Abstract: Burns remain a leading cause of injury in the paediatric population in Australia despite efforts in prevention. Advances in surgical management include novel debridement methods and blood conserving techniques. Patients with severe burns (>20%) remain significantly more complex to manage as a result of extensive alterations in metabolic processes. There appears increasing evidence to support the use of pharmacological modulators of the hyper-metabolic state in these patients. The management of a child with burns involves acute, subacute and long-term planning. This holistic approach seems optimally co-ordinated by a Burns Unit in which each discipline required to provide care to these children in order to achieve optimal outcomes is represented.

Key words: blood; burn; debridement; metabolism; multidisciplinary team; nutrition.

Burn trauma remains a significant cause of morbidity and mortality in children. In Australia, burns affect approximately 1% of the general population, of which 10% will require admission to hospital and 40% will involve children up to 14 years of age. The cost of inpatient acute burns care in Australia between 2006 and 2007 was estimated to be $65 million. Despite these worrying statistics, enhanced prevention strategies, first aid and clinical management have all helped to improve the outcome following burn injury.

We review advances in burn wound debridement, the critical care of children with burn injuries and the co-ordination of multidisciplinary care in a contemporary ambulatory care environment.

Wound Debridement

For extensive deep burns, early surgical debridement with wound closure has been shown to reduce mortality, decrease length of stay (LOS) and lead to enhanced functional and cosmetic outcomes. The optimal timing of operative intervention for heterogeneous mid-to-deep dermal burns remains unclear, although delays beyond 2 weeks need to be balanced against the risks of infection, subsequent hypertrophic scarring and long-term costs associated with delayed wound healing. Early excision of such burns, however, has been shown to be associated with increased blood loss and greater area grafted compared with waiting until day 10.

Tangential excision, first described by Janzekovic in 1968, involves serial excision of necrotic burnt tissue until a healthy base has been reached. Generally, this has been achieved by repeated shaving using a Watson-Humby knife, Goulian blade or dermatome. The aim of excision has been to remove the zones of necrosis and stasis beyond the level where the dermal vessels have been thrombosed. At the same time, viable dermis should be preserved to optimise the functional and cosmetic result. In full thickness burns, all of the dermis has to be removed until a bed of viable, well-vascularised fat, fascia or muscle remains. Traditionally, it has been believed that partial thickness burns should be debrided to a healthy base with copious, fine punctate bleeding, but recent experience under tourniquet control and with hydrosurgery has cast some doubt on this concept.

Adequate debridement remains one of the most important factors in graft take, while at the same time, the burns surgeon needs to avoid removing potentially viable dermis to reduce scarring and contracture formation. In practice, this requires considerable skill and an appropriate balance between these two conflicting requirements may be difficult to achieve. Variation in
especially on the face and around digits. Versajet has been demonstrated to have several benefits including improved precision, versatility and ease of use, which may be particularly beneficial in situations where improved haemostasis is required.

Strictures (including thromboxane and catecholamines) in the operative blood loss as it takes advantage of natural vasoconstriction at different sites and with age, together with the impact of strategies to minimise blood loss, all impact on the surgeon’s ability to assess tissue viability.

In recent years, hydrosurgery has been increasingly used to debride burn wounds. The Versajet (Smith and Nephew, Melbourne, Victoria, Australia) hydrosurgery system produces a high-pressure jet of sterile saline, directed tangentially to the burn wound surface, while simultaneously suctioning debris using the principle of the Venturi effect (Fig. 1). Postulated benefits include improved precision, versatility and ease of use, especially on the face and around digits. Versajet has been proposed to be more effective in dermal preservation as it provides an immediate assessment of the dermal plane as a result of continuous washing and aspiration. Cubison et al. in 2006 published the first case series using Versajet in children, reporting its effectiveness for cleaning and debriding superficial to intermediate depth burns. Similarly, in full-thickness burns, Versajet appears to be a valuable adjunct to conventional excision, especially when the tissue to be removed is softer than viable, unburnt tissue, as may occur when patients present 1–2 weeks post-injury. In a prospective randomized study in adults, Gravante et al. showed that operative time was less with Versajet compared with conventional debridement technique, although there appeared no significant differences in post-operative pain, healing time or contracture rates.

**Blood Conserving Techniques**

In burns, surgery debridement can result in significant blood loss: sufficient to require blood transfusion and represent a rate-limiting step in the operative treatment of patients with major burns. In full thickness burns, a grafting decision can usually be made soon after injury. In these burns, early excision and skin grafting have been shown to decrease operative blood loss and improve the survival of both adult and paediatric patients with major burns. Excision within 24 h improves operative blood loss as it takes advantage of natural vasoconstrictors (including thromboxane and catecholamines) in the burn wound. After 48 h, the burn wound becomes hyperaemic and bleeding at the time of debridement becomes increasingly problematic. Early debridement, however, is not always possible in paediatric burns in part due to the high frequency of scald burns that are usually heterogeneous, mixed-depth burns difficult to initially assess.

Blood loss had been estimated to be between 3.5 and 5% of the blood volume per 1% of surface excised. Many blood saving techniques have been used in burn surgery, including tourniquets, topical and subcutaneous adrenaline, thrombin, fibrin sealant and electrocautery. Whatever technique or combination of techniques are used, however, an appropriate compromise between minimising blood loss while allowing the surgeon to be able to determine tissue viability must be achieved.

**Tourniquets**

Tourniquets (Fr., tourniquet, turnstile) have been used in to reduce blood loss from injured limbs since antiquity, with Jean-Louis Petit (1674–1750) credited with devising a tourniquet with a screw that applied direct pressure to the major limb vessels. Tourniquet use has been well described in adult limb burns as an effective blood-conserving technique. Djurickovic et al. performed a comparative prospective study of burns greater than 5% in adults. They demonstrated that tourniquet use in limb burns was more effective in reducing blood loss when compared with 1:1 000 000 adrenaline injected below the burns eschar in trunk and limb burns (2.07 ± 0.34% of patients circulating blood volume per 1% body surface area (BSA) excised compared with 3.42 ± 0.39%, P < 0.01).

More recently, O’Mara et al. randomised 10 adult patients with bilateral extremity burns to excision without tourniquet and tourniquet without prior exsanguination. All limbs were also treated with Omiderm (Omiderm Ltd, Yavne, Israel), synthetic spray (GenTrac Ltd, Bristol, TN, USA) with a thrombin solution and adrenaline-soaked gauze. Blood loss was significantly less with tourniquet control (0.10 ± 0.29 mL/cm² compared with 0.32 ± 0.56 mL/cm², P = 0.04), with no decrease in graft take.

**Topical and subcutaneous adrenaline**

Blood-conserving techniques include application of a topical vasopressor such as adrenalin to both the debrided burn wound and donor sites. Carucci et al. and Netscher et al. demonstrated that topical vasopressors decreased the amount of bleeding and time of bleeding from donor/graft sites. More recently, Barrett et al. showed no difference in blood loss between topical adrenaline (1 in 10 000 to donor and 1 in 200 000 to graft site) and normal saline in paediatric burns. In this study, however, both groups received bovine topical thrombin (1000 units/mL in final solution) to excised wounds and donor sites that may have independently modified bleeding times. Our clinical experience with topical adrenaline (1 in 10 000) to graft and donor sites has been more consistent with early studies, with a consistent reduction in blood loss.

Traditionally, donor split-thickness skin grafts that were harvested from anatomically unfavourable sites due to a concave or uneven contour were done so following subcutaneous...
infiltration of normal saline to improve the quality of the graft. Kahalley et al. first described a modification of the ‘tumescent technique’ after his anaesthetist noticed copious bleeding from a scalp donor site and suggested adding a vasopressor to the subcutaneous saline to reduce blood loss.28 The technique has evolved to include subcutaneous or sub-eschar injection of dilute adrenaline (up to 1:500 000) to limit blood loss associated with both the debridement and harvesting of skin grafts in both adult and paediatric burns.

Beausung et al. reported a study of 29 paediatric patients with mild to moderate burns (1–12% total BSA (TBSA)) injected with an adrenaline/bupivacaine solution (1:500 000 adrenaline + 3 mg/kg of bupivacaine) prior to debridement and grafting.29 Although the many of these patients had relatively minor burns, none required blood transfusion, and there were no side effects related to adrenaline, such as a tachycardia. Subsequent graft take in this series was 95%, indicating adrenaline does not adversely affect burn depth assessment or graft take.29

Robertson et al. reported a reduction in blood loss of more than 50% and a reduced transfusion rate of nearly 50% with the use of this technique in adults.30 They also reported that no detectable arrhythmia or change in heart rate and blood pressure was associated with the use of subcutaneous adrenaline.30 Gacto et al. performed a blinded, prospective randomised controlled trial of adrenaline (1:500 000) with lidocaine (5%) versus 0.45% normal saline for donor site tumescence in adult burns patients.31 They demonstrated decreased intra-operative bleeding and post-operative pain, together with accelerated re-epithelialisation, perhaps as a result of reduced haematoma formation.31

**Thrombin**

Thrombin converts fibrinogen into fibrin, forming a blood clot. Thrombin may be directly applied onto the wound via a spray system. In Australia, only human plasma-derived thrombin is available; however, both bovine (bThrombin) and recombinant (rThrombin) remain available overseas. Two studies in the 1980s compared bThrombin with adrenaline and phenylephrine, respectively, for donor site haemostasis and found vaso-pressors both more effective and more economical.25,32

More recently, Greenhalgh et al. in a single-arm study reported that rThrombin achieved haemostasis on excised burn wounds within 20 min in 91.5% of both adolescent and adult patients. They also demonstrated that only 1.6% of patients developed anti-rThrombin antibody formation.33 Antibody formation to rThrombin has been reported at up to 21.5%, which can be problematic in patients requiring multiple episodes of grafting.34

While there appears an overall lack of high-quality evidence to determine the optimal haemostatic agent in paediatric burns surgery to minimise blood loss, it seems likely that a combination of techniques, including elevation of limbs, tourniquets and either subcutaneous or topical vaso-pressors, would be effective.20

**Hypermethabolic State**

Severe burns produce a hypermetabolic state that is much higher than any other disease: a severe burn of >40% TBSA will have a metabolic rate between 80 and 200% greater than normal.7 The hypermetabolic response seen in major burns is characterised by a hyperdynamic circulation, with an elevated cardiac output (CO), increased body temperature, increased oxygen and glucose consumption, increased CO2 production, glycogenolysis, proteolysis and lipolysis. This increased metabolic state can last up to 9 months post-burn and contributes to significant loss of lean body mass, muscle breakdown and poor wound healing.35,36

In children especially, this prolonged hypercatabolic state can have significant long-term effects on their growth and development.37 They demonstrate fatigue, difficulty concentrating, irritability, emotional lability in the months post-injury, osteoporosis, reduced bone formation and even long-term damage to the epiphyseal plate. This can lead to joint problems and linear growth arrest especially if the burn occurs during pubertal growth phase.38

In severe burns, there are two metabolic phases post-burn. The first phase, immediately after the burn and termed the ‘ebb’ phase, is characterized by hypovolaemia, tissue hypoxia, poor CO, increased oxygen consumption, decreased metabolic rate and a hyperglycaemic state.7,39,40 The second or flow phase is associated with a gradual increase in CO and a hypermetabolic state. This stage starts in the first 48 h post-burn and plateaus around the fifth day and can last up to 3 years post-burn.41 A CO of greater than 150% compared with healthy controls has been found in burn patients after only 4 days.42 The hypermetabolic state can lead to profound loss of both lean and total body mass (TBM). Chang et al. reported that a 10% loss of TBM was associated with immune dysfunction, 20% with decreased wound healing, 30% with severe systemic infections and 40% with death.43

The hypermetabolic state is a catabolic state, with an associated increase in catabolic hormones (cortisol, catecholamine and glucagon) and a decrease in anabolic hormones (growth hormone, insulin-like growth factor-1 (IGF-1)).44 Pharmacological manipulation of these agents, in an attempt to normalise metabolism, has been used in the management of paediatric burns.

**Propranolol**

Propranolol works by non-selectively blocking β1 and β2 receptors to prevent the effects of an up to 10-fold increase in catecholamine’s post-burns.45 Catecholamines act on β1 receptors on the heart to increase heart rate and force of contraction, and on β1 and β2 in the liver and muscle to break down energy stores (glycogen and fat) to glucose and free fatty acids. Propranolol blocks these effects and as a result lowers the resting heart rate, basal metabolism and decreases peripheral lipolysis.

A randomised control study was performed by Herndon et al. in 25 children with severe (>40% TBSA) burns. They found that propranolol (with the dose titrated to reduce heart rate by 20% (0.33–1.05 mg/kg 4 hourly)) decreases lean mass loss and lipid catabolism in severely burned children.44 A large, prospective, randomised control trial was recently published by Williams et al. in 406 children with burns >30% TBSA.45 They found that propranolol given at 4 mg/kg/day decreased the heart rate by
15% ($P < 0.01$), in turn, increasing the stroke volume, decreasing cardiac work and myocardial oxygen consumption. Over time, this led to a decreased proteolysis, lipolysis and muscle breakdown with no adverse effect on mean arterial blood pressure.

**Oxandrolone**

Oxandrolone is an analogue of testosterone, decreasing muscle catabolism by enhancing the efficiency of protein synthesis. It can reduce weight loss and has been shown to increase the rate of donor site wound healing. In the acute phase, oxandrolone decreases LOS, maintains lean body mass and improves body composition and hepatic protein synthesis. Murphy et al. reported in a randomised controlled trial in children with burns >40% TBSA that treatment with oxandrolone for 1 year (0.1 mg/kg) significantly improved lean body mass and bone mineral content 12 months post-burn.

**Glucose control**

Hyperglycaemia post-burns is a result of increased catecholamine, glucagon and glucocorticoid produced in the hypermetabolic state, leading to insulin resistance.

The effect of insulin control in critically ill patients was proven in a landmark study by Van Den Berghe et al., who demonstrated that insulin administration to maintain glucose levels below 10 g/dL correlated with decreased mortality (32%), infection and sepsis in 1548 critically ill surgical patients. In addition, insulin therapy has been shown to improve muscle protein synthesis, accelerate donor site healing and exert an anti-inflammatory effect.

Gore et al. demonstrated in a retrospective review of severely burned children (>60% TBSA) that poor glucose control was associated with increased blood stream infections, reduced skin graft take and subsequent mortality. Pham et al. have also shown lower infection rates and improved survival in children with >30% TBSA burns whose glucose levels were kept between 90 and 120 mg/dL with an insulin infusion.

Maintaining a euglycaemic state in patients’ burns remains challenging in a clinical environment due to large caloric enteral feeds alternating with periods of fasting for multiple interventional procedures requiring general anaesthesia.

**Recombinant human growth hormone (rhGH) and IGF-1**

In children with major burns, a decreased growth potential has been described. Contributing factors include prolonged hospitalization, multiple operations, increased body catabolism and decreased anabolic hormones. In fact, decreased serum levels of growth hormone have been reported in adults with large burns.

Recombinant growth hormone has been used in children to reduce this catabolic process. Branski et al. demonstrated in a randomised double-blind control trial using rhGH (0.05, 0.1, 0.2 mg/kg/day) in 205 severely burned children (40%) that daily injection of rhGH improved weight gain, height velocities, lean body mass, bone mineral content, CO$_2$ energy expenditure and scarring. They suggest using 0.2 mg/kg in the acute phase and 0.1 mg/kg for the following year. Adverse effects, however, including hyperglycaemia, insulin resistance and increased morbidity and mortality, have been described in adults.

IGF-1 mediates the effects of GH. When administered with rhGH, IGF-1 appears as effective in improving protein synthesis as rhGH alone but is associated with significantly less hypoglycaemia. The hypermetabolic process can have significant effects both in the short and long term in major burns patients. Pharmacological modifications of this process can significantly reduce the energy requirement and loss of lean body mass and improve the recovery for these children. No single pharmacological or non-pharmacological intervention can completely abolish this process. Recent therapies have certainly improved the morbidity and mortality and improved the standard of care for these patients. Currently, propranolol appears the safest pharmacological therapy to modify the hypermetabolic process in children.

**Feeding in Burns**

Severe burns patients have significantly increased caloric requirements, in part, as a result of their hypermetabolic state in addition to the need for calorific support for tissue repair. Adequate nutrition is paramount in preventing organ dysfunction, loss of muscle protein, decrease infection rates and promoting wound healing.

In burns, patients’ nutrition can either be administered parenterally or enterally. Enteral nutrition remains the preferred method of nutrition in burns patients with a functioning gastrointestinal tract, helping to maintain gut integrity and motility in addition to decreased bacterial translocation and sepsis. It provides first pass delivery of nutrients to the liver, reducing complications such as hyperglycaemia. In addition, enteral nutrition is easier to administer, without the requirement for central venous access and its inherent complications such as bacteraemia. Herndon et al. reported an increased mortality (63% vs. 26%) in adult major burns patients that were given enteral nutrition supplemented with total parenteral nutrition compared with enteral nutrition alone.

The timing of enteral nutrition may be a major determinant of outcome in burns patients. Early enteral feeding has been shown to decrease the hypermetabolic state, maintain gut motility and decrease both the incidence of sepsis and LOS. There has been varying evidence, however, regarding the level of benefit from early enteral nutrition. A Cochrane review, which analysed the results of three randomised controlled trials (1997–2004) with a total of 70 adult burns patients, concluded that there was no evidence to support early enteral nutrition in terms of reduced LOS and reduced mortality. In 2004, Gottschlich et al. published a prospective trial comparing early enteral versus delayed feeding in children. They also did not find a reduction in morbidity, mortality, hypermetabolism or LOS between the two groups. Early enteral nutrition remains advocated by the American Burn Association and Eastern Association for Surgery of Trauma in burns patients with functioning gastrointestinal tracts. In more recent studies, Lu et al. and Mosier et al. have shown decreased episodes of sepsis, duration...
of antibiotics, wound infections, shorter intensive care unit (ICU) admissions, increased systemic nutrition and protein synthesis in adults treated with early versus delayed enteral nutrition. Khorasani has also demonstrated that early enteral nutrition is associated with a decrease length of hospital stay and mortality in children with burns.

Multidisciplinary Team

Management of a burns patient requires a holistic approach. A modern Burn Unit (BU) involves some of the best integration of health professionals and exemplifies a true multidisciplinary approach to care (Fig. 2). Management of major burns must involve a smooth transition from acute, subacute to rehabilitation phases of management. The development of co-ordinated multidisciplinary burn units has allowed for a holistic approach to patient care.

In Australia, a multidisciplinary burns team may not be practical or financially feasible at smaller rural hospitals. It is important for larger burns centres to offer an outreach service and support to these remote and rural areas. In our institution, this is achieved via photographic and video consultations. In the USA, the establishment of BU multidisciplinary burn care has correlated with an overall survival of over 95% and a decreased LOS by 40% over the last 10 years.

Alteration of body image is only one aspect of the emotional effects of being burned. We have found that our annual burns camp remains a valuable resource for burns patients and their family as they can improve self-esteem and body image by meeting other who shares the same experience. Long-term psychological support is required as patients will meet different challenges as they go through different stages of development. Van Baar et al. reported that more than half of children with burns experience long-term sub-optimal functioning with regard to ‘appearance’, ‘itch’, ‘emotional health’, ‘parental concern’ and satisfaction with current state. While this effect was increased in burns >10% TBSA, it was prevalent even for relatively minor burns in children.

Fig. 2 The multidisciplinary burns team.
Conclusions

Burns continue to be a common injury in children despite prevention campaigns. Novel techniques in the surgical management of these burns, including more precise debridement with reduced blood loss, have improved the quality and success of grafting in children. In major burns, the hypermetabolic state may be successfully modulated to decrease mortality and morbidity, improve muscle protein synthesis and accelerate donor site healing. The management of paediatric burns patient involves acute, subacute and long-term planning, optimally co-ordinated as part of the provision of multidisciplinary care with a BU.

Multiple Choice Questions

1. A 10-year-old boy presents to hospital with 20% flame burns to his face, neck, arms and legs. He was playing with an aerosol can that caught alight. Initial assessment revealed full-thickness burns. His parents are Jehovah’s witnesses. Minimizing blood loss during his operation can be best achieved using:
   a) Tourniquet application in association with subcutaneous adrenaline (1:500 000) to debrided areas and donor sites
   b) Subcutaneous injection of 1:500 000 adrenaline to debrided areas and donor sites
   c) Tourniquet application with topical adrenaline to debrided areas and donor sites
   d) Debridement using a hydrosurgery technique instead of tangential excision with a Goulian blade

Answer:
   a. The current literature favours a combination of techniques to reduce blood loss in children with burns, including the use of a tourniquet for limbs with subcutaneous infiltration of dilute adrenaline in normal saline. While hydrosurgery appears to facilitate more precise burn wound debridement, potentially resulting in decreased blood loss, this has not been proven.

2. A 2-year-old boy sustained flame burns to 40% of his body after falling into a camp fire. He received minimal first aid and was transferred to the regional paediatric burns unit. On arrival to the hospital, he was admitted to the ICU for fluid and analgesia management. Which of the following statements is most correct?
   a) Propranolol is a selective β1 antagonist that lowers the resting heart rate, basal metabolism and decreases peripheral lipolysis.
   b) Poor glucose control is associated with increased blood stream infections, reduced skin graft take and subsequent mortality.
   c) Parenteral nutrition is superior to enteral nutrition in severe burns, requiring nutritional supplementation.

Answer:
   b. Optimal glycaemic control has been shown to be beneficial in critically ill surgical patients. In children with burns, insulin infusions that maintain glucose levels between 90 and 120 mg/dL have lower infection rates and increased survival.

3. A 4-year-old girl presents to her local country hospital with a 7% scald burn to her right flank after spilling hot tea. She was treated with 20 min of cooling with cold, running water prior to her presentation. On initial assessment, her burns appear to be superficial to mid-dermal. Her local medical officer’s management should include:
   a) Immediate transfer to the nearest regional paediatric burns unit for assessment and ongoing treatment
   b) Local dressing of burns wound and reassessment in 2–3 days
   c) Contact regional paediatric burns centre to develop a collaborative management plan

Answer:
   c. A 7% scald burn can often be managed locally in conjunction with the regional paediatric burns unit. Digital clinical images may be transferred electronically for advice on the optimal initial dressings and the need for transfer for further assessment. While the outcome of burns are often difficult to predict, involving the local burns centre can offer ongoing support if the child’s burns develop into deeper burns that require grafting.

References


