INTRODUCTION

“A humane, friendly, gentle, and encouraging approach is essential in dealing with a burned child... The burns of today are the suffering of tomorrow and the scars of a lifetime” (Gordon Bush, Paediatric Anaesthetist, 1973). Burns are a common cause of injury in children, who may subsequently require a number of operative procedures. Children are at higher risk of burns than adults due to thinner skin, slower reaction times, and less awareness about dangers in their environment. The focus of this article is the involvement of anaesthetists in management of paediatric burns patients.

The anaesthetist plays a crucial role in the management of the paediatric patient with burns. Indeed, the anaesthetist will be involved in the provision of analgesia, sedation, and anaesthesia to the patient at multiple stages. In the initial assessment of the child’s burn, appropriate first aid, resuscitation and consideration of need for referral to a paediatric burns unit should be made. A child should be considered for transfer to a burns centre with more than 5% deep burn, burn to special areas (hands, face, feet, and perineum), respiratory burn, associated with major trauma or pre-existing illnesses.

AIRWAY

Airway management of paediatric burns patients is a very specialized area in anaesthesia. A senior anaesthetist should always be involved in the clinical decision-making regarding airway management for this patient population, especially if the burn injury involved the head/neck and/or inhalational injury. A senior anaesthetist should perform the airway assessment, particularly in cases of burns involving the head/neck or accompanying inhalational injury. The airway assessment should be conducted early, as there is a high risk of complete airway obstruction due to swelling of the soft tissues of the neck.

Inhalational injury may be suspected in patients who were burned in an enclosed space, received facial burns, or lost consciousness at the time of the injury [1]. Inhalational injury has a significant impact on survival. It may comprise upper/lower airway oedema, inflammation, epithelial sloughing, increased mucus production, atelectasis, respiratory failure, obstruction, and carbon monoxide intoxication. It’s variable presentation, especially in the paediatric population, may lead to delayed diagnosis and management.

It is important to identify paediatric patients who may require definitive airway management early, as securing the airway becomes increasingly challenging with the development of oedema. In terms of identifying children with airway compromise, the anaesthetist should assess for the following signs: signed nasal hairs, productive ‘brassy’ cough, stridor, hoarseness of voice, black ‘soot’ sputum, respiratory distress, irritability, and facial swelling [2].

The Royal Children’s Hospital in Melbourne, Australia, offers clinical practice guidelines for the management of paediatric burns patients [3]. The guidelines recommend consideration of definitive airway management in any child with oropharyngeal burns and/or significant neck burns, even if the airway is not yet compromised.

If there is any clinical suspicion of airway burns, consider application of high flow oxygen via a non-rebreather mask (up to 15L/min). Maintenance of full spinal precautions may be indicated, especially in trauma patients. The decision to incubate a paediatric burns patient should always be discussed with a senior anaesthetist and all necessary precautions should be taken, including the immediate available of the difficult airway trolley.

There may be a need for definitive control of the airway in children requiring transfer to a tertiary referral centre. The Australia and New Zealand Burns Association (ANZBA) offers guidelines regarding the initial management of minor/severe burns [4]. In children with burns involving more than 10% of
There are several important concerns regarding the use of an endotracheal tube (ETT) in the airway management of paediatric burns. The ETT size is an important consideration. ETT size is usually calculated by age/4 + 4 mm internal diameter (ID) in paediatric anaesthesia. ETTS of the size calculated using this formula plus ETT 0.5mm ID smaller and 0.5mm ID larger should be immediately available when planning to secure the airway of a paediatric burns patient. For example, in a 4-year-old, a 5mm ID ETT (4/4 +4mm ID) should be available, as well as a 4.5mm ID and 5.5mm ID ETT. Depending on the nature of the burn, the anaesthetist may expect to use the smaller ETT due to significant airway oedema.

Traditionally, un-cuffed ETTS are used in children under 8-10 years, since the narrowest part of the paediatric airway is the cricoid. Cuffed ETTS are generally reserved for children with special indications or a large air leak. In children with a burns injury with potential airway oedema, an un-cuffed ETT is generally used. Once the airway oedema resolves or a significant air leak develops, the ETT may be exchanged for a larger ETT or even a cuffed ETT, although this will depend on the clinical situation and the preference of the treating anaesthetist. Cuff pressure should always be monitored.

**CIRCULATION**

The burn causes increased permeability of tissue capillaries and widespread oedema as a result of local thermal injury and generalized activation of the systemic inflammatory response. In terms of circulation, children require fluid resuscitation if the burn area is greater than 10% TBSA. Paediatric TBSA estimation charts should be used, which take into account the proportionally larger head in relation to body of children compared to adults. The Parkland formula of 3-4ml/kg/TBSA can then calculate fluid requirements for resuscitation, giving half this volume in the first 8 hours post-burn, then the remainder over the next 16 hours. Importantly, maintenance fluids for children must also be added and the resuscitation fluid volume and the response to this fluid should be monitored to adjust rates if necessary.

A patient should only be taken to theatre when appropriately fluid resuscitated. Wound debridement involves significant blood loss and there should be adequate availability of red cells and clotting factors. It has been estimated that for every 1% body surface area debrided, 3-4% of circulating blood volume may be lost. Due to loss of the natural skin barriers and extensive patient exposure, children are at risk of hypothermia; which has undesirable effects on coagulation and cardiorespiratory function. It is therefore important that the theatre environment is athermoneutral (approximately 30°C).

Burns patients are in a hypermetabolic state and particularly in children, with their higher metabolic rate and nutritional needs for growth, feeding should be established early with a nasogastric tube if required. Feeding is important to prevent loss of gut function, reduce risk of bacterial translocation across the gut wall and maintain good nutrition with high protein diet to improve chances of skin healing.

**MANAGEMENT OF THE BURN**

The burn may progress in initial days and the true depth may not be immediately obvious.

- **Superficial burns** are limited to erythema of the epidermis. These usually heal within 5 days and are not included in estimation of TBSA burnt for fluid resuscitation.
- **Partial thickness burns** involve the dermis, resulting in blistering of the skin. If adequate dermis remains, these may heal and re-epithelialise. Dressings may be continued for approximately 10 days to allow as much of the burn to heal and then skin graft if still unhealed at this time.
- **Full thickness burns** indicate the dermis has been destroyed. This burn is well-demarcated, insensitive, initially dark red and then progress to dull yellow over days. These will only heal with skin grafting and early excision of this non-viable skin reduces morbidity, mortality and the inflammatory response.

**PAIN**

Pain associated with burns is multi-dimensional, including “background” pain, “incident” pain (associated with such things as moving and coughing), and “procedural-related” pain. Children with burns will often have repeated exposure to multiple, often prolonged, procedures (such as dressing changes) [5].

The underlying pain pathology is commonly nociceptive as well as neuropathic in origin, particularly if there is direct involvement of nerves. Pathophysiological mechanisms, such as primary and secondary hyperalgesia, may result in a heightened experience of pain and a considerable number of children may go on to develop persistent pain [6].

Analgesia is a priority in treating children with burns. The anaesthetist has an important role in term of treating initial pain, “background” pain, and procedural-related pain, using multi-modal analgesia.

**INITIAL ANALGESIA**

There is a need for immediate and effective analgesia, with the route and the choice of analgesia determined by the condition of the child and the nature of their burn. In the child presenting with burns, opioid analgesia is generally the mainstay of treatment. A rapid option for pain relief is intranasal fentanyl (loading dose, 1.5mcg/kg to a maximum of 3mcg/kg). Intranasal fentanyl is generally reserved for children aged 1 year or older, in moderate to severe pain. Information regarding dosing schedule and administration technique can be found online in the Royal Children’s Hospital Melbourne clinical practice guidelines for intranasal fentanyl (RCHM, CPG, Intranasal Fentanyl) [3].

Intravenous opioids may also be required for severe pain, such as intravenous morphine (0.1mg/kg) titrated to comfort while closely observing for sedation. Concerns regarding delayed gastric emptying, which may occur after severe burns, may limit the use of oral opioids for analgesia in this setting. Regional
anaesthetic techniques may be limited by the site of the burn, concerns regarding local +/- systemic infection, and the length of time over which good pain relief will be required. The treating team may also employ simple non-pharmacological measures to provide analgesia. Indeed, measures such as cooling, covering, and immobilizing the site of the burn may provide children with some pain relief.

The child's emotional response to injury may alter their experience of pain. A bio-psychosocial management plan must not be overlooked, especially in the paediatric population where there is a role for play therapy and distraction therapy without increasing the risk of serious side effects. Such therapies should be used as often as possible to enhance the child's overall experience.

"BACKGROUND" ANALGESIA

Paediatric patients may experience "background" pain related to the burn, especially with movement. In general, paracetamol may be given if there are no contraindications. Paracetamol may be administered orally or intravenously with a loading dose of 20mg/kg (maximum 1g) and continued dosing of 15mg/kg (maximum 1g) given 6 hourly.

Non-Steroidal Anti-Inflammatory Drugs (NSAIDs) may not be appropriate in the early stages, in part due to the risk of renal complications, especially in the setting of probable hypovolaemia. In addition, NSAIDs pose the risk of increased bleeding, which may not be appropriate if the child is being considered for surgery. COX-2 selective NSAIDs, however, may be a suitable alternative because of their improved side-effect profile. NSAIDs should be avoided in children less than six months old.

Background pain is due in part to its nociceptive and neuropathic components. Indeed, burns result in damage to cutaneous nociceptors as well as conducting neurons, potentially leading to acute neuropathic pain. Repeated procedures, dressing changes, and surgery may also contribute to the development of neuropathic pain. Accordingly, there is growing evidence to support the addition of anti-neuropathic agents in the multimodal treatment of pain in paediatric burns.

Gabapentinoids (for example, Gabapentin) have been shown to cause less surface pain, itch, and procedural pain and improved "background" pain [7]. They are increasingly being used as adjunts in the management of pain in paediatric patients with burns. Indeed, Gabapentin has been shown to be effective in pain relief in paediatric patients with burns [8,9].

PROCEDURAL-RELATED ANALGESIA

Acute pain related to burns may be exacerbated by procedures, including dressing changes and bathing. Procedure-related pain is managed with analgesia +/- sedation, where appropriate. Sedation should be avoided in children with potential airway compromise.

Again, opioids are an important component of analgesia. If the child is suitable for patient-controlled analgesia (PCA) for dressing changes on the ward, an opioid with a faster onset of action (such as fentanyl or alfentanil) may be used [10]. Following the administration of intravenous opioids for the procedure, the child should be closely observed, since sedation and/or respiratory depression may follow the sudden decrease in the painful stimulus. This is more likely if other sedatives (including benzodiazepines) have been given.

Intranasal fentanyl may be administered if there is no vascular access, since the rate of onset is almost as quick. Ketamine, given as a low-dose infusion or intermittent bolus, is frequently used as an adjuct in dressing changes and other procedures related to burns. Ketamine has been shown to improve pain relief and reduce hyperalgesia as well as neuropathic pain [11].

Nitrous oxide may be used for analgesia during dressing changes and may be very effective in selected paediatric patients, but care should be taken to minimize toxicity, in particular with repeated use over longer periods. At large, general anesthesia is reserved for special circumstances, including severe burns and/or inadequate attempts to perform procedures with analgesia/sedation only.

In preparing the paediatric patient for surgery, Eutectic Mixture of Local Anaesthetic (EMLA) may be applied to donor skin site to intact skin under an occlusive dressing, however application to the burn is absolutely contraindicated. EMLA is composed of 2.5% Lignocaine (25mg/g of EMLA) and 2.5% Prilocaine (25mg/g of EMLA). The onset of EMLA is 45-60 minutes and its duration of action is 1-2 hours following removal. EMLA should be avoided in paediatric patients with methaemoglobinemia due to the rapid metabolism of prilocaine into O-toluidine, which is capable of converting haemoglobin into methaemoglobin. Local anaesthetic infiltration with Lignocaine and/or Bupivacaine is frequently used in the donor skin site under general anaesthetic.

INDUCTION AND MAINTENANCE

General anesthesia may be indicated in children with burns, including those intolerant of procedures (as discussed above) and those with potential airway compromise. Induction of general anesthesia may be achieved via intravenous and/or inhalational agents. Indeed, the chosen technique will depend on a number of patient factors and anaesthetic factors. Patient factors may include the child's age, co-morbidities, and fasting status. Anaesthetic factors may include airway concerns +/- urgency to secure the airway, intravenous access, and choice of drugs. In the acute setting, ketamine is the intravenous induction agent of choice in paediatric burns (1-2mg/kg IV induction dose), particularly in cases of hypovolaemia and/or haemodynamic compromise.

Maintenance of general anesthesia may be via volatile anaesthetic agents. Of the volatile anaesthetic agents, Desflurane is most commonly used in children with burns because of its low oil gas partition coefficient and it's fast wash-out so that the child can return to activities without delay, such as feeding. Total intravenous anesthesia (TIVA) may also be an option; however this will depend on the treating anaesthetist.

A detailed discussion regarding airway management in children with burns is beyond the scope of this article; however it is important to highlight key points. In the event of intubation, the airway should be secured with an appropriately sized endotracheal tube (as previously discussed). Endotracheal tubes...
may be placed either orally or nasally. In children with head/neck burns or possible inhalational injury requiring definitive airway management, it may be useful to consider gaseous induction with maintenance of spontaneous ventilation or even an awake fibreoptic intubation, although this may not be possible in an uncooperative/combative child.

In the case of a potentially difficult airway, ensure that any additional equipment, including the difficult airway trolley, is immediately available. In the rare event of sudden upper airway obstruction, it may be necessary to perform a needle or surgical cricothyroidotomy. In this circumstance, the presence of a surgical colleague (especially an Ear Nose Throat surgeon) will be extremely valuable.

**NEUROMUSCULAR BLOCKADE**

Burns influence the disposition of neuromuscular blocking drugs, especially non-depolarising muscle relaxants, which act via competitive antagonism of acetylcholine at the postsynaptic nicotinic acetylcholine receptor (nACh receptor) at the neuromuscular junction. An increase in the number of nACh receptors may cause resistance to non-depolarising neuromuscular blocking drugs, including both amino-steroid compounds and benzyl-iso-quinolinium compounds. This is more common in patients with burns >30% TBSA. Indeed, resistance to non-depolarising neuromuscular blocking drugs may be seen up to 3 months following the burns injury. Burns injury may also result in decreased plasma cholinesterase activity leading to reduced metabolism, and thus prolonged duration of action, of some muscle-relaxants.

Burns result in proliferation of extra-junction ACh receptors, which predisposes the paediatric patient to transient, potentially fatal, hyperkalaemia following the administration of Suxamethonium. Suxamethonium is a depolarizing neuromuscular blocking drug, which acts by binding to the alpha subunit of the nACh receptor at the neuromuscular junction leading to sustained depolarization of the post-junctional membrane. In general, Suxamethonium is safe to use, if indicated, in the first 12 hours following the burn. However, it should be avoided more than 12 hours following the burns injury for up to 12 months. The transient rise in potassium may be 3-5mmol/L or more [12].

**INTRA-OPERATIVE MONITORING**

Electrodes for electrocardiography may be placed on the anterior chest wall or away (e.g. posterior chest wall), if it is involved in the burn. Oximetry is of utmost importance. Place the oximeter on the same limb as the intravenous cannula and cover it with a plastic bag/seal to protect it from washing with debridement. Ear probes for pulse oximetry can be used. Hypoxia, carbon monoxide poisoning and cyanide toxicity may interfere with infrared analysis used impulse oximetry.

Non-invasive blood pressure measurement may be appropriate, however this must be placed where it will not interfere with the surgery and it may be necessary to change its position as surgery progresses. Invasive blood pressure monitoring may be required depending on the extent of the burns. Other end-points of intra-operative monitoring include temperature monitoring and urine output (aiming >1.5ml/kg/min) in the child with burns.

Temperature homeostasis is of utmost importance. Monitoring is essential, however it may be challenging due to a lack of sites for temperature probes depending on the extent of the injury. Anoropharyngeal temperature probe may be used in certain circumstances, with close attention to delicate skin and pressure sores. Urinary catheterization is an invaluable tool, enabling assessment of fluid balance as well as opportunistic temperature monitoring.

Oftentimes, significant exposure of the child demands active warming, including raising the ambient temperature of the operating theatre, application of a heated mattress or forced air warmer, and covering exposed areas where possible.

**ANTIBIOTIC THERAPY**

Wound infection is a major cause of morbidity and mortality in children following burns injury. This is mostly due to gram-negative bacterial colonization, despite aseptic techniques used to clean/dress the wound. Antibiotics should not be used prophylactically unless grafting is being carried out. Silver-based dressings may be used because of their broad-spectrum antimicrobial activity.

Infection can occur to the burn wound itself, donor site, or associated with invasive vascular lines or catheters. Toxie shock is a rare but serious complication seen mostly in children [13]. It is caused by overwhelming infection by toxin producing bacteria, usually staphylococcus aureus. It is often difficult to diagnose and typically presents within 2 days of the burn, in a child <2 years old with a burn <10% TBSA. Features include, pyrexia >39 degrees, leucopenia, diarrhea and / or vomiting and irritability. Treatment includes immediate hospitalization, fluid resuscitation and intravenous antibiotics.

**CONCLUSION**

Greater public awareness of risks to children and government legislation to prevent burns will hopefully see a decrease in these cases. Surgical techniques continue to be refined to optimize healing and recovery from even large burns. The successful management of children with burns requires multidisciplinary team of surgeons, anesthetists, nursing and allied health staff to support the child and their family.

**REFERENCES**


