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Original Contribution

Recipients of hyperbaric oxygen treatment for carbon monoxide poisoning and exposure circumstances☆

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Abstract

Background: Unintentional carbon monoxide poisoning is preventable. Severe cases are often referred for hyperbaric oxygen treatment. To guide prevention efforts and treatment practices, this study provides some of the most detailed current information about patients with carbon monoxide poisoning who have been treated at hyperbaric facilities across the United States and the circumstances surrounding their exposures. This study can help improve efforts to prevent carbon monoxide poisoning and enhance treatment practices.

Methods: From August 2008 to January 2010, nonidentifiable, patient-level data were reported by 87 hyperbaric facilities in 39 states via an online reporting system. This reporting system was developed collaboratively by the Undersea and Hyperbaric Medical Society and the Centers for Disease Control and Prevention.

Results: Among the 864 patients reported to receive hyperbaric oxygen treatment for unintentional, non–fire-related, carbon monoxide poisoning, most of the patients were white men aged between 18 and 44 years. Only 10% of patients reported the presence of a carbon monoxide alarm at their exposure location, and 75% reported being part of a group exposure. Nineteen patients (2%) reported a prior carbon monoxide exposure. About half (55%) of the patients treated were discharged after treatment; 41% were hospitalized.

Conclusions: The findings in this report expand the knowledge about patients with carbon monoxide poisoning. These results suggest that prevention efforts, such as educating the public about using carbon monoxide alarms and targeting the most at-risk populations, may help reduce the number of exposures, the number of persons with chronic cognitive sequelae, and the resulting burden on the health care system.

1. Introduction

Carbon monoxide is a poisonous gas that is imperceptible to humans [1]. It is produced by the incomplete combustion of hydrocarbons during the burning of fuels

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such as gasoline, wood, charcoal, propane, natural gas, oil, and kerosene [2]. Major sources of carbon monoxide include poorly maintained or ventilated home-heating systems and cooking appliances, motor vehicle exhaust, and fuel-powered equipment such as portable generators and space heaters [3]. Exposure to low levels of carbon monoxide causes symptoms such as headache, nausea, vomiting, dizziness, fatigue, and confusion; higher levels of carbon monoxide can cause disorientation, loss of consciousness, cardiorespiratory failure, and death [4,5]. The nonspecificity of these symptoms often leads to misdiagnosis and likely underestimation of nonfatal cases [1,5,6]. Unintentional carbon monoxide poisoning is preventable with minimal measures such as using a carbon monoxide alarm. Despite the ease of this minimal precaution, more than 20 000 people present to an emergency department, and approximately 450 people die each year from unintentional, non–fire-related poisoning [1,7,8]. In 2007, the symptoms displayed by an estimated 0.3% of the patients diagnosed with carbon monoxide poisoning in emergency departments, and 21.6% of the patients who were hospitalized were sufficiently severe to warrant hyperbaric oxygen treatment [7]. The Undersea and Hyperbaric Medical Society (UHMS) recommends hyperbaric treatment of patients with carbon monoxide poisoning who manifest loss of consciousness (including transient), abnormal neurologic findings, evidence of cardiac injury, significant metabolic acidosis, pregnancy, or a carboxyhemoglobin level of 25% or higher [9]. Patients who have received hyperbaric oxygen treatment for carbon monoxide poisoning have not been characterized extensively. The objective of this study is to more clearly characterize patients who have received hyperbaric treatment for carbon monoxide poisoning and the circumstances surrounding their exposures. This information can help to improve case recognition by clinical professionals and enhance education and communication to prevent more severe health outcomes that can result from carbon monoxide poisoning. Accordingly, the UHMS has partnered with the Centers for Disease Control and Prevention to collect prompt, continuous, detailed, patient-level data that are not captured elsewhere. We are aware of no similar surveillance systems elsewhere that can fulfill this role.

2. Methods

In collaboration with the Centers for Disease Control and Prevention, since August 1, 2008, the UHMS has maintained an online reporting system for those hyperbaric facilities in the United States that treat patients with carbon monoxide poisoning. Participating UHMS members voluntarily respond to a panel of 38 questions, which includes de-identified information regarding patient demographics, treatment regimens, and circumstances surrounding the poisonings on this select group of patients. A detailed description of the development and operation of the system is available elsewhere [10].

This descriptive analysis includes data from the first 18 months of system operation (August 1, 2008, through January 31, 2010), during which time patient data were reported by 87 hyperbaric facilities in 39 states. Because the approaches to preventing intentional and fire-related carbon monoxide exposures greatly differ from those to preventing unintentional exposures, only unintentional and non–fire-related poisonings were included in this analysis. Analysis was conducted using SAS software (version 9.2; SAS Institute Inc, Cary, NC). The US Census Bureau's definitions for regions of the United States were used. Missing, unknown, and other categories representing less than 5% of responses were not reported. For bivariate analysis, χ^2 Tests ($P < .05$) were used for categorical variables, and Wilcoxon rank sum tests were used for the nonnormally distributed continuous variable, carboxyhemoglobin level.

3. Results

In the initial 18 months of system operation, 864 patients were reported to have received hyperbaric oxygen treatment for unintentional, non–fire-related carbon monoxide poisoning. Demographic information for this select group of

Table 1 Characteristics of persons receiving hyperbaric oxygen treatment for carbon monoxide poisoning and circumstances surrounding the exposure, United States, August 2008–January 2010

Variable	n (%)
Sex	
Male	495 (57.3)
Female	369 (42.7)
Race/ethnicity	
Non–Hispanic white	469 (54.3)
Hispanic white	179 (20.7)
Black	156 (18.1)
Asian	36 (4.2)
Age group (y)	
birth-17	158 (18.4)
18-44	374 (43.5)
45-64	235 (27.4)
>64	92 (10.7)
Primary language	
English	691 (80.2)
Spanish	113 (13.1)
Other/unknown	58 (6.7)
Level of education	
Less than high school graduate	189 (22.0)
High school graduate	230 (26.7)
College graduate or more	91 (10.6)
Unknown	350 (40.7)

patients revealed that the median age was 36 years (range, birth to 89 years). Most of the patients were men (57%) and non–Hispanic white (54%; Table 1). Most of the patients (80%) spoke English primarily; Thirty percent of the Hispanic white patients spoke English primarily. Reported exposures also occurred more frequently in the West (34%) and during the winter (41%).

Data were also collected on the signs and symptoms of exposure; headache (66%), dizziness (51%), nausea/vomiting (46%), and loss of consciousness (44%) were the most commonly reported (Table 2). Loss of consciousness for more than 1 hour was more common among men (72%). Of the patients with evidence of cardiac ischemia (13%), most (86%) were hospitalized after hyperbaric treatment.

Participating health care workers reported information on the circumstances surrounding the carbon monoxide exposures, such as the activity of the patient when they were exposed. Five hundred forty-four patients (63%) were exposed while performing a domestic activity such as cooking or sleeping; 19% of the patients were conducting occupational tasks such as emergency response (Table 3). Of the domestic exposures, 252 (46%) were the result of a furnace or boiler, and 123 (23%) were the result of a generator. Men comprised the majority of those that reported performing home or auto repair (84%) and occupational (87%) or recreational (76%) activities when exposed. In

Table 2 Clinical end points in persons receiving hyperbaric oxygen treatment for carbon monoxide poisoning, United States, August 2008–January 2010 (n = 859)

Variable	n (%)
Most common symptoms [a]	
Headache	566 (65.9)
Dizziness	439 (51.1)
Nausea/vomiting	392 (45.6)
Loss of consciousness	374 (43.5)
Confusion	259 (30.2)
No. of symptoms per patient	
None reported	21 (2.4)
1	122 (14.1)
2	179 (20.7)
≥3	541 (62.7)
Duration of loss of consciousness [b]	
≤10 min	165 (37.7)
11-60 min	35 (8.0)
1-6 h	19 (4.3)
>6 h	6 (1.4)
Unknown	213 (48.6)
Cardiac ischemia	
No	615 (71.9)
Yes	111 (13.0)
Unknown	130 (15.2)
Prior carbon monoxide poisoning	
No	719 (83.3)
Yes	19 (2.2)
Unknown	125 (14.5)
Pregnant [c]	24 (6.5)
Initial normobaric oxygen treatment	832 (96.3)
% Carboxyhemoglobin	
Median (minimum, maximum)	22.1 (0.1-77.0)

[a] Does not total 100% because each patient can experience more than 1 symptom.
[b] n = 438.
[c] n = 369.

Table 3 Circumstances surrounding exposure in persons who received hyperbaric oxygen treatment for carbon monoxide poisoning, United States, August 2008–January 2010 (n = 864)

Variable	n (%)
Location of exposure	
Residence total	612 (71.0)
Owned	323 (37.5)
Rented	112 (13.0)
Visiting	50 (5.8)
Circumstances unknown	127 (14.7)
Workplace	127 (14.7)
Motor vehicle	46 (5.3)
Other/unknown	77 (8.9)
Activity	
Domestic (eg, sleeping)	544 (63.2)
Occupational	165 (19.2)
Recreational	50 (5.8)
Home or auto repair	37 (4.3)
Travel	22 (2.6)
Other/unknown	43 (5.0)
Most common sources [a]	
Furnace or boiler	280 (32.4)
Generator	170 (19.7)
Motor vehicle	111 (12.8)
Grill	50 (5.8)
Space heater	43 (5.0)
Fuel [b]	
Gasoline	320 (48.3)
Natural gas/propane	239 (36.1)
Diesel	13 (1.9)
Other/unknown	96 (14.5)
Carbon monoxide alarm in use	
No	618 (71.5)
Yes	85 (9.8)
Unknown	161 (18.6)
Other persons exposed	
Yes	649 (75.2)
No	177 (20.5)
Region	
West	289 (33.6)
Midwest	234 (27.2)
South	186 (21.6)
Northeast	151 (17.6)
Season	
Winter	354 (41.0)
Fall	293 (33.9)
Summer	129 (14.9)
Spring	88 (10.2)

[a] Exposure can be the result of more than 1 source.
[b] n = 662. Six exposures had multiple fuels.

contrast, women more commonly reported conducting domestic activities (55%) or traveling (55%). Seventy percent of patients who were performing home or auto repair, 63% who were participating in recreational activities, and 93% who were occupationally exposed were between the ages of 18 and 64 years. Seventy-five percent (649) of the patients reported being exposed with other people, a circumstance common among many exposures; of this group, 485 patients (75%) were in a residence and 72% were performing domestic activities. Thirty-eight patients (6%) were poisoned by charcoal use, and 49% of those poisonings occurred among Hispanic white patients. Finally, among patients who were exposed in their residence, 11% reported the presence of an alarm.

Table 4 Characteristics of persons who received hyperbaric oxygen treatment for carbon monoxide poisoning and circumstances surrounding the exposure by disposition.

Variable	Hospitalized (n = 353)	Discharged after treatment (n = 475)
	n (%)	
Sex *		
Male	220 (62.3)	256 (53.9)
Female	133 (37.7)	219 (46.1)
Race/ethnicity *		
Non–Hispanic white	204 (57.8)	250 (52.6)
Hispanic white	56 (15.9)	118 (24.8)
Black	68 (19.3)	76 (16.0)
Other/unknown	25 (7.1)	31 (6.5)
Age group (y) *		
birth-17	61 (17.4)	88 (18.6)
18-44	117 (33.4)	244 (51.6)
45-64	112 (32.0)	112 (23.7)
>64	60 (17.1)	29 (6.1)
Primary language *		
English	300 (85.2)	359 (75.7)
Spanish	26 (7.4)	86 (18.1)
Other/unknown	26 (7.4)	29 (6.1)
Cardiac ischemia *		
No	210 (59.7)	389 (82.6)
Yes	94 (26.7)	11 (2.3)
Unknown	48 (13.6)	71 (15.0)
% Carboxyhemoglobin †		
Median (minimum, maximum)	24.6 (1.0-77.0)	21.0 (0.1-46.0)
Carbon monoxide alarm *		
No	244 (69.1)	348 (73.3)
Yes	30 (8.5)	54 (11.4)
Unknown	79 (22.4)	73 (15.4)
Season of exposure *		
Winter	155 (43.9)	188 (39.6)
Autumn	101 (28.6)	183 (38.5)
Summer	53 (15.0)	62 (13.1)
Spring	44 (12.5)	42 (8.8)

* χ^2 test, $P < .05$.
† Wilcoxon rank sum test, $P < .05$.

Prior carbon monoxide poisoning was reported by 19 patients (2%). At the time of recent exposure, 15 (79%) did not have a carbon monoxide alarm, and 15 were discharged after treatment (data not shown). Most of the patients spoke English (n = 18), were between ages 18 and 64 years (n = 16), and were men (n = 13). Ten were performing domestic activities when exposed; 7 were working.

With regard to patient disposition after hyperbaric treatment, 55% of the patients were discharged after hyperbaric treatment, 41% were hospitalized, and for 4%, disposition was missing (Table 4). The discharged and admitted groups differed significantly by sex, race/ethnicity, age group, and primary language ($P < .05$). Nine percent of hospitalized patients and 11% of discharged patients reported the presence of a carbon monoxide alarm; this difference was also significant. Finally, patients who were hospitalized after treatment were significantly more likely to exhibit signs of resultant ischemia than patients who were released (27% vs 2%).

4. Discussion

Understanding why certain groups of patients experience higher rates of carbon monoxide poisoning is important for case recognition and prevention efforts. For example, higher proportions of carbon monoxide poisoning among men have been reported in populations with fatal carbon monoxide exposures; this pattern has been attributed to engaging more frequently in high-risk behaviors such as using fuel-burning tools [8]. A similar pattern is seen in this study population, given that men account for the large majority of those performing home or auto repair and occupational activities when they were poisoned. Most of the patients who lost consciousness for more than 1 hour were men. Finally, men comprise a larger proportion of patients who were hospitalized after treatment than patients who were discharged home, suggesting that men were more severely exposed.

It has been reported in smaller studies that Hispanic white patients are another population that has higher rates of severe, unintentional carbon monoxide poisoning caused by using charcoal [11,12]. In those studies, as well as this one, Hispanic white cases accounted for the largest segment or a disproportionate percentage of the population poisoned by charcoal use. This pattern has been attributed, in part, to recent immigrants' continuation of cultural practices common to their native country [13]. For our analysis, the relatively small percentage of Hispanic white patients who reported speaking English suggests that bilingual prevention messaging may be an important approach to reducing carbon monoxide exposure in this population.

Seasonal and geographic patterns seen in these unintentional carbon monoxide exposures may also be useful in clinical diagnostic and prevention efforts. Poison center calls, emergency department visits, and hospitalizations for carbon monoxide exposure are typically higher in regions of the United States with the coldest climates, presumably due to the increased use of home-heating systems, use of alternative heat sources, and motorists "warming up" their vehicles in enclosed spaces [1,4]. This may help explain why winter exposures account for a larger proportion of patients who were hospitalized after treatment. Although the reported exposures do follow the expected seasonal trends, they do not follow the anticipated geographic pattern; this is likely a reflection of the disproportionate numbers of participating hyperbaric facilities in each region (Northeast, 16; South, 27; Midwest, 23; and West 21).

Circumstances surrounding these poisonings suggest that public health education and intervention about using alarms would be effective in preventing carbon monoxide poisonings. For instance, those patients who were hospitalized after treatment, as compared with those who were discharged, were significantly less likely to report using a carbon monoxide alarm in their home. Similarly, education and intervention may increase the proportion of reported use of carbon monoxide alarms in this study population (10%), which is well below the 36% to 40% of American households with alarms in 2009 (American Housing and National Health Interview Surveys). These findings suggest that carbon monoxide alarm initiatives could be effective in reducing severe and repeated poisonings. Several other findings also underscore the potential effectiveness of alarm use for exposure prevention. Examples of these findings are that furnaces, generators, and motor vehicles were primary sources of carbon monoxide and that most of the poisonings occurred in residential settings, which has also been reported in those carbon monoxide cases presenting to an emergency department [1]. Of those reporting the presence of an alarm in the residence where they were exposed (11%), information was not available regarding the functionality of the alarm, but education regarding routine battery replacement may be able to reduce the number of similar exposures. Finally, the considerable proportion of patients who were poisoned with other people (75%) reinforces the belief that fatal exposures for groups of people can be the result of a single carbon monoxide source. Thus, education and intervention about one simple prevention measure can potentially prevent multiple poisonings and deaths. This is unique when compared with other health conditions and highlights the importance of public health efforts that could reduce the number of severe exposures and, thereby, the public health burden.

The clinical features captured by this reporting system confirm the severity of carbon monoxide exposures in patients referred for hyperbaric oxygen treatment and provide some insight into treatment practices. For instance, one of the most commonly reported symptoms, loss of consciousness, is a symptom of more severe carbon monoxide exposures [5]. The high frequency of loss of consciousness in this population likely relates its common usage as an independent criterion for hyperbaric referral. Also, higher carboxyhemoglobin levels generally cause more severe neurologic symptoms [5]; reported carboxyhemoglobin levels were significantly higher among patients who were hospitalized after treatment, which suggests more severe exposures than in patients who were released. Carboxyhemoglobin levels of 20% to 60%, however, typically do not correlate well with patient symptoms or prognosis [14]; the median levels observed in this analysis fell within these boundaries, but the range of measurements was rather wide. Information on acute cardiac injury, another sign of severe exposure and indication for hyperbaric treatment, also showed that patients who were hospitalized after treatment were significantly more likely to exhibit signs of resultant ischemia.

This analysis is subject to several limitations. The data reported by participating physicians are not nationally representative. In 2010, a survey was conducted on reporting practices among the 44 facilities that reported cases in 2009 to assess this limitation. Representatives of 26 (59%) of those reporting facilities responded to the survey. The 26 facilities reported providing hyperbaric oxygen treatment to a combined total of 523 patients with carbon monoxide poisoning in 2009. A query of the data found that these facilities reported data on 450 cases, or 86% of those treated. The 450 cases also represent 64% of the total 706 cases for which data were submitted in 2009 [10]. Accordingly, the numbers in this report are likely a significant underestimation of the total number of patients treated with hyperbaric oxygen for carbon monoxide poisoning in the United States because not every case at participating facilities is reported and not all facilities participate in the reporting system. Finally, long-term follow-up of this population of patients is not possible. Despite these limitations, this analysis includes the most detailed information on the largest population of patients treated with hyperbaric oxygen for carbon monoxide poisoning to date.

5. Conclusion

The unique information collected by this system, which is not captured elsewhere, can be used by medical and public health professionals to identify high-risk populations and reduce the burden of exposures. The results will likely contribute to a better understanding of carbon monoxide poisoning epidemiology and its magnitude and, consequently, inform and enhance prevention efforts and treatment practices. Therefore, maintaining and expanding this reporting system are vital.

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