Case study

Thermal burns from a lithium-ion battery electric scooter explosion: A case report

Abstract

Lithium-ion batteries are being increasingly implemented across a broad range of electrical devices due to their greater energy capacity and longer life-span than other battery alternatives. However, safety concerns have emerged due to their greater propensity to ignite or explode through a process named thermal runway effect. Consequently, there have been several case reports of burns injuries from lithium-ion batteries across the literature, most commonly associated with electronic cigarettes and mobile phones. Whilst there is documentation of explosions from lithium-ion batteries in electronic scooters, case reports of burns from this larger electric device are limited.

This report presents one of the first cases of a significant burn injury requiring surgery following the explosion of a lithium-ion battery in an electric scooter. We describe the mechanism of injury from the electronic scooter battery explosion and outline our management strategy for burns of this mechanism. This report highlights the increasing risk of burn injury from lithium-ion batteries in scooters and describes the pitfalls of existing safety mechanisms that contribute to the risk of burns from these batteries. We also provide a brief literature review of existing case reports of lithium-ion battery burns to compare the mechanism of injury and treatment regimen utilised by different centres to treat lithium-ion battery related burns injuries.

Key words: Thermal burn, lithium battery, electric scooter, burns surgery, wound dressings

Patient consent: All authors declare that 'written informed consent was obtained from the patient (or other approved parties) for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editorial office/Chief Editor/Editorial Board members of this journal.

1. Introduction

Lithium-ion batteries are increasingly becoming the battery of choice for electrical technology due to their high energy capacity, low cost and rechargeability.(1) There is a growing tendency towards their use in small cell electronics and portable devices, such as electronic cigarettes, laptops and mobile phones, as well as larger cells and transportation devices including motorised scooters, motor vehicles and smart grids.(2) Lithium-ion batteries function through insertion-reaction electrodes by passing lithium-ions between a lithium compound cathode and graphite anode separated by liquid electrolytes composed of soluble lithium salts.(3, 4) This technology allows increased cell voltage, charge storage capacity and battery life compared to alternative battery types.

Despite these benefits however, safety concerns have emerged due to their tendency to ignite or explode with consequential injury to users and structural damage. Whilst safety measures have been implemented and further research is being conducted to prevent these complications, reports of injury from lithium-ion battery malfunction are ongoing.(5)

2. Case Presentation

A 31-year-old man was admitted to our tertiary burns centre two hours after sustaining a thermal burn to his anterior lower abdomen, bilateral upper thighs and penis from an electric scooter explosion. Whilst plugged into a charging dock overnight, the scooter's lithium-ion battery had caught alight, and it subsequently exploded as the patient attempted to extinguish the fire. The patient was naked at the time of the incident and he received direct flash flame, thermal burns to his lower trunk, genitals and thighs.

The patient's scooter was approximately one year old. He reported he had been operating the scooter daily and it was charged overnight in an ambient, warm room. The scooter had been charging for approximately three hours at the time it exploded.

Immediate first aid was applied on scene with 20 minutes of running water and the wounds were dressed with Silver sulfadiazine ($C_{10}H_9AgN_4O_2S$) cream and absorbent cotton fibre dressing. On arrival, the patient's vital signs were normal and there was no evidence of airway involvement.

2.1 Treatment

Assessment and management of the patient's burns was made clinically and based on the surgeon's experience in line with our practice guidelines at our burns unit based upon the Australian and New Zealand Burn Association (ANZBA) recommendations.(6, 7) Initial assessment identified a mixed depth burn to 6% total body surface area (TBSA). This included areas identified clinically as full thickness and deep dermal burns mostly to anterior abdomen and bilateral anterior thighs. The anterior aspect of the penis sustained mid-dermal burns and the entire scrotum was spared (Figure 1).

Approximately two hours after burn injury

Day one post-reconstruction with split thickness skin grafts

Two weeks post- split thickness skin graft reconstruction

Figure 1: Photographic progress of patient before and after skin grafting

Within the first 48 hours the patient underwent debridement. The initial debridement consisted of full thickness excision of the deep dermal and full thickness burns to the abdomen and thighs using tangential debridement with a Watson blade,
and hydrosurgical debridement using Versajet II (Smith&Nephew) to the mid-dermal burns of the abdomen and the anterior penis. The debrided wounds were dressed with a biosynthetic silicone nylon mesh to allow for physiological stabilisation of the patient and demarcation of the burn area and depth prior to definitive reconstruction.

Three days later, the patient returned to the operating theatre and the
burns were reassessed under anaesthetic. Underneath the biosynthetic silicone nylon mesh the burns had mostly demarcated and there was healthy tissue for grafting. No further debridement was necessary, and the areas of burn excision were reconstructed with split thickness skin grafts (Figure 1). In accordance with our burns unit guidelines, the decision for skin grafting was made as healing with conservative managed through dressings was thought to take longer than two to three weeks. The grafts were dressed with methane (CH_4) gauze, silver (Ag) impregnated dressing, combination cream containing glucocorticoid triamcinolone ($C_{21}H_{27}FO_6$), gramicidin, neomycin ($C_{23}H_{46}N_6O_{13}$), nystatin (polyene macrolide with a deoxysugar D-mycosamine), and petroleum gauze.

Whilst the penis was a particular area of concern initially, having sustained mid-dermal burns, on further inspection there was evidence of good capillary refill and the decision was made to spare this area from grafting. The penis was dressed with petroleum and 3% bismuth tribromophenate gauze until healed at day 12 post operatively.

2.2 Outcome and follow up

An indwelling urinary catheter (IDC), inserted during initial assessment, was removed once penile swelling had subsided and the patient passed a trial of void with no ongoing concerns. The patient began to mobilise on day three post-graft and was discharged on day eight. The patient continued to have second daily dressings until at two weeks post-operatively the grafts and superficial burns had healed (Figure 1). The patient is currently receiving ongoing multidisciplinary scar management.

3. Discussion

Electric scooters present as a cheap, ecological alternative mode of transport to petrol-fuelled transportation. Globally, there has been a significant surge in electric scooter market demand and they are becoming the preferred mode of transport for ridesharing, food delivery and quick transportation.(8) Whilst our case report is one of the first to present injury from a lithium-ion battery powered electric scooter, with increasing use of lithium-ion battery powered electric scooters the incidence of this type of is likely to rise in future.

Recently, there has been an increasingly ubiquitous implementation of lithium-ion batteries across a range of electronic devices. These batteries have the capacity for high energy density storage and are ideal for portable devices given their lightness and absence of poisonous metals such as lead and mercury.(9) Lithium-ion batteries typically comprise of a carbon-based anode, metal oxide cathode, non-aqueous lithium electrolyte and a micro-perforated plastic separator.(10) This design delivers excellent electrochemical performance including a high energy storage and cycle life with no memory effect.(11)

Despite these benefits, there are increasing reports of ignition or explosion of lithium-ion batteries utilised by electronic devices. Several studies have identified a range of factors contributing to these events including conductor-battery exposure, overheating, short-circuiting and manufacture error.(9, 12) As lithium-ion batteries contain hazardous lithium metals and flammable solvents, this can propagate exothermic activity leading to a series of reactions described as 'thermal runaway'. Thermal runaway occurs due an uncontrolled reaction when the lithium-ion battery reaches a critical temperature (above 80-90°C) which triggers a positive feedback loop with an accelerated reaction rate and rapid increase in temperature.(13) These thermal effects result in the vaporisation of lithium and cell overpressurisation which causes ignition of the electrolyte components resulting in fire or explosion.(14)

Studies suggest that over-charging, over-heating or crushing of a lithium-ion battery powered device is likely to trigger the thermal runaway reaction. In particular, over 80% of explosions have occurred whilst the devices were being charged.(15) Accordingly, the scooter in this case report was being charged at the time of the explosion. As a battery charges, cell impedance and electrode resistance increase which results in heat generation and the battery temperature rises. Particularly if connected to other charging devices, a lithium battery can become overcharged which triggers the thermal runaway effect resulting in an explosion if the battery's safety mechanisms are insufficient.(16) Attempts have been made to minimise the risk of battery explosions during charging by improving battery thermal stability. This includes implementation of external battery safety devices such as temperature sensors and pressure valves and internal safety devices such as modifications of the cathode and anode materials.(17) However, further study to optimise these safety mechanisms is ongoing.

Patterson et al. has proposed a classification of newly emerging patterns of burns caused by lithium-ion batteries (Table 1).(16) Whilst this classification was designed for ECs, there is potential for its use in burns from other lithium-ion battery injuries. In our case report, the patient received burn injuries due to direct flash from the battery explosion to his waist and groin (Type 3). This pattern of injury reflected his position standing front-on to the scooter at the time of the explosion and resulted in direct flame-to-skin impact. Notably, the mechanism of action in this case differed to previous Type 3 injuries proposed by Patterson et al. where waist and groin injuries from EC explosions are typically due to the device being stored in a pocket. Despite this, the paper emphasises the high risk of this type of burn to the genital skin and advise for non-operative management if possible. The aim for genital burn management is to minimise long-term sequalae and preserve function whilst minimising scar contracture and urethral damage.(18) Our management of the patient in this case report is in accordance with these recommendations and at follow-up his penis had healed well without the need for skin grafting.

Table 1: Classification of burns injuries for Lithium-Ion Batteries adapted from Patterson et al.

Direct vs indirect injury	**Injury type**	**Definition**
Direct	Type 1	Hand injury
	Type 2	Face injury
	Type 3	Waist/groin injury
	Type 5a	Inhalation injury from using the device
Indirect	Type 4	House fire injury
	Type 5b	Inhalation injury from fire started by the device

Whilst there are ongoing attempts to improve battery safety mechanisms, with growing implementation of these batteries, the reports of explosions are mounting. Over the last five years, several reports of injuries from exploding lithium-ion batteries have been documented across both the media and medical literature ranging from small consumer electronics to large-capacity battery applications. Case reports of burns injuries are most frequently reported as a result of mobile phone and electronic cigarette (EC) battery accidents (Table 2). Whilst there are several news reports worldwide of electric scooter related fires, reports of patient-related injury through this mechanism are scant.(19-21) One previous case report described an electric scooter house-fire outbreak which resulted in burn injuries to four patients.(22) A recent case series also described burns in thirty patients from personal mobility devices.(1) This series outlined the injury patterns related to lithium-ion battery explosions in electronic scooters. They found that 90% of burns were associated with electric scooters that were left unattended whilst charging and 13% had full-thickness burns. Whilst this study identified that 41% required surgical management of the burns, the specific management of these lithium-ion battery burns was not explored.

Table 2: Summary of case reports documenting lithium-ion battery powered device injury causing burns to skin from 2016-2021

Author	**Electronic device**	**# patients**	**Burns depth**	**Location**	**Treatment**
Hsieh, 2021 (1)	Portable mobility devices	30	30% superficial partial thickness, 30% mid-deep dermal, 13% full thickness	Not described	41% surgical (not further described)
Ho, 2019 (23)	Electronic cigarette	3	Partial thickness (3)	Thigh, leg (3)	Enzymatic debridement (3)
Serror, 2018	Electronic	10	Partial thickness	Thigh (8),	Dressings (7),

(24)	cigarette		(5), full thickness (5)	hand (5)	surgical debridement + grafting (3)
Gibson, 2017(25)	Electronic cigarette	14	Partial thickness (10), full thickness (4)	Thigh, hand	Dressings (10), surgical debridement + grafting (4)
Jiwani, 2017 (26)	Electronic cigarette	10	Partial thickness (9), full thickness (1)	Thigh (9), hands (5), face (1)	Dressings (5), Surgical debridement +/- grafting (5)
Ramirez, 2017 (27)	Electronic cigarette	30	Not described	Thigh (19), hand (16), genitals (4), face (4), torso (4)	Dressings (21), Surgical debridement + flap (9)
Satteson, 2017 (28)	Electronic cigarette	1	Full thickness	Right hand	Surgical debridement + flap
Maraqa, 2016 (2)	Electronic cigarette	8	Partial thickness (5), full thickness (3)	Leg (7), hand (3), genitals (2), chest (1)	Dressings (6), Surgical debridement + grafting (2)
Mankowski 2016 (12)	Mobile phone	1	Partial thickness	Left lateral thigh	Dressings
Nicoll, 2016 (29)	Electronic cigarette	2	Partial thickness	Right thigh	Surgical debridement + grafting
Patterson, 2016 (16)	Electronic cigarette	1	Partial thickness	Thigh, genitals, hand	Surgical intervention
Walsh, 2016 (30)	Electronic cigarette	1	Partial thickness	Right thigh	Dressings

No specific management guidelines for lithium-ion battery burns are currently available in the literature. Some case reports of lithium-ion battery explosions describe chemical burns from alkali chemical components, suggesting the need for decontamination and irrigation and recommend against the use of water irrigation for initial first aid management.(29) In this patient's case however, the burns were in keeping with a thermal mechanism. Consequently, the patient's burns were treated in accordance with thermal burns management guidelines taking into consideration TBSA and depth of the burns. Initial management of the with copious amounts of water for 20 minutes was therefore appropriate.(31)

A range of burns management options have been employed across existing case reports, although the justification for specific management modalities is poor. Management varied from conservative treatment with conventional dressings to surgical debridement. A range of dressing types were used across case reports including silver sulfadiazine ($C_{10}H_9AgN_4O_2S$), lyophilised polyurethane membrane, bacitracin (cyclic polypeptide antibiotic) and soft paraffin dressings. One study also employed the use of enzymatic debridement using Broelain (enzyme extract) for partial thickness burns with good effect.(23) As no primary studies are available which compare the benefits of surgical and conservative management of burns from lithium-ion batteries, gold-standard practice guidelines for management of these injuries is currently unavailable.

Given the size and depth of the patient's burn, the patient in this report required debridement and skin grafting in keeping with the current evidence for management of major burns.(32) As it is widely accepted that early surgical debridement of major burns improves patient outcomes, the patient underwent debridement within 24 hours of admission.(33) After the initial burn debridement, the wound was dressed with biosynthetic silicone nylon, a biologic skin substitute which has been shown to improve healing time and reduce pain and length of hospital stay.(34) Biosynthetic silicone nylon is used in our institution to temporise a burn for later reassessment to promote definitive reconstruction. Dressings utilised in the management of this patient are part of our standard dressing perioperative prescription at our burns unit based upon the ANZBA recommendations.(6, 7, 35)

4. Conclusion

Lithium-ion batteries are becoming increasingly common across a range of electronic devices due to their high energy capacity and long battery life. Our case report described a patient who experienced thermal burns from a lithium-ion battery powered scooter and outlines their pre-operative, surgical and post-operative management at a major burns centre. This report highlights the potential dangers of lithium-ion batteries exploding or igniting due to thermal runway effect. With an increasing use of electric scooters globally, there is significant risk of further lithium-ion battery injury from these devices which highlights the need for safety improvements of these batteries in future.

6. References

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