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Acute Hand Burns in Children: Management and Long-Term Outcome Based on a 10-Year Experience With 698 Injured Hands

Robert L. Sheridan, MD, Mary J. Baryza, MS, PT, PCS, Monica A. Pessina, OTR, Kim M. O'Neill, OTR/L, Hilary M. Cipullo, MS, PT, Matthais B. Donelan, MD, Colleen M. Ryan, MD, John T. Schulz, MD, PhD, Jay J. Schnitzer, MD, PhD, and Ronald G. Tompkins, MD, ScD

From the Shriners Burns Hospital, the Department of Surgery, Massachusetts General Hospital, and the Department of Surgery, Harvard Medical School, Boston, Massachusetts

Objective
To document long-term results associated with an coordinated plan of care for acutely burned hands in children.

Summary and Background Data
Optimal hand function is a crucial component of a high-quality survival after burn injury. This can be achieved only with a coordinated approach to the injuries. Long-term outcomes associated with such a plan of care have not been previously reported.

Methods
Over a 10-year period, 495 children with 698 acutely burned hands were managed at a regional pediatric burn facility; 219 children with 395 injured hands were followed in the authors' outpatient clinic for at least 1 year and an average of >5 years. The authors' approach to the acutely burned hand emphasizes ranging and splinting throughout the hospital stay, prompt sheet autograft wound closure as soon as practical, and the selective use of axial pin fixation and flaps. Long-term follow-up, hand therapy, and reconstructive surgery are emphasized.

Results
Normal functional results were seen in 97% of second-degree and 85% of third-degree injuries; in children with burns involving underlying tendon and bone, 70% could perform activities of daily living and 20% had normal function. Reconstructive hand surgery was required in 4.4% of second-degree burns, 32% of third-degree burns, and 65% of those with injuries involving underlying bone and tendon.

Conclusions
When managed in a coordinated long-term program, the large majority of children with serious hand burns can be expected to have excellent functional results.

As survival becomes more common after serious burns,[1] the quality rather than the simple fact of survival is the focus of attention. A crucial element of a quality survival is the restoration of hand function.[2,3] This review of our experience with 495 children with 698 acutely burned hands managed over a 10-year period details a systematic approach to management of these complex injuries and the functional outcomes associated with this approach.

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Correspondence: Robert L. Sheridan, MD, Assistant Chief of Staff, Shriners Burns Hospital, 51 Blossom Street, Boston, MA 02114.
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MATERIALS AND METHODS

From January 1987 through December 1996, 495 children were admitted to the Shriners Burns Hospital in Boston with 698 burned hands. This is a 30-bed facility, certified by the American College of Surgeons and American Burn Association, that provides comprehensive care to children with burn injuries of all degrees of severity. All care is provided at no cost to families or to insurance carriers.

Children are also offered continued participation in a program of multidisciplinary aftercare until the age of 21 years. This program, also offered at no cost, consists of coordinated family services, reconstructive surgery, rehabilitation therapy, and psychological support. Children whose burns were superficial enough to be managed as outpatients were not included in the review. The records of these children were reviewed for age, sex, burn size and depth, inhalation injury, mechanism of injury, palmar involvement, surgical course, use of Kirschner wire fixation and pin-related osteomyelitis, amputation, and groin or abdominal flap use. The outpatient charts of those children followed in our outpatient burn clinic were reviewed for duration of follow-up, reconstructive surgery, and hand function at last visit.

The injured hands were managed in an organized way. A detailed initial evaluation of both the patient and the hands was first performed. Particular attention was paid to ensuring digital perfusion. Superficial burns were managed with topical chemotherapeutic agents (commonly aqueous 0.5% silver nitrate soaks) and hand therapy. Deep partial- and full-thickness injuries underwent layered excision and sheet autografting as soon as practical, usually within 72 hours of injury. Fourth-degree injuries, involving the extensors, joint capsule, or bone, were managed with staged autografting. Axial Kirschner wires facilitated functional positioning if there were open and unstable metacarpophalangeal or interphalangeal joints. Hands were ranged twice a day and maintained at other times in functional position with the metacarpophalangeal joints at 70° to 90°, the interphalangeal joints in extension, the first web space open, and the wrist in approximately 25° of extension using custom thermoplastic splints. The upper extremities were elevated to minimize edema. After grafting, hands were immobilized in functional position for 7 days, followed by passive and then active hand therapy.

The 219 children (47%) with 325 burned hands who survived and were followed in our outpatient burn clinic for ≥1 year formed the basis for a review of functional outcome and need for reconstructive procedures. These hand injuries were serious enough to require both inpatient acute burn care and speciality long-term follow-up. The average length of follow-up was 5.3 ± 3 years (64 ± 37 months). We attribute the fact that 251 (53%) of our surviving patients were not followed for >1 year to the minimal needs of those with superficial injuries and the large geographic area served by the unit.

The 325 burned hands followed in the outpatient clinic were divided into three injury and three functional categories (Table 1). Injury category I (113 hands [35%]) were second-degree injuries that required no surgery. Injury category II (163 hands [50%]) had deep injuries that required one or more operations but did not involve bone. Injury category III (49 hands [15%]) had injuries involved underlying bone and tendon. Three long-term performance-oriented functional outcome categories were defined, based on clinic chart review and hand therapy staff records. Functional category A included hands with normal or near-normal function after the injury. Functional category B hands had abnormal function but could perform activities of daily living, although they might require the assistance of adaptive devices such as padded eating utensil handles. Functional category C hands could not perform activities of daily living even with the assistance of adaptive devices. This functional categorization is based on the rehabilitation frame of reference concept[4] in which outcome is performance-oriented and focuses on the patient's net functional skills rather than on isolated components of function. Data are presented as mean ± standard deviation.

Table 1. INJURY AND OUTCOME CATEGORIES

	Description
Injury Category	
I	Second-degree burn that healed without surgery
II	Deep burn that required surgery but did not involve underlying bone
III	Deep burn involving bone and requiring the use of Kirschner wire fixation
Outcome Category	
A	Normal function
B	Abnormal function but able to perform activities of daily living
C	Hand cannot perform activities of daily living such as feeding and toileting

RESULTS

These were predominantly young children. There were 323 boys and 172 girls with an average age of 2.3 ± 5.4 years (range 1 month to 18 years) and an average burn size of 7.8 ± 26.7% (range 1 to 98%). Twenty-five (5%) of the children died. Bilateral hand burns were present in 203 children (41%). Mechanisms of injury included flame (230 [47%]), scald (111 [22%]), electric (17 [4%]), contact (101 [20%]), and grease or chemicals (36 [7%]). Palmar surfaces were involved in 480 (68%) of the burned hands, but grafting of palmar surfaces was required in only 106 (15%) of palmar wounds. Groin or abdominal flaps were used in five cases (0.7%). Axial Kirschner wire fixation was used in 61 (9%) of the injuries, but pin tract osteomyelitis was seen in only one child (1.6%). One or more partial or complete digital amputations were required in 43 (6.5%) of the hands.

Among the 219 children (representing 325 hands) followed in our outpatient burn clinic for ≥1 year (average 5.3 ± 3 years), there were 113 (35%) category I injuries, 163 (50%) category II injuries, and 49 (15%) injury category III injuries. Of those hands requiring no surgical intervention (injury category I), none required a reconstructive procedure during the first year after injury, but five (4.4%) required surgery at some time during the follow-up period, which averaged 64 ± 38 months. These included two web space releases, two finger flexion contracture releases, and one wrist extension contracture release.

Of the 163 hands that required surgery but did not involve underlying bone (injury category II), an average of 1.6 ± 1.2 (range 1 to 6) operations were required of each hand during the acute hospital stay, and 11 (7%) required one or more reconstructive procedures during the first year after injury. Subsequently, 53 of these children (32%) required a total of 94 reconstructive operations during the follow-up period of >5 years, or 0.6 ± 1 operations per child (range 0 to 5). These included 20 web space releases, 15 finger extension contracture releases, 18 finger flexion contracture releases, 10 wrist extension contracture releases, 7 wrist flexion contracture releases, and smaller numbers of other procedures.

Of the 49 hands that involved underlying bone (injury category III), an average of 3.2 ± 2.2 (range 1 to 12) operations were required of each hand during the acute hospital stay, and 11 (22%) required one or more reconstructive procedures during the first year after injury. Subsequently, 32 of these children (65%) required a total of 53 reconstructive operations during the follow-up period of >5 years, or 0.9 ± 1 operations per child (range 0 to 5). These included 20 web space releases, 15 finger extension contracture releases, 18 finger flexion contracture releases, 10 wrist extension contracture releases, 7 wrist flexion contracture releases, and smaller numbers of other procedures.

Functional outcome varied significantly with injury severity (Fig. 1). Category A functional results (normal function) were seen in 109 (97%) of the 113 hands that required no acute surgery (injury category I), 138 (85%) of the 163 deep injuries requiring autografting (injury category II), and 12 (20%) of the 49 injuries involving underlying bone (injury category III). Category B functional results (abnormal function but able to perform activities of daily living) were seen in 2 (1.5%) of the 113 second-degree injuries and 15 (9%) of the 163 deep injuries that required grafting, but only 25 (51%) of the 49 injuries involving underlying bone. Category C functional results (unable to perform activities of daily living) were seen in 2 (1.5%) of the 113 second-degree burns (related to injuries other than the cutaneous burn), 10 (6%) of the 163 injuries that required surgery (associated with injuries in addition to the cutaneous burn), and 12 (25%) of the 49 injuries involving underlying bone. Thirty hands in the long-term follow-up group required amputations; four required amputation of the arm. Of the 26 with some remnant of the hand, none had a category A functional result, 13 (50%) had a category B result, and 13 (50%) were judged to have a category C result at last follow-up.

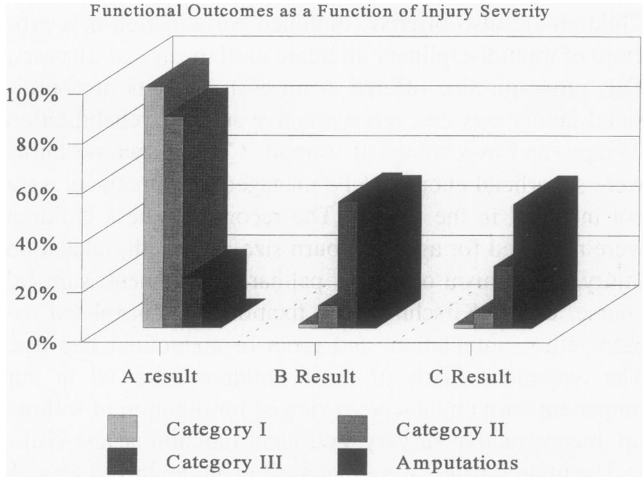

Figure 1. Functional outcome varied significantly with injury severity. Category A functional results (normal function) were seen in 97% of the hands that required no acute surgery (injury category I), 85% of the deep injuries requiring autografting (injury category II), and 20% of the injuries involving underlying bone (injury category III). Category B functional results (abnormal function but able to perform activities of daily living) were seen in 1.5% of superficial injuries, 9% of deep injuries that required grafting, and 51% of injuries involving underlying bone. Category C functional results (inability to perform activities of daily living) were seen in 1.5% of second-degree burns, 6% of deep partial injuries that required surgery, and 25% of injuries involving underlying bone. Thirty hands in the long-term follow-up group required amputations, four requiring amputation of the arm. Of the 26 with some remnant of the hand, none had a category A functional result, 50% had a category B result, and 50% had a category C result at last follow-up.

DISCUSSION

The natural history of a hand burn is determined almost completely by its initial depth. Before the 20th century, hand burns were managed by application of various topical medicines as the overlying eschar became colonized, liquefied, and separated.[5–8] This therapy did not change the natural history significantly; the outcome was a healed wound if the injury was superficial, a closed but distorted hand if the injury was deep dermal, and a chronic open wound if the injury was full-thickness. Immobilization of the healing hand has been debated for many years, but most agree that early passive and active motion facilitates an optimal functional outcome.[9–12] Although early excision of localized deep hand burns was proposed as early as the 1940s[13–15] and 1950's,[16] most hand burns were managed with topical antibacterial agents awaiting eschar separation and spontaneous wound healing until the 1980s, when the improved outcomes associated with early surgery became widely appreciated.[17–19]

Initial Evaluation

Even in the massively burned child, a timely evaluation and proper initial management of the hands can generally be effected. Important points of history include the character of the burning agent, the mechanism of injury as it relates to the possibility of other injuries to the hand, the temperature and contact time when hot liquids are involved, and prior hand pathology. A careful physical examination is mandatory. The physical examination may be difficult in children who cannot cooperate with a complete hand examination. However, even in massively injured children, examination of the acutely burned hand should include assessment of wound depth, circumferential components, associated injuries, and most importantly verification of adequate perfusion. Other injuries are excluded by examination and appropriate radiographs.

Accurate determination of burn depth can be difficult early after injury. Several diagnostic tools, such as laser Doppler, ultrasound, intravenous fluorescein, and indocyanine green have been proposed as aids in diagnosing burn depth, but none of them is more accurate than the eye of an experienced examiner.[20,21] Differentiation can usually be made among superficial burns, deep dermal or full-thickness injuries, and injuries involving extensors, joint capsule, or bone. This determination is important because it facilitates prompt surgery in those with other-than-superficial injuries, avoiding the functional problems associated with nonoperative management of deep dermal and full-thickness injuries.

Some hand burns can be reasonably managed in the outpatient setting. Daily dressing changes with wound cleansing and inspection for infection and passive ranging are essential components of optimal outpatient care. Children with small superficial hand burns who have adequate home support and no other significant injuries are candidates for outpatient management as long as they can maintain good follow-up. The costs associated with suboptimal outpatient management, such as secondary infection and contractures, make inpatient management the cost-effective alternative for all other children.

It is critical to ensure that hand perfusion is adequate because this is an area in which early surgical intervention can make a tremendous difference in the ultimate outcome. This requires that the hand be reexamined with great frequency during the entire resuscitation period. Vascular compromise results when subcutaneous tissues become increasingly edematous beneath nonelastic eschar. When assessing the adequacy of peripheral perfusion, it is important to look at signs more subtle than the loss of detectable pulsatile flow in named arteries at the wrist. Mean arterial pressure in the central system is three times higher than distal capillary pressure, and blood flow may be maintained in these large vessels when flow in distal soft tissues is impaired. If the hand is warm and soft and has pulsatile flow detectable by Doppler in the palmar arch and digital vessels, then flow is adequate. As flow is progressively impaired, the hand will become firm and cool, and Doppler flow will no longer be detectable in the palmar arch and digital vessels. Voluntary motion will become difficult, and the hand will assume a clawed position. At this point, escharotomies should be performed to prevent otherwise avoidable ischemic injury. Soft-tissue pressure measurements >30 cm H_2O support the decision to perform escharotomy but are generally unnecessary if serial examination suggests diminished perfusion.

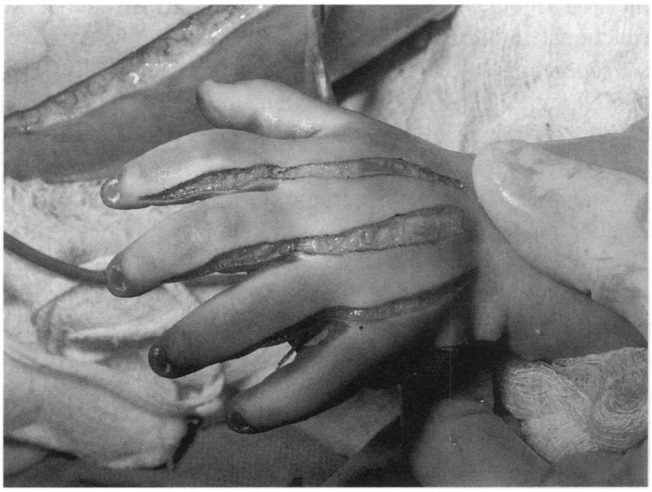

Figure 2. When perfusion is marginal or inadequate, escharotomies of full-thickness burns of the hand and digits should be performed. Incisions are carefully made with pinpoint electrocautery between the neurovascular bundle and the extensors, avoiding both structures. Incisions should be made on the radial aspect of the thumb and the ulnar aspect of the digits. The central digital incisions can be extended proximally onto the dorsum of the hand between the metacarpals to decompress the hand completely.

Technique of Escharotomy

Escharotomy is indicated to correct diminishing perfusion in the setting of decreasing temperature, increasing firmness, decreased capillary filling, and decreasing pulsatile perfusion in the superficial palmar arch and digital vessels. With coagulating electrocautery, axially oriented medial and lateral incisions are made through eschar on the arm and forearm (the former are made anterior to the ulnar styloid to avoid injury to the ulnar nerve), stopping at the metacarpophalangeal joints of the first and fifth digits. The hand is then reexamined for perfusion before performing digital escharotomies. Often, blood flow is enhanced adequately by decompression of the arm, making digital escharotomies unnecessary. Particularly in small children, improperly performed finger escharotomies can cause significant injury and are ideally done only by those experienced with this procedure. However, when perfusion remains marginal or inadequate, escharotomies of full-thickness burns of the digits should be performed (Fig. 2). Incisions are carefully made with pinpoint electrocautery between the neurovascular bundle and the extensors, avoiding both structures. A single axial incision is generally adequate; preferred placement is on the radial aspect of the thumb and the ulnar aspect of the digits. This places the incision on the side of the digit with perhaps the least functional importance should the digital nerve be exposed by separation of edematous tissue after escharotomy. The central digital incisions can be extended proximally onto the dorsum of the hand between the metacarpals to enhance decompression. Meticulous hemostasis is maintained throughout the procedure, and the success of decompression is documented by Doppler examination at its conclusion. Digital escharotomies do not result in injury to the extensor mechanism or digital vessels when properly performed.

These procedures can generally be done using aseptic technique at the bedside or in the emergency department. Although escharotomy is only modestly painful, the anxiety associated with the procedure mandates proper attention to anesthesia and analgesia. Intubated children are given a brief intravenous anesthetic. Others are treated with conscious sedation supplemented with subeschar injections of local anesthetics. Some children require a general anesthetic in the operating room to have this procedure performed properly and humanely.

Children who require fasciotomy, generally associated with high-voltage electrical injury or exceptionally deep thermal injury, are best managed in the operating room. For upper extremity fasciotomy, both volar and dorsal forearm incisions are commonly required, all the fascia encompassing the individual muscle bundles must be opened widely, a carpal tunnel release is commonly required, and dorsal hand fasciotomy is also commonly required. A curvilinear incision is ideal for volar exposure. This approach allows one to gain access to all individual muscle bundles in the volar forearm and to decompress the carpal tunnel through a contiguous incision and creates a well-vascularized flap of skin that will maintain coverage over the median nerve at the wrist on completion of the fasciotomy. On the dorsal aspect of the arm, straight linear incisions are adequate. Intermetacarpal incisions on the hand allow one to decompress the intrinsic muscles of the hand.

Hand Therapy

Proper and early hand therapy is essential. During resuscitation and initial stabilization, the hands are elevated to minimize edema and are splinted in a functional position. The optimal position is debated, but consensus includes the interphalangeal joints in extension and the metacarpophalangeal joints at 70° to 90° of flexion to maximize collateral ligament length.[22] The wrist is kept at about 20° or 30° of extension and the thumb in a neutral position with the first web space open.[22,23] Splints, which must be custom-fitted to ensure proper fit, are placed within 24 to 48 hours after injury. Hands with deep palmar burns are splinted in extension.[24] Even during periods of critical illness, children undergo twice-daily ranging by an occupational therapist, except during periods immediately after grafting. Active therapy is encouraged as soon as practical.[23] Continuous passive motion can be useful in selected adolescents,[25] but the active intervention of an interested occupational therapist is more effective, particularly in young children. Later, progressive active therapy, massage, and compression become increasingly important.[26–28] Close follow-up in the burn clinic is important, particularly in young children, because delays in needed reconstructive procedures will interfere with normal hand development.

Surgical Techniques

When caring for children with very large burns, priority is given to maximal initial surface area wound excision and closure with skin grafts, and the hands are autografted later in the patient's course. While awaiting autografting in such children, position and range must be maintained. Excision and allografting of hand burns while awaiting the availability of suitable autograft can be useful in selected children. There is general agreement that earlier surgery is associated with a better functional result and a decreased need for reconstructive procedures.[17,18,29] However, children with large injuries in whom the hands are definitively closed with autograft later in the hospital stay can also have an excellent functional result if hand position and therapy are not neglected while awaiting autografting.[30] Such quality outcomes are absolutely dependent on aggressive daily hand therapy.

Palmar surface burns frequently heal spontaneously, because the palmar skin is much thicker than the dorsal skin and children often form a clenched fist during the burning process, which protects the palm. Only 15% of palmar burns in our series required resurfacing. When the palm is deeply burned and there is a risk of loss of the palmar concavity and range, the hand is splinted with the palm extended to minimize contracture.

Most children with superficial burns of the hand achieve excellent functional and cosmetic results with topical wound care and hand therapy. Many of these children can be managed in a well-supervised outpatient program. Temporary biologic dressings are appropriate to apply if one is certain that the wound is superficial and the child can be adequately monitored.

Deep partial- and full-thickness hand burns generally require layered excision and autografting. These procedures are bloody unless the excisions are performed after exsanguination of the extremity with an elastic wrap and inflation of a proximal pneumatic tourniquet on the arm. The excision is done sequentially until a bed of viable tissue is reached. Viable tissue is recognized by a pearly white moist dermis or the presence of bright subcutaneous fat without thrombosed small vessels or extravascular hemoglobin. Recognition of viable tissue in an exsanguinated extremity with a proximal pneumatic tourniquet is an acquired skill that greatly facilitates excisions with minimal blood loss. The hands are then placed into a snug wrap of epinephrine-soaked gauze before deflation of the pneumatic tourniquet. Definitive hemostasis is secured with judicious use of pinpoint electrocautery. Hands are grafted exclusively with sheet autograft, except in those rare children with massive injuries, and grafts are secured with interrupted fine absorbable suture. Grafted hands are then covered with a gently compressive gauze wrap and placed in a thermoplastic splint in functional position, or they may be left open and held in such a splint with hooks glued to the fingernails, which are then pulled into the splint by elastic bands.[31] A compressive gauze dressing seems to be better tolerated by young children. The hands are elevated and immobilized for 7 days before reinstituting passive and active hand therapy. Skeletal immobilization has been advocated,[32] but thermoplastic splints suffice for the large majority of children.

In the presence of fourth-degree injury involving the underlying extensor mechanism, joint capsule, and bone, management can be more complex and less satisfying. The ultimate outcome is largely dependent on the degree of initial injury,[33] although in our experience most such children can be expected to have the ability to perform activities of daily living. Children with small overall surface area burns are often candidates for early débridement with groin or abdominal flap coverage.[34] In children with larger injuries, in whom flap coverage is impractical, maintenance of a functional position with splinting and therapy is critical to an optimal long-term outcome. When autografting is subsequently performed, unstable open joints are maintained in a position of function with axially placed Kirschner wires. Autografting is done wherever possible, and exposed joints and bone are allowed to granulate and subsequently are autografted. It is important to prevent desiccation of these wounds with wet dressings (such as aqueous 0.5% silver nitrate) or allograft. Joints that remain unstable after coverage is achieved are later fused by open arthrodesis. A high priority is placed on maximizing digital length.

CONCLUSION

This organized approach to serious hand burns in children was associated with normal functional results in 97% of second-degree injuries and 85% of deep injuries requiring autografting; in children with burns involving underlying bone, 70% had the ability to perform activities of daily living and 20% had normal function. Over the >5 years of follow-up, reconstructive hand surgery was required by 4.4% of children with second-degree burns, 32% of those that required acute skin grafting, and 65% of those with injuries involving underlying bone and tendon, emphasizing the critical importance of long-term involvement with these children.[35,36]

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