Wound Management of Pediatric Burns

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Abstract

The goal for treating pediatric burns is to allow the patient to heal with as little scarring as possible. Compared to older children and adults, very small children have anatomic differences that alter their treatment. They have thinner skin that leads to a higher risk for full-thickness burns. Children also tend to freeze when touching a hot item, so that the prolonged contact also leads to deeper burns. Two healing strategies are needed to treat these wounds. One must optimize reepithelialization in superficial burns to reduce scarring. Deeper burns require skin grafting, but there are techniques, such as the use of "sheet" autograft skin that lead to excellent outcomes. Strategies to treat the massive pediatric burn will also be covered. Finally, there are instances where different strategies are needed to cover exposed bone or tendon. The ultimate goal is to return the skin to as normal a state as possible.

Keywords
- children
- burns
- wound healing
- scarring
- skin grafts

Burn care in the pediatric patient can be more challenging than it is for an adult. While the principles of healing are the same, there are differences in the very young child when compared to more mature children and adults. There are also burn etiologies and pattern differences that produce burns dominating different age groups. The other issue for children is that even if they heal well, they may outgrow their scars, so they need close follow-up to ensure that their ultimate outcome is maximized. The goal is always to try to optimize functional and cosmetic outcomes. This paper will review how differences in anatomy and physiology influence wound care. The classic pediatric burns and their treatment will also be described. Treatment varies depending on the depth of the burn. For superficial burns, the goal is to optimize reepithelialization so that scarring is minimized. Deeper burns typically, but not always, require skin grafting. Techniques for optimizing skin grafting outcomes will also be described. Finally, strategies for dealing with extremely deep and extensive burns will be described. While initial care is important, it should be remembered that burn scars evolve slowly over the subsequent year. During this time, it is essential that there is a strong scar management plan in place.

Age-related Skin Differences

Prior to discussing the differences between pediatric patients and adults (starting postpuberty), it is important to consider the four key factors that influence burn depth: temperature of the burning agent, duration of contact, skin thickness, and skin vascularity. Obviously, the temperature of the burning agent influences burn depth. Clearly, contact with metal at 1,000°C will lead to a deeper burn than one at 90°C. This principle is a little more complicated since how the temperature is transmitted influences the burn. For instance, direct contact with metal or liquid will transfer heat more efficiently than superheated air; thus, a scald will be deeper than an electric flash at the same temperature. The minimum temperature required to burn the skin is around 43 to 44°C (110–111°F).[1,2] After that temperature, the duration of contact influences burn depth in a hyperbolic way. Moritz and Henriques demonstrated that for an adult, it would require 10 minutes to develop a full-thickness burn (from hot water) at 120°F, but only 1 second at 160°F.[1] This classic teaching is the basis for many regulations setting water heater temperatures at 120°F. The concept that thinner skin is more prone to full-thickness burns than thicker skin makes sense. Finally,

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the blood supply in the skin can diffuse heat and thus more vascular skin (such as in the face), will tend to have more superficial burns than those areas with poor blood supply.

These same principles need to be remembered when treating young children. There is a common belief that young children have skin that is more immature and thinner than adults. While to some extent there are age-related differences in skin qualities, the differences are not extreme. Studies looking at transepidermal water loss have demonstrated that babies born at term have epidermal function that is close to that of adults.[3,4] While epidermal maturation is complete at 34 weeks,[4] the fetus protects its skin from moisture during the last trimester in utero by creating a protective layer called *vernix caseosa*.[3] This layer is lost, however, after delivery; therefore, premature babies tend to lack the ability to prevent water loss until approaching term. Another dogma is that very young children have skin that is much thinner than adults. This concept is true, but this difference is not that extreme.[5–8] Studies using ultrasound comparing skin thickness between infants, postpubertal, and adult skin found that the differences are not that marked. The range in skin thickness between children starting at 2 months and increasing to adulthood were between 0, less than 0.5 mm, and never more than 0.8 mm, in difference. Therefore, while one should be careful with harvesting thicker split-thickness donor sites in the very young patient, the difference is not profound. It was also noted that different parts of the body had thicker skin. Skin from the abdomen or back was always thicker than the thighs. The difference in skin thickness is useful when harvesting donor sites. The back has thicker skin so it tends to scar less than thigh donor sites.[9] Interestingly, all studies demonstrated that skin thickness increased with increasing body mass index. Full-thickness skin harvested from obese patients, especially in the abdomen, have noticeably thicker dermis. Thinning the dermis is often needed to prevent epidermolysis of the graft due to inability to have nutrients penetrate the thick dermis.

There are other anatomic differences that are also important to remember with children. The younger the child, the higher the surface area to mass ratio, so that children are prone to heat loss than adults. Pediatric patients frequently need to have operating room temperatures raised to high levels just to slow heat loss. The surface areas of their thighs are smaller, so relatively less donor skin is available from thighs. The surface area of the head is greater, so more is available from the scalp. Very young children have relatively more adipose tissue which can be protective. Young children have a significant amount of subcutaneous fat in their fingers which is missing in adults. This fat may provide a barrier from underlying tendons so that grafts can be placed. Finally, their small size is an advantage since it is easy to move children, such as roll them on their sides for donor sites. One must remember, however, that a child's growth is a disadvantage since their scars do not grow as fast as they do. Therefore, there is a need for burn reconstruction as scars get tighter as they increase in size.

Classic Pediatric Burn Patterns

There are classic burn patterns in children that are age-dependent. A relatively common burn in newborns results from using warmers on their heels to improve blood draws. If the warmer is too hot or placed for too long, then deep burns can occur. Intravenous extravasation of the greater saphenous vein can also lead to full-thickness skin loss (not really a burn). Infants have little ability to escape burn injuries, so they are prone to severe burns. On occasion, parents place candles near sleeping babies and these "crib burns" can be severe. Fires after car crashes with the infant in a car seat can also lead to very deep burns. Parents drinking hot drinks while holding their children occasionally spill their drinks to cause scald burns at the areas where the liquid contacts them.

Toddlers are especially prone to burns. If one looks at the frequency of burns per age, there are two peaks, during the early pediatric period and later in young to middle-aged adults. Scalds are the most common cause of burns in children, while flame burns dominate in teenagers and adults.[10] Toddler burns are tied to their newfound mobility. Parents often have not moved items out of reach as soon as the child can creep or walk. They will tend to reach for hot liquids and pull them down. Soup spills are a common cause of injuries.[11,12] Scald burns are also a common cause of child abuse burns.[13] Burn-related child abuse peaks at the time of toilet training, therefore, toddlers are at greatest risk. The key to determine intent of injury is to match the "story" with the burn pattern. One should consider the pattern to follow two simple principles: (1) the burn occurs where the water touches the patient and (2) water follows the law of gravity. If hot liquid spills on a child, there is a classic "V-shaped" pattern as a larger volume contacts the top of the child and then narrows as the liquid drips down (►**Fig. 1**). In addition, if the child is wearing clothing, the soaked cloth keeps the water in contact longer and leads to a deeper burn. For instance, if hot water soaks a diaper or a T-shirt collar, that area will be deeper. If a child is dipped in hot water (typical abuse burn), they will have a uniform depth burn where the top of the water demarcates the burn edge (►**Fig. 2**). Typically, the child has his/her legs bent, and they enter the water heels and buttocks first. The skin is spared where skin folds touch, such as between the lower thighs and upper calves, or the inguinal creases. If the story provided by the person with the child does not match these patterns, the suspicion for abuse is higher.

Contact burns are also very common burn in pediatrics.[14] Toddlers will frequently creep along walls and will touch hot surfaces, such as an oven door, or fireplace that is flush against the wall. They also explore the world with their hands so they will touch irons, grills, and any hot item. Unlike adults, children "freeze" when contacting the hot agent, which results in deeper burns from prolonged contact (►**Fig. 3**). Young children will also place items in their mouths, therefore electric burns from chewing on electric cords lead to small but cosmetically significant commissure burns.

Fig. 1 The classic pattern of an accidental scald burn has a "V-shape" as the fluid courses down the chest. The burn is also of variable depth.

Once puberty is reached, hormones, especially testosterone, tend to lead to more risky behaviors in boys. Prior to this time, there is no gender predominance in burns, but after puberty, burns in males dominate until late in life. Teenage boys tend to play with flammable agents and fireworks. Suicides by burning also tend to increase. From puberty on, flame burns become the most common type of burn.

Healing of Superficial Burns

It is well-documented that the chance of developing a hypertrophic scar increases with delayed closure greater than 2 to 3 weeks.[15,16] This principle mainly applies to partial thickness (second-degree) burns and wounds. The key type healing for partial thickness wounds is through reepithelialization. The epithelium is made up of multiple layers of epithelial cells (keratinocytes) that create an effective barrier to microorganisms and prevent water loss (►**Fig. 4**). The bottom layer contains "basal" stem cells that have the potential for migration and proliferation to reepithelialize a wound. When uninjured, the basal cells eventually differentiate to become flat squamous cells that create the barrier. When the epithelium is transected, there are three stimuli that induce epithelial migration. The keratinocytes on the edge lose cell–cell contact inhibition so they are free to migrate over the viable wound bed. In addition, growth factors, especially epidermal growth factor, transforming growth factor-α, and keratinocyte growth factors 1 and 2 stimulate epithelial migration and proliferation. Finally, specific proteins contacting the basal cells may inhibit or stimulate migration. When an epithelial cell contacts proteins of the epidermal–dermal basement membrane (lamininis, type IV collagen), they tend to stand still. When they contact the proteins of the provisional wound matrix (fibronectin, type I or III collagen), they are stimulated to migrate.[17–20]

The migrating epithelial cells will migrate only 1 to 2 cm from the original wound edge, so if the burn is full-thickness, the wound will only heal by contraction. Wound contraction occurs after fibroblasts have deposited collagen as a matrix. Special fibroblasts, called myofibroblasts, grasp the collagen and contract by using myosin and α-actin (like muscle) to pull the edges together. When this process occurs in an area with little tension, such as the buttocks, then it closes the wound expeditiously. Unfortunately, contraction persists for months, and if it occurs over functional areas, it leads to contractures that are some of the most common complications in burns (►**Fig. 5**). Since children grow faster than their scars expand, they tend to be more prone to contractures

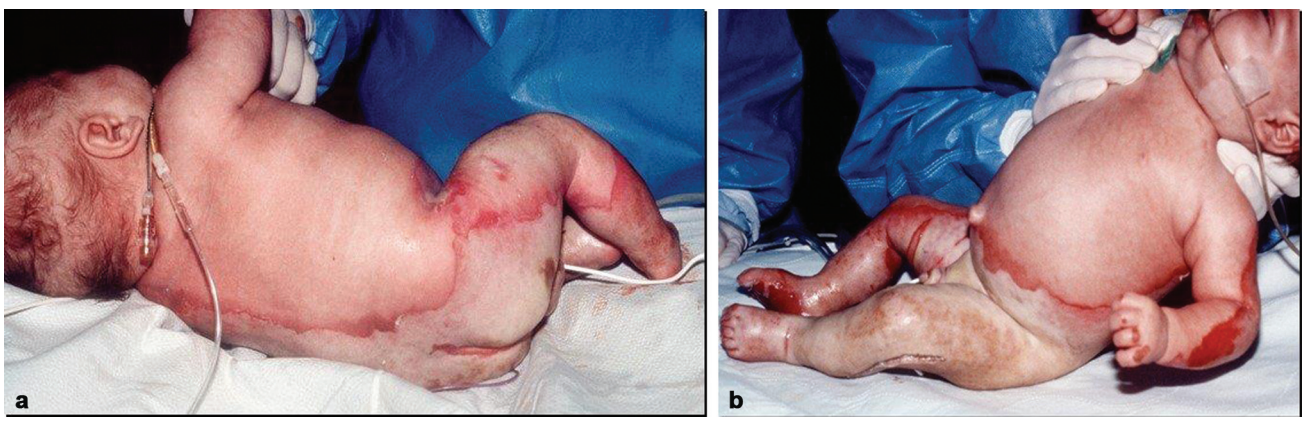

Fig. 2 The classic pattern of a child being "dipped" in hot water reveals a well-demarcated line that marks the upper-level water in a tub (**a**, **b**). The burn is of uniform depth. This is the pattern that raises concern for child abuse.

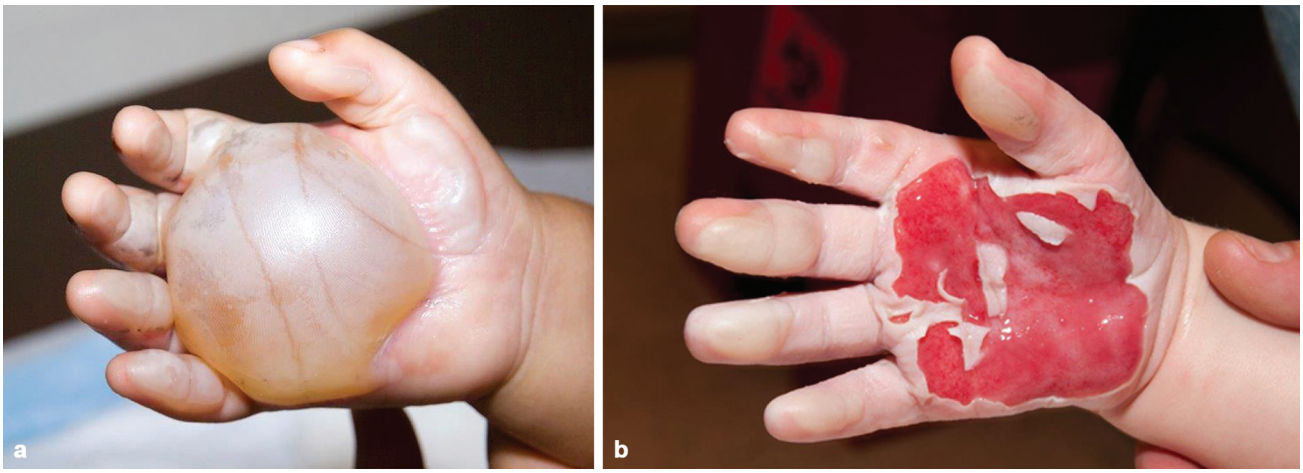

Fig. 3 Contact burns of the hand are very common in toddlers as they touch and freeze when touching a hot surface. In this case, the patient had a thick blister (**a**), that when removed, revealed a deep partial thickness burn (**b**).

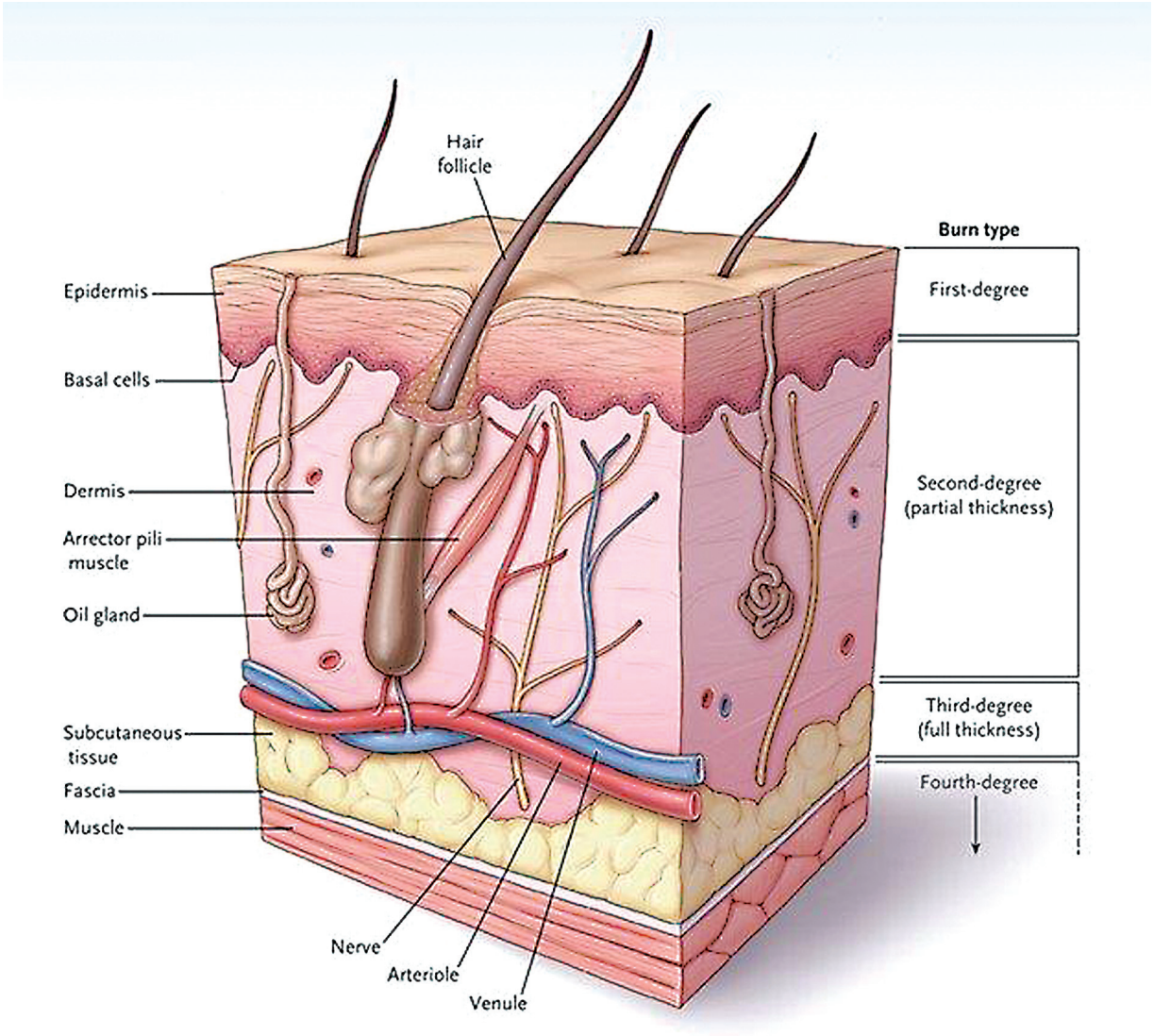

Fig. 4 The epidermis is made up of multiple layers of keratinocytes that differentiate to create an effective barrier to microorganisms and water. The bottom layer, called the basal cell layer, has the potential for proliferation and migration. (Reproduced with permission from Greenhalgh 2019[10].)

Fig. 5 A typical contracture that "pulls" edges of wounds together. Axillary and neck contractures are very common in children.

than adults. For superficial partial thickness burns, skin adnexa remains within the wound. Stem epithelial cells within the hair follicles, oil glands, etc., migrate to the surface of the viable wound and contribute to the development of a new epithelium (►**Fig. 6**).

Since the goal is to get the wound to reepithelialize within 2 to 3 weeks, one must try to avoid factors that delay epithelial migration. It is easier for epithelial cells to migrate across a moist wound than a dry wound. When a superficial wound dries, it develops a "scab" that is made of dried fibrin and serum proteins. Cells must use proteases, such as fibrinolytics, to "dissect" their way between the scab and the underlying viable tissue. This is why a scab persists until the epithelialization is complete. Therefore, one should always try to maintain a moist environment within a partial thickness wound. Ointments, with or without antimicrobial agents, work well, as long as the wounds are not allowed to desiccate. Ointments should be applied with a nonstick dressing, and they need to be changed daily. Many studies have shown that silver sulfadiazine tends to delay reepithelialization,[21] so it should be avoided when trying to get a partial thickness wound to heal within 2 to 3 weeks and minimize the chances for hypertrophic scarring. One of the best advances in wound care for superficial wound has been the development of "extended," "closed," or "biologic" dressings that are designed to adhere to the wound, maintain the optimal environment for epithelialization, and can be left in place for around a week. They can be applied as an outpatient after washing the wound and checked a week later. They have reduced the need for inpatient admissions since once the wound is covered, pain is greatly reduced. Typically, patients can be treated with acetaminophen if needed. Children often require no pain medicines. Finally, it is likely that spraying a fresh, superficial wound with autologous epithelial cells using the RECELL Autologous Cell Harvesting Device™ (AVITA Medical, Valencia, CA) would accelerate reepithelialization.[22] The only issue would be that a donor site must be harvested from the child in order to produce the spray-on cells.

Healing of Deep Burns

The strategy for dealing with deeper wounds is different than for superficial burns. Deep wounds will contract, which is

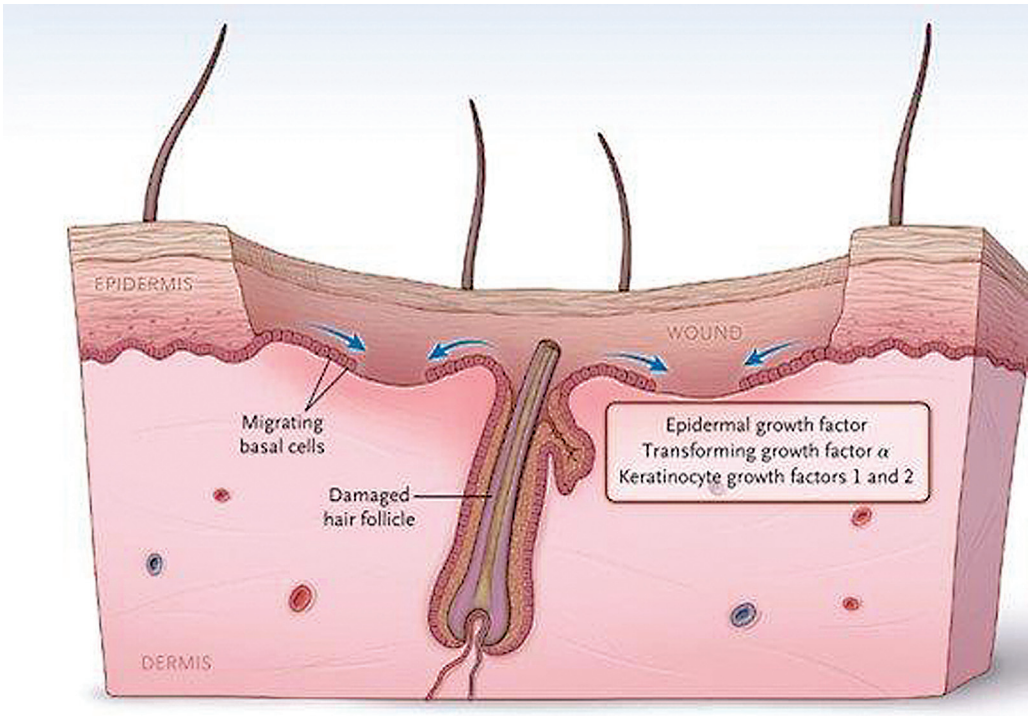

Fig. 6 Basal cells migrate from the wound edge and stem epithelial cells migrate up from skin adnexa to resurface a superficial wound. (Reproduced with permission from Greenhalgh 2019[10].)

Table 1 Principles that optimize skin graft functional and cosmetic outcomes

• Thicker grafts contract less than thinner grafts
• Place thicker grafts on more functional or cosmetic areas (hands, face, neck, upper chest)
• Balance graft thickness with the risks for donor site scarring
• Back donor sites scar less than thigh grafts
• Hide donor sites, when possible, avoid donor sites from cosmetic areas
• Sheet grafts do better than meshed grafts
• Grafts can be placed immediately on fat. There is no need to "prepare" the wound bed with a temporary graft.
• Reduce tension in the seams using "darts"
• Remember donor color differences on the face
• Earlier excision reduces intraoperative blood loss compared to delayed grafting

useful for small areas with loose surrounding tissue. A small buttock burn will contract to create a small, relatively unnoticeable scar. On occasion, allowing a small area to contract and form a scar is a reasonable option for spotty areas of deep burn. For children, the classic accidental scald burn to the chest will occasionally have small areas that remain open for 2 to 3 weeks, while the majority heals within 10 days. Placing small grafts on those deeper areas leads to a worse cosmetic outcome than leaving those areas to scar. The decision to graft or wait for those injuries takes some experience.

Most deeper burns do better with skin grafts. There are principles of skin grafting that one must consider in optimizing cosmetic and functional outcomes (►**Table 1**). Thicker grafts will resist contracting more than thinner grafts.[23] For massive burns, thicker grafts should be used on more functional or cosmetic areas, such as hands, upper chest, or face. One must remember, however, that split-thickness skin graft donor sites have the same potential for developing hypertrophic scarring as a partial thickness burn. Therefore, one must take as thick a graft as possible while minimizing the risk for donor site scarring. One strategy is to harvest skin from the back since the skin is thicker than other areas. At least one study demonstrated that scarring is higher in thigh donor sites than those taken from the back.[9] Harvesting from the back is easier in children than it is for large adults. One must also remember that it is best to harvest from an area that can be hidden, such as in the shorts area. It is easier to harvest a donor skin along the length of a thigh, but if it scars, it will be more noticeable while wearing shorts. Harvesting a split-thickness donor skin in a circumferential fashion on the upper thigh can be hidden with shorts (►**Fig. 7**). One should avoid harvesting from areas that are commonly exposed, such as from the upper chest or back, especially for girls who may wear clothes exposing those areas. Sheet grafts (grafts without meshing) are always more cosmetically acceptable than mesh grafts since the mesh pattern is permanent.[24] One must try to avoid straight seams between grafts, since straight lines tend to create more tension and lead to more scarring.[25–27] The best way to avoid straight lines is to create "darts" in the skin edges and overlap the grafts (►**Fig. 8**).[28] One should be aware of different colors of skin when placing a graft. Skin grafts from below the clavicle tend to be of different color than skin from above. During face grafting, this color difference should be considered when possible.[29] In addition, one should consider aesthetic units when placing seams on face grafts.[30]

Many strategies for grafting can be described using common pediatric burns. Toddlers tend to explore their environment with their hands and mouths. When they touch hot items (irons, fireplaces, stoves, grills) they freeze which leads

Fig. 7 Harvesting split-thickness skin from the upper thigh allows it to remain hidden with short pants.

Fig. 8 Creation of "darts" at the seam between grafts will reduce tension and reduce hypertrophic scarring. The top of the foot has a zigzag seam that does not create tension.

to prolonged contact. Therefore, deep contact burns to their palms are quite common and around 10% require grafting.[14] Outpatient full-thickness skin grafts are easily performed in these children. Under general anesthesia and using a tourniquet, the burn is excised with a Goulian knife down to bleeding tissue. The preferred site for full-thickness donor skin is from the opposite inguinal crease (in case the child needs a groin flap). An ellipse of skin is harvested from crease so that the incision lines up at the previous inguinal line. The incision is closed primarily with slow-dissolving sutures. The donor skin has the fat trimmed with scissors, and on occasion, the dermis is also thinned if it appears too thick. Hemostasis is completed at the recipient site and the graft is sutured in place. The sutures are left long for a tie-over bolster. Once the graft is in place, it is covered with a nonadherent dressing and cotton soaked in saline. The entire hand, except for the fingertips, is wrapped in more cotton, a gauze wrap, and then a self-adherent elastic wrap is applied to create a "soft cast." The self-adherent elastic wrap is very durable and extremely difficult for the child to remove. The patient is sent home with acetaminophen and instructed to keep the dressing dry. They return in 1 week where the dressing and bolster are removed, and therapy is initiated (►**Fig. 9**). Since palms (and soles of feet) lack pigment, most grafts end up hyperpigmented. The alternative of harvesting skin from the plantar foot leads to poor skin and significant pain on the foot.

Split-thickness skin grafts are typically performed as an inpatient since there is significant pain associated with the donor site. As stated in the above principles, one should strive for the best cosmetic and functional outcome especially when dealing with potentially exposed areas. For instance, for a young girl with a full thickness burn to her upper chest, any significant scarring or meshed pattern will be noticeable when she wears a "V-neck" or short sleeve shirt. The goal should be to minimize the number of seams and use a relatively thick "sheet" autograft. There are 6-inch-wide dermatomes that allow for harvesting wide skin, and when used on the back, skin can cover a large area (►**Fig. 10**). In a similar fashion, a 6-inch piece of skin can cover an entire hand in a child (►**Fig. 11**), and the majority of a hand in an adult. Sheet grafts can cover larger burns but as the area increases, so does the donor site. Typically, the harvested skin tends to shrink by around 20%, so one must always take more

Fig. 9 A full-thickness skin graft to a contact burn is easily performed as an outpatient. Other than pigmentation of the palm, the graft functions well.

Fig. 10 A large 6-inch piece of skin can cover a large, cosmetically important area with excellent results. A meshed graft would be much more noticeable.

than what is apparent. Harvesting the full width with the 6-inch dermatome takes practice, since the blade will not reach all skin with a curved surface. Injection of lactated Ringer's solution with epinephrine will allow for a flat surface with equal firmness to cover the entire width. The use of a roller pump to inject the "clysis" solution is helpful. Sheet grafts must be checked for hematomas or seromas on postoperative day 1. If there is any fluid collection, the skin should be nicked, and the fluid should be removed. Range of motion can be started on postoperative day 5.

When dealing with medium-sized (15–30%) full-thickness burns, one must consider preoperative planning. Since children have a higher surface area to mass ratio, they lose heat faster than adults. Therefore, raising the temperature in the operating room tends to reduce but not eliminate heat loss. It is not uncommon for operations to be performed at 85 to 95°F. One must also prepare for potential transfusions. One study suggested that pediatric burn patients lose around 2% of blood volume per percent burn excision.[31] So, if one is planning to excise and graft bilateral legs and feet (around 26% in an infant), then one must prepare for a loss of approximately 50% of blood volume. One must type and cross the patient for the appropriate amount of blood to avoid intraoperative problem. Despite the large area, sheet grafts may still be used on cosmetically important areas. The use of sheet grafts on the hand with meshed grafts on the arms is still a good option (►**Fig. 12**).

Full-thickness grafts to the face require more preparation and skill. The face is more vascular, therefore a patient may lose up to 4.5% of a blood volume per percent burn excision with a face excision.[31] In an infant, the entire head is approximately 18%, so the child may lose approximately 80% of a blood volume during the excision. Injection of epinephrine containing lactated Ringer's solution (2 mL of 1/1,000 epinephrine per liter) will reduce the blood loss. Excision of the eyelids, nose, and lips is more tedious but important if needed. The flatter areas of the face (forehead, cheeks, chin) should be done expeditiously. If feasible, rapid, and deep enough excision should be performed prior to spending a great deal of time with hemostasis, since subsequent excisions will restart bleeding. After the face is completely excised, meticulous hemostasis is required. Some surgeons feel that the face will require allografting or placement of a dermal substitute, but immediate autografting is often successful.

Skin harvested from below the clavicle is darker than that harvested above. Therefore, for small face burns, the scalp is a better color match (►**Fig. 13**). Scalp donors have the advantage of healing quickly (as soon as 4–5 d) since the hair follicles are so close together. Skin harvested at approximately 12/1,000th of an inch leaves the hair follicles behind (so the scalp hair grows), and little hair is transferred with the graft. Thicker grafts, however, will transfer hair and if very thick, can lead to alopecia. In addition, the short remnant hairs will act as a foreign body and lead to inclusion cysts. The best way to optimize a scalp donor is to harvest it around 12 to 13/1,000th of an inch and scrape away the hair from the dermal side. Never scrape from the epidermal side since it will destroy the epidermis and ruin the graft.

Grafts should be placed so that seams are place at the junctions of aesthetic units (at the eye level, nasolabial folds, chin lines). One should avoid seams in the middle of the forehead or cheeks if possible. One technique that minimizes seams is to harvest a wide piece of skin in a "U" or "C" shape so that the donor skin can be "wrapped around" the entire face with only one seam.[29,32] This technique has led to excellent long-term results.

Fig. 11 This figure reveals the initial burn of a 19-month-old child (**a, b**). A 6-inch piece of skin was used to cover the majority of the hand (**c, d**). Contractures are common as the hand grows, but with a few simple releases with full thickness grafts, the ultimate outcome can be excellent 10 years later (**e, f**).

Covering the Pediatric Massive Burn

Pediatric patients with massive burns (80–90%) are a significant challenge, but many children survive the massive burn.[33] Early excision has been found to be of great benefit.[34–37] In addition, earlier excision and grafting usually reduces intraoperative blood loss.[38] Our strategy is to excise the obviously full-thickness burns within the first 3 to 4 days postburn. The second day after the burn (after initial excision), the burns of the extremities and anterior trunk is excised. We use a large team so that each surgeon works on an extremity or trunk. Typically, a tracheostomy is performed prior to the excisions. Any donor skin is harvested and typically placed on the hands and arms. If there is enough skin, the feet are covered. We use smaller mesh ratio (1:1 to 2:1) on functional areas (hands, feet) and wider mesh on the remaining areas. The use of RECELL Autologous Cell Harvesting Device™ (AVITA Medical, Valencia, CA) on the wide mesh has greatly helped closing the mesh.[39] Once the donor skin is utilized, we use Novosorb® Biodegradable Temporizing Matrix (BTM; PolyNovo, Port Melbourne, Australia), to cover the remaining areas. On the next day, the back is excised and covered with BTM, and the following day the face is excised and covered with BTM. At the same time, skin is harvested for cultured epithelial autograft.

Fig. 12 Even with larger areas, sheet grafts on hands still improve functional and cosmetic outcomes. The contrast between the sheet graft on the hand with the wide mesh graft on the arm is very apparent.

Fig. 13 A scalp graft that has had the hair removed leads to an excellent color match.

When donor sites heal, the BTM is delaminated and covered with a wide mesh and RECELL. When the cultured epithelial autograft is available, a 6:1 meshed autograft skin is placed on the delaminated BTM, and the cultured epithelial autograft skin is placed over the widely meshed autograft skin. Typically, the face is the last area covered and except for extreme cases, sheet grafts are used on the BTM. This strategy has been successfully used on several massively burned children.

Fourth-degree Burns

Burns that expose tendon or bone are difficult to treat. While many of these burns may require flaps, some of these burns can be treated with simpler techniques, especially in children. Since children tend to have better blood supply, some areas with exposed tendons can be closed with grafts or dermal substitutes. With small exposures of tendons, on occasion placing an autograft skin will cover most of the wound and the vascular supply will eventually cover the tendon. Many times, dermal substitutes (Integra or BTM) can be placed, and tendons will vascularize over the ensuing weeks.[40,41] Autografts can then be successfully placed. When skull is exposed, burring the outer table will allow for granulation tissue to grow from the viable marrow. In young infants, if the bleeding is brisk enough, Integra or BTM will vascularize to allow for autografting.

Conclusion

There are strategies to minimize scarring and optimizing outcomes for pediatric burns. The goal should optimize reepithelialization in superficial burns to reduce hypertrophic scarring. Full-thickness grafts are an excellent choice for small functional areas, and they can be performed as outpatients. Larger burns require admission, but the use of wide sheet grafts can lead to excellent results. Strategies change, however, when dealing with larger burns. Despite these challenges, children do amazingly well with burns of all sizes.

Conflict of Interest
None declared.

References

1 Moritz AR, Henriques FC. Studies of Thermal Injury: II. The relative importance of time and surface temperature in the causation of cutaneous burns. Am J Pathol 1947;23(05):695–720
2 Greenhalgh DG, Lawless MB, Chew BB, Crone WA, Fein ME, Palmieri TL. Temperature threshold for burn injury: an oximeter safety study. J Burn Care Rehabil 2004;25(05):411–415
3 Visscher MO, Adam R, Brink S, Odio M. Newborn infant skin: physiology, development, and care. Clin Dermatol 2015;33(03): 271–280
4 Oranges T, Dini V, Romanelli M. Skin physiology of the neonate and infant: clinical implications. Adv Wound Care (New Rochelle) 2015;4(10):587–595
5 Seidenari S, Giusti G, Bertoni L, Magnoni C, Pellacani G. Thickness and echogenicity of the skin in children as assessed by 20-MHz ultrasound. Dermatology 2000;201(03):218–222
6 Derraik JG, Rademaker M, Cutfield WS, et al. Effects of age, gender, BMI, and anatomical site on skin thickness in children and adults with diabetes. PLoS ONE 2014;9(01):e86637
7 Saitoh A, Aizawa Y, Sato I, Hirano H, Sakai T, Mori M. Skin thickness in young infants and adolescents: applications for intradermal vaccination. Vaccine 2015;33(29):3384–3391
8 Van Mulder TJS, Van Nuffel D, Demolder M, et al. Skin thickness measurements for optimal intradermal injections in children. Vaccine 2020;38(04):763–768
9 Greenhalgh DG, Barthel PP, Warden GD. Comparison of back versus thigh donor sites in pediatric patients with burns. J Burn Care Rehabil 1993;14(01):21–25
10 Greenhalgh DG. Management of burns. N Engl J Med 2019;380 (24):2349–2359
11 Greenhalgh DG, Bridges P, Coombs E, et al. Instant cup of soup: design flaws increase risk of burns. J Burn Care Res 2006;27(04): 476–481
12 Palmieri TL, Alderson TS, Ison D, et al. Pediatric soup scald burn injury: etiology and prevention. J Burn Care Res 2008;29(01): 114–118
13 Hummel RP III, Greenhalgh DG, Barthel PP, et al. Outcome and socioeconomic aspects of suspected child abuse scald burns. J Burn Care Rehabil 1993;14(01):121–126
14 McBride JM, Romanowski KS, Sen S, Palmieri TL, Greenhalgh DG. Contact hand burns in children: still a major prevention need. J Burn Care Res 2020;41(05):1000–1003
15 Deitch EA, Wheelahan TM, Rose MP, Clothier J, Cotter J. Hypertrophic burn scars: analysis of variables. J Trauma 1983;23(10):895–898
16 Chipp E, Charles L, Thomas C, Whiting K, Moiemen N, Wilson Y. A prospective study of time to healing and hypertrophic scarring in paediatric burns: every day counts. Burns Trauma 2017;5:3
17 Woodley DT, Bachmann PM, O'Keefe EJ. The role of matrix components in human keratinocyte re-epithelialization. Prog Clin Biol Res 1991;365:129–140
18 Woodley DT, Chen JD, Kim JP, et al. Re-epithelialization. Human keratinocyte locomotion. Dermatol Clin 1993;11(04):641–646
19 Rousselle P, Braye F, Dayan G. Re-epithelialization of adult skin wounds: cellular mechanisms and therapeutic strategies. Adv Drug Deliv Rev 2019;146:344–365
20 Rousselle P, Montmasson M, Garnier C. Extracellular matrix contribution to skin wound re-epithelialization. Matrix Biol 2019;75–76:12–26
21 Rashaan ZM, Krijnen P, Klamer RR, Schipper IB, Dekkers OM, Breederveld RS. Nonsilver treatment vs. silver sulfadiazine in treatment of partial-thickness burn wounds in children: a systematic review and meta-analysis. Wound Repair Regen 2014;22(04):473–482
22 Holmes JH. A brief history of RECELL® and its current indications. J Burn Care Res 2023;44(Suppl 1):S48–S49
23 Schwanholt C, Greenhalgh DG, Warden GD. A comparison of full-thickness versus split-thickness autografts for the coverage of deep palm burns in the very young pediatric patient. J Burn Care Rehabil 1993;14(01):29–33
24 Archer SB, Henke A, Greenhalgh DG, Warden GD. The use of sheet autografts to cover extensive burns in patients. J Burn Care Rehabil 1998;19(1 Pt 1):33–38
25 Barnes LA, Marshall CD, Leavitt T, et al. Mechanical forces in cutaneous wound healing: emerging therapies to minimize scar formation. Adv Wound Care (New Rochelle) 2018;7(02):47–56
26 Harn HI, Ogawa R, Hsu CK, Hughes MW, Tang MJ, Chuong CM. The tension biology of wound healing. Exp Dermatol 2019;28(04): 464–471
27 Hosseini M, Brown J, Khosrotehrani K, Bayat A, Shafiee A. Skin biomechanics: a potential therapeutic intervention target to reduce scarring. Burns Trauma 2022;10:tkac036
28 Greenhalgh DG, Palmieri TL. Zigzag seams for the prevention of scar bands after sheet split-thickness skin grafting. Surgery 2003; 133(05):586–587
29 Greenhalgh DG. Management of facial burns. Burns Trauma 2020; 8:tkaa023
30 Cole JK, Engrav LH, Heimbach DM, et al. Early excision and grafting of face and neck burns in patients over 20 years. Plast Reconstr Surg 2002;109(04):1266–1273
31 Housinger TA, Lang D, Warden GD. A prospective study of blood loss with excisional therapy in pediatric burn patients. J Trauma 1993;34(02):262–263
32 Greenhalgh DG, Hinchcliff K, Sen S, Palmieri TL. A ten-year experience with pediatric face grafts. J Burn Care Res 2013;34 (05):576–584
33 Martens S, Romanowksi K, Palmieri T, Greenhalgh D, Sen S. Massive pediatric burn injury: a 10-year review. J Burn Care Res 2023;44(03):670–674
34 Porter C, Tompkins RG, Finnerty CC, Sidossis LS, Suman OE, Herndon DN. The metabolic stress response to burn trauma: current understanding and therapies. Lancet 2016;388 (10052):1417–1426
35 Heimbach DM. Early burn excision and grafting. Surg Clin North Am 1987;67(01):93–107
36 Sheridan RL, Tompkins RG, Burke JF. Management of burn wounds with prompt excision and immediate closure. J Intensive Care Med 1994;9(01):6–17
37 Hart DW, Wolf SE, Chinkes DL, et al. Effects of early excision and aggressive enteral feeding on hypermetabolism, catabolism, and sepsis after severe burn. J Trauma 2003;54(04):755–761, discussion 761–764
38 Hart DW, Wolf SE, Beauford RB, Lal SO, Chinkes DL, Herndon DN. Determinants of blood loss during primary burn excision. Surgery 2001;130(02):396–402
39 Holmes JHT IV, Molnar JA, Shupp JW, et al. Demonstration of the safety and effectiveness of the RECELL® System combined with split-thickness meshed autografts for the reduction of donor skin to treat mixed-depth burn injuries. Burns 2019;45(04):772–782
40 Concannon E, Damkat-Thomas L, Rose E, Coghlan P, Solanki N, Wagstaff M. Use of a synthetic dermal matrix for reconstruction of 55 patients with nongraftable wounds and management of complications. J Burn Care Res 2023;44(04):894–904
41 Silk JA, Taupin P. Serial application of meshed collagen-chondroitin silicone bilayer matrix to obtain full coverage over bone and tendon in challenging situations and medically compromised patients: a small case series. Wounds 2023;35(01):18–25

