INTRODUCTION

The anesthetic management of patients with burns is unique, especially when the percentage of body surface area (BSA) burned is greater than 10% to 15%.

PATHOPHYSIOLOGY

In both adults and children with major burns, every organ system is disrupted in some fashion.

Cardiac

Although there is some debate, it appears that acutely, after a burn injury, patients have decreased cardiac output from depressed myocardial function. In addition, cardiac output can be low because of hypovolemia secondary to tremendous third spacing from increased capillary permeability and hypoproteinemia as well as evaporative losses. Furthermore, there is increased systemic vascular resistance (SVR) because of vasoactive substance release. This decrease in cardiac output is of importance to the anesthesiologist because most medications used for induction decrease SVR and cardiac preload. Thus, it is important in patients with severe burn injuries, even...
those who are otherwise healthy, to maintain baseline hemodynamic parameters and loading conditions. Furthermore, positive pressure ventilation will exacerbate decreased preload, especially in patients who are not adequately volume resuscitated. Patients with electrical burn injuries, both low-voltage and high-voltage, are at risk for dysrhythmias and direct damage to myocardium and should be followed closely for ECG changes and arrhythmias. Nonspecific ST-T changes and atrial fibrillation are the most common ECG changes and arrhythmia associated with electrical burn injuries.

**Pulmonary**

If the burn is in a closed space, there is more likely to be an inhalation injury. The length of exposure to the agent of injury (Tables 1 and 2) and the components that are inhaled play important roles in the severity of lung injury. In a severe burn, the pulmonary system can be affected by the burn and the inflammatory response. Smoke, flame, or damaging gases result in injury or irritation of the lungs. Edema, bronchial casts, sloughing of tissues, decreased clearance by mucociliary transport, and decreased surfactant result and impair gas exchange. Circumferential burns of the chest can result in a restrictive physiology. Typically, just the upper airways are affected directly unless super-heated gases, such as steam, or small particulate matter are involved.

Lung injury can cause laryngospasm, bronchospasm, bronchitis, shunt, and decreased pulmonary compliance. The inflammatory response and capillary leak from injury elsewhere along with fluid resuscitation may result in adult respiratory distress syndrome. Bronchoscopy to remove obstructive debris, to assess the ongoing injury, and to obtain cultures for focused antibiotic treatment may be helpful before, during, or after surgery. As adult and pediatric patients with inhalation injury may develop bronchitis and reactive airways, pharmacologic treatment includes aerosolized albuterol and epinephrine, which decrease peak inspiratory pressure, pulmonary compliance, and shunt fraction while increasing the arterial to alveolar oxygen gradient. Albuterol causes bronchodilation and decreases inflammation, while epinephrine causes bronchodilation and vasoconstriction, which reduces edema. Most institutions use cuffed endotracheal tubes because high minute ventilation and positive end-expiratory pressure are often required to support ventilation and oxygenation.

**Renal**

Renal tissue can be damaged by the hypotension and low cardiac output of burn shock, especially if fluid resuscitation is not prompt and sufficient. In addition, the release of catecholamine and vasoactive substances after burn injury causes renal artery vasoconstriction and decreased blood flow to the kidneys, resulting in decreased glomerular filtration rate (GFR) and urine production. Furthermore, electrical and crush injuries cause massive muscle tissue breakdown, the release of myoglobin, myoglobinuria, and renal injury. During hospitalization, an already compromised renal function can be exacerbated by nephrotoxic medications. The hypermetabolic state after burn injury

<table>
<thead>
<tr>
<th>Particle Size (µm)</th>
<th>Deposition Area of Airway</th>
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<tbody>
<tr>
<td>&gt;10</td>
<td>Nasopharynx, larynx</td>
</tr>
<tr>
<td>3–10</td>
<td>Conducting airways</td>
</tr>
<tr>
<td>0.5–3</td>
<td>Distal airways, alveoli</td>
</tr>
<tr>
<td>&lt;0.5</td>
<td>Remain in gas</td>
</tr>
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will result in increased GFR, which may mask tubular injury. Medications given during an anesthetic may have a prolonged length of action from decreased renal excretion.\textsuperscript{11}

**Central Nervous System**

Central nervous system (CNS) dysfunction is common in burn patients. CNS injury may occur from hypoxia induced by pulmonary injury or carbon monoxide toxicity. In one study, five percent of children with burns had encephalopathy.\textsuperscript{12} The symptoms may begin more than 48 hours after the injury and are often accompanied by multiple metabolic abnormalities including hypocalcemia. The etiology is probably secondary to central nervous system dysfunction from hematologic and metabolic abnormalities. Seizures can occur after carbon monoxide poisoning\textsuperscript{13} and are usually isolated and self-limiting. Direct injury to the spinal cord and brain can occur with electric burns if current crosses these areas of the body. Cerebral edema may occur up to three days after the injury. In addition, some burn patients will become hypertensive, which can result in hypertensive encephalopathy and seizures. Encephalopathic patients will have reduced anesthetic requirements.\textsuperscript{11} Preoperative sedation may be unnecessary and should be avoided.

**Hematologic**

Coagulopathy from massive blood loss and/or reduced hepatic function will affect bleeding and coagulation negatively intraoperatively, leading to increased blood product transfusion requirements.\textsuperscript{11} During the acute phase, hemoconcentration from hypovolemia and capillary leak can cause increased hematocrit and blood viscosity. Anemia during fluid resuscitation is generally a consequence of dilution in the absence of other trauma. Thrombocytopenia can be seen secondary to early sequestration within the first week after injury of later sepsis. In the postacute phase, anemia is a consequence of chronic illness and associated bone marrow suppression in addition to operative blood loss.

Otherwise healthy patients will have adequate delivery of oxygen to vital organs with a hematocrit of 20% to 25%. During the immediate operative period, more liberal transfusion may be needed to keep up with operative losses. Fresh frozen plasma is indicated for international normalized ratio more than 1.5. Platelet transfusion should generally only be considered when the platelet count is less than 50,000/mm\textsuperscript{3}.\textsuperscript{11}

**Infectious**

Burn patients are prone to infection for several of reasons. The lack of epidermis and dermis lead to burn wound infection.\textsuperscript{14} Intubation with an endotracheal tube or tracheostomy bypasses the upper airway barriers, which prevent bacteria from entry into the lungs. Gut permeability to bacteria is also increased after a major burn. Peripheral intravenous lines, central intravenous lines, and arterial lines provide a direct route for bacteria to enter the bloodstream. Moreover, immune function is decreased by the burn injury.\textsuperscript{14} It can be difficult to determine when patients with burn injury become infected because thrombocytosis and hyperthermia are not

<table>
<thead>
<tr>
<th>Source of Heat Loss</th>
<th>Amount (%)</th>
</tr>
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<tbody>
<tr>
<td>Radiation</td>
<td>60</td>
</tr>
<tr>
<td>Evaporation</td>
<td>25</td>
</tr>
<tr>
<td>Convection</td>
<td>12</td>
</tr>
<tr>
<td>Conduction</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table 2**

Sources and amount of heat loss in unclothed adult in a 25°C room.\textsuperscript{34}
unusual. Meticulous intravascular line and respiratory care are critical for helping to prevent infections in these patients.\textsuperscript{14,15} These habits should be continued in the operating room (OR).

**Gastrointestinal/Hepatic**

The capillary leak, which occurs immediately following a severe burn, can result in abdominal compartment syndrome, which will cause decreased pulmonary compliance, oliguria, and/or hemodynamic instability. Early feeding is critical for wound healing in burn patients given the hypermetabolism that quickly arises. Because these patients often require many trips to the OR, frequent breaks in feeding may reduce caloric intake significantly and be detrimental to healing and recovery.\textsuperscript{11} Strategies to address this are program-specific and include intravenous perioperative supplemen tal nutrition and continued postpyloric feedings during the operative event.

**Endocrine/Metabolic**

Hyperglycemia can occur secondary to feeding as well as insulin resistance after injury. Serum glucose should be controlled as necessary with insulin before, during, and after surgery to improve wound healing and decrease wound infection risk. Electrolytes should also be frequently checked and repleted as necessary to prevent arrhythmias, which can result from abnormal potassium, calcium, and magnesium levels. Hyponatremia and phosphatemia are particularly common during the early postburn period and should be considered especially during protracted anesthetics.\textsuperscript{11}

**Psychiatric**

Psychiatric disorders are common among burn patients. One study showed that more than half of the survivors had psychiatric disorders 10 years after the injury, particularly posttraumatic stress disorder. In addition, pain, neurologic problems, and mobility issues can persist after burns, making a return to school and work difficult. Providers of pediatric anesthesia are used to providing care to anxious\textsuperscript{15} patients, and preoperative anxiolysis should be considered for patients without contraindications. Screening for active psychiatric issues, in both acute and reconstructive burn patients, will help insure a smooth anesthetic event.

**PHARMACOLOGY**

After a burn injury, the pharmacokinetics and pharmodynamics can be very different from those in nonburn patients because of the following:

- Fluid compartment alterations
- Changes in cardiac output
- Variability in organ perfusion
- Decreased renal and hepatic function
- Changes in serum protein levels
- Hypermetabolism

The responses of burn patients to many drugs are irregular.\textsuperscript{3} It is very important to titrate all medications to effect. Furthermore, as previously mentioned, patients who arrive to the OR acutely after a burn injury may be hypovolemic and have a depressed cardiac output. About 24 hours after a burn, the number of extrajunctional acetylcholine receptors will be significantly increased and severe hyperkalemia may occur with the use of a depolarizing muscle relaxant. In addition, burn patients will be resistant to nondepolarizing muscle relaxants (NDMR).\textsuperscript{16} These differences will persist for months.
PERIOPERATIVE MANAGEMENT

Airway

The burn patient should be approached in a similar fashion to all trauma patients, either pediatric or adult.\(^\text{11,17}\) However, there are important issues to be aware of in a burn patient and critical differences between pediatric and adult patients. The ABC’s should be assessed when the pediatric burn patient is first approached. The differences in the airway between pediatric and adult patients make the pediatric airway somewhat more difficult to manage, see below.

Pediatric Airway: Differences from Adults:

- Larger occiput
- Smaller nares
- Larger tongue relative to oropharynx
- Angled glottic opening
- Glottis is more anterior and cephalad
- Narrowest part of airway is subglottic
- Longer, narrower, stiffer epiglottis
- Higher risk of bronchospasm and laryngospasm
- Faster desaturation

If approaching a burn patient for a reconstructive surgery months or years after the initial injury, additional specific airways challenges may be present.\(^\text{18}\) These patients should be assessed for the following features, which may make obtaining control of the airway challenging:

- Face, neck, and chest contractures
- Microstomia
- Granuloma formation
- Subglottic stenosis
- Tracheomalacia
- Abnormal or small nares
- Neck scarring resulting in immobile fixed, flexed neck

Acutely, airway edema may cause distortion of the face and airway and limit movement of the neck and opening of the mouth. The tongue may be very edematous. It should be assumed that any patient with burns of the face, neck, and upper chest or signs of inhalation injury has a difficult airway.\(^\text{11,17}\) As the trachea of infants and children is smaller and flow is laminar and proportional to the fourth power of the radius; even small changes in trachea diameter from edema can have significant effects on air flow in children. Airway obstruction can develop rapidly in smaller children.

Fluid Management

During surgical treatment of an acute burn, insensible fluid loss and blood loss are typically greater than anticipated and difficult to quantitate. However, blood loss
prediction should be based on the BSA percentage to be excised and the surgical pro-
cedure.\textsuperscript{11,19} It is useful to check the hemoglobin level at frequent intervals during
extensive excisions. If evaporative losses are not replenished sufficiently, the hemo-
globin may be artificially elevated. Usually, the first sign of this is hypotension and
an increasing need for vasopressor. There are multiple formulas to calculate fluid re-
quirements in burn patients but they often overestimate requirements. Fluid adminis-
tration should be titrated to a urine output of 1 to 2 mL/kg/h.\textsuperscript{20}

Central venous pressure trend, arterial blood pressure pulse pressure variation,
urine output, serum pH, and lactate level can be used as a guide to the patient’s vol-
ume status.\textsuperscript{21–23} The lowest acceptable hemoglobin level should be determined pre-
operatively. In many situations, burn operations are proceeding simultaneously with
initial burn fluid resuscitation. Close collaboration between the intensive care unit
and the OR teams is essential.

\textit{Temperature Regulation}

Burn patients lose heat to their surroundings at a very high rate given the lack of
epidermis and dermis in the burn areas. This loss of heat is more pronounced in
children with their higher surface area to volume ratio. It is important to minimize
heat loss as much as possible. Evaporation becomes greater when the skin is lost
due to burn.\textsuperscript{11} Sources of heat loss and specific means of addressing it are presented
in Tables 3 and 4.

\textit{Intravenous Access and Monitoring}

Both vascular access and monitoring may be difficult in the acutely burned patient.
Nevertheless, it is critical to obtain vascular access and place monitors quickly. Direct
visualization may not be possible and blind peripheral or central intravenous catheters
placement may be necessary. If time and equipment permit, an ultrasound should be
used. Lines are an infection risk and should be placed aseptically and be removed
when no longer needed. However, often vascular access is necessary for long periods
of time in pediatric patients with severe burns.\textsuperscript{11,20}

Vascular considerations in severe burns are as follows:

- Place vascular access at intact skin if possible.
- Large-bore IV access is necessary in a patient with severe burn for rapid volume
  replacement.
- Intraosseous access may be necessary in patients with difficult intravenous
  vascular access.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Methods to decrease heat loss</th>
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<tbody>
<tr>
<td><strong>Source of Heat Loss</strong></td>
<td><strong>Methods to Decrease Heat Loss</strong></td>
</tr>
<tr>
<td>Radiation</td>
<td>Warm OR\textsuperscript{a}</td>
</tr>
<tr>
<td></td>
<td>Heat lamps</td>
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<tr>
<td></td>
<td>Reflective blankets</td>
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<tr>
<td>Evaporation</td>
<td>Warm OR</td>
</tr>
<tr>
<td>Convection</td>
<td>Place patient on insulated or warming blanket</td>
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<tr>
<td>Conduction</td>
<td>Cover patient with watertight material</td>
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<tr>
<td></td>
<td>Humidify ventilator gases</td>
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<tr>
<td></td>
<td>Intravenous fluid warmer</td>
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<td></td>
<td>Forced air warming blanket</td>
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\textsuperscript{a} To decrease the difference in temperature between the patient and surrounding objects.
Invasive blood pressure monitoring is needed for waveform analysis and continuous measurements.

Central venous access to trend central venous pressure and deliver vasoactive substances rapidly.

Consider central venous line interval rotation policy.

Minimize line diameter to decrease thrombosis risk.

American Society of Anesthesia (ASA) standard monitors should be used when possible. Often creativity is necessary to achieve this because monitor placement may be difficult in light of burn wounds and operative field issues. Electrocardiographic (ECG) monitoring may require needle electrodes because surface electrodes will not work. Esophageal ECG monitoring can be used. Sometimes, surface electrodes can be attached by sutures or wrapping gauze over the electrode and around an extremity. Pulse oximetry can be unreliable from either the burn, decreased extremity perfusion, or hypothermia and may need to be placed on the ear lobe, buccal mucosa, or tongue. Noninvasive blood pressure cuff can be replaced by invasive blood pressure monitoring. As mentioned previously, it is important to monitor the patient’s temperature. Either esophageal or rectal temperature can usually be assessed. The use of a precordial or esophageal stethoscope should be considered.

**Induction**

**Muscle relaxant**

As mentioned previously, succinylcholine, the sole commercially available depolarizing muscle relaxant, should be avoided after 24 hours postburn, given the increased accumulation of extrajunctional acetylcholine receptors, release of intracellular potassium with this agent, and risk of hyperkalemia and associated arrhythmias and cardiac arrest. Extrajunctional acetylcholine receptors persist for 12 months. Succinylcholine can be used at that time if necessary. Most anesthesiologists still avoid this agent unless it is unavoidable. Most other commonly available muscle relaxants, nondepolarizing, should have little effect on the patient’s hemodynamic variables. The exception is pancuronium, which will result in an increase in heart rate and blood pressure. It is rarely used given its extended half-life but may be an attractive choice in the patient who present with a volume deficit, but will remain intubated after surgery.

**Induction agent**

Most patients who present with significant burn acutely are hypovolemic. This fact should be taken into account when choosing the induction agent and dose. No agent is contraindicated. Thus, propofol could be used, but it is important to understand that blood pressure will decrease postinduction from a combined decrease in SVR and direct myocardial depression. As with most pediatric inductions, after weighing the risks and benefits, an inhalational induction can be carried out as well. Again, it is important to understand that the pediatric patient with a burn injury may be at particular

<table>
<thead>
<tr>
<th>Sedative</th>
<th>Route of Administration</th>
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<tr>
<td>Dexmedetomidine</td>
<td>Intranasal, intravenous, oral</td>
</tr>
<tr>
<td>Ketamine</td>
<td>Intramuscular, intravenous, oral</td>
</tr>
<tr>
<td>Midazolam</td>
<td>Intramuscular, intravenous, oral</td>
</tr>
<tr>
<td>Clonidine</td>
<td>Intravenous, oral</td>
</tr>
</tbody>
</table>

- [Table 4: Sedatives and routes of administration](#)}
risk for hypotension after inhaled induction secondary to a decrease in SVR and myocardial depression. However, most pediatric burn patients have few comorbidities and will tolerate this. Ketamine is an attractive choice for an induction agent because it results in CNS sympathetic stimulation and direct release of catecholamines. Blood pressure and heart rate should increase with ketamine induction. Nevertheless, ketamine does have a direct myocardial depressant effect that is usually much less than the central sympathetic stimulation and from catecholamine release. It is important to be cognizant of this in a critically ill patient who may have adrenal suppression and catecholamine exhaustion. Etomidate has virtually no effect on hemodynamic variables after induction. Thus, it would appear to be an attractive agent. However, given the risk of adrenal suppression and the relationship between increased mortality and etomidate use in critically ill adult patients, it should be avoided in most patients with significant burns.

Maintenance

There is no single agent that has been shown to be best for intraoperative anesthesia maintenance. Anesthesia maintenance can be accomplished with inhaled, intravenous, or a mixture of agents. If inhaled agents are used, nitrous oxide may have less effect on blood pressure than the other volatile agents. Patients with significant burn and resulting myoglobinuria and hypovolemia are at risk of renal injury. Sevoflurane use with a CO₂ absorbent with strong bases (KOH and NaOH) results in Compound A formation. Compound A has been shown in animal studies to cause renal injury. However, there is not a single reported case of such injury in humans. Although the conclusion is not to avoid sevoflurane use in burn patients, it is worth mentioning. It is important to note the altered pharmacokinetics and pharmacodynamics of agents in pediatric burn patients when determining maintenance agents. A greater volume of distribution may mean higher infusion rates of intravenous drugs. Opioid requirements are often greater for the same reason acutely and later because of tolerance. Thus, agents must be titrated to effect.3,24

Reconstructive Surgery

For short, minor procedures such as dressing changes in nonintubated patients, agents that will provide sedation and analgesia should be considered while maintaining spontaneous ventilation like ketamine. Dexmedetomidine is increasingly used because it provides sedation and analgesia but does not cause significant respiratory depression. However, one must understand that it is more likely to cause hypotension than propofol. If a patient has scar and contracture of the face and/or neck, the anesthesia provider should be concerned about airway distortion and difficult mask ventilation and/or intubation. The neck may have a fixed flexion; mouth opening may be limited, and/or airway anatomy may be abnormal. If these are suspected but the extent of these features is unknown, especially in a noncooperative child, a careful anesthetic plan must be formulated. A sedation plan that allows spontaneous ventilation and minimal depression of respiratory drive is important until intravenous access is obtained and the airway is secured.

Pain Management

Early pain after a burn injury can be severe.3 In some patients, it is constant; in others, it waxes and wanes. Burn-related pain is often undertreated in a clinical setting and depends on the extent of burns, amount of activity, infection, baseline pain threshold and opioid tolerance, coexistent anxiety, and/or depression. Although third-degree burns are insensate, the tissue around it is painful and sensitive. Pain arises after a
burn from nociception, hyperalgesia, and neuropathy. While healing, paresthesias and pain arise. Neuropathic pain may be opioid-resistant.\textsuperscript{11,15}

\textbf{Procedure-related pain}

Pain associated with procedures such as dressing changes and skin grafts is more severe than the baseline pain associated with burns. The multiple and frequent procedures are very upsetting to many burn patients. The pain from these procedures is often drastically undertreated because of the underestimation of pain, overestimation of the effect of pain medication, and a lack of familiarity with opioid-tolerant patients. This undertreatment can be exacerbated by a lack of intravenous catheter and the difficulty obtaining and maintaining venous access in young children.

Opioids are the mainstay of treatment of burn pain, with morphine being the most commonly used. However, patients with severe burns have prolonged hospital stays with many procedures. Tolerance to opioids is a difficult issue. Opioid-sparing anesthetics and medications should be considered. Regional anesthesia can reduce or remove procedure-related pain. However, it is important that patients continue to receive opioids for background pain. Oral medications such as acetaminophen, nonsteroidal anti-inflammatory drugs, clonidine, gabapentin, and tricyclic antidepressants have been shown to decrease perioperative nociceptive and neuropathic pain.\textsuperscript{25–29} In addition, intraoperative nonopioid medications, such as ketamine, dexmedetomidine, and lidocaine, have been shown to be opioid-sparing and to decrease postoperative pain.\textsuperscript{25,26,28–31}

Methadone, a mixed receptor agonist, is also a good alternative to the pure mu-receptor agonist opioids.

Regional anesthesia techniques (neuraxial and peripheral nerve blocks) are best for decreasing postoperative pain and opioid use and should be carried out whenever possible. In the acutely injured patient, regional techniques may not be feasible especially if the burn covers a large area. However, with subsequent reconstructive procedures, regional anesthesia may be a reasonable technique to control postoperative pain, particularly at skin graft donor sites. The relative and absolute contraindications to regional anesthesia procedures should be noted, as follows:

- Coagulopathy
- Sepsis
- Cardiovascular instability
- Hypovolemia
- Infection at site
- Patient (guardian) refusal

It is also important to understand that there may be significant variability in pain from procedure to procedure. Allowing a child to have as much perceived control as possible can decrease pain and opioid requirements. Sedation before a procedure is also important, and alternatives to benzodiazepines (dexmedetomidine, ketamine) are useful.

As mentioned, with reconstructive surgeries, patients who have had prolonged hospital stays and multiple prior surgeries may be extremely anxious. It may not be possible to place a peripheral IV before the surgery; it may be difficult to place an IV after an inhaled induction given their burn injury locations, and/or the patient may have a difficult, or potentially, difficult airway because of their burn injury location. Thus, it is important to be able to provide appropriate sedation before induction (see Table 4).
Late
Many patients with extensive burns and lengthy hospital stays remain intubated for prolonged periods of time. The most commonly used medications for sedation during this time are infusions of a combination of an opioid and a benzodiazepine. Patients quickly become tolerant and increasing doses of both medications are used. Thus, often, even when controlled ventilation is no longer necessary, patients remain on high-dose infusions of both a benzodiazepine and an opioid. Weaning these medications requires a tremendous amount of time and effort on the part of medical providers, expense as the patients often need intensive care stays while on infusions or high-dose medications, and often pain and anxiety from patients and their families as these medications are weaned.

Ketamine and dexmedetomidine can be used as adjuncts to control withdrawal symptoms, decrease opioid and benzodiazepine requirements, and speed the weaning process.\textsuperscript{15,32,33} Tolerance and tachyphylaxis can occur with long infusions of these medications.

SUMMARY
Burn patients provide numerous challenges to the anesthesiologist. It is important to understand the multiple physiologic disruptions that follow a burn injury as well as the alterations in pharmacokinetics and pharmacodynamics of commonly used anesthetics. Thought must be given to surgery during initial fluid resuscitation and the airway challenges many of these patients present. Finally, the central role of pain management through all phases of care is a constant concern.

REFERENCES