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Original Article
Thermal injury patterns associated with electronic cigarettes

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Abstract: E-cigarettes are typically lithium-ion battery-operated devices that simulate smoking by heating a nicotine-solution into a vapor that the user inhales. E-cigarette use is becoming rapidly popular as an alternative to traditional cigarette smoking. This report describes an emerging problem associated with e-cigarettes, consisting of 10 thermally injured patients seen at a single burn center over a 2-year period from 2014 to 2016. Our cohort was comprised mainly of young adults who sustained mixed partial and full thickness burns as a result of e-cigarette-related explosions. In many documented scenarios, a malfunctioning or over-heated battery is the cause. Our data support the need for increased awareness among healthcare providers and the general public of the potential harms of e-cigarette use, modification, storage, and charging.

Keywords: Electronic cigarette, e-cigarette, burns, lithium-ion battery

Introduction

Electronic cigarettes (e-cigarettes) are devices that simulate smoking by vaporizing a solution, which contains nicotine, flavorings and a solvent like propylene glycol and/or glycerin. They are commonly powered by lithium-ion batteries. E-cigarettes were first developed and patented in 2003 and were introduced into the United States market in 2007. Since that time, e-cigarette production has grown at a rapid rate; there were 288 brands available in 2012 and 466 brands in 2014 [1]. Popularity has similarly surged, with an increase in first-ever use of e-cigarettes from 1.8% in 2010 to 13.0% in 2013. There were 2.5-million e-cigarette users in 2014 [2]. Data from the 2014 National Health Interview Survey revealed that 12.6% of adults had tried an e-cigarette at least once. The percentage use by age group was highest for 18-24 year olds and declined as age increased [3]. Additional research demonstrates that e-cigarettes are the most commonly used nicotine product among high school (13.4%) and middle school (3.9%) students [4]. Among the adult and youth populations combined, most e-cigarette users are also traditional cigarette smokers-76.8% and 76.3% respectively [https://www.tobaccofreekids.org/research/factsheets/pdf/0380.pdf].

No guidelines exist for the design, manufacture, or safety testing of e-cigarettes. This has led to a multitude of product options, and variability in materials and ingredients. Materials that have been used in aerosols and cartridges include ceramics, carbonyl compounds, cadmium, nickel, lead, chromium, arsenic, rubber, plastic, foams and fibers [5-7]. Previous case reports described burns of the extremities, genitalia and face as a result of e-cigarette battery explosions [8-10]. "Vape modding", i.e. user modifications to increase vapor density by increasing heating-element temperature, has recently become popular (**Figure 5**). These modifications also increase the risk of potential thermal burn injury [6, https://www.usfa.fema.gov/downloads/pdf/publications/electronic_cigarettes.pdf].

The purpose of this report is to describe our recent experience with thermal injuries associated with e-cigarette use.

Figure 1. Case No 1. Image depicts 3 distinct areas of deeper burn in the inguinal region representing excessive heat exposure secondary to e-cigarette explosion.

Figure 2. Case No 2. Image shows distinct linear pattern of deeper burn over mid-thigh.

Figure 3. Case No 8. Image of patient's thigh with mottled area of deeper burn.

Materials and methods

The electronic medical records of 10 consecutive patients presenting to the U.S. Army Institute of Surgical Research Burn Center over a 2-year period between April 1, 2014 and March 31, 2016 were reviewed, to include photographs when available. Lund-Browder diagrams, the widely used mapping tool used to depict the pattern of partial and full thickness burns, were reviewed. Retrospective analysis of patient demographics (age at diagnosis, gender), burn-injury mechanism, depth and location, and intervention was performed.

Results

Demographic data and clinical characteristics

Over the course of 24 months, our institution treated 10 patients with burn injuries sustained secondary to e-cigarette-related explosions. All 10 patients were initially evaluated in the Emergency Department at San Antonio Military Medical Center, prior to being admitted to the Burn Center for further management. When indicated, the patients were followed up in Outpatient Burn Clinic. The complete demographic and clinical characteristics are shown in **Table 1**.

The cohort was composed of 9 males and 1 female. The mean age at diagnosis was 26 years (range, 18 to 46 y). Mean percent total body surface area (TBSA) burned was 5.95% (range, 1 to 27.25%). All patients presented with a localized burn of at least one extremity (**Figures 1-3**). Burn location was as follows: 5 were isolated to the lower extremity and/or genitalia, 1 was isolated to the upper extremity, 4 involved both upper and lower extremities, and 1 involved the face. Nine of the 10 injuries were the result of thermal injury with the remaining one a combination of thermal and blast injury, specifically affecting the face and hands. Burn depth was as follows: 4 were partial thickness, 5 were mixed partial and full thickness, and 1 was full thickness. **Figure 4** depicts the patterns of burn injury via Lund-Browder diagrams for each of the 10 patients.

Seven patients reported injury as the result of the e-cigarette battery self-combusting in their pants pocket or lap, 1 reported vaporizer explosion, 1 was actively using the e-cigarette when the explosion occurred, and 1 reported ignition of the e-cigarette lighter during a motorcycle crash.

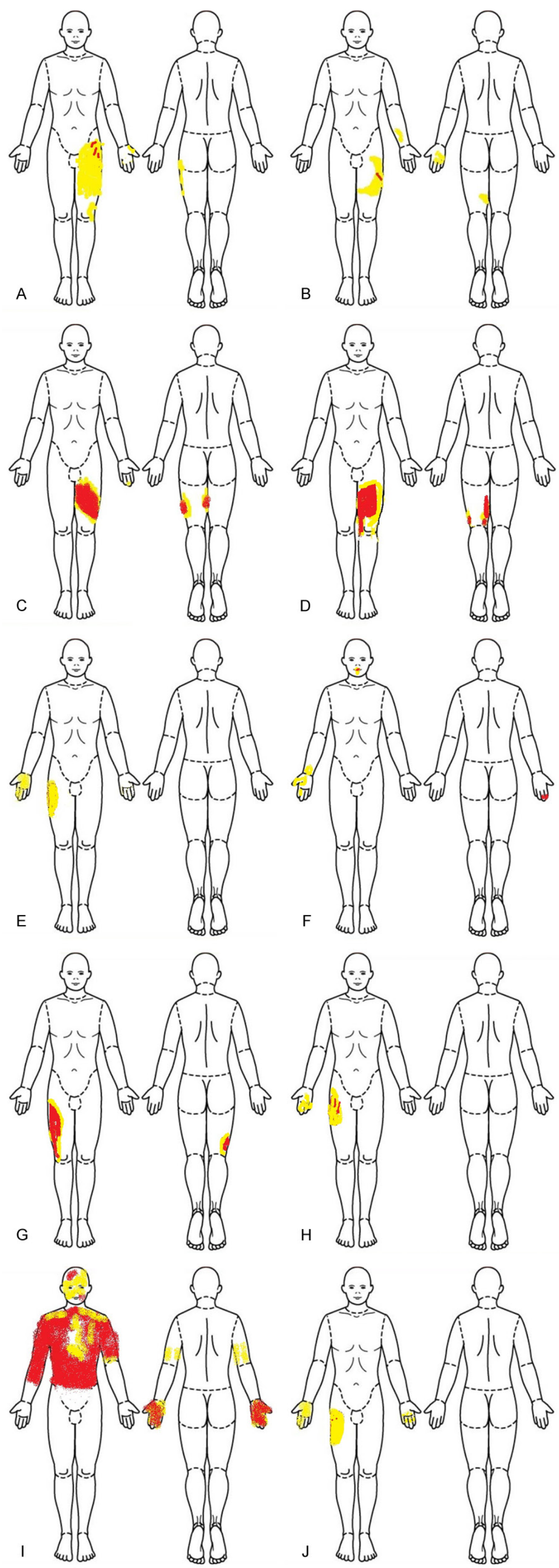

Figure 4. Lund-Browder Diagrams of the 10 patients (A-J) included in our case series. Second degree burns (partial thickness) are shaded in yellow. Third degree burns (full thickness) are shaded in red. A: Case No 1; B: Case No 2; C: Case No 3; D: Case No 4; E: Case No 5; F: Case No 6; G: Case No 7; H: Case No 8; I: Case No 9; J: Case No 10.

Interventions

Despite burn depth and extent, 5 patients were successfully treated with non-operative management using topical treatments such as bacitracin and Xeroform gauze, silver sulfadiazine cream, 5% mafenide acetate solution, or silver nylon dressings. One required surgical debridement and application of silver nylon. Due to presence of full-thickness burns, the remaining 4 underwent excision and split-thickness skin grafting.

Discussion

The principal purpose of this report is to highlight the potential for serious burn injury as a consequence of e-cigarette use. Further attention is directed toward e-cigarette batteries as the likely culprit in these injuries, resulting in similar burn-injury patterns among patients. Overall, our data support the need for increased awareness among healthcare providers and the general public of the potential risks associated with e-cigarette use.

The Federal Emergency Management Agency (FEMA) produced a composite report of 25 unique incidents of e-cigarette explosions reported in the media between 2009 and 2014. Eighty percent of these cases occurred while the battery was being charged, 8% while the e-cigarette was in use and 4% during storage or transport [https://www.usfa.fema.gov/downloads/pdf/publications/electronic_cigarettes.pdf]. Lithium-containing batteries are commonly used in e-cigarettes due to their ability to hold large amounts of energy in a small space. However, they are also especially prone to a phenomenon called "thermal runaway", wherein excessive internal battery temperature results in fire or explosion. This is particularly true in e-cigarettes due to their cylindrical design,

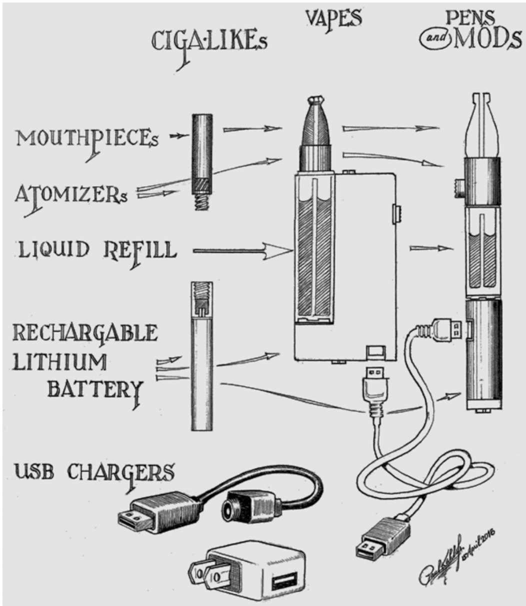

Figure 5. Various electronic cigarette designs. Illustrated here are a few examples such as ciga-likes, vapes and pens and accessories.

wherein the seal over the end where the battery resides can easily rupture when a threshold pressure is reached. Current package labeling does not warn about risk of battery explosion or over-heating [8, 11]. Given this, healthcare providers treating e-cigarette users should advise patients of the risks associated with e-cigarette use.

During a literature search for e-cigarette explosions, 3 published case reports identified the lithium-ion battery as the key component to trigger the ensuing explosion. These explosions resulted in mixed-depth partial thickness burns of the lower extremities and full thickness burns of the genitalia and/or hands in two patients, injury of the face in another [8], partial thickness burns of the abdomen in one patient [9], and isolated mixed-depth burn injury of the lower extremity in one case [10].

With more than 2.5 million e-cigarette users in the United States, and a large percentage within the age range of 18-24 years, additional work is needed to improve our understanding of the hazards associated with e-cigarette use. Moreover, we recommend development of a standardized incident reporting protocol for injuries associated with e-cigarettes so we may better characterize the problem at hand.

To conclude, we report a 10-case series of thermal injuries associated with e-cigarettes over a recent 2-year period. Our cohort was comprised mainly of young adults who sustained mixed partial and full thickness thermal burn injuries as a result of e-cigarette-related explosions. In many documented scenarios, a malfunctioning or over-heated battery is the cause. Our data support the need for increased awareness among healthcare providers and the general public of the potential harms of e-cigarette use, modification, storage, and charging.

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Disclosure of conflict of interest

None.

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Table 1. Patient demographics and clinical characteristics

Case No	Age/ Gender	% TBSA	Mechanism	Burn Depth	Location	Intervention
1	26, M	5.5	Battery self-combusted in pants pocket	Mixed partial and full thickness	Left thigh, scrotal area, left lower leg including inguinal region	Bacitracin and Silvadene cream
2	46, M	4.5	Battery exploded in lap	Partial thickness	Left thigh	Silvadene
3	19, M	3.5	Battery explosion	Mixed partial and full thickness	Left hand and forearm, left thigh	Excision and STSG
4	29, M	4.5	Battery self-combusted in pants pocket	Near-circumferential full-thickness	Left thigh	Excision and STSG
5	19, M	2	Motorcycle crash inducing ignition of in pants pocket	Mixed partial and full thickness	Right thigh	Silver nylon
6	18, F	1	Actively in use in mouth[a]	Partial thickness	Right hand	Bacitracin, Xeroform
7	38, M	5	Battery self-combusted in pants pocket	Mixed partial and full thickness	Right thigh	Excision and STSG
8	22, M	3	Battery self-combusted in pants pocket secondary to contact with keys	Partial thickness	Left thumb left antero-medial thigh	5% Sulfamylon solution
9	29, M	27.25	Vaporizer explosion engulfed clothes in flames	Mixed deep partial and full thickness	Bilateral upper extremities, face, ear, anterior chest, abdomen	Excision and STSG[b]
10	22, M	3.25	Battery self-combusted in pants pocket	Mixed partial thickness	Right thigh, right hand	Surgical debridement and Silverlon

STSG, split-thickness skin grafting. [a]Patient also sustained anterior dislocation and possible luxation/extrusion of the upper incisors with associated alveolar fracture, tissue avulsion of her upper lip and laceration of the hard palate of her mouth. [b]Six months after his initial injury, the patient underwent elective contracture releases of his axillary region and at ten months, he underwent a contracture release of both hands.

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