

Burn injuries caused by e-cigarette explosions: A systematic review of published cases

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ABSTRACT

INTRODUCTION E-cigarettes have the potential to cause burns from batteries that explode. Although e-cigarette explosion burns have been reported by the media (e.g. local online news, blogs), there is a need for a comprehensive review of published medical case reports regarding these injuries.

METHODS CINAHL and PubMed were systematically searched using common terms regarding e-cigarettes (electronic cigarette, e-cigarette, vape, vaping, electronic nicotine delivery systems) in every combination with the term 'explosion'. Peer-reviewed articles were included if they: were written in English, described case reports of burn injuries caused by e-cigarette explosions, and were published in any year. Cases were categorized by demographics, location of the e-cigarette explosion, burned body areas, types of burns, total body surface area of burns, the need for skin grafting, and the length of hospital stay.

RESULTS Thirty-one articles were included in the review and described 164 cases. Most patients (90%) were male and between 20 to 29 years old. In the majority of cases (65%), e-cigarettes exploded in pockets, compared to exploding in the face or hand. Common burned areas included the thigh, hand, genitals, and face. Burn severity was typically second-degree burns (35%) or a combination of second-degree and third-degree burns (20%). In all, 48 patients required skin grafting, with 19 reporting a median hospital stay of 5 days.

CONCLUSIONS This review has several implications, including the need for regulation of batteries, education regarding battery safety, and leveraging images of the severity of e-cigarette explosion burns to discourage the use of e-cigarettes.

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INTRODUCTION

Electronic cigarettes (e-cigarettes) are a recent innovation. In 2003, the e-cigarette was invented by a Chinese pharmacist, and by 2010 several brands were established in the United States market¹. Although three generations of e-cigarette designs have emerged over time, the basic components of e-cigarettes include: a battery, a reservoir for holding an e-juice (a solution that usually contains nicotine, flavorants, and propylene glycol and/or glycerin as a solvent), a heating element, and a mouthpiece. Specifically, the battery powers the heating element

to heat the e-juice into an aerosol, which is then inhaled through the mouthpiece¹.

E-cigarettes are growing in popularity, especially among adolescents and young adults in the United States. In 2015, a total of 24% of high school students had used e-cigarettes at least one time in the past 30 days², a 900% increase¹ since 2011. Moreover, data from the 2013–2014 National Adult Tobacco Survey indicated that 13% of young adults, age 18 to 24 years, were current users. The prevalence of e-cigarette use among these age groups resulted in a major report and call for action by the United States

Surgeon General¹.

The public health concern regarding e-cigarettes has typically focused on the chemicals that are potentially harmful (e.g. aerosols, formaldehyde, acetaldehyde, carcinogens, nicotine)¹, however, another health issue is bodily harm caused by e-cigarettes that explode³. Although the cause of these explosions has not been fully determined³, previous incidents suggest that overheating of the battery (also known as ‘thermal runaway’) may lead to explosions^{4,5}, which has also explained the explosions observed from other devices using lithium-ion batteries (e.g. smart phones, laptops)⁶. From 2009 to 2016, there were 195 e-cigarette explosions in the United States reported by the media, resulting in 133 injuries, with burns the most common injury⁴. Moreover, in 2016 alone, an estimated 1007 e-cigarette burn injuries were treated in emergency departments across the United States⁷.

It is also worth noting that besides burns, other cases of e-cigarette explosions involved a variety of serious injuries. Such injuries were inflicted to the hands^{8,9}, face¹⁰, eyes¹¹⁻¹³, mouth (e.g. lacerations, broken/missing teeth)^{8,11,14-20}, and also resulted in broken neck bones²¹. In addition, the first-ever death from an e-cigarette explosion was reported in 2018, which was due to e-cigarette shrapnel entering the person’s brain²².

Given the prevalence of e-cigarette explosions, there is a need for a comprehensive review of published case reports in peer-reviewed journals regarding injuries, especially burns. Although previous studies have reviewed the literature regarding burns caused by e-cigarette explosions, these reviews were not exhaustive of the literature²³⁻²⁶, or focused only on explosion injuries reported by the media (e.g. online news, television, blogs)^{4,27} instead of on the scientific literature. In addition, these reviews have been disseminated through journals that are meant for physicians specializing in burn injuries, as opposed to health professionals dealing with tobacco prevention and cessation. As such, the purpose of this study was to provide a systematic review of published medical case reports of burn injuries caused by e-cigarette explosions in peer-reviewed journals.

METHODS

Articles were identified by using a comprehensive list of search terms and relevant databases. During January 2018, the Cumulative Index to Nursing and Allied Health Literature (CINAHL) and PubMed were searched using common terms regarding e-cigarettes (electronic cigarette, e-cigarette, vape, vaping, electronic nicotine delivery systems) and in every combination with the term ‘explosion’. To locate additional articles, ‘berry picking’ methods of ‘backward chaining’ (searching through the reference pages of relevant articles) and also ‘forward chaining’ (searching the studies that cited relevant articles)²⁸ were used in Web of Science and Google Scholar^{29,30}.

The resulting articles were included in the literature review based on the following eligibility criteria: written in English, described case reports of burn injuries caused by e-cigarette explosions, published in peer-reviewed journals, and published in any year. Articles were excluded if they described injuries other than burns or burns that were due to reasons other than an explosion (i.e. burns from a hot e-cigarette battery that did not explode). The inclusion and exclusion of articles were documented by the recommended flow diagram of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)³¹.

The articles included in the review were then analyzed. Cases were categorized by demographics, location of the e-cigarette explosion, burned body areas, types of burns, total body surface area of burns, the need for skin grafting, and the length of hospital stay.

RESULTS

A total of 31 articles^{8,9,11,13,16-18,20,23,25-27,32-50} met the review’s inclusion criteria (Figure 1). These were published from 2015 to 2017 in a variety of medical journals. In all, the articles described 164 cases. The explosions took place in the United States, the United Kingdom, Canada, Germany, and France.

The cases varied in terms of demographics. The majority of patients (90%) were male. Of the reports that specified the patient’s age, there was a range in age from 16 to 63 years (M=1.3, Mdn=29, SD=10.5) and mostly were young (20 to 29 years) (Table 1).

Figure 1. Recommended PRISMA flow diagram for article inclusion

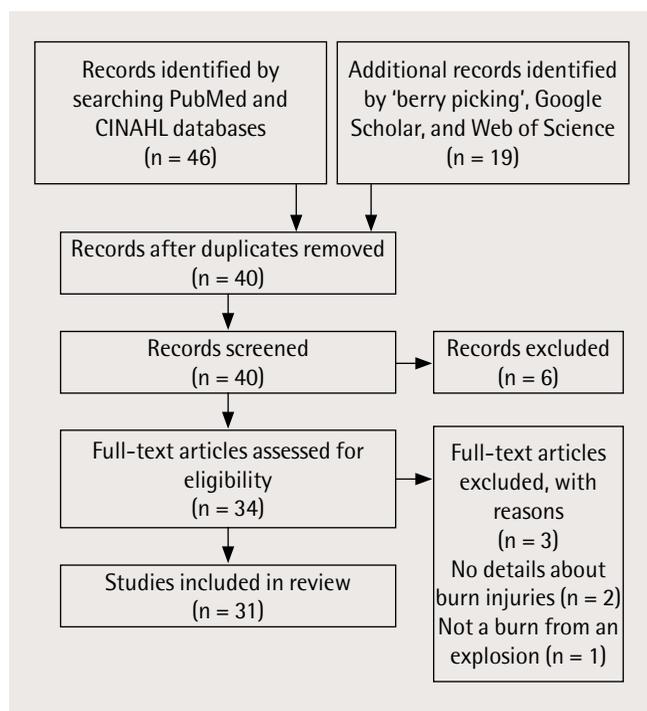


Table 1. Demographics of e-cigarette explosion cases

Demographics	Frequency (%)
Sex	
Male	147 (90)
Female	12 (7)
NA	5 (3)
Age (years)	
16–19	9 (5)
20–29	38 (23)
30–39	22 (13)
40–49	14 (9)
50–59	3 (2)
60+	1 (<1)
NA	77 (47)

The cases also varied in terms of the location of the e-cigarette explosions and in the location and types of burn injuries. In the majority of cases (65%), e-cigarettes exploded in people’s pockets (Table 2). The most common injured body areas included the thigh, hand, genitals, and face (Table 2). Burn severity was typically second-degree (35%) and a combination of second-degree and third-degree burns (20%). Reports described 84 patients’

Table 2. Location of e-cigarette explosions and description of burn injuries

Burn characteristics	Frequency (%)
Location of explosion	
Pocket	107 (65)
Face	20 (12)
Hand	16 (10)
NA	21 (13)
Burned body areas	
Thigh(s)	125 (76)
Hand(s)	65 (40)
Genitals	21 (13)
Face	21 (13)
Torso	12 (7)
Arm(s)	6 (4)
Buttocks	3 (2)
Feet	3 (2)
Degree of burns	
1st degree	1 (<1)
2nd degree	57 (35)
2nd & 3rd degree	33 (20)
3rd degree	13 (8)
NA	59 (36)
Total body surface area, %	
<1–5.6	62 (38)
6–10	15 (9)
11+	7 (4)
NA	80 (49)

total body surface area (TBSA) burns, which ranged from 0.5% to 27.25% (M=4.9, Mdn=4, SD=4.3) (Table 2). In all, 48 patients required skin grafting. Of the articles that described 19 patients’ length of stay in the hospital for treatment, the number of days ranged from 1 to 31 days (M=7.4, Mdn=5, SD=6.9).

Several reports included information regarding the context of the explosion (Table 3). Several cases reported the e-cigarette touching metallic objects (e.g. coins, car keys) in the pocket during the time of explosion. Others stated issues related to charging their e-cigarette battery. Explosions took place while e-cigarettes were being used or while being stored in users’ pockets.

Table 3. Precipitating events of e-cigarette explosion burn injuries

First author, year	Study location	Cases	Precipitating events
Anderson, 2017	USA (Kentucky)	1	The e-cigarette exploded during use
Arnaout, 2017	United Kingdom	12	Not specified
Bauman, 2016	USA (Arizona)	3	One patient changed the e-cigarette's battery and then put the device in his pocket, which contained car keys and coins. A different patient stated that his battery was over 1-year old, but he claimed to charge it correctly
Bohr, 2016	Germany	1	The patient stated that the e-cigarette (tank style) contained nicotine-free e-liquid that was diluted with water
Cason, 2016	USA (Alabama)	1	Not specified
Colaiani, 2016	USA (Massachusetts)	2	The e-cigarettes exploded in both of the patients' pockets
Gibson, 2018	USA (Oregon)	14	Of the patients, 7 reported that the e-cigarette device itself exploded, the other 7 reported that a loose lithium ion battery exploded in their pockets
Goverman, 2016	USA (Massachusetts)	5	Not specified
Harrison, 2016	USA (South Carolina)	1	The patient charged the e-cigarette's lithium-ion battery in a 120-volt outlet using an external charging device that was purchased separately from the e-cigarette
Harshman, 2017	Canada	2	The e-cigarette exploded in the patient's pocket, which also contained several coins
Hassan, 2016	United Kingdom	6	All patients stored their batteries fully charged and close to other objects, including cell phones and coins
Herlin, 2016	France	2	One patient had a battery and device (separate from each other) in his pocket that were touching metal keys
Jablow, 2015	USA (New Jersey)	1	The patient denied any misuse of the e-cigarette and was not using it at the time of the explosion
Jiwani, 2017	USA (Texas)	10	Of the patients, 7 had their e-cigarettes explode in their pockets, 1 reported a vaporizer explosion, 1 was using the e-cigarette when it exploded, and 1 reported that the e-cigarette exploded during a motorcycle crash
Kite, 2016	USA (Virginia)	1	The e-cigarette (Lone Wolf Mechanical Mod cigarette) exploded in the patient's hand
Kumetz, 2016	USA (California)	2	One patient was using the e-cigarette when it exploded. The other patient had the e-cigarette explode in the pocket
Maraqqa, 2017	USA (Michigan)	8	All of the patients' e-cigarettes exploded in their pockets
Nicoll, 2016	United Kingdom	2	One of the patient's e-cigarette battery was charged overnight and was not damaged or over-heated prior to the explosion
Paley, 2016	USA (Missouri)	2	Both patients were using their e-cigarettes when they exploded. One of the e-cigarettes was a vapor pen
Patterson, 2017	USA (Alabama)	2	One patient's e-cigarette exploded in the pockets and the other patient's e-cigarette exploded while being used
Ramirez, 2017	USA (California)	30	Some of the patients stated that the battery came in contact with a metallic object
Rogér, 2016	USA (New York)	1	The patient was using his e-cigarette when it exploded
Satteson, 2017	USA (North Carolina)	1	The patient changed the battery of the e-cigarette (Dark Horse atomizer with a SMPL Mec Mod battery device), and then the device quickly heated and exploded
Schroeder, 2016	USA (Pennsylvania)	1	The patient's e-cigarette exploded in his pocket
Serror, 2017	France	10	Of the patients, 8 had the e-cigarette exploded in their pockets, and 2 patients' e-cigarettes exploded while being used
Shastri, 2016	USA (California)	1	The patient denied misuse of the e-cigarette, and also stated he was paid to test products for an e-cigarette company, and that the cigarette he used was an experimental model that was customizable and large. The e-cigarette exploded while the patient was using it
Sheckter, 2016	USA (California)	3	Each patient reported that their e-cigarette exploded in their pockets
Smith, 2017	USA (Florida)	10	Of the patients, 1 reported pouring nicotine liquid into the e-cigarette when it exploded, 2 reported the e-cigarette exploded while they were driving, 6 reported the e-cigarette exploding in their pockets, and 1 reported the e-cigarette exploding in the hand
Toy, 2017	USA (California)	25	Of the patients, 18 reported the e-cigarette exploding in their pockets
Treitl, 2017	USA (Florida)	3	Each patient reported that their e-cigarette exploded in their pockets
Walsh, 2016	United Kingdom	1	The patient reported charging his e-cigarette overnight and the battery being in contact with keys in his pocket when it exploded

DISCUSSION

The primary aim of this study was to systematically review and synthesize evidence on case reports of burn injuries caused by e-cigarette explosions. A total of 31 studies reporting 164 patients were included in this systematic review, finding that e-cigarette explosions happened most often in pants pockets and among young men. The burn injuries were usually on the thighs and hands, and ranged in severity. To the best of our knowledge, this is the most comprehensive review on this topic. There are implications both in terms of public health prevention and future scientific research on this issue.

Although the scientific community is divided regarding the benefits or harms of e-cigarettes^{51,52}, the findings from this literature review side directly with the potential harm of e-cigarettes, due to explosion injuries. The findings have important implications regarding regulation, public health advocacy, and education, as other experts have also emphasized^{53,54}.

First and foremost, e-cigarette manufacturers should invest in research and development to improve the safety features of e-cigarette batteries. Brown and Cheng⁵⁵ of the FDA's Center for Tobacco Products have called for e-cigarette manufacturers to investigate the unknown failure mechanisms and create standardized protocols for testing e-cigarettes. In addition, Brown and Cheng recommend that manufacturers prevent thermal runaway by using circuits that protect against overcharging, integrating cut-offs for thermal power, and using internal overpressure relief mechanisms⁵⁵. By ensuring proper design in regard to safety, manufacturers can help to prevent e-cigarette explosions and consequent injuries.

Second, health professionals should advocate the regulation of e-cigarette batteries and the prohibition of e-cigarettes in areas that could cause major damage by explosions. For example, given the United States Food and Drug Administration's (FDA) new authority over the packaging, labeling, and sale of e-cigarettes⁵⁶, the FDA could mandate for e-cigarette retailers to provide information about potential explosions to customers. Voicing concern about e-cigarettes from a public health perspective is vital for the implementation of needed policy. In addition, it is important to advocate the prohibition of

e-cigarettes in places where they are currently being used that could cause larger explosions and injuries, such as in airplanes^{57,58}.

Third, the findings indicate that public health professionals and e-cigarette manufacturers need to improve efforts to inform with regard to safe handling practices for e-cigarette batteries. Although the FDA has created a webpage dedicated to tips for avoiding explosions (e.g. use device specific batteries and chargers, replace batteries if damaged or wet, keep e-cigarettes away from metal objects, do not charge batteries overnight)³, research suggests that the FDA's webpage is not among the most searched sites regarding e-cigarette batteries⁵⁹. Manufacturer websites and information included with e-cigarette packaging are often lacking information about battery explosions or not providing credible material to users⁵⁹. The results from our review suggest that this information should be targeted towards groups which experience e-cigarette injuries most often, such as young males.

Finally, information and images of the severity of e-cigarette explosion burns could be used as leverage for prevention efforts. Research indicates that fear appeals using graphic images can be effective in improving attitudes and changing health behaviors^{60,61}. For instance, interventions that show images of smoking's impact on premature facial wrinkles can instill motives for smoking cessation⁶²⁻⁶³. Research suggests that knowledge of e-cigarette explosions may deter young people from using e-cigarettes^{67,68}. As such, public health professionals should consider using graphic images of e-cigarette explosion injuries in educational materials to prevent or reduce e-cigarette use.

Limitations

The limitations of this study should be considered when interpreting this review's findings. First, it is obvious that the specific search terms and databases used in this review cannot be expected to locate every relevant published article. As such, the conclusions from the articles may not mirror all published research on this topic. Second, several of the studies did not include detailed information about each patient; therefore, the extent of all the patients' burns may not exactly reflect that of the review's findings. Finally, by only researching medical case studies,

our findings do not cover people that experienced an explosion but did not visit a hospital for treatment.

CONCLUSIONS

This study was the first to systematically and thoroughly review published medical case reports on e-cigarette burn injuries. The severity of burns and the commonly injured locations (e.g. thigh, hands, genitals, face) strongly indicate a need for improved e-cigarette construction and for health professionals to advocate regulation of e-cigarette batteries, as well as insist on improved dissemination of information on explosions, for safety and prevention purposes.

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