

Original Article

Dermal substrate application in the treatment of pediatric hand burns: clinical and functional outcomes

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Received August 10, 2023; Accepted November 14, 2023; Epub December 15, 2023; Published December 30, 2023

Abstract: Background: Hand burn injuries are common among pediatric patients. Management of deep partial thickness and full thickness hand burns varies by center, with some favoring upfront autografting and others using dermal substrates (DS) as biologic dressings to accelerate burn wound healing. Achieving best outcomes is critical in children given the propensity of burn wound scars to affect hand function as a child grows and develops. Given potential complications associated with autografting in children, our center often prefers to treat pediatric hand burns initially with DS, with subsequent autografting if there is failure to heal. In this case series, we examined the outcomes of this practice. Methods: We conducted a retrospective review of pediatric burn patients with <10% total body surface area (TBSA) burns who underwent application of DS to hand burn injuries between 2013 and 2021. Burn mechanism, patient demographics, wound treatment details, healing and functional outcomes, and complications were collected. Descriptive statistics were computed. Results: Fifty patients with hand burns and overall <10% TBSA burns underwent application of DS to hands. Median age at the time of injury was 4.1 years (IQR: 1.8, 10.7) and 29 patients (58%) were male. Eighteen (36%) patients had bilateral hand burns, 10 (20%) had burns to their dominant hand, 6 (12%) their non-dominant hand, and 16 (32%) had unestablished or unknown hand dominance. Subsequent autografting was required in 5 (10%) patients treated initially with DS; four of these patients had full thickness injuries. Five (10%) patients developed contracture at the site of DS application for which two underwent scar release with tissue rearrangement, one underwent laser treatment, and two were managed conservatively. Most patients had splints (94%), or compression garments (54%) prescribed to aid in functional recovery. Conclusion: Children with hand burns who underwent DS application healed well with few requiring autografting or developing contractures. Most patients who needed autografting had deeper injuries. Most patients who developed a contracture required additional procedural intervention. Recognizing factors that contribute to the need for autografting after initial treatment with DS can help direct intervention decisions in pediatric patients with hand burn injuries.

Keywords: Occupational therapy, dermal substrate, hand burn, pediatric

Introduction

Burns are a common mechanism of injury, requiring a hospital visit in nearly 400,000 patients per year [1]. Hand burns are particularly common in children and present a high risk for complications [2-4]. The small surface area of the hand with the high concentration of joints makes it vulnerable to functional complications that can affect development and quality of life, particularly as the child grows [3, 5-7]. The high prevalence of functional complications and consequent rehabilitation needs are well-recognized [2-4, 7-10]. Furthermore, chil-

dren are uniquely susceptible to adverse outcomes due to the ongoing growth of their hands around the scarred tissue and their ongoing cognitive and emotional development, which can make adherence to rehabilitation recommendations challenging [2, 7-9, 11, 12].

In patients with burn injuries, use of various dermal substrate (DS) products to stimulate dermal regeneration and hasten wound healing is becoming more common. DS application is thought to enhance dermal regeneration through provision of a scaffold of extracellular matrix molecules (collagen, elastin, and proteo-

glycans) that promote native cellular engraftment, migration, differentiation, and proliferation [13]. By preparing the wound bed for grafting or by improving the rate of dermal and epidermal regeneration, dermal substrates show promising functional and cosmetic outcomes. DS use for adult hands burns with or without autografting has increased due to these improved results [14-18]. Although the frequency of DS application in children is increasing as well, long-term functional outcomes following DS use on pediatric hand burns are unknown [14, 19-22].

The objective of this study was to evaluate outcomes after use of DS on pediatric hand burns, through assessment of contracture formation and need for subsequent interventions. We present the largest retrospective review to date of a single institution's experience using DS as part of the initial management on deep dermal and full thickness pediatric hand burns.

Methods

Study overview

We conducted a retrospective review of pediatric burn patients under 18 years old with less than 10% total body surface area (TBSA) burns who underwent application of DS to the hands at our American Burn Association-verified Pediatric Burn Center between January 2013 and December 2021. Cases were identified among patients enrolled in our institutional burn registry, which captures data from the electronic medical record for all patients admitted with burn injuries. Patients were included in the study if they had a burn distal to the wrist as well as less than 10% TBSA burn, while also undergoing application of DS to the hand(s). This TBSA cutoff was selected a priori due to the potential physiologic consequences of $\geq 10\%$ TBSA burns, which could portend a higher likelihood of critical and/or systemic illness that could confound results [23-25]. This study was approved by the Institutional Review Board of Nationwide Children's Hospital (Columbus, Ohio, United States of America) with an appropriate waiver of patient consent.

Chart review was performed to include patient demographics, burn mechanism, wound characteristics, wound treatment details, and complications from the day of surgical assessment

in the Emergency Department to the most recent follow-up appointment. All patients were between one and ten years out from injury at the time of data collection. Race, as specified by the patient or caregiver using fixed categories, was collected to describe the cohort.

Clinical wound management

All burn wounds were initially managed with pain control and debridement. If the burn wound appeared to be persistently deep partial thickness with failure to heal or full thickness, patients then underwent tangential excision of the wound with either sharp instruments or hydrosurgery (Versajet Hydrosurgery System; Smith and Nephew, Hull, UK). During the initial excision, a dermal substrate was applied which consisted of various materials (Primatrix[®] n=42 [TEI Biosciences, Inc.; Boston, MA], Acell[™] n=2 [ACell, Inc.; Columbia, MD], EZ Derm[®] n=9 [Molnitycke Health Care, US, LLC; Norcross, GA]) with placement of a nonadherent dressing. The wound was then reassessed 4-7 days postoperatively. If the wound appeared to be healing well, further treatment with dressing changes was pursued. If the wound was not healed within 2-3 weeks, a skin graft was applied. One patient with extensive, full thickness injuries underwent planned staged autografting on postoperative day 6 following DS placement, in which the DS was used to improve the wound bed for planned subsequent grafting.

Clinical outcomes

The primary outcome of this study was functional outcomes after application of dermal substrate for hand burns as measured through contracture formation and need for subsequent interventions. Secondary outcomes included time to wound healing and adherence to adjunct therapies.

Patients were routinely assessed by a burn-trained rehabilitation therapist (either occupational therapy or physical therapy) in our outpatient clinic, and prescribed range of motion exercises, splints, and scar management therapies as appropriate. Range of motion was measured through clinical observation and goniometric assessment. Patients were considered to have developed a contracture if diminished range of motion was noted by a burn surgeon and/or burn-trained rehabilitation therapist

Dermal substrate for pediatric hand burns

Table 1. Patient demographics

	n=50 (%)
Age at injury, years (IQR)	4.08 (1.82, 10.65)
Male sex	29 (58)
Race	
White	37 (74)
Black	8 (16)
Multi-racial	2 (4)
Unknown/other	3 (6)
Ethnicity	
Non-Hispanic	47 (94)
Hispanic	3 (6)
Hand dominance	
Both hands injured	18 (36)
Only dominant hand injured	10 (20)
Only non-dominant hand injured	6 (12)
Single hand injured, hand dominance not established at time of injury	7 (14)
Single hand injured, hand dominance unknown	9 (18)
Insurance coverage	
Medicaid	32 (64)
Commercial	18 (36)
Burn mechanism	
Flame	18 (36)
Contact	15 (30)
Scald	13 (26)
Friction	4 (8)
Length of stay (IQR)	5.0 (2.0, 7.8)
Total body surface area burned (IQR)	2.5 (1.0, 4.0)
Proportion of burn as hand burn (IQR)	50% (25%, 100%)

during isolated or composite joint movement of the fingers and hand. Attempts were made to have either the same surgeon or burn-trained rehabilitation therapist complete range of motion and scar assessments across appointments for consistency.

Time to wound healing was defined as the number of days post-injury until the wound was determined to be closed and no longer requiring dressing changes. Compliance with adjunct therapies and functional outcomes were assessed based on burn-trained rehabilitation therapist notes in the electronic medical record.

Statistical analysis

Summary statistics were used to describe the patients. Continuous variables were described with medians and interquartile ranges, while categorical variables were described with co-

unts and proportions. Statistical analysis was performed using SAS 9.4 (SAS Institute Inc., Cary, NC).

Results

Patient demographics and clinical characteristics

Among the 50 children with hand burns treated with DS, the median age was 4.1 years (Interquartile range: 1.8, 10.7) (**Table 1**). Males comprised 58% (29/50) of our study population. Most patients were white (74%, 37/50), while we had 16% (8/50) black patients, and 4% (2/50) were multi-racial. Over one-third (36%, 18/50) of patients injured both hands, 20% (10/50) their dominant hand, 12% (6/50) their non-dominant hand, and 32% (16/50) had unestablished or unknown hand dominance at the time of injury.

Dermal substrate for pediatric hand burns

Table 2. Operative details and outcomes

	n=50 (%)
Length of stay/TBSA, days (IQR)	2.0 (1.2, 4.0)
Hospital day of index operation (IQR)	4 (2, 5)
Time to wound healing, days (IQR)	23 (14, 36)
Compression garments prescribed	27 (54)
Splint prescribed	47 (94)
Overall compliance with adjunct therapy	
Good	24 (48)
Fair	14 (28)
Poor	5 (10)
Unknown	7 (14)
Subsequent autografting	5 (10)
Contracture	9 (18)
Scar release	3 (6)
Laser therapy	4 (8)

Overall, median TBSA burned was 2.5% (IQR: 1.0%, 4.0%). Nearly half (44%, 22/50) of patients had isolated hand burns. Among children with multifocal burns, the most common locations for other areas of burn injury were arms (n=22), legs (n=10), and head/neck (n=5).

Flame burns accounted for 36% (18/50) of all injuries, contact burns 30% (15/50), scald burns 26% (13/50), and friction burns 8% (4/50). Patients were hospitalized for median of 5.0 days (IQR: 2.0, 7.8).

Outcomes

Median time to wound healing for those with DS alone was 23 days (IQR: 14, 36) (Table 2). Most patients were fitted for splints (94%, 47/50) or compression garments (54%, 27/50) to aid in functional recovery, and 54% (27/50) were prescribed both therapy modalities. Overall compliance with adjunct therapies was determined by burn-trained rehabilitation therapist assessment as documented in the electronic medical record. Patients were considered to have “good” compliance if they used splints and/or compression garments more than half of the time they were prescribed, “fair” for intermediate use, and “poor” if they never used these therapies. Most (76%, 38/50) patients had good or fair compliance and 10% (5/50) had poor compliance.

Overall, 90% (45/50) of burn wounds treated with DS healed without contracture. Of the 10%

(5/50) of burn wounds that developed contracture, 2 underwent scar release with local tissue rearrangement, 1 underwent laser treatment, and 2 required no further procedural intervention (Table 3). In looking at therapist assessment of the patients who developed a contracture, 3 patients had fair compliance with prescribed therapies, 1 poor compliance, and 1 unknown.

Among all patients, 90% (45/50) healed with DS alone (Table 4). Of the 10% (5/50) that required an autograft, all were rated to have fair or poor compliance with prescribed therapies. Four patients underwent full-thickness skin grafting, and one patient underwent split-thickness skin grafting. Three of these grafted patients developed contractures, while 2 patients had no complications. Since autografting was a rare event in our series, we focused on the details of these patients and their care to see if we could identify any common themes.

Cases requiring autografting

Case #1: The patient was 1.1 years old when he touched a hot iron with the palm of one hand. He underwent application of Primatrix® on post-injury day 3 and was prescribed a splint to use, with which he had poor compliance. The wound was healed by postoperative day 26; however, the patient developed contracture and functional impairment of his hand, so he underwent scar release with full thickness skin grafting on postoperative day 165. Following this procedure, he had hypersensitivity of the graft site but no further functional impairment. Notably, the patient and his family are non-English speaking.

Case #2: The patient was 1.7 years old when he fell into a fire pit and burned the palm of one hand. He underwent application of Primatrix® on post-injury day 3 and was prescribed a splint to use, with which he had fair compliance. The dermal substrate did not adhere well, in which he underwent full thickness skin grafting on postoperative day 24. The wound was healed by postoperative day 52 from his index operation and postoperative day 26 from his grafting. The patient developed flexion contractures of the grafted sites that resolved with serial casting.

Dermal substrate for pediatric hand burns

Table 3. Characteristics of patients who developed contractures

TBSA (%)	Age (years)	Mechanism	Hand burned	Dermal substrate used	Adjunct therapy adherence	Time to wound healing (days)	Contracture management
1	1.2	Hot iron	Dominance not established	ACell	Poor	27	Scar release
0.5	1.8	Hot iron	Dominance not established	Primatrix®	Fair	36	Laser therapy
8	3.2	Scald	Both	Primatrix®	Unknown	39	No intervention
2	0.9	Fireplace	Both	Primatrix®	Fair	51	No intervention
3	1.7	Hot coals	Dominant	Primatrix®	Fair	52	Scar release

Table 4. Characteristics of patients who underwent autografting

TBSA (%)	Age (years)	Mechanism	Burn depth	Hand burned	Burn location	Dermal substrate used	Overall time to wound healing (days)	Graft details	Graft-associated complications
1	1.1	Hot iron	Deep partial thickness	Not established	Palm	Primatrix®	26	Scar release with FTSG POD 165 due to functional impairment	Graft site hypersensitivity
3	1.7	Hot coals	Full thickness	Not established	Palm	Primatrix®	52	FTSG POD 24 for delayed wound healing	Flexion contractures, resolved with serial casting
4.5	2.4	Hot coals	Full thickness	Not established	Dorsal fingers, joint involvement	Primatrix®	44	FTSG POD 15 for delayed wound healing	Scar hypertrophy and pruritis, resolved with fractional CO ₂ ablative laser treatment with topical steroid application
0.5	11.3	Treadmill	Full thickness	Non-dominant	Palmar fingers, joint involvement	ACell™	39	FTSG POD 21 for delayed wound healing	Flexion contractures, resolved with serial casting
1.5	13.6	Grease	Full thickness	Unknown	Dorsal hand, circumferential fingers	Primatrix®	32	Planned staged STSG POD 6	Flexion contractures with scar hypertrophy, pain, and pruritis, improved with capsular contraction release and fractional CO ₂ ablative laser treatment with intralesional steroid injection

Dermal substrate for pediatric hand burns

Case #3: The patient was 2.4 years old when she fell into a fire pit and burned the dorsal surface of the proximal interphalangeal joints of three fingers of one hand. She underwent application of Primatrix® on post-injury day 3 and was prescribed a splint and compression garments to use, with which she had fair compliance. The dermal substrate did not adhere well, so she underwent full thickness skin grafting on postoperative day 15. The wound was healed by postoperative day 44 from her index operation and postoperative day 29 from her grafting. The patient developed hypertrophy and pruritis of the graft site that resolved with fractional CO₂ ablative laser treatment with topical steroid application.

Case #4: The patient was 11.3 years old when her hand became caught in a treadmill belt, causing friction burns to the palmar surface of the proximal and distal interphalangeal joints of four fingers of one hand. She underwent application of ACell™ on post-injury day 5 and was prescribed a splint and compression garments to use, with which she had fair compliance. The dermal substrate did not adhere well, so the patient underwent full thickness skin grafting on postoperative day 21. The wound was healed by postoperative day 39 from her index operation and postoperative day 18 from her grafting. The patient developed flexion contractures of the grafted sites that resolved with serial casting.

Case #5: The patient was 13.6 years old when she had a cooking accident, leading to grease burns to one hand that spanned the palmar surface of the proximal interphalangeal joint of one finger, three fingers circumferentially, and the dorsal surface of the metacarpophalangeal and distal interphalangeal joints of her thumb. She underwent escharotomies and application of Primatrix® on post-injury day 1 and was prescribed a splint and compression garments to use, with which she had poor compliance. The patient underwent a planned application of split thickness skin graft on postoperative day 6. The wounds were healed by postoperative day 32 from her index operation and postoperative day 26 from her grafting. The patient developed flexion contractures of the grafted sites with hypertrophy, pain, and pruritis that improved with capsular contraction release and fractional CO₂ ablative laser treatment with intralesional steroid injection.

Discussion

Children with deep partial thickness or full thickness hand burns who underwent dermal substrate application had a low rate of contracture formation or need for subsequent autografting. The fact that 90% of our population was successfully treated with DS alone without need for autografting means that these patients avoided both the morbidity of a second operation for grafting and the need for donor site healing. DS-treated patients did not sacrifice long-term outcomes, as only 10% of our population developed contracture. Our institutional data show that initial treatment of pediatric hand burns with DS is safe and potentially preferable to upfront autografting.

Of the five patients who did require autografting, four required autografting when their DS did not adhere well. DS in these cases served as a bridge to autograft and in most cases improved wound contour, increased wound bed readiness for grafting, and reduced the total body surface area that needed to be grafted. None of the scald or flame burn patients required grafting, while of the five patients who required autografting, three sustained contact burns, one sustained a friction burn, and one a grease burn. All of these mechanisms are likely to cause deeper burns than a scald or flash flame, and of the five patients who underwent subsequent autografting in our cohort, four had full thickness injuries. It is therefore unsurprising that these deeper wounds did not heal with DS alone. All five patients had fair or poor splint compliance, but the importance of splints in terms of DS adherence is unclear. Recognizing factors that contribute to the need for autografting after initial treatment with dermal substrate can help direct intervention decisions and set family expectations for pediatric patients with hand burn injuries.

Children are uniquely prone to developing more clinically significant burn injuries. Due to thinner dermal layers, infants and toddlers are more likely to develop deeper burns from lower temperatures over shorter contact times than older patients [26, 27]. The skin of the hands is thin in comparison to other areas of the body, so pediatric hands are particularly susceptible to deeper injury [28-30]. Hand burns can have serious impacts on quality of life through disease-specific disabilities such as in appear-

Dermal substrate for pediatric hand burns

ance, range of motion, and fine motor function [12, 31]. Hypertrophic scars on hands of children are especially problematic because the scar does not grow, and as the child's hand rapidly grows around it, functional deficits can develop due to tension. Any treatment of pediatric hand burns must make minimization of hypertrophic scar and long-term function as the primary goal.

Studies about hand burns in children often focus on patients that were managed nonoperatively and compare them to those that needed grafting. To our knowledge, this is the first study to interrogate the practice of DS application in children with hand burns and report outcomes. One prior study identified children managed nonoperatively or with primary autografting had an approximately 5% complication rate, including graft loss and wound infection [32]. Among our patients, 10% required autografting for any indication after DS application, but 90% were able to avoid the morbidities associated with primary autografting. Due to inclusion of patients managed nonoperatively in most other studies, comparison of time to healing between our patients and those previously reported in the literature is challenging. Another study reported an average healing time of 10 days among their 52 patients, though 94.2% (49/52) in this cohort were managed nonoperatively or with debridement and dressings alone [27]. Time to wound healing among our patients was 23 days, but our inclusion criteria specified DS application, which excluded all patients that healed without any operative intervention.

DS has already been shown to have efficacy in wound management in adults. Although more commonly used in treatment of deep partial thickness injuries, DS can be applied in select full thickness injuries, with the goal of improving the wound bed in preparation for planned future autografting. One case report detailing the use of DS in the management of full thickness hand burns in a geriatric patient found successful neovascularization of the wound bed in preparation for staged autografting [14]. Other studies looking at DS application for complex and/or chronic wounds have found 76%-80% wound healing among adults, including some patients with complex comorbidities [19, 22, 33]. Improved cosmesis in wound healing in children compared to adults is well-docu-

mented and thought to be due in part to lower rates of comorbidities. Therefore, it appears that DS could potentially play a more significant role in treatment of pediatric patients as compared to adults [34-36].

Gross and fine motor skills vary with age and developmental stage, which presents challenges in determining functional outcomes in children. Standard measures of sensation such as vibration thresholds, temperature and texture discrimination, and two-point discrimination were developed and validated among adult patients. Although they have been successfully used in children as young as 6 years old, they can be difficult to interpret when applied to the youngest patients [12, 37-40]. Furthermore, most validated instruments are skills-based, have specific age ranges, and do not provide the specificity to track nuanced differences in movement following burn injury, such as decreased fluidity or use of a compensatory or less refined grasp or pinch pattern. Consequently, the primary measures of functional outcomes used in this study were clinical assessment of contracture development due to ease of measurement, regardless of developmental stage. Among patients who developed contractures, all had longer than the 24-day average healing time. This finding is consistent with prior literature demonstrating a greater degree of scar and contracture formation in burns taking longer than two weeks to heal [41-43]. Additionally, all patients who developed contractures were under 5 years old at the time of injury, suggesting that younger age may present increased risk, either due to rapid growth at that phase or due to difficulty with compliance with range of motion or splinting recommendations.

There are limitations to our study that are important to discuss. First, since this is a retrospective study, data included are limited to information recorded in the electronic medical record. As such, standardized scoring systems of scar characteristics could not be reported due to the high degree of missingness. Second, as patients were not randomized, physicians may have chosen DS for particular burn wounds and not for others, which would affect outcomes. Third, while our study includes patients who had injuries as early as 2013, in 2015, our institution transitioned to primarily using a sin-

gle DS product (Primatrix®), which can limit generalizability of our findings for institutions that use different products.

Despite these limitations, our case series represents a novel and robust description of treatment of pediatric hand burns with dermal substrate. Given the high rate of wound healing among children with hand burns after DS application and the low rate of contracture, the findings of this study suggest that it is reasonable to consider initial application of DS for hand burn wound management. In patients who go on to need grafting after DS applications, good functional outcomes are still achieved in the majority of cases.

Future research is warranted to explore long-term outcomes of DS application to hand burns in children. These outcomes are of particular importance to examine in patients who are treated before age 5, due to the intensification of fine motor skill development and growth in size of the hands throughout childhood. Furthermore, prospective comparison of DS, primary autograft, and nonoperative management stratified by mechanism of burn, burn depth, and degree of joint involvement, would help to generate a set of recommendations. Finally, given the variety of DS products available, prospective comparison of DS products based on burn characteristics may help elucidate which product is most likely to yield optimal outcomes for pediatric hand burns.

Conclusions

Ultimately, children with deep partial thickness and full thickness burns treated primarily with dermal substrates had a low rate of requiring a subsequent autograft. These patients had excellent functional outcomes with a low rate of contracture formation in follow-up of 1-10 years after their burn injuries.

Disclosure of conflict of interest

None.

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Dermal substrate for pediatric hand burns

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Dermal substrate for pediatric hand burns

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