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ANESTHESIA FOR TRAUMA (JW SIMMONS, SECTION EDITOR)

Anesthetic Management of the Burn Patient

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Abstract Burn victims are among the most challenging patients to care for. Major burn patients require immediate attention for airway management, evaluation of inhalation injury, and fluid resuscitation. Patients with extensive burns usually require multiple procedures and extended hospital stays. In these patients, the evaluation of vascular access, availability of blood products, and determining where to place standard and advanced monitors are important in planning. Lastly, postoperative pain management and complications of prolonged mechanical ventilation are challenging issues that constantly need to be addressed.

Keywords Burns · Electrical · Thermal · Chemical · Tube exchange · Excision and grafting

Introduction

The number of burn patients seeking treatment in the United States reaches 450,000 annually, with 40,000 hospitalized and 3400 deaths [1••]. Seventy-five percent of deaths due to burns occur at the scene or on initial transport [2]. Flame-related injuries account for 46 % of burn injuries [2]. Severe burns, greater than 40 % total body surface area (TBSA), occur in approximately 35,000 patients annually [3]. Mortality from burn injuries correlates with several risk factors including age greater than 60, more than 40 % TBSA burns, and the presence of inhalation injury [3]. The presence of all three risk factors carries a mortality rate of 90 % [3]. Jeschke et al. attempted to find a TBSA burn cutoff value in adults and pediatric patients above which mortality and other complications greatly increase. Results showed "cutoff" values of 60 and 40 % of TBSA burns in pediatric (<16 years) and adult patients, respectively [4]. In an editorial, Greenhalgh points out that although these cutoff values provide some usefulness they cannot be used to determine treatment, since the prognosis of burn patients depends on numerous factors [5].

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Burn Classification

Burn depths are classified by degrees. First-degree burns are characterized by damage to the epidermis. These areas are erythematous and painful. These minor burns usually resolve within a week without scarring. First-degree burn areas should not be factored into the calculation of TBSA for fluid resuscitation, as it may lead to over resuscitation [6]. Second-degree burns are divided into superficial and deep. Superficial second-degree burns involve the outer dermis and clinically can produce blistering and pain to touch. These wounds usually heal within 21 days without scarring. Deep second-degree burns involve the deep dermis and show blistering, reduced pain, and diminished sensation to touch. Excision and grafting may be required. Third degree, full-thickness burns involve the entire dermis. These wounds may appear leathery, white or red, and although patients may feel pressure on deep palpation, there is no pain in the affected area. Excision and grafting is usually required. It is important to note that patients frequently have different degrees of burns throughout their body and therefore some areas may be insensible to pain while other areas are extraordinarily painful.

Patients may present to the emergency department (ED) or specialized burn center with injuries ranging from minor burns to catastrophic injuries that may ultimately lead to death. Thermal, electrical, and chemical are three common types of burns found in the inpatient setting.

Causes of thermal burns include fire, steam, hot water or oil, and other hot objects. Most thermal burns occur as a result of fire in adults or as a result of scalding in children.

Electrical burn injuries vary from thermal injuries by the fact that most tissue destruction may not be grossly visible. As electricity travels through the body it causes tissue destruction along its path. Entry sites may be small depending on voltage and causing agent (e.g., power line, electrical socket, lighting strike). Exit sites may be more explosive and larger than entry sites.

Chemical burns can be caused by a myriad of substances. When these occur close to facial structures they may cause swelling and edema leading to airway obstruction. If chemicals are ingested or aspirated they can cause gastrointestinal or airway injuries. Most chemical burn wounds are treated by irrigation with copious amounts of water.

Inhalation injuries may result from exposure to flames, smoke, or other gaseous products. Damage to upper and lower airway structures occurs upon exposure and may continue to progress when the patient arrives to the hospital and during the first few hours. Heat can cause direct injury to airway structures leading to inflammation and rapidly progressing edema. Products of combustion (e.g., carbon monoxide, soot, cyanide) can cause direct injury to the airway, lungs, and ability to maintain oxyhemoglobin saturation and ventilation. Signs of soot in the airway or the presence of singed nasal hairs or facial burns should increase suspicion of extensive airway exposure to the inciting event. Patients suspected of having smoke inhalation should be placed on a non-rebreather (NRB) mask with flow rate at 15 LPM (up to 90 % FiO_2) and have an arterial blood specimen drawn for measurement of carboxyhemoglobin (COHgb). Patients with COHgb values greater than 20 % require tracheal intubation and mechanical ventilatory support. Patients with values of 10–20 % may be treated with a NRB mask if otherwise stable.

Airway Management

Upon patient's arrival, standard Advanced Trauma Life Support (ATLS) indications for securing the airway apply. These include Glasgow Coma Scale (GCS) score ≤ 8, apnea, severe maxillofacial fractures, inadequate respiratory effort, hemodynamic instability, risk for aspiration, closed head injury with need for hyperventilation, and risk of obstruction [7]. Patients who require an immediate definitive airway should undergo tracheal intubation. Although some patients may not initially require airway intervention, factors such as large fluid requirements, and facial or upper torso burns may result in respiratory compromise at later stages. Securing the airway once interstitial edema has worsened may decrease the success rate of intubation. Therefore, early intubation should be considered in patients with a worsening airway and increased risk for delayed respiratory compromise.

The administration of induction agents for airway management in the ED or the operating room should be guided by the patient's hemodynamic condition. The intubating dose for propofol may need to be reduced significantly due to its vasodilatory effects. Burn patients, either upon presentation or during hospitalization, may have fluid deficits and a large dose of propofol may lead to a significant decrease in blood pressure and cardiovascular collapse. Etomidate remains the most frequently used induction agent for rapid sequence induction and intubation outside the operating room. It is commonly used for its cardiac and hemodynamic stability. Although it is clearly established that etomidate causes adrenal cortical suppression via the inhibition of 11-beta hydroxylase, a single dose has not been shown to increase morbidity or mortality in burn patients. In contrast, etomidate has been reported to increase mortality in the intensive care unit (ICU) when used as a sedative infusion [8]. Therefore, the repeated use of etomidate should be avoided. This is applicable to burn patients, as recurrent operative procedures requiring numerous anesthetics are common. Ketamine has several properties that make it a popular selection for anesthesia induction in burn patients. Two main features are its analgesic properties and its potential for increasing or maintaining blood pressure. However, one must keep in mind that many burn patients are catecholamine depleted and that a large dose of ketamine may uncover its myocardial depressant effects and result in hypotension.

Muscle relaxation for emergent intubation is frequently achieved by the use of succinylcholine or rocuronium. Patients who have suffered thermal or chemical burns should not receive a depolarizing muscle relaxant 24–48 h after injury. Upregulation of extrajunctional receptors may lead to a hyperkalemic response after such period. Patients with acute electrical burns differ from those with thermal injury. The use of succinylcholine is discouraged even in the immediate period of electrical injury because these patients may have hyperkalemia from tissue and muscle destruction. Therefore, even a small rise in extracellular potassium may lead to deleterious effects. Rocuronium (1.2 mg/kg) can be used for muscle relaxation during rapid sequence induction in these patients.

Airway adjuncts such as supraglottic airways, video laryngoscopes, and flexible intubation endoscopes are valuable devices in patients with anticipated or unexpected difficult airway. Video laryngoscopes have proven to be useful in certain difficulty airways. Grade 3 or 4 laryngoscopic views are frequently improved with video laryngoscopes containing acute angle blades. Flexible intubating endoscopes can also be very helpful in patients whose tracheas are difficult to intubate and for diagnostic or therapeutic intervention.

Common Surgical Procedures

Burn patients may undergo a variety of surgical procedures. Four common procedures include escharotomy, excision and grafting, extensive dressing changes, and tracheostomy. These procedures may take place in a warmed resuscitation area, operating room, or ICU.

Escharotomies are performed when dead tissue may compromise perfusion or ventilation. Vascular compromise may follow full-thickness circumferential burns, most commonly in extremities; and large burns to the torso may impede ventilation. In such cases, escharotomy should be performed as soon as possible to avoid vascular, neurological, or ventilatory compromise.

Excision and grafting procedures are performed to remove dead tissue from patients and replace with viable skin. Operating rooms should be kept warm during the operative procedure, as excision of large areas of skin contributes to heat loss when exposed to cold ambient temperature. Although electrical burn patients may not suffer as large surface area burns as those with thermal or chemical injuries, the same considerations apply regarding heat loss. Skin grafts onto previously damaged areas are usually performed with autologous or allogeneic grafts. Epinephrine may be used on donor sites to reduce blood loss. The topical application or subcutaneous infusion of diluted epinephrine solutions have the potential to increase heart rate and blood pressure. This is important to note as an elevated blood pressure may give the clinician false reassurance of a patient's hemodynamic status.

Minor dressing changes are frequently performed at patient's bedside. Extensive dressing changes or those that require significant patient movement can be extremely painful. ICU patients on mechanical ventilation often receive sufficient analgesia to tolerate large dressing changes. Ketamine's amnesic and analgesic properties along with maintenance of blood pressure, airway reflexes, respiratory rate, and tidal volume make it a good option for dressing changes performed under monitored anesthesia care (MAC).

Securing the tracheal tube (TT) may present a challenge in patients with face or upper torso burns. Commercial products which aid in securing TTs or suturing them to patient's teeth may be necessary. When TTs are secured with tape, frequent checks are necessary to prevent impairment of face venous drainage by circumferential taping. Tracheostomy is often performed in patients with extensive burns requiring prolonged mechanical ventilation. However, the procedure may be difficult in certain patients due to edema and difficulty in positioning.

Preoperative Management

During the preoperative evaluation of a burn patient several areas need to be addressed. Although a comprehensive preoperative exam is required, several key issues are specific to burn patients. The patient's vital signs and fluid status are of upmost importance. As the TBSA of burns increases and depth of burn varies, the amount of resuscitative fluid required is more difficult to quantify. Patients are frequently over- or under-resuscitated. Heart rate, blood pressure, urine output quantity and quality, and data from invasive monitors such as systolic pressure variation (SPV), pulse pressure variation (PPV), and stroke volume variation (SVV) may help in the assessment of volume status. Preoperative evaluation of electrolytes and renal function is also important, as metabolic derangements may occur during large burn procedures.

Thermal or chemical burn patients who otherwise do not require an electrocardiogram (ECG) based on history do not usually require one for the operating room. Patients who suffer electrical burns routinely receive an ECG upon presentation. Patients who have a normal ECG at presentation do not require further cardiac monitoring regardless of route of electrical current. Patients with abnormal ECG (including sinus tachycardia) on presentation should receive cardiac monitoring for 24 h after admission.

Because electrical burns may cause rhabdomyolysis, the preoperative evaluation of these patients should include knowledge of the burn, route, and estimation of muscle damage. Measurement of enzymes such as CPK, SGOT, SGPT, and LDH aid in evaluating the extent of muscle destruction, along with urine analysis for the presence of myoglobin.

Critically ill burn patients have high caloric demands and require intravenous or enteral nutrition. These patients also frequently undergo multiple surgical procedures that would cause enteral feeds to be held due to fasting rules. Because this may lead to multiple delays in nutrition, fasting rules in certain burn patients have to be altered. The risk–benefit analysis of attempting to avoid aspiration in someone who already has a secure airway versus the consequences of poor nutrition favors continuing feeds. Therefore, enteral feeds should be continued in patients with a secure airway if no airway intervention will take place (e.g., TT exchange, tracheostomy).

Obtaining consent for anesthesia is a frequent challenge in burn patients, as these patients are frequently receiving mechanical ventilation and sedation. Health care proxies may not be immediately available to provide consent for such frequent procedures. Fahy and associates reported that the use of a single consent for serial anesthetics was an effective way of decreasing time spent obtaining multiple consents [9•]. This may also remove the appearance of inefficiency that health care surrogates perceive if they are contacted repeatedly for consents on frequent but similar procedures (e.g., grafting, dressing changes).

Intraoperative Management

The amount of damaged tissue in burn patients varies greatly among surface and depth. In patients with large TBSA damage, a large area may be prepped and exposed for both excision and grafting. Frequently, one must improvise when attempting to find the best method to apply the American Society of Anesthesiologists (ASA) standard monitors.

Pulse oximetry and a non-invasive blood pressure cuff need to be placed on extremities that are not on the operative field. If this is not possible, specialized earlobe pulse oximetry probes may be used. An arterial line for beat-to-beat pressure monitoring and frequent blood sampling is commonly used during extensive burn procedures. Arterial lines may be prepped into the sterile field if a non-operative site is unavailable. The concomitant use of a non-invasive blood pressure cuff when an arterial line is in place is recommended, as it will serve as back-up if the arterial line malfunctions intraoperatively. Line placement through burn sites is discouraged but sometimes impossible to avoid. ECG leads should be placed as close as feasible to their standard locations. The ability of electrodes to adhere to burned tissue may not be adequate. In such instances, stapling of electrodes may be necessary.

The crystalloid and colloid requirements for burn procedures can vary greatly. Therefore, the required IV access for such procedures varies as well. Large-bore peripheral access is frequently sufficient for administration of fluids. Patients with large surface area burns often arrive to the operating room with central access. Smaller sized triple-lumen catheters (e.g., 7 Fr.) are commonly used in ICU patients since they provide multiple ports for various infusions and medications. These catheters also allow access for blood sampling if an arterial line is not in place. However, many of these central catheters are not sufficient, and quite frankly inferior to large bore peripherals for administering large amounts of blood products. The substantial length of these catheters adds a significant amount of resistance. Larger single-lumen or multiple-lumen catheters (e.g., 9 Fr.) allow for faster infusion rates of crystalloids and blood products. Large area burn procedures may frequently require the transfusion of copious amount of products. The use of ultrasound for line insertion may be beneficial, as landmarks may be obliterated due to edema. Moreover, patients frequently have multiple lines during prolonged stays and the evaluation of vessel patency before attempts may increase cannulation success.

The pharmacokinetics of medications used in the induction and maintenance of anesthesia may be affected in burn patients. Factors such as changes in volume of distribution and protein drug-binding help explain the unconventional behavior of medications in these patients [1••]. Sedatives and analgesics are commonly used as continuous infusions in the ICU. Patients may have an increased tolerance for such medications. High opioid requirements are common in patients who received opioid infusions throughout a prolonged ICU stay. Such patients, even after extubation and in stable condition, may require large doses of opioids to achieve analgesia after procedures. Non-depolarizing neuromuscular blocking drug (NMBD) requirements may be significantly increased to achieve standard muscle relaxation. Upregulation of acetylcholine receptors contributes as one of the reasons for the increased requirements.

The development of hypothermia is a significant concern when treating burn patients. Patients are susceptible to hypothermia due to loss of the skin barrier, which increases thermal loss and impairs thermoregulation. Ambient temperature in the operating room should be increased to avoid heat loss via all mechanisms, especially radiation. In addition to increasing ambient temperature, forced-air warming blankets should be used on non-sterile sites to prevent cooling and help rewarm patients. In situations where large TBSA burns and operative exposure do not provide sufficient area to place a non-sterile forced-air warming blanket, a sterile one can be used. Sterile forced-air warming blankets may be placed on surgical fields that are not being immediately worked upon and moved to other parts of the body throughout the case. Fluid warmers for administration of crystalloids and blood products should also be used during burn procedures. Warmed fluid administration of small volumes or at low flow rates is not effective in warming a patient. Large fluid administration through a fluid warmer, especially at high rates, can help maintain or increase a patient's temperature. Blood products, which are commonly kept in cold storage, should be warmed before administering in patients who are susceptible to hypothermia.

Fluid management is one of the most important aspects of the care of the burn patient. Patients usually present to the operating room after their initial fluid deficit has been replenished. The use of albumin for initial resuscitation of burn patients has been reviewed elsewhere [10, 11]. Some suggest that although it may not decrease edema formation in injured tissue, non-injured areas may experience less edema [10]. Park et al. reported decreased mortality and duration of mechanical ventilation in patients sustaining more than 20 % TBSA burn who received albumin in the first 24 h after injury [11]. After initial resuscitation, vitals signs, urine output, and dynamic parameters such as SPV, PPV, or SVV can help the clinician decide if a patient is properly resuscitated. The most commonly used crystalloid solutions include Lactated Ringers (LR) and 0.9 % sodium chloride (NaCl). One caveat with large amounts of NaCl is the development of hyperchloremic metabolic acidosis. For this reason, LR or other equivalent solutions (e.g., isolyte, plasmalyte) are preferentially used in these patients during extensive procedures.

Type and cross-matched packed red bloods cells (PRBC) should be available before procedures with anticipated blood loss. Fresh frozen plasma (FFP) should also be included if significant blood loss is expected. Although the preoperative hemoglobin and hematocrit (H/H) may be useful, the interpretation of these values depends on the patient's volume status. A patient who may be under-resuscitated in an attempt to decrease edema may have a significant decrease in H/H after fluid administration in the OR.

The use of tranexamic acid (TXA) in trauma patients has increased within the past few years, especially since the CRASH-2 study was released [12]. However, insufficient data exist on the use of TXA in burn patients. These have been limited to case reports and small studies [13, 14]. Further research is needed to determine if TXA reduces blood transfusion requirements or mortality in burn patients. If TXA is found to be beneficial, one interesting issue to evaluate is how multiple administrations of TXA through multiple burn procedures would affect outcome.

Glucose control in critically injured patients has proven beneficial. Burn patients are in a catabolic state where glucose control plays an important role. Patients often receive continuous insulin infusion in the ICU and this can be continued in the operating room [15•]. One caveat of glucose control has always been the risk of hypoglycemia. Although prior studies in critically ill patients recommended a glucose target range from 90 to 140 mg/dl, recent studies in burn patients have suggested a range of 130–150 mg/dl, as it may decrease morbidity and mortality without the risk of hypoglycemia [16•].

Postoperative Management

Postoperative pain is mostly managed by the use of systemic opioids. Patient-controlled analgesia (PCA) can be used in patients who can follow commands and have the physical ability to utilize the IV administration remote. Intraoperative administration of opioids allows patients to emerge from anesthesia with adequate pain relief. For patients who will undergo tracheal extubation immediately after the surgical procedure a regional anesthetic block is an excellent adjunct. Regional anesthesia for postoperative pain control, especially at skin donor sites, can significantly decrease the amount of postoperative opioid consumption, decrease postanesthesia care unit recovery time, and increase patient satisfaction. Femoral or fascia iliaca blocks are commonly utilized, as the anterior and lateral thigh are common skin donor sites.

Patients who are to remain intubated postoperatively also require postoperative analgesia. An opioid approach is more commonly used than a combined approach. Patients may receive intraoperative opioid boluses or infusions that can be continued after surgery. Infusions of opioids in mechanically ventilated patients provide analgesic effects as well as sedative effects.

The transport of patients between the ICU and the OR who require high levels of ventilatory support is best achieved by the use of ICU mechanical ventilators. Patients with low levels of support can be transported using bag-valve ventilation. A positive end expiratory pressure (PEEP) valve can be attached to the bag-valve device to prevent atelectasis during transport.

Although it may not occur immediately, re-intubation or TT exchange in ICU burn patients may be required. Inability to drive adequate volumes is a common reason to be called for evaluation of a TT. This can be due to a positive pressure ventilation leak or high pressure from tube occlusion. When low tidal volumes are being delivered due to a leak, one must verify that the TT cuff has not migrated into a supraglottic position. Advancement of the tube in such circumstances should not be performed blindly. A variety of methods for TT advancement include direct laryngoscopy, video laryngoscopy, or the use of a flexible endoscope through the TT. Inserting an airway exchange catheter blindly carries the risk of being inserted into the esophagus if the TT is supraglottic. If the TT is to be advanced, it should be done under direct vision to assure the softened tube is not coiling in the posterior pharynx. The addition of a rigid catheter through the TT as an adjunct increases the rigidity of the TT for easier advancement.

TTs that are partially occluded with hardened secretions may also need to be exchanged. Exchanging TTs in burn patients may prove especially challenging once resuscitation and edema has caused airway and facial swelling. The use of video laryngoscopes and airway exchange catheters, where a conduit to the airway is never lost, can be extremely advantageous. One caveat of airway exchange catheters is the possibility of pushing airway debris distally when the catheter is inserted blindly through the TT. This can thrust a significant amount of debris into the tracheobronchial tree or form a hard plug in the distal portion of the TT causing total obstruction. One method to avoid this is to look through the TT with a flexible endoscope for inspection before placing an airway exchange catheter. If a high amount of debris is seen, exchanging the airway via direct laryngoscopy or video laryngoscopy represents better options.

Conclusion

Major burn patients present many challenges for airway management, vascular access, and hemodynamic and pulmonary support. Upon initial arrival, the severity of a patient's burns should be assessed along with the immediate or impending need for a secure airway. A patient's mental status, hemodynamics, and urgency of airway intervention are important factors when deciding how to best secure their airway. After initial patient stabilization, severely injured patients are frequently hospitalized for a prolonged period of time and will require numerous operative procedures. Escharotomies, excision and grafting, extensive dressing changes, and tracheostomy are common operative procedures performed. Attention must be given to the preoperative assessment of each patient. Intraoperative concerns include monitoring, crystalloid and blood management, and prevention of hypothermia to name a few. Lastly, postoperative analgesic requirements are frequently increased. Patients may benefit from a multimodal approach to pain relief including regional blocks. The ultimate goal is to provide care that will lead to an optimal functional outcome.

Compliance with Ethics Guidelines

Conflict of Interest Christian Diez declares that he has no conflict of interest. Albert J. Varon has received royalties from Cambridge University Press for co-editing *Essentials of Trauma Anesthesia* (textbook), and has received honoraria from the American Board of Anesthesiology for serving as an Associate Examiner.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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