

# Upper Extremity Friction Burns in the Pediatric Patient: A 10-year Review

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**Background:** Upper extremity friction burn due to powered home equipment is a growing problem in the pediatric population. The purpose of this study was to review the etiology, presentation, characteristics, and treatment of this particular type of pediatric mechanism of injury.

**Methods:** A retrospective chart review using International Classification of Diseases, version 9, codes for patients treated at a large tertiary care, free-standing children's hospital was performed to identify all patients presenting with an upper extremity friction burn from 2003 to 2012.

**Results:** Sixty-nine patients sustained upper extremity friction burns. The average age at the time of injury was 3.3 years (range, 0.7–10.6) with presentation to our center occurring 16.6 days (range, 0–365 days) following injury. Mean follow-up was 23.3 months (range, 2–104). Mechanism of injury included treadmills (n = 63) and vacuum cleaners (n = 6). Twenty-eight operations were performed on 21 patients (30%). All patients requiring a surgical intervention sustained injury via treadmill mechanism ( $P = 0.0001$ ). Unlike treadmill burns, vacuum cleaner injuries affected the dorsal hand or a single digit ( $P = 0.00004$ ). Scar hyperpigmentation was more prevalent in these patients compared with the treadmill group ( $P = 0.003$ ). All vacuum-induced burn patients had full range of motion and function with conservative treatment alone, whereas only 55.6% of treadmill burn patients had full recovery of range of motion and 50.8% recovery of full hand function.

**Conclusions:** Friction burns from vacuum cleaners are less prevalent, have different injury patterns, and can be treated conservatively with excellent functional outcomes. Treadmill friction burns result in more significant injury and risk for dysfunction, requiring surgical intervention. (*Plast Reconstr Surg Glob Open* 2018;6:e2048; doi: 10.1097/GOX.0000000000002048; Published online 4 December 2018.)

## INTRODUCTION

Burns are the fifth most common cause of nonfatal injuries in the pediatric population, resulting in the hospitalization of more than 500,000 children annually. Pediatric burns are most commonly caused by scald injury from hot liquids, or from direct contact with flame or hot objects.<sup>1</sup> Although less common, burns can also result from friction due to a resistive force generated by 2 surfaces moving against one another. This interaction results in the build-up of heat and physical deformation that subsequently causes a combination of thermal burn and

mechanical injury. Most injuries affect the upper extremities, commonly the hands, and can be full-thickness in nature, requiring surgical intervention, such as debridement and/or skin grafting. If left untreated, these injuries can lead to infection and scar contracture, resulting in further morbidity and potential need for surgical intervention.<sup>2–4</sup>

Injuries from home exercise equipment such as treadmills are an increasingly recognized injury. From 2007 to 2011, there were an estimated 70,302 emergency department-treated injuries from mechanical home exercise equipment in the United States<sup>5</sup> In addition, the incidence of pediatric treadmill-related friction injuries has been increasing since the 1990s, rising from 45,942 in 2007 to 49,065 in 2009.<sup>6</sup> Friction burns may also be caused by vacuum cleaners. This particular mechanism of injury is less common, with few reports in the literature. In this retrospective chart review, the authors seek to describe pediatric friction burns of the upper extremity resulting from treadmills or vacuum cleaners. In addition, we

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identify differences between these 2 mechanisms of injury with regard to presentation, characteristics, treatment, and outcomes.

## MATERIALS AND METHODS

A retrospective review was undertaken for pediatric patients with friction burns who underwent treatment by the Division of Plastic and Reconstructive Surgery at Children's National Medical Center from 2003 and 2012. After obtaining approval from the institutional review board, the study cohort was identified by performing a search within the accounting division of Plastic and Reconstructive Surgery using International Classification of Diseases, version 9, and Current Procedure Terminology codes. Inclusion criteria consisted of patients who were evaluated by the Division of Plastic and Reconstructive Surgery for upper extremity friction burns. Exclusion criteria included patients who presented with a burn sustained from a different mechanism (eg, scald or flame). Medical records were investigated to obtain comorbid medical conditions, treatment regimens and follow-up. Demographic data, clinical presentations, treatments provided, and outcomes were recorded and compared with distinguish between mechanisms of injury.

Outcome measures included scar quality, range of motion (ROM), and functional limitation. Due to the retrospective nature of this study and difficulty in convincing families to bring their children for follow-up appointments, formal evaluation of hand function was not routinely performed. Instead, both provider and/or parental impressions of outcome measures were used as proxies.

Statistical analyses and comparisons were performed using Microsoft Excel (Microsoft Office Professional Plus 2010, Version 14.0.7166.5000). Nonpaired two-tailed Student's *t* test was used to analyze continuous data; chi-square analyses were performed for categorical data.

## RESULTS

Sixty-nine patients sustained upper extremity friction burns over this study time period (Table 1). The average age at the time of injury was 3.3 years (range, 0.7–10.6), and patients presented to plastic surgery at an average of 16.6 days (range, 0–365) following injury. Mean follow-up was 23.3 months (range, 2 weeks to 104.4 months). Mechanism of injury included treadmills (group 1; *n* = 63) and vacuum cleaners (group 2; *n* = 6). Conservative therapy varied but included gentle cleansing of wounds without general anesthesia and twice daily dressings with silver sulfadiazine, bacitracin, and/or petrolatum-based bandages and ointments. Indications for surgical intervention included failure of open wound to close within 2–3 weeks of conservative therapy (*n* = 13), contracture release (*n* = 7), and significant exposure of flexor tendon (*n* = 1). Twenty-eight operations were performed on 21 patients (30%) including surgical debridement (*n* = 5), excision/primary closure (*n* = 1), contracture release (*n* = 7), full-thickness skin grafting (*n* = 9), split-thickness skin grafting (*n* = 5), and tendon repair (*n* = 1; Fig. 1). The mean time to closure of open wounds was  $19.4 \pm 14.8$  days (range,

9–34 days), with a significant difference between patients who required surgery versus those who healed by secondary intention ( $26.3 \pm 70.7$  days versus  $16.5 \pm 19.2$  days;  $P < 0.05$ ). Three patients (14%) required acute surgical intervention within 2 days of injury based upon depth of injury. All patients requiring surgical intervention sustained injury via treadmill mechanism, (Fig. 2). Compared with patients managed with conservative treatment alone, surgical patients tended to be older ( $4.09 \pm 1.99$  years versus  $3.05 \pm 1.78$  years,  $P = 0.9$ ) and present later from the time of injury ( $25.9 \pm 85.4$  days versus  $12.8 \pm 30.5$  days,  $P = 0.7$ ), though these differences did not reach statistical significance. Burns sustained by these patients were more severe, including full thickness injuries ( $P = 0.0001$ ) and disabling early flexion contracture ( $P < 0.05$ ).

When comparing mechanisms of injury, patients with vacuum-induced burns tended to be younger ( $P = 0.9$ ) and present later from time of injury ( $P = 0.3$ ) when compared with treadmill injuries, though once again, these differences did not reach statistical significance. Burns from vacuum cleaners involved a single digit (most often the thumb) or dorsal hand as opposed to multiple digits without thumb involvement in treadmill injuries ( $P < 0.00005$ ; Fig. 3).

Outcomes measures included scar quality, ROM, and functional limitations (Table 2). Hypertrophic scars were only noted in patients injured by treadmills ( $P < 0.0005$ ), while hyperpigmented scarring was more prevalent in patients with vacuum-induced trauma ( $P < 0.005$ ). Patients injured by treadmill had worse functional injuries and outcomes compared with patients injured by vacuum cleaners; the latter group had no ROM or functional limitations. Per contra, full ROM was documented in 35/63 patients (55.6%), 15.9% had some limitations, and ROM was not assessed in 28.5% of patients injured by treadmills. Likewise, normal functional use of the injured hand was noted in only 50.8% (32/63 patients) of treadmill-injured patients, with 6.3% having functional limitations, and 42.9% without documentation of function. In patients who underwent surgical procedures, a trend toward full ROM and functionality was noted in patients who had intervention within 3 weeks of injury, but numbers were small and this difference did not reach statistical significance ( $P > 0.05$ ).

Based on these results, the following treatment algorithm has been instituted at our Division for patients presenting with upper extremity acute friction burn injuries (Fig. 4). Patients suffering from vacuum cleaner trauma are managed with conservative therapy alone and carefully followed. On the other hand, we recommend surgical intervention for patients having significant open wounds from treadmill-induced injuries who either fail 2–3 weeks of conservative therapy or present after this time frame, as they appear to have poorer prognosis for achieving full ROM and functionality.

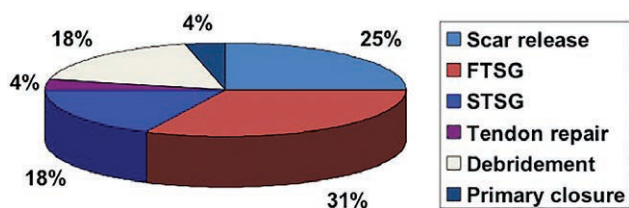
## DISCUSSION

The hand is the most common area of the human body to suffer trauma in the pediatric patient.<sup>7,8</sup> Our study, similar to other investigations,<sup>9,10</sup> documented that younger

**Table 1. Patient Demographics and Treatment Factors**

Patient Factors	All	Surgical	Nonsurgical	P	Treadmill	Vacuum	P
Total patients	69	21	48		63	6	
Average age (y)	3.3	4.09±1.99	3.05±1.78	0.9633	3.54±1.86	1.53±0.920	0.9993
Sex, n (%)							
Male	40 (58)	12	28		36	4	
Female	29 (42)	9	20		27	2	
Presentation (d)	16.6	25.9±85.4	12.8±30.5	0.7341	14.8±49.9	37±81.06	0.2957
Average F/U (mo)	6.6	12.1	4.2		6	13.1	
Burn laterality (67), n (%)							
Right	38 (57)	17	21		34	4	
Left	21 (31)	1	20		19	2	
Bilateral	8 (12)	3	5		8	0	
Burn location							
Dorsal	16	5	11		13	3	
Volar	34	10	24		32	2	
Radial	4	0	4		3	1	
Ulnar	6	0	6		4	2	
Forearm	5	2	3		5	0	
Hand	21	9	12		18	3	
Wrist	3	2	1		3	0	
Fingers*	55 (S 10, M 45)	16 (S1, M 15)	39 (S 9, M 30)		52 (S 7, M 45)	3 (S 3, M 0)	0.00043
Thumb	5	3	2		3	2	0.009896
Index	24	6	18		24	0	
Middle	42	12	30		41	1	
Ring	39	14	25		39	0	
Little	9	4	5		9	0	
DIPJ	16	3	13		16	0	
PIPJ	16	6	10		16	0	
MCPJ	1	0	1		1	0	
Proximal phalanx	4	0	4		4	0	
Middle phalanx	9	0	9		9	0	
Distal phalanx	5	0	5		5	0	
Webspace	2	2	0		2	0	
Burn depth							
Partial thickness	36	6	30	0.000136	33	3	
Full thickness	21	14	7		20	1	
Unspecified	12	1	11		10	2	
Wound care/treatment							
Silvadene	32	11	21		30	2	
Bacitracin	10	0	10		8	2	
Xeroform	12	7	5		11	1	
Peroxide	4	1	3		4	0	
Unknown	14	4	10		14	0	
Surgical patients, n (%)	21 (28 procedures)				21	0	0.030144
Scar release	7 (25)				7	0	
FTSG	9 (32)				9	0	
STSG	5 (18)				5	0	
Tendon repair	1 (3.5)				1	0	
Debridement	5 (18)				5	0	
Excision/primary closure	1 (3.5)				1	0	

\*S, single digit; M, multiple digits; DIPJ, distal interphalangeal joint; PIPJ, proximal interphalangeal joint; MCPJ, metacarpophalangeal joint; FTSG, full thickness skin graft; STSG, split thickness skin graft.



**Fig. 1.** Twenty-eight operations performed in 21 patients (all treadmill-induced injuries) including surgical debridement (n = 5), excision/primary closure (n = 1), contracture release (n = 7), full-thickness skin grafting (FTSG) (n = 9), split-thickness skin grafting (STSG) (n = 5), and tendon repair (n = 1).

children, particularly those under the age of 5 years, are especially prone to injuries. This observation should not be surprising, given the natural curiosity young children have for their environment. Pediatric upper extremity

friction burns due to common home appliances are becoming increasingly more recognized. Children coming into contact with these devices are particularly vulnerable to friction burns because their skin is thinner and their hands often lack callous formation.<sup>11</sup> The topic of pediatric burns sustained from mechanical home exercise equipment such as treadmills has been explored appreciably in the last decade. On the other hand, injuries sustained from vacuum cleaners occur far less commonly and thus, only a few cases are reported in the literature. In our series from Children’s National Medical Center, we encountered 69 pediatric patients with friction burns, 63 of them due to treadmill mechanism and 6 from vacuum cleaners. Thirty percentage (21 children) of the study population required surgical intervention, all of whom sustained their injuries from a treadmill.



**Fig. 2.** Treadmill-induced burns involving the volar surface of multiple digits. While most patients were treated conservatively with local wound care (A, B), patients with more severe, full-thickness burns required surgical intervention including skin grafting (C). Due to persistent flexion contracture of the index finger, the patient on the bottom left required secondary contracture release (D).

Previous reports on these types of injuries focused on treadmills and did not differentiate from other mechanisms of friction burn, such as vacuum cleaners. In 2007, Wong et al.<sup>12</sup> treated 44 children (median age 2.8 years) who sustained friction burns from treadmills over a 6-year period. Seventy-five percentage of these injuries involved the hands, 59% of these lesions were full-thickness burns, and almost half of the study population required skin

grafting, with 3 patients requiring reoperation due to scar contracture on follow-up.<sup>12</sup> A 2008 retrospective chart review by Jeremijenko et al.<sup>13</sup> described 37 children (median age 3.2 years) with these types of burns, 100% of which required skin grafting for the full-thickness or deep partial friction burns. Almost all the injuries involved the upper limbs.<sup>13</sup> Likewise, a 2011 retrospective chart review spanning 6 years (2005–2010) by Juang et al.<sup>6</sup> documented



**Fig. 3.** Vacuum-induced burns to the right dorsal hands of 2 children. These burns healed with conservative treatment alone.

**Table 2. Outcomes after Surgical and Nonsurgical Management**

Patient Outcomes	All	Surgical	Nonsurgical	<i>P</i>	Treadmill	Vacuum	<i>P</i>
Total patients	69	21	48		63	6	
Scar contracture							
None	29	9	20		27	2	
Minimal	8	2	6		8	0	
Severe	7	5	2	0.049112	7	0	
Scar quality							
Good	12	2	10		9	3	
Hypertrophic	9	3	6		9	0	0.00032
Hyperpigmented	5	1	4		2	3	0.00301
Immature	12	4	8		12	0	
ROM							
Full	41	10	31		35	6	
Limited	10	5	5		10	0	
Unknown	18	6	12		18	0	
Functionality							
Full	38	9	29		32	6	
Limited	4	2	2		4	0	
Unknown	27	10	17		27	0	

19 children who required treatment for treadmill-related injuries, 21% of which required skin grafting and 21% having hypertrophic scarring. The hand was involved in 79% of burns.<sup>6</sup> Most recently, Noffsinger et al.<sup>14</sup> documented their experience at a regional level 1 pediatric burn center with patients injured by treadmill and contact hand burns. In their series, the authors noted that treadmill hand burns were more severe than contact hand burns, requiring more surgical intervention and greater length of medical care.<sup>14</sup>

To our knowledge, the current report is the first in the literature that includes a series of pediatric friction burns caused by treadmills and vacuum cleaners. Though vacuum burns were relatively uncommon in comparison to treadmill injuries, they also appear to be less severe than treadmill burns in our series. Our results clearly document differences in the injury patterns and outcomes of patients affected by these 2 home

devices that are likely explained by the physical properties of each machine. The friction surface of a vacuum cleaner is better protected from inadvertent extremity contact than is the relatively exposed motorized belt of a treadmill machine. In addition, treadmills consist of a running platform with a rubberized belt moved by a motor that can reach speeds of 12–25 miles per hour and these belts are made of firm rubber that can withstand the repeated and sustained impact of adult weight and shoes during home exercise. Vacuum cleaners, on the other hand, are powered by relatively low-strength motors that rotate stiff nylon bristles on a vacuum's brush cylinder.<sup>15</sup> Although the power generated by vacuum cleaners is significantly less than that of treadmills, the brush cylinders continue to rotate even when the vacuum's peripheral cleaning hose is being used, which can increase the likelihood that a child will access the nylon bristles and receive an injury.<sup>16</sup>

Whereas most treadmill-related friction burns are extensive and often require surgical intervention, those from vacuum cleaners are usually less damaging. However, studies exploring vacuum cleaner-related friction burns in the pediatric population are lacking. To our knowledge, only 3 reports have been published (Table 3). Initially reported in 1998, vacuum injuries have resulted in described thumb or hand burns for 12 children.<sup>15-17</sup> Conservative treatment included mupirocin 2% cream, Bactigras, DuoDerm, or Mepitel in combination with a protective bandaging of the hand compared with tangential excision and skin grafting employed in 4 cases where surgery was indicated for depth of thermal injury. There were no long-term functional deficits or contracture formation, though follow-up was lacking.<sup>15-17</sup>

In our own series, patients with both vacuum- and less severe treadmill-related injuries had excellent outcomes with nonoperative management, though mean follow-up was limited to 23.3 months. Out of our study population of 69 children, 69.6% were conservatively managed with local wound care only and excellent outcomes with overall full ROM in 86.1% of patients and full functionality in 93.5% of patients who had adequate follow-up and evaluation. Six sustained vacuum cleaner-related friction burns of the upper extremities (3 partial-thickness burn, 1 full-thickness burn, 2 unspecified). All 6 children were treated conservatively with Silvadene, Bacitracin, or Xeroform, and absence of scar contracture was noted by an average of 9.43 months of follow-up. Although all these children regained full ROM and functionality, there was a significantly greater incidence of hyperpigmented scars resulting from the vacuum mechanism ( $P = 0.003$ ), which has not been previously reported. The etiology of this hyperpigmentation is unclear. Although topical Silvadene use has been associated with hyperpigmentation<sup>18</sup> and systemic silver ingestion with skin pigmentary changes known as argyria,<sup>19,20</sup> patients injured by treadmills who were treated conservatively did not demonstrate such hyperpigmentation in our study.

In addition to differing in severity of injury and subsequent scar formation, friction burns can also be distinguished by location of injury in our study. Although injuries from both vacuum cleaner and treadmill mechanisms involve the upper extremities, our data suggested that burns from vacuum cleaners are more likely to involve a single digit (most often the thumb), as opposed to multiple digits and no thumb involvement in treadmill burns ( $P = 0.00004$ ). Although injury localization has not been previously explored in depth, several studies have briefly mentioned where injuries most commonly occurred in their individual subjects; Wong et al.<sup>12</sup> observed that within their study population, treadmill injuries most commonly occurred to the third and fourth digits. Grob et al.<sup>16</sup> documented that vacuum cleaner injuries resulted in friction burns of a single digit, including the thumb. Juang et al.<sup>6</sup> reported that the treadmill mechanism lead to injuries involving multiple digits, not including the thumb. Although never previously differentiated, these observations are consistent with the data presented from our institution.

**Table 3. Literature Review of Vacuum-induced Friction Burns**

Study	Year of Publication	Average Age of Patient	No. Patients	Distribution	Types of Injuries	Surgical Repair	Time to Surgery	Nonsurgical Treatment	Outcome	Follow-up
Rubin et al. <sup>17</sup>	1998	9 mo	1	Right volar thumb	Full-thickness friction burn	No	N/A	Conservative treatment	Full resolution in 4 wk	N/A
Macgregor <sup>15</sup>	2002	Under the age of 2 y	4	All injuries sustained on the palmar aspect of the hand.	Superficial injuries	No	N/A	Mupirocin 2% cream, mepitel dressing, band-ages (100%)	Full ROM	N/A
Grob et al. <sup>16</sup>	2003	1.5 y	7	Palmar aspect of middle and ring finger (1), index finger (2), dorsum index finger (1), dorsum hand (1), volar aspect of thumb (1), great toe (1)	Full-thickness injuries	57% had operative tangential excision and skin grafting	<5 d	Bactigras applied on alternate days; DuoDerm until epithelialized (43%)	Full ROM with no sign of contracture	Average of 3.7 mo (1-10 mo)

N/A, not applicable.

Limitations to our study deserve discussion. First, due to its retrospective nature, the data were collected from records that were not specifically designed for the study, thus being lower quality than prospectively gathered data. Confounding factors cannot be ruled out and differential losses to follow-up may bias results. In addition, our children's hospital is a large pediatric tertiary care center, thereby introducing an unavoidable selection bias, as patients with less severe injuries may have been managed in the community and not referred to us for evaluation. Third, formal testing of hand function was not performed in this study, instead relying on parental opinion and provider clinical evaluations. Due to the relative young age of our patients, metrics such as the Jebsen Hand Function Test are not applicable, while other tests of function in the pediatric population (eg, Pediatric Arm Function Test) are not designed for assessing hand outcomes after burn injuries. The authors also underscore that selection bias and the relative lack of patient numbers in our group of vacuum cleaner injuries limit the strength of our conclusions. Lastly, follow-up in our study was variable and short, with a mean period of 23.3 months. Unlike adult patients, the pediatric patient poses unique challenges associated with growth and development over time, thereby mandating longer follow-up and potential management/intervention until reaching skeletal maturity.

### CONCLUSIONS

Friction burns to the upper extremity from treadmill and vacuum mechanisms pose a growing and significant health hazard for the pediatric population. The results of our study suggest that injuries associated with treadmills are more prevalent and of greater severity than those seen with vacuum cleaners, though the low number of patients in the vacuum cleaner group limits the validity of this conclusion. Compared with treadmill burn injuries, friction burns from vacuum cleaners are less common, have different injury features such as involvement of only a single digit (usually the thumb) or dorsum of the hand, and can be treated conservatively with excellent functional outcomes. Per contra, friction burns associated with treadmills have measureable morbidity and often require surgical intervention. Although short-term dysfunction and good outcomes were documented even with treadmill injuries, long-term follow-up is necessary.

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