Pediatric burns: the forgotten trauma of childhood

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A burn is an injury caused by thermal energy or by chemical or physical agents having a similar effect to heating or cooling. A deep burn may be defined as one that has not healed within 12 days and represents either a deep partial-thickness or a full-thickness burn.[1] For the purposes of this review children have been defined as those younger than 16 years.

Although burns are a form of trauma that optimally require multidisciplinary care, they have often been managed and studied quite separately from other types of injury.[2,3] This may reflect their dramatic appearance, the nature of the surgery involved and the potentially devastating cosmetic, functional and psychological consequences, especially in the growing child.[3,4] This separation may have created an artificial barrier among interested parties, hindering the development and application of advances in prevention, diagnosis, treatment and rehabilitation.[3,5–7]

Epidemiologic features

Burns remain a common mechanism of injury in children but an uncommon cause of death. The Australian Bureau of Statistics defines a child as any person younger than 15 years.[8] In 1994, trauma collectively accounted for one-third of all deaths in Australian children between 1 and 14 years of age compared with just 3% of all adult deaths.[8] Similarly, between 1991 and 1995, fire-related injuries accounted for 7% of all pediatric trauma deaths compared with 1% of adult trauma deaths.[2,9] Overall, in 1992 Australia's child injury death rate was 9.2 per 100 000, Canada 9.1 per 100 000 and Sweden 5.0 per 100 000.[8] Data published in 2001 indicated little change, with Australia and Canada continuing to trail Sweden and the United Kingdom in terms of childhood injury mortality.[9] Perhaps more worryingly, in the context of burn injuries, Australia, Canada and the United States, along with Korea, remain the worst 4 of the 15 most populous member states in the Organisation for Economic Co-operation and Development for the number of children dying as a result of fires.[9]

Burn injuries in children who survive are also more common and more severe than in adults, even after allowing for adult occupational injuries and suicide.[2,3,10] In the US, Rossignol and colleagues[10] reviewed childhood burn injuries in New England between July 1978 and July 1979. Of those with burns requiring admission 41% were under 19 years of age. Although there were 30.7 burns per 100 000 person-years in young people overall, this rate increased to 96.7 per 100 000 in children under 3 years of age. Similarly, Spady and colleagues[11] reviewed the frequency and pattern of injuries seen in all children under 11 years of age in Alberta between 1985 and 1998. Of the 96 359 children enrolled, burns requiring a medical consultation occurred in 9556 (9.9%).[11] In Australia from 1995 to 1996, boys under 4 years of age had the greatest frequency of admission for burn injuries of all ages (142/100 000 people) and nearly double that of the next highest group, adult males between 20 and 24 years of age.[2] Ng and associates[7] reviewed trauma admissions to the pediatric intensive care unit of the Kwong Wah Hospital in Hong Kong between July 1996 and December 1999. The 28 trauma patients admitted accounted for 7% of all admissions, with nearly equal numbers admitted as a result of motor vehicle injuries and of burns. A recent global review of burn injuries, although highlighting the problem of inaccurate data, estimated that over 38 000

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children required hospitalization each year in the US alone.[12]

Scalds continue to be the most common cause of burn injury in children, with hot water the most frequent agent.[6,7,13] Between January 1997 and December 2002, 17 237 children under 5 years of age were treated for burns in the emergency department of approximately 100 US hospitals that participated in an audit by the Consumer Product Safety Commission.[13] Nearly two-thirds (65.7%) of these burns were due to scalds.

Although most studies have suggested a decrease in the number of children suffering burn injuries over the last 2 decades, there appears to be some variation among countries and even regions, with some areas reporting an increase.[2,13–16] Eadie and associates[15] reviewed children admitted with scald injuries to the Welsh Centre for Burns and Plastic Surgery, UK, between 1956 and 1991. They found that the number of patients admitted increased by nearly 50% despite a very modest increase in the local pediatric population. Two more recent studies have indicated that many children continue to suffer scald injuries in the home.[13,16]

In part, this apparently conflicting information may reflect a failure to compare equivalent information.[12] Patients presenting to an emergency department with burns may be compared with those admitted to hospital with burns, for example. Viewed in the context of inevitable gaps in data collection, a confusing picture may emerge. O'Connor and Cripps[2] reviewed all Australian burn admissions between 1993 and 1996. Interestingly, they found that the number of large (> 30%) total body surface area (TBSA) burns decreased over this time, whereas the total number of patients increased owing to a rapid rise in the number of smaller, deep burns. This suggests that although the pattern of injury may be changing, the overall burden of trauma has remained constant.

First aid

An important factor influencing the outcome of a burn wound injury, recognized since the time of Galen, has been cooling.[17–20] Nguyen and colleagues[21] reviewed all children with burn injuries admitted to the National Burn Institute, Hanoi, Vietnam, between 1997 and 1999. Forty-nine percent of children who did not receive prompt cooling of the wound suffered deep burns compared with just 33% of those who received immediate cooling. Cooling was found to be significantly (p = 0.007, 95% confidence interval [CI] 0.41–0.87) associated with a reduction in the need for subsequent skin grafting.

Australian and New Zealand Burns Association guidelines, reflected in the Emergency Management of Severe Burns course, recommend treatment with cold running tap water for a minimum of 20 minutes as soon as possible after the burn injury.[21–23] Hypothermia should be avoided, and treatment up to 3 hours after the burn may be beneficial.[21,23]

Despite evidence of the efficacy of first aid, its application in both the pre-hospital and hospital environments has been inconsistent.[21,23–26] After the establishment of their burn unit in Vorarlberg, Austria, in 1988, Beer and Kompatscher[25] attempted to standardize first aid treatment of burns. Education in the form of lectures, courses, publications and advertisements on radio and television advised on correct treatment.[25] During a 10-month period in 1994, 73 patients with burns were audited.[25] Although cooling was performed in 77%, this occurred for an average of 5–10 minutes only.[25] A prospective study of 109 children with minor (< 10% TBSA) burns in Sydney, Australia, presenting to an emergency department between 1998 and 1999, found that only 45 (41%) received optimal first aid, even after admission to the state's sole pediatric burn unit.[23] Allison[24] performed a mail survey of ambulance services, burn units and plastic surgery specialist surgeons in the UK in 2001. The response rate varied between 58% (plastic surgeons) and 79% (ambulance service). Fifty-eight percent of ambulance services had no burn treatment policy, although 84% (26) used some form of cooling. Of the burn units and plastic surgeons surveyed, only 68% considered cooling of the burn wound important, with a recommended cooling time ranging from less than 1 minute to 2 hours (median 15 min). In January 2005, O'Neill and colleagues[26] reported 63 patients admitted following burn injury to University College Hospital in Ireland, and found that the correct first-aid guidelines had been followed in only 23%.

In part, poor compliance reflects a lack of knowledge. A survey of 654 parents attending a pediatric hospital emergency department in Stony Brook, NY, indicated that in some cases as few as 21% were aware of correct first-aid treatment for simple pediatric emergencies including burns.[27] Skinner and Peat[28] performed a prospective 4-month study of 121 adult and pediatric burn patients presenting to Middlemore Hospital in Auckland, New Zealand, in 2002. Thirty-eight percent of children under 10 years of age received inadequate first aid and suffered longer inpatient stays; a lack of first-aid knowledge was the main contributing factor.[28,29]

Experimental studies in a rodent model have suggested that benefits of cooling on epithelial cell activity and edema formation may be restricted to the first hour after the burn.[30] Conflicting data and the lack of information on the optimal duration of cooling support the need for further studies in this area.[21]

Airway management

Although airway burn injury is a unique form of trauma, the general principles of airway management used in the care of any injured patient should be applied, based on Advanced Trauma Life Support guidelines.[31] The narrower airway in children predisposes to obstruction, especially in the presence of edema complicating a major burn.[3,32] Compounding factors include a large tongue, hypertrophied tonsils and adenoids.[32] In this scenario, early endotracheal intubation represents a potentially life-saving intervention in children with an airway or major thermal injury. Any delay in securing the airway may lead to an emergent surgical procedure to secure the airway under extremely difficult conditions. Once the airway has been secured, great care must be taken to protect and maintain both its patency and position.

Inhalational injury represents a major cause of burn death in children, a problem compounded by greater difficulties in the diagnosis than in adults.[32] Flexible bronchoscopy represents the most reliable diagnostic tool.[33] A combination of nebulized heparin and *N*-acetylcysteine is effective in reducing both the mortality and morbidity of inhalational injury in children.[34]

Fluid resuscitation

Although controversial, a number of general guidelines remain with respect to fluid resuscitation. First, children suffer proportionally greater fluid losses than adults with equivalent burn injury.[32] Thus, they require resuscitation fluids, typically a warmed crystalloid solution such as Hartmann's solution, in addition to their normal maintenance fluids, which should include a carbohydrate, such as half-normal saline with 5% dextrose.[22] Second, these fluids should be begun early, ideally within the first hour after the burn injury, with 50% of the calculated total volume given within the first 8 hours.[22] Third, the TBSA of the burn, remembering the greater contribution of the head and neck area (18% in the first year of life with 1% taken off and added equally to both lower limbs for each year of life until 9 years of age), should be used as a guide to fluid resuscitation.[22] Fluid resuscitation is advised for all burns greater than 10% TBSA in children, with its efficacy assessed by standard hemodynamic parameters and an hourly urine output of 1 mL/kg.[3,22,32] Lower urine outputs may be associated with hypoperfusion and higher outputs with increased tissue edema. Vascular access in children with major burns may be difficult, but an intraosseous cannula is one option when intravenous access cannot be promptly achieved in children younger than 6 years.[32]

Predicting outcome after burn wounds

Expeditious treatment of a deep burn is associated with a superior cosmetic outcome and will reduce the incidence of subsequent contractures and scarring.[3,6,35] This should facilitate an earlier return to normal activities.

Deitch and associates[36] sought to determine the risk factors associated with hypertrophic burn scars. They prospectively assessed the outcome of 245 burn wounds thought to be superficial or of moderate partial-thickness depth in 59 children and 41 adults admitted to the Shreveport Burn Unit, La., between 1980 and 1981. They compared the influence of anatomic site, racial origin, age and depth of burn on the subsequent development of hypertrophic scarring. Follow-up was for a minimum of 9 months, and a hypertrophic scar was defined as one in which there was an elevated area of 2 cm or greater within the burn wound, independent of the use of pressure therapy. Analysis of their results indicated that the most important attribute associated with development of a raised burn wound scar, over and above race or anatomic site, was duration of wound healing or the depth of the burn. In children, there was a 6% risk of hypertrophic scarring if the wound healed within 10 days, but this risk increased to 42% if the wound healed within 14–21 days.

In order for deep burns to be optimally treated, therefore, they should be diagnosed and treated early. The ability to diagnose deep burns, or in other words predict burn wound outcome, remains difficult. Traditionally, serial clinical examination has been used to assess burn depth. From this approach alone, the typical reported diagnostic accuracy ranges between 50% and 65% in adults and children — little better in some cases than the toss of a coin.[37] Diagnostic accuracy appears reduced in children by the mixed-depth nature of the most common burn injury, the scald.[1,37] In addition, the difficulties associated with repeated and often painful clinical examination of the burn wound in an uncooperative toddler further compromise wound prognostication.[1,37]

Many techniques have been proposed to assist in predicting burn wound outcome, including thermography, the use of dyes and radioisotopes, ultrasonography, objective analysis of the reflection of light by the wound and histopathological analysis of burn-wound biopsies.[1,37] None have stood the test of time, with serial examination by an experienced burns surgeon being the standard.[3,37] In 1964, however, Yeh and Cummings[38] described the use of a laser to measure the stream of a colloidal suspension in a tube. This was based on the optical equivalent of the Doppler effect.[39] Subsequently, the technique was adapted to measure cutaneous blood flow, initially using a probe in contact with the skin surface.[39] Later, reflected laser light was captured by a series of photodiodes, enabling skin blood flow to be assessed without direct contact, a technique termed laser Doppler imaging (LDI).[40] Superficial burns likely to heal within 10–12 days typically exhibit dramatically increased blood flow, in contrast to deep areas which reveal normal or reduced flow.[1,41]

The use of this technique to predict burn wound outcome was first reported by Niazi and colleagues in adults in 1993.[41] The first report of this technique in children, in 2002, documented a sensitivity and specificity of 90% and 96% respectively, for LDI in 57 children with an age range of 5 months to 15 years (median 1 yr 10 mo).[1] This compared with figures of 66% and 71% for the clinical diagnostic accuracy of experienced burns surgeons. Logically, optimal results would appear to occur when the scan images are assessed in conjunction with the clinical appearance of the burn wound, in much the same way that a surgeon would review a patient's radiologic findings in conjunction with the clinical examination. Even when the clinician reporting on the LDI scan is blinded to the clinical appearance of the burn wound, however, the result of the LDI scan has been found to have a mean sensitivity of 85%.[42] LDI has been further validated in several recent clinical studies.[43,44] It has also been of value in allowing objective comparison of burn wounds in trials, enabling equivalent burns to be allocated to different treatments, quantifying scarring in burn patients and even guiding fluid resuscitation.[45–47] Although the scanner is expensive, the ability to accurately predict burn wound treatment allows for optimal treatment planning and use of inpatient resources including operating room time.[1,42,43]

Burn wound excision and grafting

Surgical management of the burn wound means meticulous debridement with tangential excision until viable tissue has been reached. This technique, originally described by Janzekovic,[48] is usually performed with a Watson or Goulian knife.[49] Blood loss may be considerable with this method but may be reduced by operating within 48 hours of the burn, the use of topical or subcutaneous adrenaline, procoagulant agents such as thrombin and, in limb burns, pneumatic tourniquets.[49]

Primary wound closure, despite the advent of cultured epithelial autograft (CEA) (or cultured keratinocytes from the patients' own skin), remains normally achieved through the use of split-skin grafting.[49] Especially in major burns, when donor sites may be limited, split-skin grafts of a more consistent depth can be harvested with a powered dermatome.[49] Meshing the split-skin graft, with ratios ranging from 1:1 to 6:1, facilitates drainage of blood and serum from the burn, enhances conformation of the graft to the wound bed and when expanded allows a greater area to be covered.[3,49] Although surgical staples have been used to secure grafts in major burns, their subsequent removal may be complicated and painful in the awake pediatric burn patient; smaller grafts in particular may be adequately secured with histoacryl glue, absorbable suture material or an adhesive, conformable dressing.

Burn wound healing and skin substitutes

Skin cover in the child with major burns continues to be a serious clinical problem, often requiring repeated harvesting of split skin from increasingly fragile donor sites. Increased patient survival has stimulated the need for improved outcome in the quality of the burn wound, which should be functionally and cosmetically satisfactory.[6,50,51] An autograft, even when available, does not always provide ideal results, leading to an ongoing search for the ideal skin substitute.[3,52,53] In 1975, Rheinwald and Green[54] described the successful in vitro culture of human keratinocyte colonies, leading to the first reported clinical application in 1984.[55] Although not an ideal skin substitute, lacking the complex 3-dimensional framework of the dermis and epidermis of normal skin, increasing use and experience with cultured epithelial autograft has been reported.

In Australia, Paddle-Ledinek and colleagues[52] reported their experience with sheet cultured epithelial autograft in adults and children treated between 1990 and 1996. Overall, 17 patients with 55%–95% TBSA full-thickness burns achieved an average take of 53% and 7 patients with deep partial-thickness burns an average take of 73%. Carsin and associates[50] reported their experience between 1991 and 1996 with sheet cultured epithelial autograft from a commercial laboratory in 30 adults with a mean 78% TBSA burn. They found that cultured epithelial autograft provided permanent coverage of a mean 26% TBSA, greater than that achieved with conventional grafting. Cultured epithelial autograft has been shown to be incorporated into the healing burn wound, with cells present in studies undertaken up to 8 years after the original grafting procedure.[56,57] A few reports, usually with small numbers of adults with severe burns, have been less encouraging: no take of cultured epithelial autograft and a fatal outcome, or scar management programs that need to be adapted to reflect the reduced physical stability of cultured epithelial autograft.[58,59]

Experimental studies and clinical data have suggested that the application of cultured epithelial autograft in the form of a spray may be more effective: cultured keratinocytes are preconfluent at this stage and therefore more likely to both proliferate and migrate.[60,61] Successful take of cultured epithelial autograft may be enhanced, especially in wounds that are difficult to access and dress, by combining keratinocytes in suspension with a fibrin sealant to promote adhesion and prevent "run-off."[60,62,63] This technique may also be helpful in expediting healing of split-skin donor sites.[64] More recently co-culture of melanocytes with epidermal cell sheets has been performed to enhance cosmetic outcome and promote repigmentation in healed burns.[65]

Summary

Burn injury in children represents a unique form of trauma that requires an experienced, multidisciplinary team for optimal outcomes. Burns remain common in children, particularly among lower socioeconomic groups, with major burns being more commonly associated with a fatal outcome than in adults. Ideal first aid appears to be frequently under-used, despite clinical and laboratory evidence of its efficacy. Predicting burn wound outcome continues to be problematic, although newer techniques such as laser Doppler imaging appear to offer great potential. The ideal skin substitute remains to be developed, but the evolving use of cultured epithelial autograft in burn wound management suggests that it will secure a place in the therapeutic armamentarium of burns surgeons.

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