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Original Contributions

CARBON MONOXIDE POISONING FROM PORTABLE ELECTRICAL GENERATORS

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☐ **Abstract—Background: Portable electrical generators have been responsible for over 800 accidental carbon monoxide (CO) poisoning deaths in the United States from 1999–2012. Objectives: Because mortality figures are typically the only data reported with regard to the adverse effects of generators, we describe a nonfatal segment of the poisoned population to further emphasize the significance of the problem. Methods: Unidentifiable information about patients treated in the United States with hyperbaric oxygen for acute CO poisoning was prospectively reported by participating centers. Those patients poisoned by portable generators were selected for analysis. Results: Of 1604 patients reported from August 1, 2008 to July 31, 2011, there were 264 accidentally poisoned by portable generators. Exposures occurred in 151 incidents in 33 states. In 99 incidents, poisoning occurred in a residence. Average patient age was 37 ± 20 years (range 1 to 90+ years). Of those poisoned, 146 (55%) were non-Hispanic white, 57 (22%) were black, 52 (20%) were Hispanic white, 4 (2%) were Asian, and 4 (2%) were Native American. English was spoken by 96%. The most common symptoms included headache (62%), dizziness (52%), and loss of consciousness (50%). Blood carboxyhemoglobin levels averaged 22.7 ± 9.0% (range 2.3–48.3%). Thirty-six patients demonstrated evidence of cardiac ischemia. Conclusions: Acute, severe CO poisoning from portable electric generators is common in the United States, likely affecting an estimated 4000 individuals annually, occurring predominantly in residential settings, and affecting English language-speaking individuals.**

Institutional Review Board exemption was obtained as this project was performed as disease surveillance and data collected in a patient unidentifiable fashion.

☐ **Keywords—carbon monoxide; poisoning; electrical generators; prevention**

INTRODUCTION

Carbon monoxide (CO) poisoning remains common in the United States despite efforts to prevent it through public education, exposure-specific legislation, and carbon monoxide alarms. According to the U.S. Centers for Disease Control and Prevention (CDC), there are 400–500 accidental, non-fire-related CO poisoning deaths annually (1). Further, it is estimated that CO poisoning results in approximately 50,000 emergency department (ED) visits each year (2).

The U.S. Consumer Product Safety Commission (CPSC) monitors CO mortality resulting from the use of consumer goods such as engine-driven tools, charcoal grills, and heating systems (3). Concern has arisen about the number of CO deaths related to the use of portable, gasoline-powered electrical generators (4). The CPSC estimates that from 1999 through 2012, there were over 800 consumer generator-related poisoning fatalities in the United States (4).

In an effort to reduce the number of generator-related poisoning deaths, the CPSC mandated the placement of a CO warning label on new portable generators in 2007 (5). This seems to have had minimal effect, as CPSC mortality data show more deaths annually since 2005 related to generators than the entire category of heating systems combined (3).

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Mortality data are only part of the picture. As implied previously, about 100 ED visits for CO poisoning occur for each accidental death. When CO-poisoned patients reach medical care, death is relatively rare (6). However, despite maximal medical treatment for CO poisoning, a significant proportion of individuals will manifest chronic brain injury (7). In an attempt to raise awareness about the significance of the generator-related CO poisoning problem, it is the purpose of this article to describe the number and characteristics of those who survive to receive medical care. It is hoped that this information will not only emphasize the national magnitude and significance of generator-related CO poisoning, but also help guide the quest for effective solutions.

METHODS

From August 2008 to October 2011, the Undersea and Hyperbaric Medical Society maintained an online system for surveillance of cases of acute CO poisoning treated with hyperbaric oxygen. When a patient was treated in a facility enrolled in this voluntary program, facility staff logged on to a secure Web site and entered nonidentifiable demographic and epidemiologic data about the exposure. The system was operated in conjunction with the CDC in an effort to expand surveillance of CO poisoning and also to test the hypothesis that teaming with a medical specialty society is an effective way to perform disease surveillance. Complete details of the program are available in other publications (8,9).

During the first 3 years of operation (August 1, 2008–July 31, 2011), there were 1912 patients reported treated with hyperbaric oxygen for CO poisoning at 63 facilities in 42 U.S. states. It has been estimated that the system captured approximately 43% of patients receiving hyperbaric oxygen therapy for CO poisoning, based on historical data (10). Among 1604 persons reported who were treated for accidental CO poisoning, 264 (16%) were poisoned in incidents involving generators, forming the basis for this report.

Simple descriptive statistics and unpaired two-way *t*-test were utilized to analyze the information from the 32 data fields collected for each patient.

Our Institutional Review Board (IRB) determined that this project was exempt from IRB review because it was disease surveillance involving the study of existing data collected by survey and the information was submitted to the collection center in a patient-unidentifiable manner.

RESULTS

The 264 individuals treated with hyperbaric oxygen for generator-related CO poisoning were exposed in 151 incidents from 33 states, with patients treated per incident ranging from one to ten. Distribution of incidents by season was 31 spring, 23 summer, 42 autumn, and 55 winter. Relation to specific weather events was not collected due to the potential that such information could lead to patient identification.

Distribution of incidents by state is illustrated in Figure 1. States reporting 10 or more incidents in 3 years included Pennsylvania (15 total incidents, 27 patients), Maryland (13 incidents, 19 patients), Michigan (12 incidents, 17 patients), Illinois (10 incidents, 17 patients), North Carolina (10 incidents, 15 patients), and Kentucky (10 incidents, 14 patients).

Generator fuel was reported in 129 incidents and included gasoline in 119, propane 7, diesel 2, and kerosene 1.

Patient gender and age were: 146 (55%) males with average age 38 ± 20 years (mean ± SD; range 1–85 years), and 118 (45%) females with average age 36 ± 20 years (range 4–90+ years). Of those poisoned, 146 (55%) were non-Hispanic white, 57 (22%) were black, 52 (20%) were Hispanic white, 4 (2%) were Asian, and 4 (2%) were Native American. The primary language spoken was English by 228 (86%), followed by Spanish 26, Vietnamese 2, and unknown 8. Of the 28 patients with a non-English primary language, 17 also spoke English. Therefore, only 11 of 264 (4%) were reported who did not speak English.

Activity at the time of poisoning was classified as domestic in 101 (67%) incidents and occurred in a residence in 99 (66%). Domestic refers to those activities relating to a home or family relations, such as sleeping. Work was the activity being pursued in 34 (23%) incidents and occurred in a workplace such as a warehouse in 17 (50%), a residence in 12 (35%), and several other locations involving a single incident. Recreation was the activity being pursued at the time of poisoning in five (3%) incidents, occurring in such places as a boat, cabin, or camping trailer.

The most common symptoms reported included headache 164 (62%), dizziness 137 (52%), loss of consciousness 132 (50%), nausea and vomiting 131 (49%), and confusion 71 (27%). Endotracheal intubation was performed in 18 (7%) patients.

Blood carboxyhemoglobin (COHb) levels averaged 22.7 ± 9.0% (range 2.3–48.3%). Time from the end of CO exposure to measurement of COHb was estimated in 182 cases, averaging 1.9 ± 2.4 h (range 0–22 h). Thirty-six patients were felt to have evidence of cardiac ischemia, as defined by the reporting facility. Cardiac enzyme testing was abnormal in 28, electrocardiogram demonstrated changes consistent with ischemia in 17, and two had other abnormal tests suggesting ischemia, such as an echocardiogram. Specific test values were not reported.

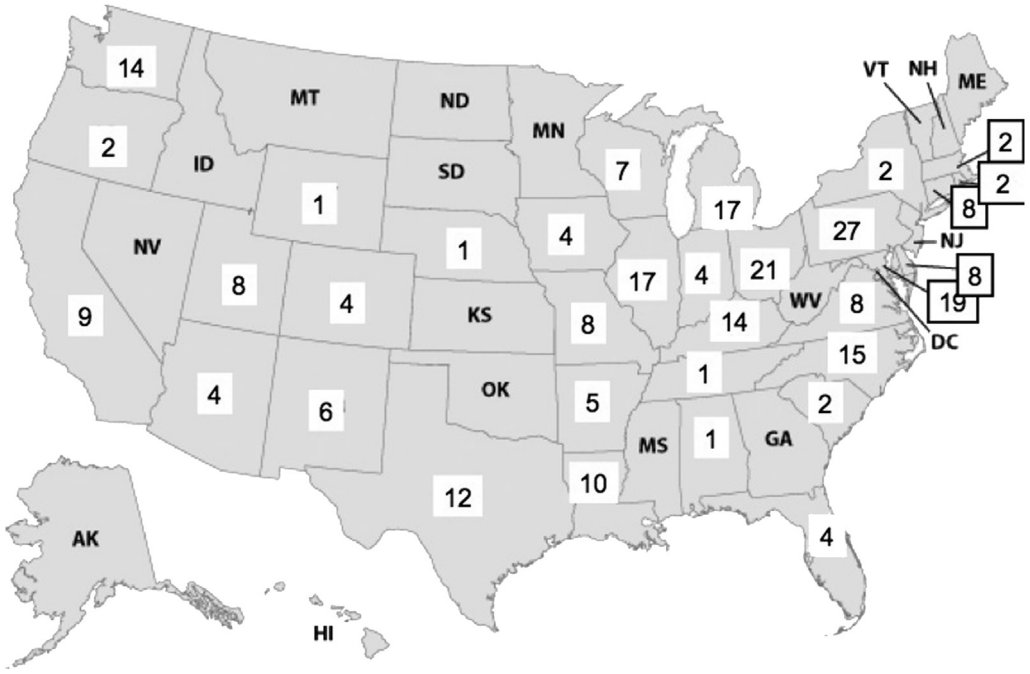

Figure 1. Map of the United States shows the number of incidents of generator-related carbon monoxide poisoning reported per state from August 1, 2008 through July 31, 2011, accounting for 264 total patient cases.

DISCUSSION

These findings underscore the significance of portable generator-related CO poisoning in the United States. Articles on CO poisoning often describe the experience of a single institution, but these data were collected through a nationwide network, demonstrating that this is not just a regional problem.

Several reports in the literature have associated generator-related CO poisoning with the aftermath of storms, both hurricanes and ice/snow storms (11–13). After hurricanes, generators are commonly used to power refrigerators and air conditioners, although one report emphasized their use to power video games to entertain children (14).

In winter storms, generators are often used for lighting and operation of heating systems.

Whether or not CO exposure from a portable electrical generator is storm associated, poisoning typically results from improper generator use. Reports have included operation of these CO-emitting devices within the house, in garages to power the fan of a furnace that is also located there, and outdoors on decks immediately adjacent to through-wall air conditioners, thereby entraining CO into the house. A recent study demonstrated that CO passes easily through gypsum drywall, illustrating the danger of operation within an attached garage (15).

When the CPSC was considering a CO warning label for generators, we contacted past patients treated in our facility for generator-associated CO poisoning to determine the reason they had used a portable generator in a hazardous fashion (16). Prior to this survey, speculation for such action included fear of generator theft, avoiding exposure of the generator to the elements, and lack of an extension cord to allow more distant placement. These were rarely the reason. In a majority of cases, the person operating the generator was simply unaware of the CO risk. When they were aware, they did not understand the ventilation requirements for safe operation. Although this suggested that a warning label on the device would mitigate the problem, it did not do so when it was mandated by the CPSC in 2007. This is probably because generators have a long life span and labels were placed only on newly manufactured and sold units. People could continue to be poisoned by older units with no warning label.

The total magnitude of generator-related CO poisoning can only be roughly estimated. Over the 3-year period studied, 88 accidental cases were reported in our system annually. As noted previously, cases reported through this system were felt to represent approximately 45% of the CO-poisoning cases treated with hyperbaric oxygen. Assuming that there was no bias toward or against reporting generator-related cases, this would extrapolate to approximately 200 cases treated with hyperbaric oxygen per year. Because about 5% of patients seen annually in EDs for CO poisoning in the United States are treated with hyperbaric oxygen, one

could further extrapolate the total number of generator-related CO poisonings to be 4000 each year (10).

A variety of solutions have been proposed for this problem. These include the following: incorporation of a CO sensor in the device that turns off the unit when ambient CO reaches a specified level; incorporation of a catalytic converter in generators; and production of a low emission generator (17,18). Mandating the installation of residential home CO alarms could potentially help, and this is being done by many states (19).

Limitations

The greatest limitation to this study relates to the method by which data were collected. As noted, participation in this reporting network was voluntary and not every U.S. hyperbaric oxygen facility that treated patients for CO poisoning during the 3-year study period took part. In addition, of the 17 states from which no generator-related cases were reported (Figure 1), nine did not have a participating center and therefore no reports would be expected. Furthermore, participating facilities could have neglected to report some of their generator-related cases. In a quality check of the reporting system, it was found that facilities were reporting 86% of their total CO poisoning cases (8). Both of these situations would result in under-reporting such that the magnitude of the problem of generator-associated CO poisoning in the United States is underestimated. The cases reported in this article should be considered a minimum estimate of the issue.

CONCLUSION

Carbon monoxide poisoning from portable electrical generators is common in the United States, affecting an estimated 4000 individuals annually. Available mortality data suggest that public education efforts and a warning label have not had an impact on the incidence. It is clear that something more has to be done to address this problem, and a multipronged approach may be most effective. Some solutions that have been proposed include such things as development of low emissions generators, installation of a CO-sensing engine cut-off mechanism, and incorporation of a catalytic convertor.

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ARTICLE SUMMARY

1. Why is this topic important?

It is estimated that for the 14-year period from 1999 through 2012, there were over 800 consumer generator-related poisoning fatalities in the United States. Generator-related carbon monoxide (CO) poisoning deaths now exceed those from home heating systems.

2. What does this study attempt to show?

To date, only national mortality data have been available for generator-related CO poisoning. To the authors' knowledge, this study is the first to demonstrate the significance of the morbidity also related to CO poisoning.

3. What are the key findings?

The key findings are that, of patients treated with hyperbaric oxygen in the United States from 2008–2011 for generator-related CO poisoning, the problem is a national one; almost all patients speak English, and poisonings continue despite a warning label placed on new generators. Extrapolation of our numbers suggests that approximately 4000 individuals are poisoned annually in the United States by this mechanism.

4. How is patient care affected?

By emphasizing the significance of the problem, this study lends support to the U.S. Consumer Product Safety Commission's conclusion from mortality data that warning labels and public education have not been sufficiently effective, and that attention must turn to alternative solutions for poisoning prevention.