Debridement Techniques in Pediatric Trauma and Burn-Related Wounds

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Significance: Traumatic injuries are the leading cause of morbidity and mortality in children. The purpose of this review is to provide an overview of the initial assessment and management of traumatic and burn wounds in children. Special attention is given to wound cleansing, debridement techniques, and considerations for pain management and psychosocial support for children and families.

Recent Advances: Basic and translational research over the last 5–7 years has advanced our knowledge related to the optimal care of acute pediatric traumatic and burn wounds. Data concerning methods, volume, solution and timing for irrigation of acute traumatic wounds, timing and methods of wound debridement, including hydrosurgery and plasma knife coblation, and wound dressings are presented. Additionally, data concerning the long-term psychosocial outcomes following acute injury are presented.

Critical Issues: The care of pediatric trauma and burn-related wounds requires prompt assessment, pain control, cleansing, debridement, application of appropriate dressings, and close follow-up. Ideally, a knowledgeable multidisciplinary team cares for these patients. A limitation in the care of these patients is the relative paucity of data specific to the care of acute traumatic wounds in the pediatric population.

Future Directions: Research is ongoing in the arenas of new debridement techniques and instruments, and in wound dressing technology. Dedicated research on these topics in the pediatric population will serve to strengthen and advance the care of pediatric patients with acute traumatic and burn wounds.

SCOPE AND SIGNIFICANCE

WHILE TRAUMATIC INJURIES are the leading cause of morbidity and mortality in children, the majority of injured children are cared for by providers without pediatric-specific training or expertise. The purpose of this review is to provide an overview of the initial assessment and management of traumatic and burn wounds in children. Special attention is given to wound cleansing, debridement techniques, and considerations for pain

management and psychosocial support for children and families. Additionally, considerations for transfer to centers with specialized expertise in injured children are discussed.

TRANSLATIONAL RELEVANCE

Pediatric traumatic and burn wounds represent a major public health burden. The majority of the literature on management of these wounds in children is experiential

or case-based, with few basic or translational studies published. This review presents existing data for techniques of wound irrigation, debridement, and initial dressing types. Gaps in the scientific literature are highlighted.

CLINICAL RELEVANCE

Traumatic injuries are the leading cause of morbidity and mortality in children, with unintentional injury ranking as the number one cause of death, disability, and medical cost in children greater than 1 year of age.^{1,2} Soft tissue wounds and burns require immediate care and necessitate that the treating physician have a thorough working knowledge of appropriate management. The definitive management of these injuries may require specialist care from a pediatric trauma surgeon, burn surgeon, or plastic surgeon; however, all providers who treat children should have an understanding of the initial management of traumatic wounds and burns.

DISCUSSION OF FINDINGS AND RELEVANT LITERATURE

Initial assessment of pediatric trauma/burn patients

Treatment of traumatic wounds begins in the trauma bay, as soft tissue injury is a source of potential blood loss, infection, insensible fluid losses, and temperature dysregulation and is additionally a source of pain and psychological distress to injured children and their family. The initial assessment of the injured child should follow the American College of Surgeons Advanced Trauma Life Support (ATLS) protocol, prioritizing life-threatening injuries in the initial evaluation, followed by a head to toe secondary survey. Soft tissue wounds may constitute a life-threatening injury if they involve major vascular structures or if ongoing blood loss causes hemodynamic instability. Certain types and patterns of injuries can indicate possible non-accidental trauma, especially the presence of polytrauma, posterior rib fracture, linear or patterned bruises and burns, and bruises and fractures in non-ambulatory patients.³⁻⁶

The unique physiology of pediatric patients puts them at a higher risk of significant morbidity and mortality from burns and traumatic wounds. Younger patients have thinner skin and a higher body surface area to volume ratio than do adults. As a consequence, children are more susceptible to higher insensible fluid losses, which can affect their hemodynamics faster than an adult patient with similar injuries, and temperature dysregulation, which can lead to or exacerbate coagulo-

pathy.⁷ Furthermore, skin thickness is directly correlated with age in pediatric patients; the younger the patient, the more sensitive the skin is to burns. For example, if part of a person's body is immersed in water heated to 130°F (54.4°C), an adult's skin will sustain a burn injury in 30 s, while a child's skin will be burned in 10 s, and in less than 5 s for an infant. An infant's skin will burn within 1 s if exposed to water heated to 140°F (60°C).^{6,7} It is therefore unsurprising that young children demonstrate such morbidity with the common scald burn.

Initial wound assessment

Initial assessment of traumatic wounds should characterize the type of injury sustained (Table 1). Thorough inspection of the wound is required to evaluate the size and depth of the wound, whether any deep or neighboring structures are injured, and whether there is any contamination or foreign body in the wound bed.

Total body surface area and fluid resuscitation. For all burn type injuries, including road rash, the depth of the burn and total body surface area (TBSA) should be calculated and documented. TBSA in children can be determined in multiple ways. A common method is the "Rule of nines," which subdivides the body into segments with surface areas that are multiples of 9%, modified for the pediatric patient at various ages to take into account the disproportionate size of the head and extremities in infancy and early childhood (Fig. 1). The Lund and Browder nomogram uses similar concepts, but segments the body into smaller subunits for more accurate assessment. Additionally, a rapid method to approximate TBSA is to use the surface area of the patient's palm, which represents ~1% TBSA.^{6,7}

Calculating TBSA is critically important for determination of the scope of the burn injury, for accurate communication with other healthcare providers on the treatment team, and to begin fluid

Table 1. Types of pediatric traumatic and burn wounds

Type of wound
Laceration
Abrasion
Road rash*
Open fracture
Scald*
Thermal burn*
Chemical burn*
Electrical burn*

Initial assessment of traumatic and burn wounds involves classification of the type of wound. Wounds marked with asterisk (*) require calculation of TBSA involved.

TBSA, total body surface area.

Figure 1. TBSA determination. Multiple methods of estimating TBSA for pediatric burn wounds exist. The "Rule of Nines," demonstrated on the right in an adult patient, subdivides the body into segments with defined surface areas that are multiples of nines, modified for the pediatric patient at various ages to take into account the disproportionate size of the head and extremities particularly in infancy and early childhood. A commonly used alternative is the "Lund and Browder" nomogram, which segments the body into smaller subunits for more accurate assessment. TBSA, total body surface area.

resuscitation. Multiple formulas have been developed to calculate the volume needed for appropriate fluid resuscitation, with variables usually consisting of the percent burn TBSA, weight of the patient in kilograms, and the body surface area of the patient in square meters based on their weight in kilograms. The two of the most commonly utilized formulas, and the two that are utilized at the authors' institution, are the Parkland Formula and the Cincinnati-Shriner's Formula for pediatric burn patients. The Parkland Formula is as follows:

$$4 \frac{\text{mL}}{\text{kg}} \times \% \text{ kg} \times \% \text{ TBSA} = x \frac{\text{mL}}{24\text{h}}$$

The Cincinnati-Shriner's Formula is as follows:

$$\left(4 \frac{\text{mL}}{\text{kg}} \times \% \text{ kg} \times \% \text{ TBSA} \right) + (1500 \text{ mL} \times \text{m}^2) = x \frac{\text{mL}}{24\text{h}}$$

These formulas are designed to give an estimation of the total volume of IV fluid a patient will need over the first 24 h period after the burn injury was sustained (not from time of clinical presentation). After the total volume is calculated, it is then divided in half; the first half of the total volume is given over the first 8 h, and the second half is given over the next 16 h. It is critical to recognize that these calculations are only an estimation, and these should be primarily used as a starting point in the resuscitation. Each patient will ultimately have different resuscitation requirements based on other components of their clinical picture at the time of injury. Additionally, in recent years the significant morbidity of over-resuscitation has been recognized.^{6,7} Urine output is the best available marker of fluid status in the resuscitative period.^{6,7} Therefore, the best way to proceed with IV fluid resuscitation in the burned pediatric patient

is to start the IV fluid at the calculated hourly rate, and then titrate the rate up or down based on the patient's urine output. For children less than 1 year, goal urine output is 2 mL/kg/h, and for children greater than 1 year, goal urine output is 1 mL/kg/h.

Not every burn patient requires IV fluid resuscitation. Children who are younger than 10 years require IV fluid resuscitation if their burns total greater than 10% TBSA. Children who are older than 10 years require IV fluid resuscitation if their burns are greater than 15% TBSA.⁷ In most cases, IV fluid of choice is Lactated Ringer's solution given its physiologic nature and lesser acidity when compared to normal saline. Children younger than 2 years have limited glycogen stores and may easily become hypoglycemic; they should therefore additionally receive D5 ½ normal saline as maintenance fluid during their resuscitation.

Below is a sample calculation of fluid resuscitation volume using the Cincinnati-Shriner's Formula for a 13-month-old child who is 10 kg (body surface area is 0.5 m² based on nomogram) and who sustained 11% TBSA burn:

$$\left(4 \frac{\text{mL}}{\text{kg}} \times 10 \text{ kg} \times 11\% \text{ TBSA}\right) + (1500 \text{ mL} \times 0.5 \text{ m}^2) = x \frac{\text{mL}}{24\text{h}}$$

$$(440 \text{ mL}) + (750 \text{ mL}) = 1190 \frac{\text{mL}}{24\text{h}}$$

- Total estimated volume to be given over 24 h is therefore 1,190 mL, with half of that volume (595 mL) given over the first 8 h (74.4 mL/h), and the second 595 mL given over the subsequent 16 h (37.2 mL/h).
- In addition, this child is less than 2 years, and therefore will require maintenance fluid containing dextrose to prevent hypoglycemia. She should therefore additionally receive 40 mL/h of D5 ½ NS.

Burn wound depth. Burns are further characterized by depth (Table 2). Superficial or first-degree burns, such as a sunburn, involve the epidermis

only, and appear as erythema. Although these burns can be painful and the dry epidermis does slough off, the barrier function of the skin is not compromised. Therefore, first-degree burns do not result in loss of fluid or pose an increased risk of infection, and so they are not included in the TBSA calculation. Partial thickness or second-degree burns extend into but not through the dermis. Partial thickness burns are further subdivided into superficial partial thickness and deep partial thickness. Superficial partial thickness burns penetrate into the papillary dermis and initially appear blistered and moist with blanchable erythema. Deep partial thickness burns penetrate into the reticular dermis and appear dry and either pale or with non-blanchable erythema. Full thickness or third-degree burns extend through the dermis and into the subcutaneous tissue. They are leathery and appear either white or charred. Fourth-degree burns extend into the deep structures such as tendons, muscle, or bone. All second, third, and fourth degree burns are included in the TBSA determination. It can often be difficult to initially determine whether a burn is partial or full thickness; in this case burns are recorded as indeterminate, and they are included in the TBSA calculation.

Pediatric burn transfer criteria. As part of the initial assessment of the child with burn injuries, it is essential to determine whether adequate care can be provided to the child at the current facility, or whether transfer to a specialized burn center is warranted. The American Burn Association has established recommended criteria for transfer for pediatric patients to a specialized burn center (Table 3).^{7,8}

Initial wound management

Irrigation. The first step in management of any traumatic wound is thorough irrigation, which serves to clean the wound and facilitate complete inspection. Sterile saline is the solution of choice due to ready availability and its isotonic nature, although studies show no difference in outcomes when using saline versus water⁹ or additives to fluids.^{10–12} The volume of irrigation should be sufficient to

Table 2. Burn wound characteristics

Type of burn	Depth of skin involved	Included in TBSA calculation	Considerations
First degree	Epidermis	No	No compromise of skin barrier function
Superficial partial thickness (second degree)	Papillary dermis	Yes	Appear blistered and moist, blanchable erythema
Deep partial thickness (second degree)	Reticular dermis	Yes	Appear dry, non-blanchable erythema
Full thickness (third degree)	Into subcutaneous tissue	Yes	Leathery appearance
Fourth degree	Deep structures (tendon, muscle, bone)	Yes	

Table 3. *Criteria for transfer of pediatric burn patients to a specialized burn center*

Criteria
Size of burn <ul style="list-style-type: none"> • $\geq 10\%$ TBSA Partial Thickness • $\geq 1\%$ TBSA Full Thickness
Smoke inhalation or suspected airway involvement
Burns to specific anatomic sites <ul style="list-style-type: none"> • Face • Hands • Feet • Perineum
Concomitant trauma or medical comorbidities
Age < 2 years
Lack of qualified personnel or equipment

clear all debris from the wound and to decrease the bacterial load. Animal models demonstrate that greater volumes remove more bacteria, and that greater volumes are required to achieve similar bacteria-reducing results when using low pressure versus pressurized irrigation systems.¹³ Studies suggest that while high-pressure irrigation, such as the wound irrigation systems by Stryker Surgilav™ or Zimmer Pulsavac Plus™, demonstrates superior early cleaning of the wound, tissue damage sustained during this irrigation technique contributes to rebound bacterial colonization 24 h after irrigation and subsequent wound healing delays. Therefore, although an ongoing multicenter trial comparing high and low pressure irrigation systems is not yet complete, existing evidence indicates greater efficiency at early removal of bacteria and debris from contaminated wounds with a possible late effect of tissue damage and wound healing delays.¹⁴ Additionally, earlier irrigation improves bacterial clearance: irrigation within 3 h decreases bacterial load by 70%, versus 52% at 6 h and 37% at 12 h.¹⁵ With irrigation, any clot that has formed will be disturbed, and bleeding may resume. Hemostasis may be achieved with direct pressure, or may require operative intervention with suture ligation of small bleeding vessels or more extensive exploration for vascular repair or ligation.

Debridement. Traumatic wounds will often require debridement as an integral component of wound management. Tissue devitalized by absent or tenuous blood supply is poorly penetrated by systemic antimicrobials and provides an ideal medium for bacterial proliferation.¹⁶ Debridement facilitates wound healing by removing necrotic tissue and contaminants to decrease bacterial load, control the inflammatory milieu, create a uniform

bed for eventual grafting or biologic dressing application, and to avoid traumatic tattooing.¹⁷ There are a variety of debridement techniques available, which may be suited to different types of wounds (Table 4). Debridement techniques can be broadly categorized into mechanical debridement, enzymatic debridement, and bio-debridement. Mechanical debridement includes wet to dry debridement, rough debridement, sharp debridement, and surgical debridement using strategies for enhanced sharp debridement or alternative tools such as the plasma knife or water jet. Enzymatic debridement uses either the body's own enzymes (autolytic debridement) or exogenous enzymes (*e.g.*, collagenase-based dressings) to break down and remove the necrotic tissue. Bio-debridement uses biologic agents (*e.g.*, maggots) to selectively remove necrotic tissue.

Debridement of burn wounds. Burn wounds are first cleansed with a mild antimicrobial detergent (*e.g.*, chlorhexidine). The mechanical action of rubbing the wound removes slough, exudate, and debris, allowing for improved assessment of the TBSA and depth of the burn. Wound cares are performed in a warm ambient temperature room to minimize temperature loss from the de-epithelialized skin. Almost all blisters, except those that are very small or over the palm and sole, are de-roofed; all other blisters will break at a later time, and the resultant crusting and sloughing of the blister contents disrupts wound healing by preventing a clean, uniform wound base.¹⁷ Once the wound has been debrided down to a clean base, ointment is applied to keep the skin moist and to provide a barrier protection from bacteria and debris. A wide variety of ointments have been studied, most commonly bacitracin and silver sulfadiazine, but no consensus has been reached on which may be most efficacious.¹⁸ A dressing is then applied to keep the

Table 4. *Debridement techniques*

Debridement type
Mechanical debridement <ul style="list-style-type: none"> • Wet to dry dressings • Rough debridement • Sharp debridement • Surgical debridement <ul style="list-style-type: none"> ◦ Enhanced sharp debridement ◦ Plasma knife ◦ Water jet
Enzymatic debridement <ul style="list-style-type: none"> • Autolytic debridement • Exogenous enzymes (collagenase-based, papain-urea)
Bio-debridement <ul style="list-style-type: none"> • Maggots

ointment in place, cover the wound, and prevent further trauma to the area.

The gold standard of debridement is conventional surgical debridement, which can take several forms. Full excision, removing skin down to or including fascia, was historically standard practice in excision of burns. However, although it definitively removed all necrotic tissue, it often resulted in major deformities. Tangential excision, removal of necrotic tissue by sequential layered excision of devitalized tissue to the level of vitalized tissue as evidenced by punctate bleeding, has replaced full excision as the standard technique. Tangential excision results in favorable cosmetic and reconstructive outcomes by limiting the amount of tissue excised to only that is necrotic, allows the surgeon to determine the true extent of the injury intraoperatively, and reduces mortality in burn patients.¹⁹ Varying knives are used to achieve specific effects; Goulian/Weck knives are used for excisions on surfaces with smaller area or more contours, requiring a higher degree of precision, whereas Watson or Humby knives are used on larger, flatter surfaces (Fig. 2).¹⁹ These knives can be fitted with skin guards to control the thickness of tissue excised. The surgeon further controls the thickness of

excision by varying the angle of the blade to the skin surface. Downfalls to tangential excision include the possibility of incomplete removal of devitalized tissue, uneven depth of tissue removal, and higher risk of clinically significant bleeding. Meticulous surgical technique, the use of electrocautery, and adjuncts including topical hemostatic agents, injection of a tumescent fluid containing dilute epinephrine below the area of excision, and tourniquet use on extremities lessen this risk.^{17,19} Methylene blue, which is preferentially taken up by non-epithelialized tissue, can be used to highlight areas of necrotic and nonviable tissue for debridement.²⁰

Timing of debridement. Excision before the natural separation of the eschar from the underlying tissue is defined as early excision, and excision done after this separation is late excision.¹⁹ Early excision prepares wounds that are not expected to achieve closure on their own within 3 weeks for closure. Historically, wounds were evaluated for signs that they would achieve closure without surgical intervention at the 10-day mark. Currently, tangential excision facilitates intraoperative determination of wound depth, allowing better and earlier characterization of the true depth of the burn, and minimizing the spread of the burn injury by removing neighboring necrotic tissue. Therefore, delayed excision is now rarely done, except in those wounds in which even intraoperative determination of burn depth is challenging (e.g., electrical burns). Additionally, there has been an increase in immediate excision, done within the first 24 h of injury.¹⁹ The goal of early excision is earlier wound closure, which in turn reduces burn sepsis and other wound-related complications.

Enzymatic debridement. Enzymatic debridement uses exogenous enzymes for selective degradation of nonviable tissue, sparing healing and healthy tissue. This technique can be used in patients with infected or contaminated wounds. Enzymatic debridement requires frequent wound cares, with application of the enzymatic agent either daily or twice daily after cleansing of the wound bed. Multiple agents are available, including collagenase and papain-urea, in ointment and spray form.²¹ These are applied directly to the wound bed after cleansing with either sterile saline or a pH-balanced solution. A dressing is then applied over the wound; gauze is most commonly utilized, although other options include non-adherent dressing, thin foams, and transparent film dressings. Enzymatic debridement is often used in combination with other debridement techniques,

Figure 2. Specialized knives for wound debridement. (A) Goulian/Weck knives are ideally suited for burns in small areas or contoured surfaces. (B) Watson or Humby knives are typically used on larger, flat surfaces. To see this illustration in color, the reader is referred to the web version of this article at www.liebertpub.com/wound

for example, following initial surgical debridement and used for serial debridement with bedside sharp debridement at each enzymatic agent dressing change. In a meta-analysis, collagenase was found to be more effective than placebo for debridement of pressure ulcer, leg ulcers, and partial-thickness burn wounds. Additionally, in children, there is evidence that debridement with collagenase achieves equivalent time to closure when compared to surgical excision alone, and that combined treatment may reduce the need for additional surgical excision.²¹

Technological advances in debridement. Several recent technologic innovations have emerged in mechanical debridement techniques. Hydrosurgery, using pressurized sterile saline coupled with a localized vacuum, has been developed to remove necrotic tissue while sparing viable tissue underneath.¹⁷ When compared with conventional dermatome escharotomy in a prospective, randomized control trial, the Versajet™ system was shown to be faster in burn debridement on small surface area, highly contoured areas (e.g., hand, face, genitalia), but slower in large areas (e.g., trunk, arms, legs).²² Its cutting width of 14 mm is ideal for small and contoured areas of excision, but it is suboptimal at debriding larger areas and excising full-thickness burns and tough, leathery eschars.²³ Plasma-mediated debridement, commonly referred to as the plasma knife or “coblation” technique, utilizes bipolar radiofrequency current between two electrodes in saline, exciting the electrolytes thereby creating plasma, which breaks the weaker molecular bonds within necrotic tissue preferentially over viable tissue.¹⁷ However, although it is able to minimize blood loss by debriding selectively the necrotic tissue, there can be tissue damage at the cut edges, leading to delays in re-epithelialization.²³

Choosing the location for debridement. Debridement can take place at the bedside and in the operating room. Bedside debridement can occur in the Emergency Department or in the Trauma Bay; as an inpatient in the PICU, Burn Unit, or general care ward; and in the outpatient setting in a clinic procedure room. Choosing among these locations is a function of the urgency of the debridement, the stability of the patient, the anesthetic requirement, and the type of equipment required. For example, a patient who presents to the Emergency Department with road rash on his leg, covering a total of 5% TBSA, and who is in severe pain may benefit from semi-urgent irrigation, debridement, and dressing in the Trauma Bay under moderate se-

dation provided by a Pediatric Emergency Medicine physician. In this case, the patient's pain, anxiety, and wound are addressed as efficiently as possible, resulting in a treated wound and placement of an appropriate dressing which will also contribute to pain reduction and facilitate getting the patient to the next phase of care. Frequently, patients who require serial debridement as a part of their ongoing wound care undergo these procedures at the bedside or in a specialized procedure room while an inpatient in the PICU or Burn Unit. Finally, patients whose wounds do not require inpatient hospitalization but do require ongoing specialized wound care may undergo minor debridement and wound cares in an outpatient clinic setting.

Bedside debridement consists principally of mechanical debridement, either by scrubbing the wound or sharp debridement. Bedside debridement should aim to remove devitalized tissue from the wound edges and, if present, from the wound bed itself. Depending on the age of the wound at presentation, particularly if it is a burn, exudate and biofilm may have already begun forming on the wound bed and should be removed completely. Biofilms consist of a polymicrobial colony of organizing bacteria in a matrix of protein, polysaccharide, and glycolipid; they form within hours of injury and are strongly associated with impaired wound healing.²⁴ Due to their adherent nature, they require vigorous mechanical cleaning to remove.

For bedside debridement, necessary supplies can be organized into four categories: anesthetic, sterile field, debridement, and dressing. Achieving sufficient anesthesia such that the patient is comfortable and calm is a critical component to the success of the debridement procedure in pediatric patients. Bedside debridement in appropriately selected patients can take place with a combination of local anesthetic, distraction techniques, anxiolytics, and/or sedation provided by an appropriately credentialed provider (these methods are further addressed below). Sterile field supplies should consist of a sterilizing solution such as chlorhexidine scrub and sufficient sterile drapes or towels to create the sterile field around the wound. Debridement supplies will consist of sterile saline for irrigation, gauze for mechanical scrubbing, forceps for tissue handling, and a scalpel (blade nos. 10 or 15, depending on the size of the wound and precision required). Dressing supplies should include the anticipated dressing to be placed after the debridement to keep the wound clean.

Indications for operative management of traumatic wounds in pediatric patients are similar to

that of adult patients, including more precise debridement and hemostasis that cannot be achieved without surgical instruments, exploration of deep or large wounds requiring anesthesia for patient tolerance, and maintenance of a sterile working field in large or difficult to access wounds. Special considerations for pediatric patients include their lower tolerance for painful and lengthy bedside procedures, and greater need for strict hemostasis and thermoregulation.

Supplies debridement in the operating room vary depending on the type of wound. For tangential excision, Goulian, Gumby, and Watson knives will be required depending on the size and anatomic location of the wound, with the smaller Goulian blade being used for areas with small contours such as the hands and feet. Any special equipment such as the Versajet or plasma knife should be ready if the surgeon anticipates using these tools for a particular case. An irrigation system should additionally be available in cases of contaminated wounds. Dressing supplies specific to the anticipated final wound at the end of the case should also be available. These supplies are discussed in detail below.

Pain management. Successfully managing pain and anxiety in the setting of acute injury evaluation and wound cares serves to ease patient and family discomfort, improves the ability to thoroughly examine and treat the wounds, and reduces the risk of the child developing post-traumatic stress disorder (PTSD) in the future.²⁵ Intravenous administration of fast acting opioids is the mainstay of treating acute pain in the pediatric patient. These can be combined with benzodiazepines to treat anxiety, or with ketamine or propofol to achieve sedation. Sheridan *et al.* have noted that increased opiate dosing in the first 7 days of hospitalization in pediatric patients who sustained major burns is associated with a significant reduction in stress levels and PTSD symptomatology.²⁵

Trained child life specialists, who use non-pharmacologic methods of play, preparation, and education to help the patient more effectively cope with their injuries, are key adjuncts to successful management of pediatric pain and anxiety and their family's situational anxiety. Child life specialists work directly with the child to help with age-appropriate understanding of the situation, engage the patient and their family with recreational and therapeutic play, and teach coping techniques. These members of the team are a great source of emotional support and education to the patient and their family, and allow the medical

team to work holistically and efficiently in the care of the patient.²⁶

Initial dressing management. Placement of initial dressings should occur early in the management of traumatic wounds, after cleaning and debridement. Dressings can be applied in the trauma bay, at bedside in the inpatient unit, or in the operating room after surgical debridement. Principles of wound dressings are to maintain a moist and clean wound bed with minimal mechanical disruption to facilitate reepithelialization, prevention of wound progression (which can occur with desiccation), preparation of the wound for closure, and control or reduce the microbial burden to minimize risk of developing a wound infection.⁶ Options range in sophistication from simple saline-moistened gauze to antimicrobial-impregnated dressings to negative-pressure wound therapy to biologic dressings.²⁷ In the trauma bay it is typical to apply simple dressings after bedside debridement. These consist of a medium to keep the wound bed moist, clean, and protected, with an overlying layer of gauze to further protect against debris and mechanical shear forces. An antibiotic-impregnated petroleum-based ointment can be applied directly on top of de-epithelialized skin, such as wound sustained from road rash or burns. Silver-impregnated ointment (*e.g.*, silver sulfadiazine) may also be applied to de-epithelialized skin as an antimicrobial ointment. Ointments generally require wound washing, removal of old ointment, and application of fresh ointment and dressings twice daily. Petroleum impregnated gauze products (*e.g.*, bismuth tribromophenolate-impregnated Xeroform), can be directly laid on the wound bed to retain moisture, and may also contribute antimicrobial properties. In highly exudative wounds, dressings are chosen to help manage this increased fluid production.²⁷ A foam-based dressing, with or without impregnated silver for antimicrobial properties, can be applied directly to the wound bed, secured with gauze or absorptive compressive dressings, and allowed to remain in place for up to 7 days.^{28,29} Alternatively, negative pressure wound therapy can be utilized to control wounds producing excess fluid.

A key consideration in choosing the appropriate dressing for pediatric traumatic wounds is the frequency and complexity of subsequent dressing changes. Pediatric patients can have substantial fear and anxiety surrounding dressing changes, related to both the pain of manipulating the wound and injured body parts, the psychological trauma of seeing the injury, and anticipatory anxiety related

to procedures. Depending on the patient's age, ability to tolerate dressing changes, and the size and complexity of the dressing, wound cares may take place at bedside with intravenous or oral analgesics and anxiolytics, in a procedure room with sedation, or in the operating room with anesthesia. When changing dressings at bedside, a multidisciplinary approach can facilitate a smooth and successful dressing change. Team members include specialized burn/wound nurses, child life specialists to help provide non-pharmacologic comfort and care of the patient during the procedure, pediatric anesthesiologist, and the surgeon. Wound care nurses are key team players, helping with both wound debridement and dressings in patients requiring serial debridement in the Burn Unit or PICU and with outpatient follow-up. Pharmacologic management should include premedication with longer acting analgesics and anxiolytics to help ensure optimal pain control both during and after the procedure. Fast-acting intravenous analgesics and anxiolytics should be administered in frequencies and dosages sufficient to achieve acceptable pain and anxiety control during the dressing change. Patients requiring high doses of these medications should have their dressings changed under sedation or in the operating room.

The type of dressing should be chosen to minimize discomfort and frequency of changes. Newer dressings, consisting of foam or hydrocolloid fiber sheets impregnated with silver (e.g., Acticoat, AquacelAg, MepilexAg), can be applied directly to the debrided wound bed and left in place for several days. These dressings absorb exudate and provide antimicrobial function by a sustained delivery of silver ions to the wound bed.³⁰ By reducing mechanical shear on the wound surface, providing padding, and substantially reducing the frequency of dressing changes, these dressings allow decreased patient pain and anxiety and decreased wound care responsibilities for the caregiver.^{6,27-29} AquacelAg has been shown to be superior to petrolatum gauze dressing with antibiotic ointment in reducing mean pain scores, number of dressing changes, nursing time, and time to reepithelialization while also increasing caregiver satisfaction.³⁰

Negative pressure therapy. Negative pressure therapy is a bridge technique used to promote wound healing before definitive closure in those wounds that are not amenable to immediate primary closure. Negative pressure wound therapy aids in achieving rapid time to granulation, decreasing time to definitive closure with either delayed primary closure, secondary intention, or soft tissue coverage with

grafts or flaps.^{31,32} Negative pressure therapy can be implemented using the commercialized vacuum-assisted closure therapy system or can be made from simple dressing supplies under an occlusive dressing attached to a suction device. Although it does require attachment to a suction source, it has the advantages of comfort while in place due to decreased mechanical shear and relatively infrequent dressing changes (every 48–72 h). It is applied to a clean and debrided wound bed; further debridement of nonviable tissue can take place at each dressing change until the wound bed is fully demarcated. Chariker *et al.* presented a series of 24 pediatric patients with complex upper and lower extremity injuries secondary to trauma treated with negative pressure therapy. Granulation was noted by day 4 in all wounds, and duration of vacuum therapy averaged 10 days with 3.4 dressing changes in wounds closed primarily and 17 days wounds closed by secondary intention.³¹ Multiple studies have described the mechanism of action of negative pressure wound therapy, which induces lymph and interstitial fluid movement in addition to blood flow and angiogenesis, thereby reducing edema and bacterial load, resulting in faster wound granulation and epidermal migration.^{31,32} Unfortunately, there is no consensus on the negative pressure settings, type of foam used, frequency of dressing changes, or adjunct layers used with negative pressure dressings in pediatric patients.³¹⁻³³ However, some recommendations can be made based on the available data. Because very young patients (<2 years) have a higher rate of granulation tissue formation, it is recommended to use V.A.C. WhiteFoam (polyvinyl alcohol foam) rather than the more commonly seen black V.A.C. GranuFoam (polyurethane foam) to prevent ingrowth of granulation tissue into the pores of the foam, which would then lead to increased wound trauma during dressing changes.³³ Additionally, because children younger than 2 years of age have more delicate skin and soft tissues and less soft tissue coverage over underlying structures, negative pressure from 50 to 75 mmHg is recommended. This reduced negative pressure does not seem to impact the length of time to wound healing, likely due to this age group's increased rate of granulation tissue formation.³³ For children older than 2 years, negative pressure from 75 to 125 mmHg is recommended.³³ There additionally is a paucity of data regarding the use of intermittent versus continuous negative pressure settings in pediatric patients. Existing data indicate that intermittent settings promote faster granulation tissue formation due to the increased microdeformation of the wound stimulating increased angiogenesis; however, the frequent change

in pressure may be too painful for some pediatric patients to tolerate.^{31,33}

SUMMARY

The care of pediatric trauma and burn-related wounds requires prompt assessment, pain control, cleansing, debridement, and application of appropriate dressings. Ideally, a knowledgeable multidisciplinary team cares for these patients. A limitation in the care of these patients is the relative paucity of data specific to the care of acute traumatic wounds in the pediatric population. The vast majority of the wound care literature comes from the adult chronic wound population. Much of the available literature on traumatic wounds comes from the military population, in which blast wounds and other etiologies of traumatic wounds that are uncommon to the civilian population are a high proportion of the wounds studied. Although wound care strategies have been successfully extrapolated to the pediatric acute wound population, practicing truly evidence-based medicine will not be possible until the data specific to these patients is available. In some areas, however, the pediatric literature is well developed. The study and practice of multidisciplinary care in the injured child has made significant progress in recent years, leading to the advent of multimodal analgesic and anxiolytic strategies, child life services, specialized nursing care, and subspecialized surgical care of pediatric traumatic wounds. Research is ongoing in the arenas of new debridement techniques and instruments, and in wound dressing technology. Dedicated research on these topics in the pediatric population will serve to strengthen and advance the care of pediatric patients with acute traumatic and burn wounds.

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TAKE-HOME MESSAGES

- The care of pediatric trauma- and burn-related wounds requires prompt assessment, pain control, cleansing, debridement, and application of appropriate dressings.
- The majority of the wound care literature comes from the adult chronic wound population, with a relative paucity of data specific to the care of acute traumatic wounds in the pediatric population.
- Research is ongoing in the arenas of new debridement techniques and instruments, and in wound dressing technology.

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Abbreviations and Acronyms

ISPeW = International Society for Pediatric Wound Care
 PTSD = post-traumatic stress disorder
 TBSA = total body surface area