MAIN TOPIC

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Anesthesia and pain management in pediatric burn patients

Abstract Patients with severe burn injury are a challenge for the pediatric anesthesiologist. Today with adequate care many children survive their trauma and have a good chance for complete functional and psychological rehabilitation. The anesthesiologist has to provide excellent care even for patients in suboptimal or unstable condition to enable wound debridement and grafting, because only rapid skin closure will stabilize the patient. Adequate pain treatment during all phases of burn treatment is mandatory.

Key words Analgesics · Anesthesia · Burn injury · Pain management

Introduction

Severe burn injury is a leading cause of life-threatening pediatric trauma. The anesthesiologist will be a member of the interdisciplinary team caring for these patients at the site of the accident, during transport, in the emergency room, or in a specialized burn unit. This article will delineate principles for providing safe anesthetic care in spite of the specific complications associated with burn injuries [14, 42, 48, 51, 67, 69]. Some of the major problems during the three phases of treatment, initial resuscitation, debridement and grafting, and reconstructive surgery, will be addressed. The anesthesiologist's tasks include resuscitation in the initial phase, providing safe anesthesia even for unstable patients during surgical procedures, and analgesic treatment during the rehabilitative period, and may be quite demanding.

Initial approach

The initial management of a scald or flame-burn injury includes the same immediate concerns toward life-support as in any other trauma patient: establishing a clear airway, initiating adequate volume resuscitation to stabilize the circulation, and evaluation for additional injuries.

Airways and respiratory system

One of the most impressive and life-threatening complications of thermal injury is swelling and distortion of the upper airway after inhalation of superheated air, steam, or chemicals [18]. Excessive edema formation after neck and face injuries, especially in infants and small children may also contribute to airway obstruction, resulting in hypoxemia and respiratory failure. Heat and excessive edema mainly obstruct the upper airway due to macroglossia and swelling of the hyper- and hypopharyngeal soft tissue. Today's fires produce a number of different chemicals from burned plastics. Chemical injuries mainly originate from small, caustic particular products of combustion (e. g., chlorine or cyanide, sulfur and nitrogen dioxide), which may be carried deep into the small airways and even to the alveoli [18, 65], causing small-airway obstruction, bronchiolar edema, and destruction of surfactant. Direct irritation of the bronchioli may cause severe bronchospasm, which usually responds well to standard bronchodilator therapy [13].

Subtle damage of small airways and lung tissue may not be obvious until later in the course of the disease, when increasing oxygen demand and inability to wean a patient from the ventilator will draw attention toward hyaline membrane formation. Inhalation of carbon monoxide (CO) always has to be suspected in any flame injury originating from a fire in an enclosed space [13, 14, 42, 67]. CO poisoning may cause only subtle signs like restlessness or headache, but may aggravate to an "unexplained" encephalopathy. It is important to bear in mind

that CO poisoning is not detected by pulse oximetry, since carboxyhemoglobin is measured as oxyhemoglobin.

Clinically observed respiratory distress may be caused by any combination of the described disturbances of gas exchange [13, 18, 33]. Decreased compliance of the respiratory system due to lung injury and/or circumferential burns of the thorax and abdomen necessitates increased inspiratory force during spontaneous respiration that may easily result in hypoventilation [71]. Although the diagnosis of smoke inhalation by itself is not an indication for endotracheal intubation [13], supportive treatment consists of early intubation and mechanical ventilation with application of high inspired oxygen concentrations. It is much easier to extubate a patient after a few hours of "unnecessary" intubation than to intubate a patient with an edematous and distorted airway. Intubation should be performed extremely gently by the most experienced person available with an uncuffed endotracheal tube (ETT), usually one size smaller than expected according to age and weight [7, 13]. If airway compromise is already evident, a difficult intubation can be anticipated, and it is prudent to manage the case in the same way as acute epiglottitis [42]. Tube leakage in combination with decreased compliance due to restricted chest wall expansion during inspiration may complicate mechanical ventilation. In most cases this can be overriden by appropriate ventilator adaptations. Whenever inhalation injury is suspected direct inspection of the airway by bronchoscopy should be performed.

Primary tracheostomy in the pediatric age-group is rarely indicated [7, 13, 37]. Glucocorticoids have no place in the treatment of inhalation injury; neither inhalational nor systemic application have demonstrated any favorable effect on outcome; instead, morbidity and mortality from infectious complications are increased [41, 65]. Prophylactic antibiotic treatment will only lead to selection of resistant bacterial strains with consecutive difficulties in adequately treating future sepsis [31]. Patients with CO poisoning may benefit from hyperbaric oxygenation even if treatment is instituted several hours after the inhalation event.

Resuscitation

Children with a burn wound in excess of 12%–15% of body surface area (BSA) need volume resuscitation to compensate for fluid losses into the burn wound and the interstitial space due to generalized edema formation. Poor systemic perfusion may lead to vital-organ dysfunction, while poor local perfusion may aggravate the severity of burn-tissue damage, e.g., converting viable second-degree into third-degree burns. For further details reference may be made to standard texts [39, 42, 73]. There is no "golden formula" [54] and as a consequence, until today no generally accepted single concept or formula or an "ideal solution" for rehydration therapy exists.

Controversy exists over which type of fluid should be given: crystalloid (isotonic or hypertonic), colloid, or a combination. A variety of different protocols have been

developed and successfully applied [5, 19, 22, 54, 73, 74]. Adequate volume restoration can be accomplished with 3–5 ml crystalloid solution/% burn · kg body weight (Bw) in addition to age-appropriate maintenance fluids. The widely used Parkland formula suggests 4 ml/%BSA burn · kg Bw. There is no place for electrolyte-free or glucose-containing solutions in the initial phase of volume resuscitation in burn patients. The accuracy of replacing circulating volume as measured by vital signs, e.g., adequate blood pressure, urine output > 1.5 ml/kg · h, near-normal acid-base status, and adequate central venous pressure and serum sodium levels, seems to be more important than the type of fluid used [5, 72]. All given formulas are only guidelines, and therapy has to be individualized according to vital sign monitoring.

The problems of disease transmission through blood products and costs do not allow liberal use of fresh frozen plasma (FFP) for volume therapy. Albumin solutions are not routinely used during the first 8–24 h posttrauma because they unfavorably influence lung water formation [5], wound edema, and healing [73]. If colloid solutions are necessary to preserve adequate circulating volume, artificial colloids should be used; hexaethylstarch (HES) or penta-fraction have been shown to be very effective [6, 53, 72]. HES may also be used in infants [3]; its maximum daily dose should be limited to 25–30 ml/kg. This limit is a consensus among European pediatric anesthesiologists derived from adult dosages, and has not yet been evaluated in prospective dosage studies in pediatric patients. In our own experience untoward effects have not been observed. In small infants packed red cells (RBC) are frequently necessary to preserve adequate circulation even if no surgical procedures are undertaken. Patients with electrical burns, severe inhalation injury, or accompanying trauma may need volume and blood products in excess of the dosages given here. Every patient has to be carefully assessed for associated trauma, especially after traffic accidents or explosions.

Physiologic changes relevant to anesthesia

Cardiovascular system

Cardiac output is initially low, mainly due to hypovolemia. The clinical significance of myocardial depression caused by a cardiodepressant factor despite adequate volume resuscitation is debatable, since it has not been regularly observed even in centers with high case loads [14]. The massive fluid efflux from the intravascular compartment is not only due to hypoproteinemia, but also results from massive production of various mediator substances [28], which cannot be fully counteracted by high levels of circulating catecholamines.

Renal system

An electrical burn or an ischemic or crush injury of an extremity may release significant amounts of myoglobin, which may damage renal tubules and impair renal function. During the hypermetabolic state with increased cardiac output and renal blood flow, elimination of drugs by glomerular filtration may be accelerated [46]. Nevertheless, sepsis, continued shock, or nephrotoxic antibiotics may impair renal function. Urinary output and quality should be monitored continuously and a transurethral or suprapubic catheter inserted.

Hepatic system

If prolonged hypoxia and/or hypovolemic shock are avoided, no specific complications of the hepatic system are to be expected.

Hematopoietic system

A reduction in RBC numbers as well as thrombocytopenia and a moderate to significant increase in white cell count, even in the absence of sepsis, are often observed [16, 35, 40]. Hematocrit (Het) should be kept between 25% and 30%. Septic patients with adult respiratory distress syndrome may benefit from the increased oxygen transport capacity of higher RBC counts. As stated above, FFP is only indicated in significant coagulopathies. Thrombocyte transfusions are of no clinical benefit unless the platelet count is below 50,000/mm³ and excessive bleeding is observed. The potential for disease transmission should limit the administration of blood products to carefully assessed situations. In our own practice the restrictive use of blood products has not influenced clinical outcome in an unfavorable direction.

Pharmacology

Pharmacokinetics and -dynamics are strikingly altered by a number of physiologic changes in burn trauma: changes in fluid compartments, cardiac output, organ perfusion, renal and hepatic function, as well as hypo- and dysproteinemias alter drug effects and metabolism [4, 46]. The patient's reaction to most drugs is unpredictable, and consequently, careful titration to the desired effect is warranted. Well-established standard dosages are often misleading. Burn victims are very sensitive to induction of life-threatening hyperkalemia by depolarizing muscle relaxants and show an abnormal resistance to nondepolarizing relaxants, even several months posttrauma. Nevertheless, facing the potential of irreversible cardiac arrest, succinylcholine should never be used in burn victims. Increased dose requirements of nondepolarizing muscle relaxants to produce satisfactory intubation conditions have been demonstrated [49]; thio-pental and propofol effects may also be altered in burn patients [8, 17].

Metabolic

Due to the high metabolic demand, patients with burn injury need high caloric nutritional support via either the enteral or parenteral route [34, 75]. After the initial phase, gastric emptying is not prolonged, and intake of clear liquids until 2 h prior to surgery seems to carry no additional risk [36]. Intestinal tube feeding does not need to be discontinued prior to surgery, especially if a concomitant nasogastric tube allows preoperative suctioning of gastric contents. Prolonged fasting times are unnecessary. Parenteral hyperalimentation should be stopped during anesthesia to prevent hyperglycemic episodes [14, 69].

Anesthesia

Preoperative evaluation

According to age, the patient and parents should be completely informed about the planned anesthesia and its risks, but also need assurance that everything will be done to comfort the child and protect its well-being. The patient with a thermal injury needs the same thorough evaluation as any other child coming in for surgery. Besides a complete medical history, a brief physical examination should include lung auscultation, assessment of chest compliance, and inspection of the neck and oral cavity to evaluate for difficulties with (re-)intubation. Depending on the extent of the burn injury, the laboratory studies should include a complete blood count, coagulation studies, serum electrolytes, blood urea nitrogen, serum protein, and creatinine clearance. Arterial blood gases and a chest radiogram supply additional useful information. The baseline level of consciousness and muscle strength should be noted for postoperative comparison.

Primary wound care (with the exception of fascial decompression) is not an urgent procedure and should be postponed until after initial patient stabilization.

Transport to and from the operating room (OR)

Patients should receive an effective premedication through one of the usual routes depending on the individual situation. Even after many surgical procedures, children may be very worried about what will happen in the OR. If the child complains of pain, it is unprofessional to simply reply that it will be over in a minute: everyone should be educated to react properly with empathy and sufficient pain treatment.

All lines, including the ETT, have to be safely secured before transport. It is extremely annoying if central or arterial lines are unintentionally removed by the patient or accompanying staff. Extreme care has to be taken not to dislodge an ETT: it may not be easy to mask-ventilate a patient with an edematous face covered with cream for local treatment. (In two of our patients ventilation through a nasal tube, the tip reaching only into the hypopharynx like a nasal CPAP tube, has been a life-saving maneuver.) Addi-

Table 1 Calculation of expected blood loss [42]

Surgical procedure	Predicted blood loss
<24 h since burn injury	0.45 ml/cm ³ burn area
1–3 days since burn injury	0.70 ml/cm ³ burn area
>4 days since burn injury	0.90 ml/cm ³
in infected wounds	1.0–1.25 ml/cm ³
Predicted blood loss $\times$ 1.3 = Relative blood loss %	
Body weight (kg)	

tional oxygen and a transport ventilator may be helpful en route. Any severely burned patient, especially one with an ETT in place, has to be continuously monitored during transport with an electrocardiograph (EKG), pulse oximeter, and precordial stethoscope; pulse quality should be checked regularly. If the transport is expected to be longer than 10 min, serial blood pressure (BP) measurements should be available. Special care should be taken to minimize heat loss.

If transfer from the bed to the operating table is expected to be painful, sufficient analgesia (i.v. opioid, ketamine) is mandatory. For anxious patients, especially after prolonged hospitalization, it is our practice to start the induction with the patient in bed unless a difficult airway is anticipated.

Induction and maintenance

No single anesthetic agent or technique has been demonstrated to be superior to others in burn patients. Anesthetic procedures have to be individualized based on the needs of the patient and the experience of the anesthesiologist. Before induction of anesthesia, a large-bore i.v. line should be in place to enable rapid volume replacement; a second line should be established after induction. Unburned sites are preferred for venous and arterial catheters. If problems with rapid venous access occur, an intraosseous infusion is a particularly valuable tool [30]. Central venous catheters (CVC) are helpful for intensive care purposes, but have too small a diameter for rapid volume replacement.

If access sites through unburned tissue are scarce, CVC access through burned tissue should be used first because of the inevitable secondary burn-wound colonization: these sites may cause additional infectious problems if they have to be used subsequently. With increased skill and experience, newer materials, and better care, reports of serious infectious or embolic complications are not frequent [23, 66]. Indications for arterial catheters should be liberal, utilizing the usual sites based on the skill of the operator as well as the patient's situation [12]. In experienced hands and with proper care, the infection rate is low [25]; even prolonged use of the femoral arteries seems to be safe [68]. In selected cases we have left femoral arterial catheters in place for more than 30 days without any unfavorable effects.

During the first 1–2 weeks after a severe burn injury patients may be quite sensitive to any anesthetic agent, showing unpredictable cardiovascular instability. Unrecog-

Table 2 IV dosages of frequently used analgesics [32]

Tramadol	0.5–1.0 mg/kg ^a
Pentazocine	1.0 mg/kg
Morphine	0.1–0.3 mg/kg · h
Fentanyl	2–10 µg/kg · h
Ketamine	2–5 mg/kg · h
Methadone	0.1–0.15 mg/kg ^a

^a Bolus

nized hypovolemia may be responsible for additional circulatory problems.

I.v. induction techniques with thiopental, ketamine, or propofol have all been successfully applied [8, 17, 47]. While ketamine may be used even in unstable patients, thiopental and propofol should be used with extreme care, i.e., careful titration to effect. The high lipid content of propofol limits its use during initial resuscitation [8] and in septic patients [29]. For minor procedures, ketamine or propofol as single agents are useful [20, 48, 56], since adequate spontaneous respiration is preserved in most cases. In our own practice, we have found the combination of propofol and ketamine extremely valuable.

Induction by inhalation is frequently used, but care must be taken not to create additional problems for the airway and circulation [70].

Maintenance may be accomplished using nitrous oxide and a muscle relaxant in combination with appropriate doses of opioids, which may be significantly higher than expected, especially after prolonged intensive care with the necessity for analgosedation. Low-dose inhalational agents in combination with opioids may also be used safely. Even repeated exposures to halothane do not seem to cause problems like halothane hepatitis in this age group [14]. The OR should be adequately prewarmed to prevent hypothermia and additional heat loss through the traumatized skin. Evaporation losses of extracellular fluids have to be taken into account.

Monitoring should include a precordial/esophageal stethoscope, serial BP measurements, pulse rate (and quality), EKG leads, pulse oximetry, and end-tidal CO₂. If perfusion of the fingers and/or toes is poor the tongue or the buccal mucosa may be suitable alternative sites [17, 57]. The surgeon should outline the planned procedure and estimated blood loss to allow preparation of an appropriate amount of blood products. Tangential burn-wound excision will produce a higher blood loss than fascial excision; an infected wound will bleed more intensely than a non-infected site. Since blood loss can not be reliably assessed clinically during surgical procedures (for estimates see Table 1), frequent measurements of hemoglobin and Hct are necessary. Being a sensitive parameter of adequate perfusion, urinary output has to be monitored continuously.

Management of pain associated with severe burn injury

Pain sensations associated with a serious burn injury may start within 5 min of trauma or may be delayed for several

hours because of endogenous analgesia [10]. Pain will be a constant, potentially horrible companion for the child until wound healing is completed. Due to the need for repeated painful procedures, undertreatment of pain aggravates anxiety. Anxiety, pain, and depression then coexist, resulting in a vicious cycle where pain perception is magnified by fear and anxiety. In some patients severe behavioral changes are seen, e.g., "learned helplessness" as a form of major depression or stress-induced-analgesia (SIA) (passivity and withdrawal despite appropriate analgesia) [38]. This absence of normal patterns of pain behavior may lead to the erroneous conclusion that pain therapy is sufficient [52].

Pain assessment in burn care units requires frequently repeated assessment of the current pain score, quality, and location of pain. The visual analog score has been shown to be a reliable and valid measure of self-reported pain [9, 58]. For younger children or those with lower developmental levels, behavioral observation seems to be more practical (crying, eating, sleep disturbance, etc.).

Background pain

Pain-generating mechanisms include nociception, hyperalgesia, and neuropathy. Burn-related pain is very often severe but inconstant, and frequently underestimated by caregivers [58, 62]. Usually there is background pain, its intensity depending mainly on the extent of the burn injury, the extent of third-degree burns, physical stimulation, infection, previous painful experiences, and anxiety [2, 45]. Third-degree burn tissue is insensate and dead, but is always surrounded by regenerating areas from which pain may arise, and even full-thickness burns are often intermixed with partial-thickness areas in which sensation is intact [45, 62]. After escharotomy nerve fibers in the underlying tissue become sensitive, and with progressing wound healing, regeneration of peripheral nerve fibers causes paresthesias and pain. This mechanism may explain the occasional observation of opioid-resistant pain associated with intense burns, resembling more neuropathic than trauma pain. Opioid resistance is a well-recognized feature of neuropathic pain [11, 44, 50].

Procedure-related pain

Pain related to burn-dressing changes, skin grafts, or other interventions is more intense than background pain [2, 63]. Children often describe the repeated procedures as more distressing than any other aspects of burn disease or treatment. It has been shown that most patients suffer severe pain during procedures, even with opioid medication [63]. Children are four times more likely to receive little or no analgesia during procedures compared to adults [50, 62]. One reason may be underestimation of pain and/or overestimation of pain relief by drugs through care providers due to an internal conflict in the care provider, who is concomitantly the "pain inflictor" and the "pain reliever" [11, 63].

Treatment of background pain

Initial therapy includes (preferably regional) cooling of the burn wound and providing sufficient pain relief in minor burn injuries only. Unfortunately, a number of primary-care providers are unable to rapidly establish an i.v. line in young children. Therefore, primary analgesia is often started insufficiently with rectal doses of acetaminophen and chloral hydrate. Small, incremental i.v. doses of analgesic drugs carefully titrated to the patient's need while preserving cardiovascular and respiratory stability seem to have the best effect for initial pain relief. Aspirin should be avoided due to its side effects. Anxiety and background pain relief may be augmented with psychotropic drugs (e.g., benzodiazepines, chloral hydrate, levomepromazine) [32, 58].

For continuing background pain, the administration of opioid agonist-antagonists or agonists is necessary in most cases. Ketamine is a suitable alternative. Anxiolysis or hypnosis is achieved with benzodiazepines, barbiturates, or propofol, the i.v. route being preferred. Morphine is still the most widely used substance. Unusually high dosages are often necessary because of altered pharmacokinetics [26, 58, 59]. The pharmacokinetics of fentanyl in burn patients are not known [1]. For long-term pain relief, orally given methadone and sustained-release morphine formulas are proven remedies. As adjuncts, non-steroidal anti-inflammatory drugs should be used, taking into account the somewhat neuropathic character of pain caused by wound healing. With specialized nonpharmacologic treatment, patients may have sufficient relief with nonnarcotic analgesics and/or reduced narcotics [27, 38, 52]. Even successful treatment without opioids is possible [24].

Long-term opioid administration produces tolerance in most patients, especially if invasive procedures are frequently managed with high-dose opioid analgesia/anesthesia [58]. The observation that a combination of morphine and low-dose clonidine infusions seems to be beneficial in these cases is consistent with our own experience [43].

Regional anesthesia should always be considered for burn trauma limited to an extremity or for surgery during the reconstructive phase. The use of continuous regional anesthetic techniques may be limited by coagulopathy, cardiorespiratory instability, hypovolemia, sepsis, and an increased potential for infection in many cases.

Various topically applied substances have proven to have insufficient effects if used alone (ketorolac, glucocorticoid, EMLA) [55, 60, 61].

If analgesic medication is prescribed on an "as-needed" basis, frequent self-assessment of the patient or assessment by a family-member or nurse is mandatory to detect the need for analgesia immediately and take proper measures for treatment of even low-level pain. I.v. patient-controlled analgesia protocols have been successfully established with morphine, fentanyl, and piritramid.

Treatment of procedure-related pain

Besides well-described interindividual variability in opioid requirements, there may even be a difference from procedure to procedure in every individual [2]. Depending on the anticipated stress, sedatives may be added. Non-pharmacologic methods should also be utilized. A treatment strategy that allows the child as much control as possible over the procedure seems to have a strong analgesic effect (e.g., let the child help with a dressing change, giving him as much choice as possible and even the right to a "time-out") [38]. Parent participation during painful procedures has no proven advantages, but should be considered as an option [21]. In general, opioid analgesics can be used liberally. Since in some cases opioids alone fail to provide adequate pain relief, procedures are carried out with the child under general anesthesia despite the potentially higher risk of aspiration and the necessity for withholding food prior to surgery. On the other hand, general anesthesia for debridement may result in fewer operations due to improved efficacy [2, 58, 64].

Ketamine in combination with a benzodiazepine or propofol to reduce the adverse psychodynamic effects may be used in analgesic and anesthetic dosages depending on the desired effect. Only health personnel with some expertise in airway management should administer ketamine in anesthetic dosages [1]. There is no "one-fits-all" protocol for adequate analgesic treatment. Assessment of each individual and constant observation allows highly individualized pain treatment. Each burn unit should have a standardized protocol with only a few drugs well-known to the entire staff to reduce the likelihood of untoward events. Patients will be grateful for adequate pain relief and psychological and social rehabilitation will be enhanced.

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