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ANALYSIS OF ELECTRONIC CIGARETTE-RELATED INJURY PRESENTING TO U.S. EMERGENCY DEPARTMENTS, 2008–2017

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Abstract—Background: Several types of injuries associated with electronic cigarette malfunction have been reported in the literature since their introduction to the U.S. market in 2007. The traumatic consequences of electronic nicotine delivery system (ENDS) malfunction remain an under-researched topic. **Objectives:** Using information from a national database of emergency department (ED) visits, we sought to characterize the nature and frequency of ENDS injuries over a 10-year study period. **Methods:** Archived information from the National Electronic Injury Surveillance System was accessed for the years 2008 to 2017. Incidents related to ENDS-related trauma were manually identified. Data extracted included patient demographics, injury type and location, and patient disposition. **Results:** A total of 49 incidents were recorded during the years 2008 to 2017, including 18 cases in 2017, 25 cases in 2016, five cases in 2015, and one case in 2013. There were no identified ED visits for an e-cigarette-related burn or explosion prior to 2013. Using statistical weights, the estimated annual national incidence is 835 cases. Most of the injuries were thermal burns. The primary location of injury was in the lower extremity, followed by the upper extremity and hand. **Conclusions:** Our study demonstrates a significant increase in the number of ENDS-related injuries over the study period, particularly in males under the age of 45 years. This rise mirrors the growth of the ENDS market and this trend can be expected to continue. As the use of ENDS is expected to increase, physicians should become familiar with the nature of associated injuries. © 2019 Elsevier Inc. All rights reserved.

Keywords—e-cigarette; electronic cigarette; ENDS; vape; NEISS; tobacco cessation; burn injury; burn

INTRODUCTION

Since their introduction to the U.S. market in 2007, electronic cigarettes have become a popular method of nicotine consumption that is perceived as a healthier alternative to cigarette smoking. By 2017, the number of U.S. adults who had used an e-cigarette device reached 6.7% (1). Among U.S. high school students, this number was as high as 12%. Compared with the 15.5% of U.S. adults who regularly smoke cigarettes, 3.7% regularly use an e-cigarette device. Market research estimates a global growth of 22.36% between the years 2015 and 2025 (2). It can be expected that the medical community should become familiar with the use and operation of an electronic cigarette device.

Although there are many models of electronic nicotine delivery systems (ENDS), the principal function of the device remains similar throughout. A solution of propylene glycol, nicotine, and added flavors is held in a reservoir close to a mouthpiece. A coil or atomizer, powered by a lithium-ion battery, is activated by the user and results in the vaporization of the nicotine solution. The vapor is inhaled from the device in a manner similar to smoking a cigarette or pipe.

Lithium-ion batteries contain flammable electrolyte solutions that can ignite if they escape the battery capsule. Burn injuries as a result of lithium-ion battery malfunction are not a new phenomenon, although ENDS-related events may hold the potential for more severe injury. Because these devices are often held close to the head

and upper extremity, a burn or blast from a battery can be traumatic (3). Whereas much of the current literature regarding electronic cigarettes has been focused on the safety of the inhaled vapor and the modality's efficacy as a smoking cessation method, the consequences of electronic cigarette malfunction remain an under-researched topic.

There have been a number of fires and explosions attributed to the lithium-ion batteries overheating in ENDS reported in the literature. These reports have mirrored the rise of ENDS use in the United States. ENDS-related injuries have been reported in both the literature and the media from as early as 2009 (4). In 2016, Brownson et al. reported having treated 15 patients at their center for ENDS-related lithium-ion battery explosions between October 2015 and June 2016 (5). Although many case reports have focused on injury to the head and neck, subsequent research has emerged showing many of these patients present with major corporeal burn injuries (6,7).

In 2017, the United States Fire Administration published a report entitled "Electronic Cigarette Fires and Explosions in the United States: 2009–2016" (8). Therein they reported 195 electronic cigarette fires in that timeframe from both the National Fire Incident Reporting System and media reports. They observed a steady increase in the annual rate of fire reports over the study period. It was shown that 133 (68%) of these fires resulted in injury, mostly requiring emergency department (ED) treatment. The study reported that a majority of the injuries requiring hospitalization involved burns to the head and neck region. A similar study using hospital or ED data would be able to supplement this report by targeting different sources. Using information from a national database of ED visits, we sought to characterize the nature and frequency of injuries associated with ENDS over a 10-year study period.

METHODS

The National Electronic Injury Surveillance System (NEISS) is a national database of consumer product-related injury data maintained by the Consumer Product Safety Commission (CPSC). ED visits from over 100 hospitals, including eight children's hospitals, are recorded as a probability sample for the 5000 + EDs in the United States (9). The inclusion criteria involve hospitals with at least six beds and an ED. Patient visits are recorded nightly at participating hospitals and sent to the NEISS. All visits related to a consumer product are selected for inclusion in the annual database.

The incidents are recorded in datasets accessible without cost through the CPSC. The variables coded include the patient's age, gender, race, ethnicity, geographical region, injury diagnosis, affected body

parts, and disposition. In addition, a short narrative is included by the hospital's NEISS coordinator. Subsequent analysis at the CPSC integrates the visit into the annual database and associates the incident with a code based on the consumer product involved. Statistical weights are assigned to each incident and can be used to compute national incidence statistics.

NEISS archived information was accessed for the years 2008 to 2017 through Microsoft Excel datasets (Microsoft Corporation, Redmond, WA). These datasets contained a total of 3,828,450 incidents that were searched for ENDS-related trauma. Of the available demographic data for the NEISS, including population size, average age, and gender, no significant differences were noted between years. Inquiry with the CPSC revealed that the population of hospitals largely remained stable within the study period. Typically, a product code can be found to modify the search criteria. However, we did not find a product code for ENDS devices. As this was an unreliable search method, specific terms were searched for in the case narrative section. Search terms, included "cig," "vape," "vapor," and "nicotine," were searched for via the Microsoft Excel "Find" function. Cases were identified that involved an electronic cigarette device as the source of trauma, specifically, cases that involved malfunctioning of the device. Cases involving accidental ingestion of nicotine solution and inappropriate use of an ENDS were excluded.

For the analysis, the patients were grouped by ages <18, 18–29, 30–44, 45–60, and >60 years. Injury locations that were reported included the head, shoulder, lower arm, hand, lower abdomen, upper leg, and lower leg. Dispositions included treated and discharged, treated and observed, treated and transferred to another hospital, and hospitalized. We considered patients from the former two groups as requiring hospitalization for our analysis. Incidents in the NEISS are assigned a statistical weight that corresponds to the number of times such an incident occurred nationally that year. These weights were utilized in the national estimates of ENDS trauma. As the datasets utilized contained anonymized patient data, no institutional review board was required for this study.

RESULTS

A total of 49 patients were identified between the years 2008 and 2017. There were 18 cases in 2017, 25 cases in 2016, five cases in 2015, and one case in 2013 (Figure 1, Table 1). There were no identified ED visits for an e-cigarette-related burn or explosion prior to 2013. Of these 49 patients, 47 (95.6%) were male. Three (6.1%) of the patients were below the age of 18 years, 26 (53.1%) were between 18 and 29, 14 (28.6%) were between 30 and 44, 5 (10.2%) were between 45 and 60, and one (2.0%) patient was above the age of 60 years.

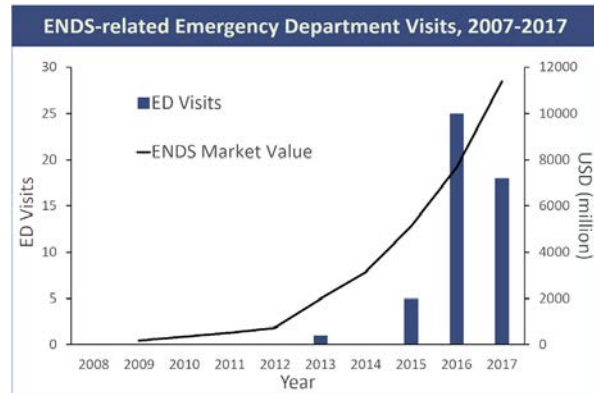


Figure 1. ENDS-related trauma presenting to NEISS Emergency Departments during the years 2008–2017 alongside the ENDS U.S. retail revenue (10). ENDS = electronic nicotine delivery system; ED = emergency department; NEISS = National Electronic Injury Surveillance System.

Twenty (40.8%) were identified as non-Hispanic white, 3 (6.1%) were identified as black, one (2.0%) was identified as Hispanic, and 25 (51.0%) did not have a race identified. The most common location for injury was the upper leg, with 29 (59.2%) cases; additionally, hand (14.3%) and lower trunk (8.2 %) were the next most common sites of injury (Figure 2). Of the patients evaluated, 13 (26.5%) required hospitalization.

Utilizing the provided statistical weights, a national estimate of ENDS-related trauma was projected to 1866 over the 10-year study period. By year, there were 25, 171, 944, and 726 cases in 2013, 2015, 2016, and 2017, respectively. Averaging both the 2016 and 2017 projections as a modern incidence of ENDS trauma, we estimate that approximately 835 incidents occur annually in the United States.

DISCUSSION

Our study shows a rise in the number of ENDS-related ED visits in the NEISS in the years 2008–2017, with a

Table 1. ENDS-Related Trauma Presenting to NEISS Emergency Departments During 2008–2017

	2013	2015	2016	2017	Study Period Total
Head		1 (16)	1 (16)		2
Shoulder	1 (25)				1
Lower arm			1 (15)	2 (155)	3
Hand		1 (38)	3 (169)	4 (114)	8
Lower abdomen			3 (93)	1 (15)	4
Upper leg		3 (117)	16 (636)	10 (427)	29
Lower leg			1 (15)	1 (15)	2
Total	1 (25)	5 (171)	25 (944)	18 (726)	49

ENDS = electronic nicotine delivery system; NEISS = National Electronic Injury Surveillance System. Values in parentheses are projected national annual incidence numbers.

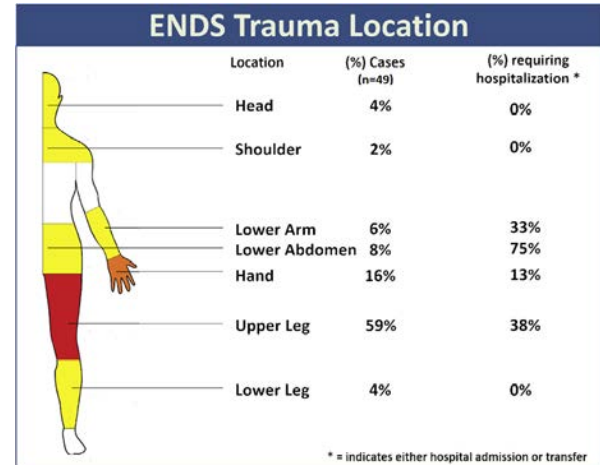


Figure 2. Breakdown of ENDS injury location and percent requiring subsequent hospitalization (n = 49). ENDS = electronic nicotine delivery system.

projected national average of 835 cases annually. This increase follows the growth in the U.S. ENDS market value over the same time and can be expected to rise alongside it in the future (Figure 1) (10). The U.S. ENDS market value involves the domestic retail revenue of ENDS devices and other products, and the steady growth over the past decade mirrors the increased use of ENDS in the United States as reported by the National Center for Health Statistics (11).

Recent media reports have highlighted at least two deaths in the United States secondary to ENDS-related injury. The first, in May of 2018, involved a man who was discovered in a home fire by emergency services with burns over 80% of his body surface (12). However, upon autopsy, it was determined that he was killed by penetrating trauma to the cranium, after explosion and projection of metal fragments from the ENDS casing. It was determined that the man was using a battery mod at the time, and representatives from the manufacturer of the device blamed the battery as the source of the explosion. A “mod” is an umbrella term for a modification to the ENDS device meant to add additional functionality or improve performance (13). Of note, these can include battery modifications that modulate the energy flow to the atomizer for higher or more uniform temperatures. Additionally, a man died in January of 2019 after a stroke caused by injury to the carotid artery in an ENDS explosion (14). Preliminary reports indicated that the man was using a battery mod as well. Due to the variety of battery, mod, and charger specifications, we speculate that this can lead to damage to the battery and increase the risk of malfunction.

That the most common locations for injury in our study were the upper leg or lower trunk reflects the fact that these devices are carried in the pants pocket and

can malfunction even when not in use (Figure 2). Additionally, as pockets are more common in modern male clothing, this may have contributed to the overwhelming male majority in this study. It could be hypothesized that females are more likely to carry an ENDS device in a purse and are less likely to be injured by a battery malfunction. A 2016 report using the National Fire Incident Reporting System found that equal numbers of ENDS-related fires occurred while the device was in use as occurred when the device was in the pocket (8). We propose that the relatively low number of face and hand burns in our study may be due to the fact that the device can be quickly discarded when it malfunctions in use. Additionally, patients with significant burns to the head and neck may have been sent directly to burn centers and would not have been included in NEISS. Fires that occur in the pocket will have clothing as a fuel source and can lead to more extensive burns. This is supported by the fact that lower abdomen and thigh burns more often required hospitalization and those of the hand and face did not. However, that other studies have shown high levels of device malfunction while in use highlights the potential for significant injury to the upper extremities as well as the head and neck (8). Indeed, both deaths reported as a result of ENDS-related trauma involved penetrating injury to vital structures in this region.

Two similar studies have been performed: one an analysis of ENDS-related injuries in the 2016 NEISS dataset, as well as another characterizing the incidence between 2015 and 2017 (15,16). In the first article the authors used similar search criteria and came across similar patterns of injury location and patient disposition. One difference that we found in our study involves the frequency of injury based on age. In their study, Corey et al. found approximately 10.7% of their cases involved patients between the ages of 18 and 24 years (95% confidence interval 0–24.8) (15). We found 30.6% of our patients within this same age group, suggesting a significant injury burden to this young age group. In the second article, published in September of 2018, the authors performed a similar search between the 2015 and 2017 datasets, estimating 2035 ENDS-related injuries. The methods used more inclusive search criteria and were able to identify more cases. The NEISS currently does not have a standard product code for ENDS, and these studies highlight the value of the database for analyzing ENDS trauma. The introduction of a standard product code would allow for easier and more comprehensive studies in the future.

Limitations

Despite a significant rise in the number of ENDS-related ED visits in the past 10 years, the frequency of the annual

events remains below 1000 cases. The CPSC states that national estimate weights are unreliable when there are either <20 NEISS cases or 1200 estimates (9). Although the authors note that certain national projections included in this study may not be stable, the clear rise in events moving forward means that subsequent studies will include larger numbers of cases and subsequently stronger projections. Although authors did not note significant differences in the population sizes, average age, and gender distribution between years, the authors recognize that this is an incomplete picture of the study population.

As mentioned before, introducing an ENDS-specific product code in the NEISS database will lead to more robust data retrieval and may prevent cases from being lost or overlooked. A limitation of this study is that the NEISS only includes cases where first contact with the medical field is in an ED. Patients who were sent directly to specialty burn centers would not have been recorded. This would include patients with full- or partial-thickness facial burns or inhalational injuries. This may have affected the distribution of injuries reported. Additionally, the study cannot account for patients who suffered injuries that were never treated. Finally, patients injured by fires started by an ENDS may not have had mention of the device within the case narrative and would not have been included in search criteria. As reports have highlighted ENDS as a significant fire risk, there may be additional injuries caused indirectly by fires started in the home or workplace (8).

CONCLUSIONS

To our knowledge there has not yet been a study that has characterized the incidence of ENDS-related ED visit trends over the past decade. As the use of ENDS is expected to increase, physicians around the country in both primary care and ED settings should become familiar with the nature of ENDS-related trauma. Effective interventions will center around regulating lithium-ion battery quality or utilizing alternative battery designs. The ENDS industry is in its nascent stages, and the marked popularity of the product has led to many competing manufacturers quickly entering the market. The authors believe this research will help better characterize the safety of lithium-ion batteries used in ENDS products. As the market continues to grow and designs continue to change, subsequent studies will be needed to further characterize the hazards of this emerging technology.

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ARTICLE SUMMARY

1. Why is this topic important?

Electronic cigarettes are quickly becoming a popular method of nicotine consumption, primarily in younger age groups. As the number of electronic nicotine delivery system (ENDS) users increases, associated injuries will be encountered more frequently in the medical setting.

2. What does this study attempt to show?

Using a national database of emergency department visits, the authors project the national incidence of ENDS-related trauma in the United States during 2008–2017 and characterize the associated injuries.

3. What are the key findings?

Forty-nine incidents related to ENDS malfunction were reported between 2008 and 2017. An estimate for the modern incidence was projected to 835 cases annually. Over the past decade the ENDS market has grown to almost \$12 billion, and the frequency of injuries has risen alongside it. Injuries predominantly affected the upper leg and abdomen, and these patients were the most likely to require subsequent hospitalization.

4. How is patient care impacted?

These data can be used to educate physicians on the nature of ENDS malfunction in both the emergency and primary care settings. Additionally, it can inform regulators and lawmakers on the safety of these devices.