Carbon Monoxide Exposure and Poisoning Cases in Wisconsin, 2006–2016

Grace M. Christensen, MPH; Paul D. Creswell, PhD; Jon G. Meiman, MD

ABSTRACT

Introduction: Carbon monoxide (CO) poisoning is responsible for over 450 deaths and 21,000 Emergency Department visits annually in the United States. In Wisconsin, multiple large-scale CO poisoning events have occurred in recent years. This analysis explores trends in CO exposure events in the state from 2006 through 2016.

Methods: Wisconsin Poison Center (WPC) CO exposure data from January 1, 2006 through December 31, 2016 was analyzed for trends over time. CO poisoning cases were classified using the Council of State and Territorial Epidemiologists case definition.

Results: During the study period, 3,703 persons were exposed to CO and 2,148 were poisoned. On average, 337 persons were exposed annually over this period, with an annual average of 195 suspected and probable poisoning cases per year, as reported to the WPC. Large-scale events (≥ 5 persons) accounted for 4.8% (n = 104) of all events. Using data extracted from WPC case notes for large-scale exposures, the most common source of exposure was furnaces or water heaters (20.2%; n = 21) followed by fire (8.7%; n = 9).

Conclusions: Despite public health efforts to reduce CO exposures, CO poisoning continues to affect Wisconsin residents. Efforts to prevent large scale CO poisonings should focus on awareness of CO exposure within the home, as well as the risk in public or occupational settings. Moreover, these efforts should focus on improving the use of CO detectors in all settings to prevent exposure. The WPC can be used as a resource for clinicians in cases of CO exposure and poisoning.

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INTRODUCTION

Carbon monoxide (CO) is a colorless, odorless, and nonirritating gas that is often described as a silent killer because exposure may not be detected until the onset of severe symptoms. Symptoms of CO poisoning are nonspecific and include headache, nausea, vomiting, dizziness, confusion, chest pain, and loss of consciousness. Severe poisoning can result in myocardial injury, coma, and death.[1,2] CO exposure is especially dangerous for pregnant women, as poisoning can result in miscarriage of the fetus.[3,4] Sources of CO include internal combustion engines, fires, and gas-powered appliances such as furnaces and stoves.[3,4] CO poisoning occurs frequently and is a leading cause of non-drug poisoning mortality in the United States. The Centers for Disease Control and Prevention (CDC) estimate that unintentional, non-fire-related CO poisoning is responsible for 450 deaths and 21,000 Emergency Department (ED) visits annually in the United States.[3]

Large-scale CO poisoning events have been described in case studies and have occurred in settings such as churches, ice hockey arenas, schools, and occupational environments.[5-12] While these are described as "large-scale events" due to the large number of persons exposed, there is currently no definition of a large-scale CO poisoning event used in the literature. In the past decade, several high-profile, large-scale CO poisoning events have occurred in Wisconsin. For example, 74 people were poisoned at a youth hockey tournament in 2014 due to a poorly maintained ice resurfacer; 123 people

Figure 1. Carbon Monoxide Poisoning Cases and Exposure Events by Year in Wisconsin, 2006-2016

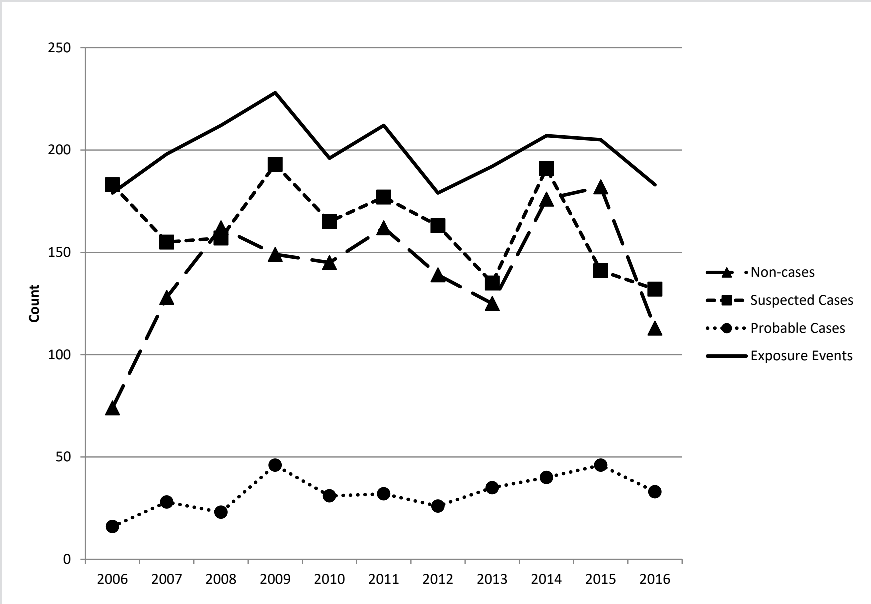
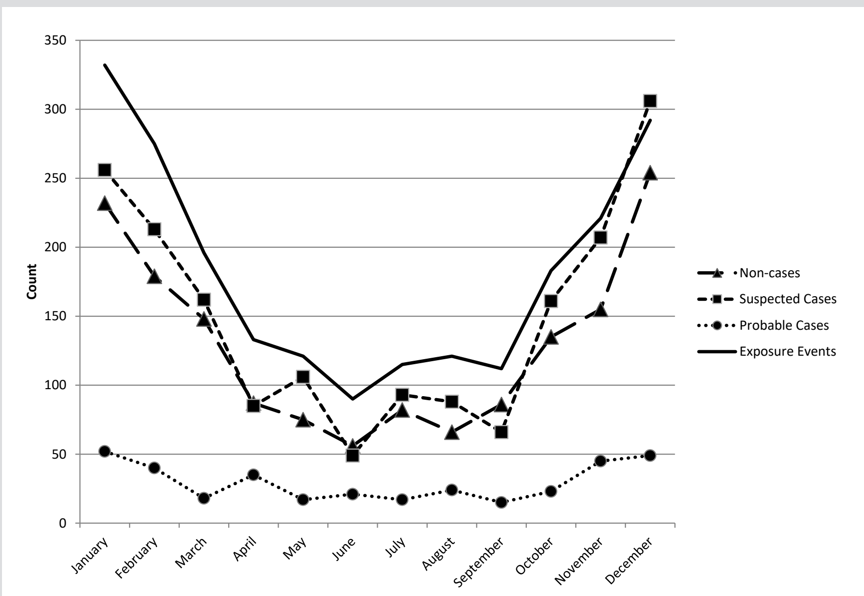


Figure 2. Carbon Monoxide Poisoning Cases and Exposure Events by Month in Wisconsin, 2006-2016



were exposed at a movie theater in 2015; and 31 workers were poisoned in 2017 following an occupational exposure at an appetizer manufacturing facility.[7,11,13] In the case of the hockey tournament, players and game attendees complained of nonspecific symptoms, such as headache and difficulty breathing, but CO exposure was not suspected until a player lost consciousness in the locker room.[7]

Despite case reports of large-scale CO poisonings, epidemiological studies that assess the frequency and severity of poisonings caused by large-scale CO exposure events are lacking. CO poisoning was not a reportable condition in Wisconsin until July 2018 (Wisconsin Statute § DHS 145.04) and surveillance data are limited. However, the Wisconsin Poison Center (WPC) serves as a passive surveillance system for chemical poisoning exposures and illnesses in the state. Although not all exposures are reported to the WPC, this database still constitutes the best available data source to assess trends in CO exposure events.

Using WPC data, this paper aims to describe CO exposure events in the state of Wisconsin from January 1, 2006 through December 31, 2016. Large-scale exposure events are described and evaluated for temporal trends.

METHODS

Carbon Monoxide Exposures

To identify individuals exposed to CO during the study period, data were collected from the WPC, a certified poison control center for the state of Wisconsin. Calls to the WPC are managed by Specialists in Poison Information (SPIs) who are physicians, nurses, or pharmacists trained in poison information. Calls are received from the public as well as health care professionals. The National Poison Data System (NPDS) houses WPC data and was queried for CO exposure calls that occurred during the 2006-2016 study period. Exposure calls with the substance "carbon monoxide" during the specified time period were included in this analysis. An exposure call is defined as a call about a concern relating to an exposure to a substance. In some instances, SPIs determine that an exposure initially believed to have occurred never actually occurred; these calls are labeled with medical outcome "Confirmed Non-Exposure" and were removed from the dataset prior to analysis. All exposures reported to the WPC are given a medical outcome using the American Association of Poison Control Centers (AAPCC) classifications. The AAPCC defines a minor effect as symptoms of the exposure that were minimal and resolved rapidly. Moderate effects are more prolonged than minor effects and usually require some form of medical treatment. Major effects are considered to be life-threatening or result in significant disability or disfigurement. More information on NPDS medical outcome definitions can be found in the NPDS annual report or coding manual.[14]

CO Poisoning Cases

CO poisoning cases were identified and classified using the 2014 Council for State and Territorial Epidemiologists (CSTE) case definition.[15] CSTE defines a suspected case in poison control center data as record of an individual with "exposure" as the type of call where the substance was CO and a minor medical outcome was reported. Probable cases are defined as CO exposure records with a moderate or major medical outcome or where death was reported. Confirmed cases meet the suspected or probable definitions and have a positive environmental exposure consistent with CO poisoning as indicated in the case notes.[15]

CO Exposure Events

In this analysis, CO exposures with a common carbon monoxide-emitting source were grouped and defined as 1 CO exposure event. An event may involve 1 or more people and, as such, may involve more than 1 call to the WPC. Exposure events were classified into 2 categories: poisoning events and nonpoisoning events. A poisoning event involved at least 1 case of CO poisoning, suspect or probable, as defined by the CSTE case definition. For the purposes of this analysis, we defined large-scale events as exposure events involving ≥5 persons. This threshold was chosen to describe large-scale events in order to select events large enough to be at the tail end of the distribution (ie, between 95th and 99th percentile), while simultaneously providing a sufficient sample of events to monitor across time. Sensitivity analyses using higher cut-points showed similar trends but were less stable with regards to rate fluctuations due to low sample sizes. Case notes for large-scale events were abstracted and reviewed for information involving source of exposure and mention of CO detectors. Case notes for non-large-scale events <5 persons were not reviewed and detailed exposure information was not available.

Table 1. Demographic Characteristics of Carbon Monoxide Exposed Persons by Case Designation, Wisconsin, 2006-2016

	Non-poisoning Cases		Suspected Cases		Probable Cases		Total Events		
Variable	**N**	**%[a]**	**N**	**%[a]**	**N**	**%[a]**	**N**	**%[b]**	***P*-value[c]**
Total	**1555**	**41.99**	**1792**	**48.39**	**356**	**9.61**	**3703**	**100**	**-**
Sex									
Male	686	39.56	837	48.27	211	12.17	1734	46.83	
Female	842	43.74	941	48.88	142	7.38	1925	51.98	<0.001
Missing[d]	27	61.36	14	31.82	3	6.82	44	1.19	
Age Category									
≤5	358	65.93	167	30.76	18	3.31	543	14.66	
6-12	96	36.09	149	56.02	21	7.89	266	8.43	
13-19	195	34.76	315	56.15	51	9.09	561	7.18	
20-29	181	34.28	301	57.01	46	8.71	528	15.15	
30-39	89	24.12	223	60.43	57	15.45	369	14.26	
40-49	93	27.68	172	51.19	71	21.13	336	9.96	<0.001
50-59	151	48.40	147	47.12	14	4.49	312	9.07	
60-69	42	32.06	59	45.04	30	22.90	131	3.54	
70-79	30	41.67	32	44.44	10	13.89	72	1.94	
80+	12	30.77	14	35.90	13	33.33	39	1.05	
Missing[d]	308	56.41	213	39.01	25	4.58	546	14.74	
Exposure Site									
Public Area	52	27.66	108	57.45	28	14.89	188	5.08	
Residence	1390	46.15	1359	45.12	263	8.73	3012	81.34	<0.001
Unknown	11	50.00	9	40.91	2	9.09	22	0.59	
Workplace	53	15.92	230	69.07	50	15.02	333	8.99	
Other	49	33.11	86	58.11	13	8.78	148	4.00	

[a] Calculated as a row percent.
[b] Calculated as a column percent.
[c] Chi-square test statistic.
[d] Missing categories were not included in the chi-square statistic.

Statistical Analysis

All data were analyzed using SAS version 9.4 (SAS Institute Inc., Cary, North Carolina). Counts of cases and individuals exposed by demographic, exposure site, and temporal characteristics were calculated. Counts of exposure events by event characteristics were also calculated. Two-by-two tables were used to obtain chi-square statistics. Trends in proportions of cases over time and large-scale events over time were calculated using the Cochran-Armitage trend test.

RESULTS

CO Exposures and Poisoning Cases

During the 2006–2016 study period, 3,703 individuals were exposed to CO, which resulted in 1,792 suspected and 356 probable cases of CO poisoning (Figure 1). On average, 337 persons were exposed annually over this period with an annual average of 195 suspected and probable poisoning cases per year. Men were more likely to be poisoned than women ($P < 0.001$, chi-square) (Table 1).

Of the 2,148 suspected and probable CO poisoning cases, 1,640 (76.4%) were from acute exposure, 263 (12.2%) from chronic exposure, and 185 (8.6%) from acute-on-chronic exposure. The majority of poisoning cases (83.4%; n = 1,792) had a minor medical outcome; 320 (14.9%) had a moderate outcome, 33 (1.5%) had a major outcome, and there were 3 deaths (0.1%). Eighty-seven (4.1%) cases received hyperbaric oxygen treatment.

There was not a significant trend in proportion of exposures that resulted in cases of CO poisoning over time ($P = 0.12$, Cochran-Armitage Trend test). Chi-square tests showed there was a significant difference between the proportion of cases among residential and non-residential exposures, with those exposed in

Table 2. Carbon Monoxide Exposure Event Characteristics, Poisoning vs Nonpoisoning Events, Wisconsin, 2006-2016

	Non-poisoning Cases		Poisoning Events		Total Events		
Variable	**N**	**%[a]**	**N**	**%[a]**	**N**	**%[b]**	***P*-value[c]**
TOTAL	**735**	**33.55**	**1456**	**66.45**	**2191**	**100**	**--**
Caller Site							
Health Care Facility	111	17.65	518	82.35	629	28.71	
Public Area	5	41.67	7	58.33	12	0.55	< 0.001
Residence	528	41.67	739	58.33	1267	57.83	
Unknown	2	66.67	1	33.33	3	0.14	
Workplace	20	27.78	52	72.22	72	3.29	
Other	69	33.17	139	66.83	208	9.49	
Exposure Site							
Public Area	13	21.31	48	78.69	61	2.78	
Residence	650	37.19	1098	62.81	1748	79.78	< 0.001
Unknown	9	45.00	11	55.00	20	0.91	
Workplace	40	15.44	219	84.56	259	11.82	
Other	23	22.33	80	77.67	103	4.70	
Persons Exposed per Event							
1	521	34.21	1002	65.79	1523	69.51	
2	102	32.59	211	67.41	313	14.29	
3	47	30.92	105	69.08	152	6.94	0.72
4	35	35.35	64	64.65	99	4.52	
5+	30	28.85	74	71.15	104	4.75	
Reason							
Intentional - Other	10	23.26	33	76.74	43	1.96	
Intentional - Suspected suicide	20	14.18	121	85.82	141	6.44	
Unintentional - Environmental	541	37.08	918	62.92	1459	66.59	< 0.001
Unintentional - Occupational	32	14.75	185	85.25	217	9.90	
Unintentional - Other	123	39.81	186	60.19	309	14.10	
Unknown	9	40.91	13	59.09	22	1.00	

[a] Calculated as a row percent.
[b] Calculated as a column percent.
[c] Chi-square test statistic.

residential settings more likely to be classified as non-cases than as cases ($P < 0.001$, chi-square). Conversely, occupational exposures are more likely to result in case status than non-case status ($P < 0.001$, chi-square), compared to nonoccupational exposures.

CO Exposure Events

Over the study period, there were 2,191 CO exposure events, 1,456 (66.5%) of which resulted in at least 1 CO poisoning case. Trends were observed in month of exposure but not year. Winter months—November through February—accounted for 51.2% of exposure events. January had the highest number of events (15.15%; 332) and June had the fewest (4.11%; 90) over the 11-year period (Figures 1 and 2).

The majority of CO exposure events (79.8%; n = 1,748) occurred in residential settings followed by occupational settings (11.8%; n = 259). A total of 61 (2.8%) events occurred in public areas. Of residential exposure events, 1,098 (62.8%) resulted in at least 1 case of CO poisoning. Of the 259 workplace exposure events, 219 (84.6%) events resulted in at least 1 case of CO poisoning (Tables 1 and 2). Large-scale events (≥ 5 persons), either residential or in a public area, accounted for 4.8% (n = 104) of all events (Table 2).

Of 104 large-scale exposure events identified, 75 (72.1%) included at least 1 case of carbon monoxide poisoning. The median number of individuals exposed during large-scale events was 5 (range: 5–72); all but 1 event had 5 to 15 persons exposed; the outlier had 72 persons exposed. On average, 43.7% of those exposed (range 0%–100%) during large-scale events developed CO poisoning. The number of large-scale events each year was unstable ranging from a minimum of 3 in 2015 to a maximum of 15 in 2011 with an average of 9 per year. There was no significant trend in proportion of events that were considered large-scale events over time ($P = 0.79$, Cochran-Armitage trend test). The vast majority (86.5%; n = 90) were in residential settings, followed by occupational settings (8.7%; n = 9) and public areas (4.8%; n = 5).

Using data abstracted from WPC case notes for large-scale exposures, the most common source of exposure was furnaces or water heaters (20.2%; n = 21) followed by fire (8.7%; n = 9) (Table 3). The presence or absence of CO detectors was mentioned in 53 (51.0%) of large-scale event case notes. Of the large-scale event case notes reviewed, 41 (39.4%) mentioned a CO detector present at the site of exposure. It was noted in 12 (11.5%) that a CO detector was not present.

DISCUSSION AND CONCLUSIONS

Carbon monoxide poisoning continues to be a significant public health issue in Wisconsin and results in an average of 195 poisoning cases every year based upon poison center data. Despite public health efforts to reduce CO exposures, the number of poisonings reported to the WPC has remained relatively constant from year to year. Nationally, CO poisoning is responsible for over 21,000 ED visits annually.[3] Poisoning can result in long-term health effects like memory loss and other neurological impairments.[16] The economic burden of CO poisoning in the United States has been estimated at $1.3 billion annually as a result of direct health care costs and lost earnings.[17]

Analysis of WPC data revealed that CO exposures in Wisconsin peak in the winter months and decline in the summer. The seasonality of CO poisoning in northern states is well documented and is due to increased use of gas heating equipment in the winter months.[3,4,16] Residential exposure events were the most common

(79.8%; n = 1,748). The risk of CO exposure from gas-powered household appliances, such as furnaces, water heaters, stoves, generators, and vehicles, is well-documented and is reinforced by these findings.[3,4,16] Residential exposures were also the most common exposure site among large-scale events; 20.2% of large-scale event exposure sources were home furnaces or water heaters, indicating a departure from the literature that primarily provides case studies of large-scale CO poisonings in public areas.[5-12]

CO poisoning events described in the literature are very large and have involved 25 to 184 individuals poisoned.[5-10] In our sample, only 4.75% of events affected 5 or more people, and of those events, all but one affected fewer than 15 individuals. The outlier event was the poisoning at a youth hockey tournament in 2014, with 72 records.[7] This finding suggests that while there are CO poisoning events affecting dozens of persons in public areas, as documented in the literature, it is much more common that families are exposed to CO and poisoned in their homes. As such, efforts to prevent large-scale CO poisonings should focus on awareness of CO exposure within the home, in addition to public or occupational settings. Moreover, these efforts should focus on improving the use of CO detectors in all settings to prevent exposure.

Although poison control data can provide detailed event information, poison centers rely upon reports from the public and health providers and likely underestimate the true incidence of CO poisonings. A public health investigation of a large-scale exposure at a hockey tournament discovered that only 72 (48.0%) individuals exposed had records in WPC data. During this incident, over 150 people were exposed and 92 went to the ED.[7] An occupational exposure investigation found that of 41 workers that went to the ED, only 7 (17.0%) records were found in WPC data for this event. Additionally, it was discovered that only 2 of the 5 EDs visited by the workers called the WPC.[11] These investigations underscore the limitations of using poison control center data as a passive surveillance system and indicate that these data underrepresent the true number of CO exposure events as well as the number of people exposed during these events. Residential exposures are likely to be either reported in full or missed completely because family members are likely to present to the same ED; whereas larger public site or workplace exposures are likely to present to multiple EDs.

The findings presented here reinforce the need for improved prevention efforts and improved surveillance activities to better characterize the burden of CO poisoning. Use of CO detectors with audible alarms is effective in alerting potential victims of its presence, reducing symptoms from exposure.[18,19] Large-scale poisoning events in hockey rinks spurred enactment of a 2013 law requiring detectors at public venues in Minnesota (Minnesota Statute § 4620.4550). Wisconsin requires CO detectors in all homes and apartments that have gas-powered appliances, but does not require them in workplaces or public areas (Wisconsin Statute § 101.149). CO poisoning is a reportable condition in Wisconsin as of July 2018. By making the condition reportable to public health, there will be increased awareness of the condition among health care providers. Additionally, the Wisconsin Department of Health Services will gather improved exposure information to identify the true burden of CO exposure as well as information on which CO sources should be targeted through public health messaging.

Table 3. Sources of Carbon Monoxide Large-Scale Events as Described in Wisconsin Poison Center Case Notes

	N	%
Ice resurfacer	1	0.96
Vehicle [a]	7	6.73
Fire	9	8.65
Fireplace or wood stove	5	4.80
Furnace or Water heater	21	20.18
Generators	3	2.88
Gas-powered stove or grill	8	7.69
Other gas-powered equipment [b]	3	2.88
Unspecified	47	45.20

[a] Includes cars, recreational vehicles, forklifts, and pallet lifters.
[b] Includes gas-powered saw, laundry machine, and pool equipment.

Finally, clinicians should be maintaining a high index of suspicion for CO poisoning when patients present with nonspecific symptoms without obvious cause. Nonspecific symptoms such as headache and nausea contribute to underdiagnosis.[20] In 1 study of ED visits, 37 patients presenting with a headache were investigated for evidence of carbon monoxide exposure. Seven (19%) of these patients had carboxyhemoglobin levels > 10%, and 6 of the 7 had a definite or probable toxic CO exposure. None of these patients were suspected of having CO poisoning until the clinician received the test results. Additionally, 3 of the 7 patients with CO poisoning had cohabitants with symptoms of CO poisoning.[21] Increased awareness of CO poisoning among health care providers is necessary for proper diagnosis and treatment of the condition. The WPC center can be used as a resource for clinicians.

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