler is also a potential choice for short-term hemodynamic monitoring in burn-injured patients [26]. Monitoring of myocardial contractility trends may provide better insight into resuscitation adequacy than either fluid status or preload, based on reports that the early hypodynamic stage of burn injury may be, in larger part, due to myocardial depression rather than hypovolemia [26]. Indeed, underresuscitation and compromised cardiac performance both contribute to hemodynamic instability immediately following burn injury [55]. Similarly, a retrospective review by Etherington and colleagues [55]
of transesophageal echocardiography (TEE) at a regional burn center over a 5-year period reported that TEE was used most commonly to determine the cause of unexplained hypotension. TEE was found to provide valuable real-time information regarding ventricular filling, contractility, and valvular competence, with no attendant major complications. However, no randomized controlled trials exist to assess the utility of echocardiography in determining end points of resuscitation in the management of burn-injured patients.

Intraoperative maintenance of body temperature is critical, yet challenging, in patients with major burns, who can lose up to 1°C every 15 minutes if proper warming techniques are not used. Heat loss results from a combination of increased vascular permeability with fluid extravasation, loss of heat at the site of burn injury, and generous administration of intravenous fluid [56]. Basal metabolic rate in burned patients is significantly elevated and increases further in proportion to burn size as ambient temperature decreases [57]. Many detrimental perioperative complications are associated with hypothermia; specific to burn injury, however, decreased body temperature during burn excisions may increase blood loss and worsen morbidity and mortality [56]. For example, a decrease in intraoperative body temperature as small as 1°C in patients undergoing burn excision is associated with a significant increase in postoperative acute lung injury [56]. Therefore, efforts to minimize intraoperative heat loss should include increasing the temperature in the operating room to higher than 25°C, using convective warming devices and warmed intravenous fluids, minimizing skin surface exposure, and encircling nonoperative extremities in impervious plastic wrap to prevent evaporative heat loss.

Pharmacology

Major burn injury can lead to changes in medication pharmacokinetics and pharmacodynamics that may vary depending on the burn severity and the time elapsed after burn injury [58–65]. Burn injury results in plasma protein loss through injured skin and increased free-fraction concentration of protein-bound drugs. Volume resuscitation results in further plasma protein dilution and increases the volume of distribution (Box 4) [3,58]. Clinical effects of these altered pharmacokinetics include a reduction in the therapeutic index of drugs with high protein binding, and altered effectiveness of regular doses of analgesic drugs attributable to an increase in volume of distribution [3]. In addition, pharmacodynamic modification at the drug-receptor interaction level also plays a significant role after burn injury [3]. Several commonly used and representative medications are discussed in detail here.

Hypnotics

Propofol clearance and volume of distribution are increased in patients with major burns during the hyperdynamic phase of burn injury [58,59]. Specifically, propofol pharmacokinetics are determined by the interplay between (1) increased cardiac output, hepatic clearance, and renal clearance; (2) decreased binding of serum protein; and (3) pulmonary dysfunction [59,65].
Increased cardiac output increases cerebral blood flow, which typically increases anesthetic depth, but this may be less recognizable with propofol given that the drug itself may reduce cerebral blood flow by up to 50% [65]. Despite a burn-induced hepatic ischemic-reperfusion injury, hepatic clearance continues to account for the majority of total propofol clearance [65]. Decreased plasma proteins increase the free propofol fraction, particularly during prolonged administration, such that both hepatic and renal clearance can be elevated [65]. Smoke-inhalation injury may alter pulmonary blood flow and reduce the known propofol uptake and elimination that takes place in the lungs [65]. These pharmacokinetic changes, in addition to pharmacodynamic alterations at the level of the receptor possibly causing increased drug resistance, contribute to a decreased hypnotic effect of propofol [59,65]. Therefore, in comparison with nonburned surgical patients, those with major burn injuries may require larger bolus doses or increased infusion rates of propofol to attain or maintain therapeutic plasma drug concentrations [58,59].

**Neuromuscular blocking drugs**

Succinylcholine can be safely used immediately after acute burn injuries for tracheal intubation; however, its use at a time point greater than 24 hours after burn injury is contraindicated, owing to the risk of acute hyperkalemia and life-threatening dysrhythmias. However, the length of time a hyperkalemic response may manifest after burn injury is unclear [3]. Acute hyperkalemia after use of a depolarizing neuromuscular blocking drug (NMBD) is thought to result from the proliferation of extrajunctional acetylcholine receptors, in numbers proportionate to the magnitude of burn injury [3]. Related to this, plasma pseudocholinesterase is decreased in burn injury by as much as 50%, and may contribute to increased sensitivity to, or prolonged effects of, succinylcholine [60].

Conversely, resistance to nondepolarizing NMBDs is well described after major burn injury [60,62,64]. Resistance to nondepolarizing NMBDs may...
take several days to manifest, is typically only observed if the burn injury is greater than 20% TBSA, and may persist up to 18 months after burn wounds have healed [62,64]. The decreased effectiveness of nondepolarizing NMBDs after burn injury is thought to be multifactorial, with both delayed onset time and decreased duration of action reported. As with succinylcholine, the burn-induced upregulation of acetylcholine receptors, including immature, fetal-type acetylcholine receptors, at the neuromuscular junction has been implicated in the pharmacodynamics changes of nondepolarizing NMBDs in patients with burns [62,64,66,67]. Other reasons for such resistance include enhanced renal elimination caused by increased glomerular filtration, and alterations in the medication profile of these agents by circulating factors seen in burn injury, including prostaglandins and α₁-acid glycoprotein [64]. An increased rocuronium dose of 1.2 to 1.5 mg/kg for rapid-sequence induction has been recommended to counteract these effects in patients with major burn injury [62].

In contrast to the other nondepolarizing NMBDs, atracurium and cisatracurium are broken down by organ-independent pathways (eg, Hofmann elimination). However, resistance to these drugs still occurs because of their similar pharmacodynamic mechanisms. For example, the increased atracurium dose required for 50% maximal depression in twitch in burn-injured patients cannot be explained by pharmacokinetics or alterations in plasma protein binding alone [68]. As for cisatracurium, no research has specifically addressed the effect of burn injury on its duration of action. However, it can be inferred that cisatracurium may, too, have an altered pharmacodynamic profile, and dosing should be adjusted accordingly.

Given the increased resistance to nondepolarizing NMBDs and the decreased levels of pseudocholinesterase, mivacurium should be used cautiously, as it will have a slower onset and increased duration of action in burn-injured patients [60]. The decrease in pseudocholinesterase does not offset the decreased affinity of the acetylcholine receptors for NMBDs, and the onset of action remains prolonged [60].

**Opioids**

Opioid requirements are increased in burn-injured patients for several reasons that have not been fully elucidated [59]. A decreased volume of distribution and clearance of morphine has been reported, with an expected increase in elimination half-life [69]. Similarly, burn injury affects fentanyl pharmacokinetics via an expanded volume of distribution rather than increased clearance or metabolism [61]. However, a separate study found no significant difference in morphine pharmacokinetics between adults with and without burn injury [70]. Nevertheless, pharmacokinetic findings cannot completely explain the increased resistance to opioids among burn patients, suggesting that other parameters, such as intrinsic pharmacodynamic opioid-receptor alterations, may be the primary cause [61,69,71,72]. Opioid tolerance is an important factor that makes pain management challenging throughout all phases of burn care, and is characterized by increasingly poor response to standard doses of
analgesics. Opioid tolerance may be apparent after as little as 2 weeks of uninterrupted opioid use, or in patients with preexisting recreational opioid abuse. It is not uncommon for burn-injured patients to manifest opioid tolerance requiring dosing that far exceeds common textbook recommendations.

**Intraoperative fluid administration**

Standard intraoperative fluid administration is adjusted for the magnitude of burn excision (large excisions incur more blood loss), the depth of burn (partial-thickness burn excisions involve more blood loss than full-thickness burn excisions), the specific hemostatic techniques used (eg, topical epinephrine), and the surgeon’s possible use of tumescent fluid administration. Fluid repletion must be carefully optimized so as to not underresuscitate or overresuscitate, both of which may lead to further complications in the postoperative period.

**Maintaining hemostasis**

Excessive blood loss during burn excision is a major complication of surgical burn care. Budny and colleagues [73] estimated that the mean intraoperative blood loss in an adult patient undergoing excision and grafting of burn wounds could be as high as 117 mL/%TBSA burn wound excised. Multiple techniques have been used to minimize intraoperative bleeding, such as application of topical thrombin, use of compressive devices (tourniquets), staged procedures, and topical or subcutaneous injection of vasoconstrictors (epinephrine, vasopressin analogues, or phenylephrine) [74–78]. Tourniquet use during burn-wound excision and grafting has also been shown to reduce the rate and amount of intraoperative blood loss [3,79]. Systemic effects of topically applied or subcutaneously injected vasoconstrictors during burn excision can be significant (eg, increased blood pressure, heart rate, or serum glucose), yet unpredictable. Intravenous tryglycidyl-lysine vasopressin during burn-wound excision is reported to result in decreased blood loss because of its selective action in reducing dermal blood flow; however, no cardiovascular parameters have been analyzed [75]. Mitchell and colleagues [80] demonstrated decreased blood loss in skin donor sites infiltrated with subcutaneous phenylephrine (5 μg/mL). Systemic effects of phenylephrine were not appreciated, but the study was not powered to expose such differences.

Topical epinephrine is the most commonly used technique for limiting blood loss during both burn excision and donor skin harvests. A comparison of topical epinephrine use during skin grafting in burned and nonburned patients reported increased levels of serum epinephrine and lactate, a higher lactate/pyruvate ratio, and higher heart rates in burn-injured patients [81]. Similarly, McQuitty and colleagues [82] demonstrated increased levels of plasma epinephrine when topical or subcutaneous epinephrine was used for surgical hemostasis. However, the results of these studies are contrary to others reporting no difference in catecholamine levels or hemodynamic parameters in burn-injured patients receiving topical or subcutaneous epinephrine solutions [83,84]. Further
studies are necessary to better define practices aimed at decreasing intraopera-
tive blood loss during excision and grafting of thermal injuries.

Transfusion guidelines
With advancements in fluid resuscitation and implementation of early excision
and grafting, burn surgery has seen improved survival in the past 30 years [78].
Despite the efforts to decrease hemorrhage intraoperatively, burn excision may
still be accompanied by significant blood loss. Traditionally the erythrocyte
transfusion trigger has occurred when hemoglobin has decreased to less than
10 g/dL. However, with publication of the Transfusion Requirements in Crit-
cical Care (TRICC) trial and the American Society of Anesthesiologists transfu-
sion guidelines, intensivists and anesthesiologists have since recognized the
potential benefits of a more restrictive transfusion threshold (~7 g/dL) [85–87],
although this more restrictive policy has yet to be uniformly implemented,
with transfusions still occurring at a mean hemoglobin level of 8.6 ± 1.7 g/dL
in intensive care units across the United States [88]. A recent survey of United
States burn centers reported that the hemoglobin transfusion threshold for pa-
tients with greater than 20% TBSA burns also remained high, at 8.1 g/dL, and
that more transfusions were associated with both higher mortality and infec-
tious complications [89].

Despite its obvious risks, the concept of an objective transfusion trigger for
burn-injured patients in the operating room is challenging, given (1) their un-
predictable hemodynamics owing to intensely painful surgical stimulation,
hyperdynamic cardiovascular physiology, and common intraoperative use of
topical vasoconstrictors; and (2) the inability of clinicians to accurately assess
intraoperative blood loss. In clinical practice, serial hemoglobin measurement
in euvoletic patients is the tool most commonly used to determine the need
for intraoperative transfusion.

Despite extensive research, no consensus exists regarding the appropriate
use of blood products for patients with major burn injury. One recent study
explored this issue, analyzing data from 2 3-year periods, before and after im-
plementation of an institutional blood-conserving protocol that included early
excision and donor harvesting with use of epinephrine- and thrombin-soaked
gauze followed by 10 to 14 minutes of pressure, electrocautery, and tourniquets
to minimize blood loss [90]. Use of this protocol was successful in reducing
transfusion requirements from 1 in every 3 patients with burn injury to 1 in
every 25, and demonstrates one valuable approach to minimizing intraopera-
tive blood loss using routinely available techniques.

Various innovative methods of reducing blood loss and assessing transfusion
requirements in burn-injured patients have been reported. One such approach
uses perioperative hemodilutional autologous blood transfusion (HABT). Imai
and colleagues [91] demonstrated that patients with less than 20% TBSA burns
who received HABT had reduced allogenic transfusion requirements.
Although total blood volume loss was unchanged, HABT significantly reduced
the actual loss of red blood cells, coagulation factors, and platelets. Activated
recombinant factor VII (rFVIIa) has also been used to minimize blood loss in burn-injured patients. In a single-center pilot study, Johansson and colleagues [92] showed that 2 empiric doses of 40 µg/kg recombinant rFVIIa (at incision and 90 minutes later) decreased the total number of blood products transfused in burn patients undergoing excision and skin grafting by 59%. Confirmation of these and other novel techniques is necessary, however, before widespread clinical adoption is possible.

Regardless of the advancements in intraoperative burn management, emphasis on the individual patient and accurate clinical judgment remains a vital component. Clinical judgment and the acuity of blood loss play a pivotal role in transfusion of burn patients, with clinical assessment using markers of hypoxemia, perfusion (base deficit, serum lactate), erythrocyte mass, and coagulation as key assessment tools. As Curinga and colleagues [93] concluded in their review of burn and transfusion, the quest for a universal transfusion trigger should be abandoned, and instead such decisions should be tailored to the individual needs of each patient.

Local and regional anesthesia
The use of local anesthesia, such as topical anesthetic creams or localized infiltration, is common in patients with burn injury. Local anesthetic creams allow nerve endings in the superficial layers of skin to be anesthetized; however, the time to peak effect may be on the order of hours, and the duration of action may be inadequate for both postoperative pain and initial dressing changes [94]. Furthermore, the amount of cream that can be safely used is ambiguous, given the concern for local anesthetic toxicity with unpredictable drug absorption from open wounds [94]. For smaller burn injuries, however, this may be a helpful adjunctive technique.

An alternative approach to local anesthesia is tumescent infiltration of lidocaine and epinephrine into subcutaneous tissue. This approach has gained widespread popularity in plastic surgery, in particular for liposuction and hair transplant. By creating swelling and firmness of the surgical area, donor harvests and burn excisions can also be more easily performed following such infiltration. In addition, large areas of body surface can be anesthetized with less surgical bleeding, and postoperative analgesia achieved. Although subcutaneous injection of dilute epinephrine or lidocaine has been variably adopted for burn escharotomy, debridement, excision, and grafting, studies reporting this tumescent technique are limited. However, high-dose lidocaine (up to 7 mg/kg) with epinephrine is reported to result in minimal blood loss, excellent postoperative analgesia for up to 8 hours, and easier surgical dissection [95].

The use of regional anesthesia is typically limited to smaller burns on isolated extremities, where the burn injury does not involve the site of needle placement. Peripheral nerve blocks may achieve sufficient surgical anesthesia, but placement must take into consideration that skin donor sites and burn-injury sites are often in different anatomic locations, particularly because
patients often have more intense postoperative pain from the split-thickness skin donor site than from the grafted burn wound. The use of regional anesthesia can provide intraoperative anesthesia, improve postoperative analgesia, and promote rehabilitation. For example, a study by Gupta and colleagues [94] assessed peripheral nerve blocks of the lower extremity for graft sites in 50 patients with 1% to 15% TBSA burns, reporting that patients had sufficient analgesia during the procedure, with no patients requesting that the procedure be aborted secondary to pain. Similar results were reported for ultrasound-guided lateral femoral cutaneous nerve blocks during skin harvesting from the lateral thigh to avoid general anesthesia [96]. First described by Dalens and colleagues [97], the fascia iliaca compartment block is a modification of the 3-in-1 femoral block [98], and has been reported in conjunction with general anesthesia to reduce pain at split-skin donor sites of the thigh [99]. Patients who received both a ropivacaine bolus and infusion during the operation demonstrated significantly reduced postoperative morphine consumption [99]. Critics of the fascia iliaca compartment block, however, state that the block requires large anesthetic volumes and may initially limit rehabilitation because of motor weakness [96]. Epidural or spinal anesthesia may also be used for operative burn care, although extensive surgical debridement with risk for significant blood loss and attendant hypovolemia is a relative contraindication for these techniques [3].

In summary, although some studies have shown some potential benefit of regional anesthesia in patients with burn injury, regional anesthesia often cannot be used, at least as the sole anesthetic, given the distribution of burn injury, the need for donor skin harvests at distant sites, or other associated injuries that the patient may have sustained. However, regional anesthesia may prove advantageous in targeting specific aspects of burn-injury management, such as intraoperative care of small and/or localized burns.

**POSTOPERATIVE PERIOD**

In the immediate postoperative period, clinical judgment should determine the most appropriate time for tracheal extubation, particularly if the patient has received large intraoperative fluid volumes, has had preexisting airway abnormalities, or has received excessively high intraoperative doses of opioids. Postoperative mechanical ventilation is generally indicated in patients with preoperative mechanical ventilation, as well as those undergoing delicate sheet grafting to the face/neck, in an effort to minimize motion and graft disruption in the initial postoperative days. Because of the frequent presence of unpredictable opioid tolerance, when postoperative extubation is planned, opioid dosing should ideally be titrated and individualized before emergence using spontaneous ventilation, targeting a respiratory rate of 10 to 20 breaths per minute and a normal expired carbon dioxide concentration. However, owing to the intense pain associated with these procedures, additional opioids and/or low-dose ketamine may be necessary in the postanesthesia care unit. Pain management and procedural sedation remain key treatment priorities.
throughout the remainder of the postoperative period, with care strategies detailed elsewhere for burn-injured adults and children [100,101].

**SUMMARY**

Hospitalized burn-injured patients frequently require surgical treatment, yet pose a myriad of pathophysiologic challenges to acute and intraoperative care, whether treated at a community hospital or a specialized burn center. Optimal perioperative care requires a comprehensive preoperative assessment and attention to risk factors (eg, burn shock and resuscitation, difficult airway anatomy, inhalation injury) that predispose these patients to increased morbidity and mortality. Anticipation of these issues, as well as altered pharmacokinetics and pharmacodynamics, will help ensure safe and effective perioperative management of patients with burn injury, including guidance to surgical and nursing colleagues regarding challenges in pain management.

**References**


