Update in Anaesthesia

Trauma in children

Paediatric burns and associated injuries

Reprinted with revisions from Pittaway AJ. Managing Paediatric Burns. *Anaesthesia Tutorial of the Week* 78 (2007)

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Summary

Despite the temptation to immediately attend to the burn, it is vital to remember the ABCDE approach to a victim of trauma. Severely burnt children may well have other major injuries not obviously apparent.

CASE SCENARIO

A 5-year-old boy is brought to your hospital at midnight from a housefire. He had been rescued from his upstairs bedroom by a neighbour who had subsequently jumped to the ground with him. His rescuer, who suffered a fractured ankle, tells you that when he found him in his smoke-filled room, he was 'deeply asleep' and his sheets were smouldering.

On examination he is sleepy but rouseable, and cries when disturbed. His pyjamas are charred across the chest and left arm. His respiratory rate is 25 breaths per minute, pulse is 130 beats per minute, blood pressure is 75/40, and capillary refill time is 4 seconds. A pulse oximeter reads 99%. You notice soot around his nostrils.

EPIDEMIOLOGY

Cutaneous burns, or thermal injury, can be conveniently divided into scalds and flame burns. Flame burns are frequently associated with flammable liquids spilt onto clothing. Scalds are burns specifically caused by contact with hot liquids. They also often involve clothing, which prolongs the duration of harmful contact between hot liquid and skin. The World Health Organization (WHO) estimates there are 265,000 deaths per year worldwide attributed to burns, with greater than 95% occurring in low and middle-income countries (LMIC). Most fatalities occur in house fires, where death by smoke inhalation is the usual cause.

Burns are the 5th most common cause of non-fatal childhood injury, and the 11th leading cause of death in children aged 1-9, with comparable incidence between males and females. Children are particularly prone to burns due to the inability to recognise danger in the younger age groups and the risk taking behaviours of the older child. As well, children have thinner skin, lose proportionately more fluid, are more prone to hypothermia and mount a greater Systemic Inflammatory Response than adults. Through prevention mechanisms and better treatment modalities, high-income countries have made significant advancements in lowering the rate of paediatric deaths due to burns. The same is not true for LMIC children, where prevention and treatment advances have been incompletely applied, and where mortality from burns remains more than 7 times higher.

Mortality following a burn occurs as a bimodal distribution. Early deaths occur due to airway obstruction (eg smoke inhalation and associated oedema), carbon monoxide poisoning, refractory shock or co-existing trauma. With good resuscitation techniques, this early mortality can be reduced to 5%. Late mortality often occurs as a result of wound sepsis and multi-organ failure. A coordinated multidisciplinary approach to patient care can also reduce this late mortality.

PATHOPHYSIOLOGY

Two factors determine the severity of a burn – its temperature and the duration of contact with it. Cell death occurs exponentially quickly as temperature rises. Temperatures as low as 40 degrees centigrade can rapidly inflict significant injury in young children.

Scalds caused by water below its boiling point in brief contact (the majority of such injuries) are not surprisingly less severe than scalds caused by liquids e.g. cooking oil at higher temperature, or liquids which are in skin contact for a longer time. Infants or those children physically unable to move themselves away from the burning agent are susceptible to this latter mechanism.

Flame burns have a higher temperature and cause the most severe injuries. Histologically, the burnt skin consists of a central coagulated, necrotic area surrounded by zones of venous stasis and hyperaemia. The capillary leakage that occurs in these outer two areas is the result of both direct heating and secondary inflammation. Burnt epidermis permits large evaporative fluid losses of up to $200 ml.m^{-2}.h^{-1}$. These and other fluid losses cause hypoalbuminaemia and the clinical picture of shock. Nevertheless, in the first hour after a burn, the commonest cause of death is smoke inhalation. The burning contents of enclosed rooms contain a lethal mixture of hot, noxious gases, soot particles and depleted oxygen level.

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EARLY MANAGEMENT OF SIGNIFICANT BURNS

Despite the temptation to immediately attend to the burn, it is vital to remember the ABCDE approach to a victim of trauma. Severely burnt children may well have other major injuries not obviously apparent, either as a result of an associated blast injury or in their efforts to escape the fire e.g. by jumping from a window.

Airway and inhalational injury

The airway, as well as breathing and circulatory systems should be rapidly assessed whilst you administer high-flow oxygen and establishing monitoring. You may need to immobilise the cervical spine with collar, sandbags and tape or manual inline stabilisation (with an assistant). Obtain further history. The patient's airway may be affected either by inhalational injury (which if present increases mortality by up to 50%) or by thermal injury to the face. Whilst the latter is usually obvious, indicators of the former may be more subtle. Environmental factors that can contribute to inhalational injury include fire in an enclosed space or fire associated with explosion. Loss of consciousness is also associated with inhalational injury. The following features on examination also point to an inhalational injury:

- Soot around the nose/mouth/in sputum, burning of eyelash/brow & nasal hairs
- Drooling, dysphonia or dysphagia, stridor.

Approximately 60% of flame facial burns will have an associated smoke inhalational injury. Inhalation of hot dry gases tends to cause supraglottic injury to the lungs, whereas steam inhalation also results in deeper, parenchymal injury. The shockwave from a blast can cause a mixture of chest injuries: barotrauma and contusion to the lung and blunt trauma. Any suspicion that an inhalational injury has occurred should make you consider immediate, elective intubation. Airway oedema can develop very quickly and make later attempts at securing the airway extremely difficult.

There are several considerations about endotracheal intubation that are particular to burns patients:

- Expect to use a smaller endotracheal tube than calculated due to airway oedema
- Do not cut the endotracheal tube, as facial swelling can be dramatic and 'bury' the end of an inappropriately short tube somewhere within the mouth
- The tube should also be inserted sufficiently far that the distal end is not 'drawn' out of the trachea by the effects of proximal mucosal oedema
- A tracheostomy might not be feasible for a prolonged period if the tissues of the neck are injured, but may help prevent long-term complications such as tracheomalacia and subglottic stenosis if done earlier during hospital stay
- It is useful to site a nasogastric tube at the same time to allow gastric decompression and early feeding, which is important in any burn affecting >10% body surface area.

Breathing

Tachypnoea, hypoxaemia, and eventual cyanosis suggest a lung parenchymal thermal injury, which will almost certainly require ventilatory support. Invasive arterial monitoring, if available, prevents the need for repeated blood sampling and provides important metabolic, respiratory and haemodynamic information. An Acute Respiratory Distress Syndrome frequently supervenes which requires specialist critical care, including protective ventilation strategies, regular bronchoalveolar lavage, and timely tracheostomy insertion if required. Circumferential burns to the chest (or abdomen in infants) can restrict chest wall excursion and require urgent excision – escharotomy. This procedure is not without difficulties; the potential for severe blood loss, hypothermia, and difficult positioning are all significant considerations.

Carbon monoxide poisoning

Fire produces carbon monoxide (CO) when organic chemicals burn in low oxygen environments. Inhaled CO combines with haemoglobin with 200 times the affinity of oxygen

to form carboxyhaemoglobin. Thus, less oxygen is delivered to the tissues. Pulse oximeters cannot distinguish oxyhaemoglobin from carboxyhaemoglobin, giving erroneously high (or falsely 'normal') readings. If possible, carboxyhaemoglobin level should be measured (some blood gas analysers do this) and if between 5-20%, the child should remain on high-flow oxygen, which speeds the dissociation of carboxyhaemoglobin.

Metabolic acidosis and coma are associated with levels >20%. Whilst hyperbaric oxygen therapy is the treatment of choice where available, use intubation and 100% oxygen where it is not to treat carboxyhaemoglobin levels over 20%.

Other poisons e.g. cyanide can sometimes accompany the incomplete combustion of common household plastics. Cyanide poisoning presents as metabolic acidosis, coma and unusually high venous oxygen saturation (cyanide prevents cells from using oxygen).

Circulation

Hypovolaemic shock occurring in the first few hours after a significant burn must be assumed to be due to another injury, which must be sought. Obtain the largest venous access possible, preferably in two unaffected sites. Burnt skin can be cannulated if necessary, although the skin creases over the femoral vessels are often spared. Finding unaffected sites for non-invasive monitoring can be problematic; non-invasive blood pressure measurement may be difficult with extensive limb burns and non-adhesive ECG electrodes can be stapled directly to burnt skin. Urine output measurement, ideally via urinary catheter is essential to monitor haemodynamic status and guide ongoing fluid resuscitation in the shocked burnt victim. Send initial blood samples should be sent for complete blood count, electrolytes, glucose and cross-match. Haematocrit rises initially as a result of plasma loss but anaemia may then follow due to haemolysis, recurring surgical blood loss and sepsis-induced marrow suppression. A significant catabolism develops; early excision and skin cover of the burn can reduce this hypermetabolic state, although protracted protein loss can occur up to a year after burn injury.

Fluid calculation

Shocked children should initially be managed as would any shocked child: warmed IV saline 0.9% boluses of $20ml.kg^{-1}$. Non-shocked children with burns of greater than 10% will require IV fluid resuscitation, which can be calculated according to total body surface area (TBSA) burnt, with the following (Parkland) formula:

% TBSA x weight in kg x 4 ml

TBSA involvement can be calculated in adolescents using the 'rule of nines' (Figure 1A), and can be calculated with Lund-Browder modification in infants and children (Figure 1B). Give half of this volume over the first 8 hours since the burn occurred and the rest over the next 16 hours; this is in addition to the normal daily fluid requirements of the child. The type of fluid used is generally a crystalloid such as compound sodium lactate (Hartmanns) or 0.9% saline. Colloid has not been shown to confer any additional benefit in the early stages of burn management.

There are criticisms of the Parkland formula, especially with the extremes of injury, in which the Parkland formula tends to underestimate fluid resuscitative needs with large

TBSA burns, and overestimate resuscitative needs with small TBSA involvement. Other formulae exist that can assist in guiding fluid resuscitation, which can alternatively be used, especially in these extremes of injury. These formulae are guides only, for you to use in conjunction with regular clinical assessment and measurement of urine output, which should be maintained at >2ml.kg^{-1}.hour^{-1} in children. Of note, significant over-resuscitation with fluids can result in abdominal or extremity compartment syndrome or severe pulmonary insult causing worsening gas exchange.

There has been renewed interest in resuscitation using oral rehydration, and while this may be appropriate for minor burns <10-15%, you must be cautious in the patient with more extensive burns due to the high incidence of ileus.

(A) Rule of 'nines'

(B) Lund-Browder diagram for estimating extent of burns

Adapted from U.S. Department of Health and Human Services [Public domain] (http://www.remm.nlm.gov/burns.htm)

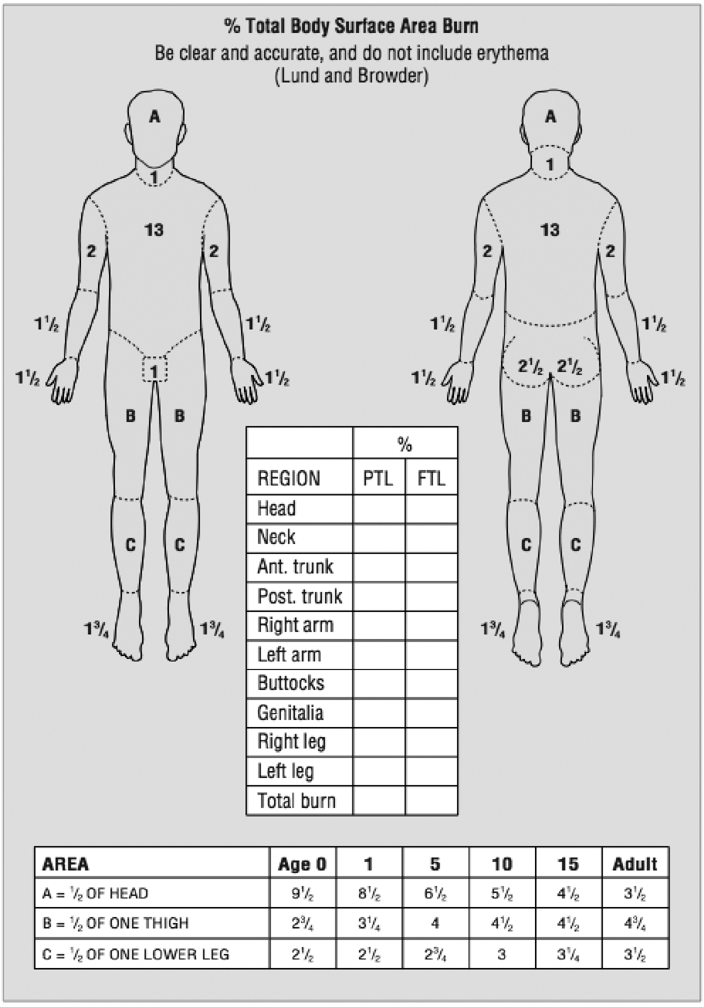
Neurological Assessment

A rapid assessment of conscious state is part of the trauma primary survey. Reduced conscious state could have many causes such as head injury, hypoxaemia, inhalation of toxins, shock or pre-existing disease states (e.g. diabetes).

Exposure and secondary survey

It is important to fully undress the child to estimate the full extent of the burn, but once done ensure the child is covered again as rapid heat loss occurs. Warm the room if necessary. If taking the child to the operating room, the temperature should be raised, aiming for a warm "thermoneutral" environment. This reduces the patient's energy expenditure as well as helping to prevent hypothermia.

Although beyond the remit of this article, it is important to think of significantly burnt children as trauma victims and conduct a thorough head to toe examination once the initial stabilisation has been completed.



REGION	% PTL	% FTL
Head		
Neck		
Ant. trunk		
Post. trunk		
Right arm		
Left arm		
Buttocks		
Genitalia		
Right leg		
Left leg		
Total burn		

AREA	Age 0	1	5	10	15	Adult
A = ½ OF HEAD	9½	8½	6½	5½	4½	3½
B = ½ OF ONE THIGH	2¾	3¼	4	4½	4½	4¾
C = ½ OF ONE LOWER LEG	2½	2½	2¾	3	3¼	3½

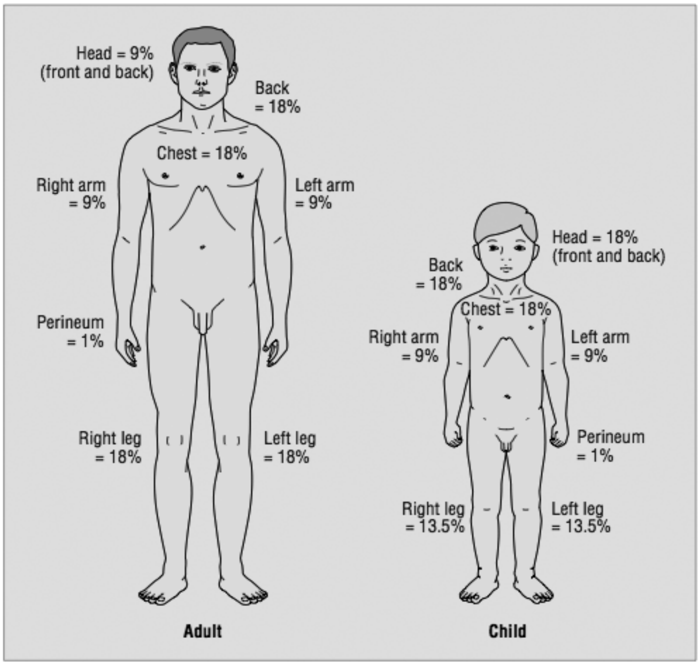


Figure 1: *Estimating Percentage Total Body Surface Area in Children Affected by Burns*

FURTHER SUPPORTIVE MEASURES

Optimal dietary support is extremely important in view of the hypermetabolic state; a patient with a burn of 40% Body Surface Area can lose up to 25% of body weight in 3 weeks if not optimally supported. Starting enteral feeds as soon as practically possible can help to prevent gastroparesis and meet the high metabolic demand.

Some centres are using partial beta blockade (e.g. propranolol to decrease heart rate by 20%) in children who remain tachycardic after the initial resuscitation phase despite appropriate fluid replacement and adequate analgesia. This further reduces the hypermetabolic state. This has been associated with an increased net protein balance and reduced energy expenditure.

BURN ASSESSMENT

Severity is related to surface area affected and depth. Also, burns to certain areas of the body warrant specialist attention e.g. hands, feet and perineum in order to achieve a good functional outcome.

Area

Burn area is often assessed with the aid of charts (Figure 1). The familiar 'rule of 9' and adult burn charts are not suitable for use in children younger than 14 years because of the variation in the relative size of their heads and limbs with age. A useful rule states that the area of the child's hand (palm and adducted fingers) is approximately equal to 1% of their total body surface area, whatever their age. Alternatively, a Lund-Browder diagram can be used.

Depth

Burns are classified into groups dependent upon depth:

- Superficial - epidermis only; skin appears red, no blisters
- Partial thickness - epidermis/dermis; skin appears pink/mottled, some blisters
- Full thickness - dermis/deeper layers, appears white/charred, painless (although marginal areas may still be painful).

Superficial burns are painful but heal rapidly. Partial thickness burns come in 2 varieties – those in which epidermal 'islands' persist around sweat glands and hair follicles and those more severe burns in which these 'islands' are destroyed. The former are painful and take up to 2 weeks to spontaneously heal. The latter may be less painful (due to destruction of nerves) but take longer to heal and may require surgical excision and grafting in order to do so. Full thickness burns require early excision and grafting to reduce infection and improve morbidity and mortality. In practice, the exact depth of many partial thickness burns are difficult to determine with accuracy on initial presentation, however surgical management often comprises early cleaning and covering in theatre under anaesthesia.

FURTHER MANAGEMENT

Analgesia

Burnt children are likely to experience significant pain – titrate boluses of IV morphine 0.1mg.kg^{-1} until comfortable, carefully observing their level of sedation. Ketamine, if used for anaesthesia/dressing changes, provides excellent analgesia. Later, oral analgesics are preferred – though beware non-steroidal anti-inflammatory drugs because of the observed predisposition to gastric stress-ulceration.

Wound care

Leave blisters intact. Cold irrigation and compresses can be soothing but run the risk of excessive heat loss and should only be used for <10 minutes in situations with superficial/partial thickness burns of <10-15%. Cling film if available may be applied loosely to protect and prevent fluid loss. Cover burns with sterile towels and avoid repeated exposure.

Wound infection is a major cause of late fatality following a burn; gram-negative bacterial colonisation occurs early, despite aseptic techniques in cleaning the wound. Suitable dressings should be applied early both to reduce this colonisation and to provide some analgesia. A variety of silver (Ag) based dressings are commonly used due to their antimicrobial gram-negative, gram-positive and anti-fungal activity.

Antibiotics should not be used prophylactically. Take care to diagnose sepsis and wound infection; this can be difficult as frequently the patient's temperature increases due to the raised metabolism. If a patient is unwell, particularly with fever, rash, drowsiness, low serum sodium concentration and lymphopaenia, you must exclude other causes of sepsis (eg line-related infection) and consider the diagnosis of toxic shock syndrome. This is potentially fatal and should be treated with antibiotics and fluids. Consider further dressing change and possibly fresh frozen plasma.

OTHER ANAESTHETIC CONSIDERATIONS

Suxamethonium is safe to use, if indicated, in the first 24 hours after a burn. Following this, concerns about causing acute severe hyperkalemia precludes its use for up to a year. To complicate matters, resistance to non-depolarising muscle relaxants is often seen for up to 3 months.

In the acute situation, ketamine is the intravenous induction agent of choice (2mg.kg^{-1}), particularly in cases of hypovolemia. Clearly, it is very important to try to fluid resuscitate any hypovolemic patient prior to anaesthetizing them, just as in any other emergency situation. If you suspect a significant inhalational injury with impending upper airway obstruction, treat the patient as you would any such case: either a gaseous induction, maintaining spontaneous breathing, or if you have one and are confident of your skills (and the child!), an awake fibreoptic technique (impossible in non-cooperative children). In the extreme and catastrophic case of complete, sudden upper airway obstruction you should be prepared to perform an emergency surgical airway. Having an appropriately skilled (i.e. ENT) surgical colleague scrubbed and standing by with the necessary instruments to hand can be immensely reassuring in such cases.

FINAL POINTS

The most effective strategy for burns management involves prevention. Widespread education, safety procedures and devices such as smoke alarms can help to prevent many thousands of deaths per year.

Finally, it is important to remember that occasionally burns are caused by non-accidental injury. If you suspect this due to pattern of injury, delay in presentation or inconsistencies in the history then you must investigate with experienced colleagues to prevent further future injury to the child.

CASE SCENARIO DISCUSSION

The history has several clues as to the likely type and extent of the injuries. He was found 'deeply asleep', probably unconscious, in an enclosed burning room (his sheets were smouldering). The fact that the rescuer sustained a broken ankle suggests he may also have traumatic injury. The pattern of charring to his pyjamas raises the possibility of circumferential chest burn. His initial vital signs indicate that he is shocked. The reduced level of consciousness in the context of soot around the nostrils strongly suggests an inhalational injury, despite the normal pulse oximeter reading. He will require early definitive airway management.

After giving high inspired oxygen and applying an immobilising hard cervical collar resuscitation proceeds according to the familiar ABCDE approach. Upon removing his pyjamas, he is seen to have an extensive area of pink-blistered skin across his chest and left arm. Unfortunately, no burns chart is available so the extent of the burnt area is estimated using the 'child's palm + adducted fingers = 1%' rule. Using this method the burn, which has partial thickness characteristics, is estimated at 20%.

Using the Parkland formula (and assuming a weight of [age+4] x2 i.e. [5+4] x2=18kg), the fluid bolus required over the ensuing 24 hours is: 20x18x4=1440ml. 720ml should be given over the first 8 hours since the burn and the rest over the next 16 hours. This is in addition to the normal daily maintenance requirements. Estimated weight enables calculation of drug doses e.g. morphine bolus $0.1 mg.kg^{-1}$ = 1.8mg.

Endotracheal tube size is estimated in the usual way: age/4+4 i.e. 5/4+4=5. It is prudent to have smaller tube sizes available than the estimated size in case of airway oedema.

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