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Burns in Pediatric Trauma Patients

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Abstract

Introduction: The diagnosis and management of burns may be delayed in trauma patients due to other life-threatening injuries. Improved recognition of common patterns of simultaneous burns and trauma may facilitate early identification and treatment.

Methods: The Children's Hospital at Westmead (CHW) is the only burn referral center and a major tertiary pediatric trauma center in New South Wales (NSW). A retrospective review of all patients admitted with trauma and an associated burn injury between January 2014 and January 2020 was performed to identify patterns in mechanism of injury and management.

Results: A total of 2,441 patients were recorded on the trauma registry from January 2014 to January 2020. When correlated with the burns registry, 115 of these patients sustained 118 burns. The majority of injuries occurred in males (67%) aged 12 to 15 years of age. Common mechanisms were Motor Vehicle (MV) crash passengers (2.6%), falls (0.9%), MV *vs*. pedestrian (15.7%), Motorbike (MB) (3.5%) and bicycle (4.3%) crashes. These resulted in recognizable patterns of injury: MV passengers sustained airbag chemical (0.1%) and friction burns (0.3%); MB injuries included exhaust contact (0.4%) and tire friction (0.7%) burns; pedestrians and cyclists dragged behind vehicles sustained friction burns (5.2% and 2.6%); rope friction burns occurred in hanging; Non-Accidental Injury (NAI) burns were heterogeneous (scald, chemical, friction and contact burns) with a high median Injury Severity Score (ISS 29).

Conclusion: Nearly 5% of pediatric trauma patients sustain burn injuries. This study identified typical patterns depending on the mechanism of injury. Improved recognition should facilitate earlier recognition and treatment of burns in pediatric trauma patients.

Keywords: Friction; Burns; Trauma; Shear injuries

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Introduction

Burns continue to be an important mechanism of injury in children [1]. The diagnosis and management of burns may be delayed in multiple trauma patients due to other, potentially life-threatening injuries [2]. Recognition of common patterns of injury might facilitate earlier identification, first aid and treatment of simultaneous burn in pediatric patients. This has individual patient and hospital ramifications with simultaneous burns in pediatric trauma likely to affect scar outcomes, mortality and length of stay [3]. The frequency and mechanisms of burns have been studied in adult patients with non-burn trauma [4-8]. A simultaneous burn was found in 0.38% of non-burn adult trauma patients [8]. Motor vehicle collisions and assault were most commonly associated with flame burns [8]. Patients with trauma and a secondary insult with a burn in adult populations had a higher mortality and longer length of stay than burn patients alone despite a similar TBSA [8]. In contrast, the etiology of pediatric burns in trauma has not been well reported, aside from small case series of specific injuries including airbag facial burns or car tire friction burns [9-12]. A recent pediatric study reported no difference in mortality rate or complications in combined burns and trauma patients, despite the increased length of stay [3]. This suggests children may have a different mechanism of both trauma and the simultaneous burns. Pediatric trauma typically occurs as a result of motor vehicle collision, motorbike, and bicycle, pedestrian hit by vehicles, falls and burns [13]. Friction burns occur as part of deep abrasions during road traffic accidents in adult studies [4,7]. Children are particularly vulnerable to friction burns because their skin is thinner, making them a vulnerable population [14]. The true depth and severity of these injuries may be difficult to diagnose, especially at presentation with other, apparently more severe and potentially life-threatening injuries. We conducted a review of our trauma patients with burn

injuries with a focus on identification of patterns of injury to help reduce any diagnostic delays to allow timely and effective burn first aid and facilitate optimal care of any associated burn injury.

Materials and Methods

The Children's Hospital at Westmead (CHW) is a major pediatric trauma center and the sole pediatric tertiary burn referral center in New South Wales (NSW), one of the largest states in Australia with an estimated population of 8.17 million. The CHW is a 300-bed teaching tertiary care pediatric center affiliated with The University of Sydney. Patients are transferred to CHW from both NSW and the Australian Capital Territory (ACT) by road or air. Following approval from the CHW Ethics Committee (ETH00576), a retrospective review was undertaken of pediatric trauma patients with burns who underwent treatment between January 2014 and January 2020. The study cohort was identified by performing a search of the Sydney Children's Network (SCHN) trauma registry and correlating this with the NSW Statewide Burns Injury Service (SBIS) registry. The SCHN trauma registry recorded flame, contact, scald, electrical, explosion, chemical and some friction burns. The SCHN trauma registry was filtered to facilitate a review all recorded soft tissue injuries, when correlated with the SBIS Burns registry this revealed a subset of these were friction burns that were recorded as abrasions by the trauma registry. Abrasions (defined as an excoriation or circumscribed removal of superficial layers of skin or mucus membranes) were frequently recorded in trauma patients and often managed in wound clinics. There was a subset of traumatic abrasions which met the criteria for friction burns and underwent specialized burns care including surgery without recording the injury in the trauma registry. Friction burns are caused by resistance between two surfaces in contact to prevent motion; this causes physical deformation (mechanical abrasion) and generates heat (burn) resulting in a deeper burn [2]. SCHN Trauma registry was reviewed for all trauma mechanisms, the ISS and most frequent injuries in the pediatric population. This was then correlated with the SBIS burns registry to identify the most common burns mechanisms associated with these injuries and identifying any burns

Table 1: Mechanism of injury with associated injury and pattern of burns.

Mechanism of Injury (Count)	Associated Trauma Injury	ISS		
		Median	Range	Burns Type
Motor Vehicle	Head 17% (106)	1	0-75	Friction burns 0.3% (2)
Crash Passenger/Driver (621)	Spine 7.9% (49)			Chemical burn 0.1% (1)
	Upper limb 6.3% (40)			
	Chest 5.6% (35)			
	Abdominal/Pelvic 8.3% (56)			
	Lower limb 2.9% (18)			
Falls (405)	Head 50.1% (203)	4	0-75	Friction burns 0.2% (1)
	Spine 6.2% (25)			
	Upper limb 11.7% (47)			
	Chest 4.9% (20)			
	Abdomen 10.6% (43)			
	Lower limb 8.2% (33)			
Motor Vehicle versus Pedestrian (327)	Head 26% (85)	2	0-75	Friction burns 5.2% (17)
	Spine 2.4% (8)			Contact burn 0.3% (1)*
	Upper limb 11.5% (37)			
	Chest 9.5% (31)			
	Abdomen-Pelvis 10% (33)			
	Lower limb 22% (72)			
Motor Bicycle (284)	Head 29.6% (84)	2	0-75	Friction burns 0.7 % (2)
	Spine 9.9% (28)			Contact burn 0.4% (2)
	Upper limb 15.2% (43)			
	Chest 7.4% (21)			
	Pelvis 3.2% (9)			
	Abdomen 13.9% (39)			
	Lower limb 15.8% (45)			
Bicycle (186)	Head 27.7% (70)	4	0-75	Friction burns 2.6% (5)
	Spine 7.5% (14)			
	Chest 3.8% (7)			
	Upper limb 15.1% (28)			
	Abdomen 12.3% (23)			
	Lower limb 5.2% (10)			

Notes: *Includes patient run over by ride on lawn mower

Table 2: Mechanism of all burn injury.

Mechanism of burn	Number	Median TBSA (range)	Burn Depth	Median SSG Operations (Range)	Median LOS Days (range)
Friction	33	2% (0.3%-61.1%)	Full (16)	1 (0-6)	4 (1-87)
			Partial (13)		
			Superficial (4)		
Flame	31	18% (0.1%-85%)	Full (18)	1 (0-6)	11 (1-148)
			Partial (11)		
			Superficial (2)		
Scald	28	19.50% (0.2%-46.6%)	Full (19)	1 (0-5)	20 (1-111)
			Partial (8)		
			Superficial (1)		
Explosion	13	15% (0.2%-70%)	Full (10)	1 (0-5)	13 (1-92)
			Partial (1)		
			Superficial (2)		
Electrical	4	0.70% (0.1%-1%)	Full (4)	1 (0-1)	8 (2-9)
Contact	4	0.70% (0.4%-2%)	Full (2)	0 (0-3)	18 (1-54)
			Partial (1)		
			Superficial (1)		
Smoke Inhalation	2	0.10%	Not Specified (2)	0 (0)	3 (3)
NAI	1*	-	-	-	-
Chemical	1	0.30%	Superficial (1)	Not Specified	Not Specified
Total	118		Full (67)	1 (0-6)	
			Partial (34)		
			Superficial (10)		
			Not Specified (2)		

Notes: Three (3) patients had dual burns mechanisms (friction and contact)
*NAI patient deceased - not referred to burns service and no documentation on size/depth

that were missed in the trauma registry. The SBIS database allowed assessment of burn injuries including depth and size, treatment and timing of diagnosis. STROBE guidelines for the study were met.

Results

A total of 3,057 patients (age 0 to 18 years) with were recorded on the trauma registry over the 6-year period between January 2014 and January 2020. Of these 2,441 sustained soft tissue injuries. After correlating with the SBIS registry, 115 patients (4.7%) sustained concomitant burns, with 3 patients sustaining dual mechanism of burns (friction and contact). One patient died from traumatic injuries and thus the simultaneous burn was not referred to the burns service. Seven patients presented with a burn on a separate occasion to the trauma presentation in an unrelated injury (Figure 1). Concomitant burns in trauma were occurred in 4.6% of patients and resulted in a high ISS (median 9). Although affecting only a small number of patients, the patterns of traumatic injury can suggest a concomitant burn injury (Table 1). Although abrasions are frequently reported, friction burns are rarely recorded in trauma data. Friction burns accounted for 33% of all burns in trauma patients. Despite a low TBSA (2%), friction burns were often partial-full thickness with 36% (12/33) requiring SSG (Table 2). All simultaneous burns were recognized within 2 days of the trauma admission during the tertiary survey. Three patients developed subsequent hypertrophic scars or tattooing. Males were significantly more likely to sustain both trauma and associated burn (67%) injuries. There was an increase in rate of trauma and burns in the young male adolescent group aged 11 to 15 yrs of age, particularly for explosion and flame burns. An increase in traumatic burns in the 3-year-old age group occurred mostly as a result of scald burns in conjunction with falls or non-accidental injuries. Friction burns injuries occurred across the age groups although majority (45%) occurred in adolescents between 12 to 15 yrs of age. The injury mechanisms and patterns of burn injury were age specific. Infants aged 2 yrs of age most frequently sustained Motor Vehicle (MV) vs. pedestrian injuries (45%), whilst motorbike (14%) and bicycle (14%) trauma typically occurred in adolescents.

MV passengers

MV crashes are the most frequent cause of trauma with 68% children either the passenger or driver. Although there was a relatively low ISS (mean 4.3) they were associated with 18% head/facial injuries and higher chest 5.6% and abdominal 7.5% injuries than other mechanisms of injury. Associated burn injuries included two road-related friction burns and an airbag-related friction and chemical burn, two of which were managed with a Split Skin Graft (SSG).

MV *vs*. pedestrian

Majority of MV versus pedestrian injuries occurred in infants, with 13% occurring in children two years of age. Children struck by a MV had a high mean ISS 7.0, as a result of head (18%), spine (2.4%) and abdominal (7.6%) trauma. Friction burns occurred most frequently in MV vs. pedestrian injury (4%) group from both the tire (Figure 2) and being dragged along the road (Figure 3). Thirty five percent (6/17) required split skin grafting. A child reversed over by a

Table 3: Prevention of burns in pediatric trauma.

Prevention strategies for burns in traumatic injuries include:
- Wearing protective clothing (helmet, shoes, and protective pads over elbows and knees) when cycling, skateboarding, riding a motorcycle or engaged in other sports [7,16].
- Discouraging children from playing around fast-moving rotational parts (lawnmower and car tyres) and increasing parental awareness to 'look back' [29].
- Preventing road related injuries [7,16] and proper restraint and seating position [23] to reduce airbag, seatbelt and other abrasion injuries.
- Regulated use of motorcycles/ATV/go-cart/golf cart/other small engine vehicles with restrictions or supervision and training [1,30,31].
- Recognition of patterns of NAI [32] and self-harm behaviors.

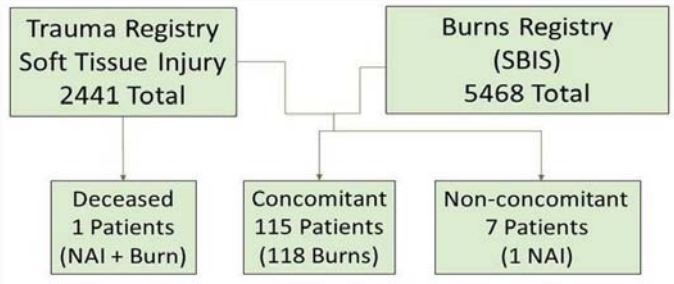

Figure 1: Method of data collection- Trauma and SBIS databases.

Figure 2: Pedestrian versus car tyre friction injuries a) post injury b) post split skin grafting c) healing d) follow-up.

Figure 3: Pedestrian dragged by motor vehicle sustaining 'road rash' friction burns a) post injury b) post-split skin graft.

lawnmower sustained a contact burn in addition to a degloving injury which was treated with dressings and a free flap.

Recreational injuries

The next most common groups to sustain abrasions were recreational activities including, bicycle (51%), MB (35%), go-kart (26%), scooter and skateboard injuries (7.5%). Bicycles have twice the rate of friction burns compared to MB (Table 1), however only one bicycle injury was managed with SSG and the remainder with dressings. MB also resulted in two exhaust contact burns in teenagers who did not require grafting. MB however had a higher ISS (6.3 vs. 5.9%), more spinal injuries (9.9 vs. 7.5%) and lower limb fractures (femur 8 vs. 1%, tibia/fibula 7 vs. 2%) than bicycle injuries. Bicycle injuries had higher rates of head injury (21 vs. 19%), abrasions (51 vs. 35%) and groin lacerations (6 vs. <1%), correlating with the reduced use of helmets and protective clothing (MB 70 vs. bicycle 50%).

Rope/Ligature injuries

The incidence of self-inflicted hanging increased with age (peak 13 to 15 yr olds) and was twice as likely in males with a 30% mortality (2/7). Accidental injury occurred in young children after entanglement in a blind cord or a washing line, and in an older child after entanglement in rope while falling off a horse (Figure 4), which was the only case reported as a friction burn that required grafting.

Non-accidental injury (NAI)

NAI caused the most severe trauma (ISS median 29, range 0% to 43%) with a mortality of 20%: All surviving patients required admission to intensive care. Eighty percent of NAI occurred in children <1 year old with 90% in those <2 years of age. This mechanism of injury resulted in the highest percentage of head (95%) and spine (28.6%) injury. Two scalds and one chemical burn were sustained as a result of NAI. One child underwent 15 operations and 5 grafting surgeries. One child died from extensive traumatic injuries resulting from NAI, but the unknown mechanism of concomitant burn was consistent with a 'branding contact burn'. One child sustained a friction burn that was not referred to the burns service and recovered with dressings. Seven patients obtained a burn on a separate occasion to the trauma presentation and one of those was investigated for NAI.

Prevention strategies

Prevention strategies for burns in traumatic injuries are considered in Table 3.

Figure 4: Rope friction burn a) post injury lateral b) post injury AP c) post-split skin graft.

Discussion

Burns occur in conjunction with other trauma mechanisms more frequently (4.6%) in pediatric patients than in adult populations (0.38%) [8]. This likely reflects differing patterns of traumatic injury and that skin in children is thinner and more likely to suffer a deeper burn injury from an equivalent injury in an adult [15]. Children are prone to sustain severe injuries in motor-vehicle collisions when improperly restrained or in wheeled-recreational activities without adequate protective equipment. They are vulnerable to non-accidental injuries, and may be victims of accidental injuries including reversed over by motor vehicles. These mechanisms frequently result in friction burns, which accounted for 33% of all burns in pediatric trauma patients. This is distinct from adult trauma patients who mostly sustain flame burns and have a lower percent of friction burns [8]. Our study is the first to provide a broad overview of patterns of burn injury in pediatric trauma, aiming to increase recognition and early treatment particularly first aid for burns within the secondary survey [16]. Abrasions recorded in trauma registries are a heterogeneous group and may include a subset of friction burns, perhaps not recorded in trauma registries or recognized as a friction burn. Friction burns are recognized in burns literature as a combination of the mechanical (abrasion) and thermal (heat) energy, which results in an intense inflammatory response [2,11,17-19]. The coefficient of friction between the skin and other surface can be very high, generating considerable heat [2,11]. The shear forces, particularly when not perpendicular to the skin, result in physical deformation of dermal layers and damage the sub-dermal vascular plexus [11]. The breakdown products of metabolism accumulate, leading to necrosis and a secondary cellular level injury and hyperemia [11]. The shear physical force, then secondary thermal burn result in a delayed, deep burn which may be missed or underestimated on initial review [11]. The severity of friction burns may be predicted by the speed of the movement, the hard surface the body contacts with and the degree of clothing covering the body part [2]. Despite a low TBSA (2%), friction burns were often partial-full thickness with 36% requiring grafting, which is consistent with other literature from both burns unit and trauma unit publications (skin grafting in 21% to 100%) [9,11,14,17,20]. In trauma these burns can be complex: Friction results in devitalized tissue and pressure forces foreign debris through the dermis (i.e. gravel in road accidents-'road rash') risking scarring, infection [4-9] and tattooing [7,9,14]. Early recognition of these concomitant burns in trauma patients, particularly friction burns will allow early referral to specialist burns surgeons in centers where the trauma surgeon may not have dual specialization in burns, or the burns center may be in an entirely separate hospital. Timely treatment by a burns specialist reduce these risks and monitoring for the development of aforementioned complications [21,22]. Airbag injuries have a recognized pattern of injury also seen in this study with associated head, facial, and spine fractures, ocular injuries and burns [21,24]. The burns are multi-factorial with cumulative effects: contact with hot expelled gases and the hot airbag itself, friction burns and chemical burns from sodium azide [21,23,24]. This reacts with water to cause toxic and explosive hydrazoic acid, which then reacts with cupric oxide to form sodium hydroxide, causing severe chemical burns [12,23,24]. Numerous high temperature gases (carbon monoxide, dioxide, nitric oxide, ammonia, hydrocarbons) and various other metallic oxides are also released producing a corrosive alkaline aerosol [21,23,24]. A teenage front seat passenger required grafting after sustaining an airbag-related facial burn from a combination of chemical exposure and friction burn in our study. Car tire burns result from a combination of friction, shearing and compression forces [9]. The severity of the injury is influenced by deceleration, with burn severity dependent on the amount of energy absorbed by the affected tissues [9]. In infants dragged behind a car this particularly affects their proportionately larger heads. These head and neck abrasions are prone to bleeding due to increased vascularity [2]. The 'look back' prevention campaign aimed to increase parental awareness of children playing behind reversing vehicles [29]. This is distinct from degloving injuries which are a more severe non-burn soft tissue injury which exposes bone/tissue, and requires flap coverage [9]. These degloving injuries typically occurred in children reversed over by lawnmowers, a well-recognized mechanism [25]. In contrast, friction burn from MB, bicycle and skateboard injuries typically occurs over bony prominences (chin, elbows, knees, hands) [2] and is associated with lower limb and upper limb fractures. Children less than 5 years of age who sustain hand burns are at risk of significantly impaired fine and gross motor function [26]. Our study found MB had higher ISS, spinal injuries and lower limb fractures. Bicycle related head and soft tissue injuries in our study were correlated to decreased used of helmets and protective clothing. Contact burns from exhaust systems is mostly seen as a result of MB accidents but may occur with all-terrain vehicles, cars and other more unconventional vehicles. Although small in size, exhaust burns in children tend to be full-thickness and requiring surgery [1]. In addition to thinner skin, children often lack fitted protective gear and the ability to free themselves from entrapment under a heavy vehicle in a timely manner resulting in a longer exposure time [1]. Children are also more likely to have MB crashes due to ergonomic disadvantages in age- related physical, cognitive or hazard-evaluation skills and motorbike factors (low weight, rapid acceleration and turning) which contribute to loss of control [27]. Twenty eight patients in our study were less than six years of age reaffirming previous studies that age restrictions on motorbike usage is essential

to prevent trauma [1,27]. Rope burn (blister formation) or ligature marks (patterned abrasions caused by ligature material) [28] occurred through either accidental (rope, washing line and blind cord) or deliberate (self-harm) mechanisms in the current study. Only one case was classified as a friction burn and required split skin grafting, although this may be the result of a high mortality (30%) from hanging injury [28,29]. Hanging can occur accidentally (blind cord/ washing line) in younger children or deliberately with intention to cause harm [28,29]. Similar to previous studies [28,29], the incidence of self-inflicted hanging increased with age (peak 13 to 15 yr) and is twice as likely in males. Accidental hanging can be reduced by safety legislations, including breakaway device or cord tensioners to improve safety standards for blind manufacturers [29]. Self harm may be reduced by earlier detection of suicidality and intervention [28]. Burn injuries are a known mechanism of NAI. Consistent with other studies, the current study had cases which did not identify the circumstances of burns either from neglect (unwitnessed injury) or deliberate injury [27]. This included severe scalds and chemical burns with mechanisms that did not account for the injury, or a burn whose appearance was consistent with a 'branding' contact burn but no explanation provided for how injury was sustained. To increase recognition of NAI, literature recommends any burn injuries in children less than 12 months old age group should prompt clinicians to consider inflicted injury, particularly if the injury is not consistent with developmental milestones, unwitnessed, has an explanation that is lacking or inconsistent [27]. Non-accidental injury had 20% mortality with all surviving patients admitted to intensive care, with the highest ISS scores. Limitations of this study include the single center design and thus relatively smaller numbers which do not allow determination of statistically significant complications. The burns literature has clearly established that a delay to burns diagnosis, first aid and subsequent treatment results in poor outcomes and complications including scarring/contractures [21,22]. All patients in the cohort were referred to the center as trauma patients. The study did not review patients who were admitted directly under burns care with concomitant trauma to reduce bias in assessment of prevalence of burns in trauma. Thus aside from a small percentage of large burns sustained in conjunction with major trauma (e.g. explosion injuries) who would be preferentially transferred to this hospital, the patients are representative of any pediatric trauma patients. Pediatric surgeons admitting trauma patients are often dual qualified as burn surgeons in our center. It is expected that relatively fewer burn injuries would be missed during secondary and tertiary survey compared to a center without burns expertise. Although there remains the small possibility some patients referred to wound clinics (either pediatric or plastic surgery departments) may have a burn that were not recorded and managed with dressings. This study has increased recognition of concomitant burn injuries in the aforementioned patterns of injury particularly during the secondary survey, and the subsequent referrals to burn specialists from trauma surgeons in our department. In conclusion, trauma patients sustain a concurrent burn injury in 4.6% of cases, significantly higher than in the adult literature. Children have a higher rate of burns than adults in trauma due to non-accidental injury and friction burns sustained from a variety of mechanisms including pedestrian *vs.* MV and MB related injuries. Burn injuries can be initially overlooked during the secondary survey missing the critical time for first aid or not recognized as burns at all, in the case of some friction burns initially recorded as simple abrasions. The mechanism of trauma can help predict the pattern and severity of burn injury. This should enable earlier involvement of burns clinicians to optimize long-term outcomes.

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