Epidemiology of severe carbon monoxide poisoning in children.

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Mendoza JA, Hampson NB. Epidemiology of severe carbon monoxide poisoning in children. Undersea Hyperb Med 2006; 33(6):439-446. Objective: To describe the characteristics of severe pediatric CO poisoning cases treated with hyperbaric oxygen (HBO_2) to determine key features that might aid prevention efforts. Design: Using data on 250 consecutive children treated with HBO_2 for CO poisoning at Virginia Mason Medical Center in Seattle, we calculated descriptive statistics and used Fisher's Exact test to determine differences in case frequency of CO sources with respect to race/ethnicity. Results: There were 236 (94%) unintentional and 14 (6%) intentional poisonings. Loss of consciousness occurred in 50%. The average initial carboxyhemoglobin level was 19.0 $\pm$ 10.3% (mean $\pm$ SD; range 0.3% to 57.6%). Months with the highest proportion of incidents were November (15%), December (12%) and January (14%). Children 0-2 years old were most often poisoned by charcoal briquettes (40%), in contrast to older children who were most often poisoned by motor vehicle. Females were most often poisoned by charcoal briquettes (28%), in contrast to males in which motor vehicle exhaust predominated (41%). Minorities were disproportionately affected by CO poisoning compared with non-Latino whites ($P<0.001$). Overall, motor vehicle exhaust predominated for Non-Latino whites (33%), while Non-Latino blacks (55%) and Latinos (71%) had significantly higher proportions of poisonings by charcoal briquettes ($P<0.001$). All intentional cases occurred in adolescents aged 15 to 17 years, 71% of these in males, mostly by motor vehicle exhaust (79%). Conclusions: Severe pediatric CO poisoning demonstrates a seasonal pattern with key sources of exposure varying by gender, age, and race/ethnicity. Minorities are at increased risk for severe CO poisoning. Intentional CO poisoning occurs primarily among adolescent males and by motor vehicle exhaust. Prevention efforts should take these factors into consideration.

INTRODUCTION

Carbon monoxide (CO) is a major cause of unintentional and intentional poisoning in U.S. children. A comprehensive, long-term, national study using data from 1979-1994 reported that 38.2% of poisoning deaths for 10-19 year olds in the U.S. were attributable to carbon monoxide(1). A recent CDC article on unintentional, non-fire-related carbon monoxide exposure leading to emergency department visits reported that the nonfatal rate for CO exposure in children aged $\leq$4 years was 8.2 per 100,000 persons—the highest rate for any age group of children or adults (2). Additionally, previous reports have shown that certain populations are at increased risk for CO poisoning from specific sources. For instance, Latinos are at increased risk for CO poisoning from charcoal briquettes (3), and children who ride in the back of pick-up trucks have a unique risk for CO poisoning, as well (4). These reports and others (5,6) have provided important characteristics and risk factors for pediatric CO poisoning. However, several gaps in the pediatric literature remain, including data on: 1) seasonal variability of pediatric CO poisoning, 2) race/ethnicity as a risk factor for pediatric CO poisoning, and 3) characteristics of intentional CO poisoning in children. In particular, we hypothesized that Latino children would be at greater risk for CO poisoning by charcoal briquettes than their white peers. This study was designed to provide information on these three important areas in an attempt to assist in development of prevention strategies for pediatric CO poisoning.

METHODS

Data Source

The Virginia Mason Center for Hyperbaric Medicine (VMCHM) in Seattle has maintained a log of all patients referred for hyperbaric oxygen (HBO_2) treatment of CO poisoning since its first patient was treated in November 1978. This log contains patient information including name, date of birth, race/ethnicity, gender, reason for referral/ HBO_2 treatment, source of CO poisoning, carboxyhemoglobin (COHb) level, and reason for CO poisoning (intentional versus unintentional), as recorded by Center staff. We used this log as the primary data source and extracted information on all pediatric patients treated for CO poisoning at the VMCHM from November 1978 to November 2004. The VMCHM serves as the primary referral center for HBO_2 treatment of severe carbon monoxide poisoning in Washington, Idaho, and Montana, and is the only hyperbaric facility accredited by the Undersea and Hyperbaric Medical Society (UHMS) in the region. Carbon monoxide cases sent to VMCHM for HBO_2 treatment are severe in nature and are referred by tertiary care hospitals whose physicians have determined, in consultation with VMCHM hyperbaric specialists, the need for HBO_2 treatment. When patient data in the log was incomplete, present author J.A.M. obtained case information by conducting a retrospective chart review of the appropriate medical center records. This study was reviewed and deemed exempt by the Virginia Mason Medical Center (VMMC) Institutional Review Board.

Subjects

We defined a case as a subject less than 18 years of age treated with HBO_2 with a history of CO exposure and symptoms consistent with CO poisoning, and/or an elevated blood carboxyhemoglobin (COHb) level (>2%) (7). COHb levels reported represent the initial measurement obtained, either during initial workup at an outside facility or after referral to VMCHM, resulting in a variable amount of time and oxygen (O_2) treatment between CO exposures and sampling blood for COHb measurement. As the need for hyperbaric treatment was determined prior to transfer, all patients referred received HBO_2 treatment. Criteria utilized at VMCHM to advise hyperbaric treatment of a patient with CO poisoning are those recommended by the UHMS (transient or prolonged unconsciousness, neurological signs, cardiovascular dysfunction, severe acidosis, or elevation of COHb level to the range of 25-30%) (8).

Case characteristics were defined as follows: 1) race/ethnicity, as identified by a health care professional in the medical record; 2) CO source from motor vehicle exhaust, charcoal briquettes, fire, generator, furnace, boat exhaust, or other (natural gas leak, indoor swimming pool heater, propane heater, kerosene heater, propane lantern, wood stove, or gas powered compressor); and 3) reason for poisoning as intentional versus unintentional, as documented in the medical record.

Statistical Analysis

We calculated descriptive statistics such as percentages by case characteristics. We used Fisher's Exact test and a Chi square test to determine differences in case frequency of CO sources with respect to race/ethnicity. In order to test for confounding by age and gender, we used a multinomial logistic regression model in which CO source was the dependent variable and the case characteristics of race/ethnicity, age, and gender, were independent variables. For the Fisher's exact test and the multinomial regression model, we further collapsed the CO source category into motor vehicles, charcoal briquettes, and other. We used Stata version 8.2 for Windows for all analyses.

RESULTS

A total of 250 pediatric patients were treated for CO poisoning over the 26-year period, poisoned in 162 separate incidents. As shown in Table 1, the average age was 8 $\pm$ 5 years (mean $\pm$ SD, range <1 year to 17 years), 49% were female, and the majority of children were Non-Latino white (51%) followed by Latino (20%), Non-Latino black (8%), and Asian (6%). When compared to US Census data for Washington State in 2000 (9), a greater number of Latinos, non-Latino blacks, and other minority races were treated for severe CO poisoning (Table 2).

Table 1. Case characteristics of study subjects.

	Number	Percent	Mean, Std Dev.
Age (years)	250		8.0 +/- 5.1
Carboxyhemoglobin level (%)	242		19.0 +/- 10.3
Female	122	48.8	
Race/ethnicity			
Non-Latino white	128	51.2	
Non-Latino black	20	8.0	
Latino	51	20.4	
Asian	15	6.0	
Other/unknown*	36	14.4	

*Includes Native Americans

Table 2. Comparison of study sample race/ethnicity to Washington State data from the 2000 US Census data for children < 18 years old.

	Study Sample		Washington State US Census 2000	
	Number	Percent	Number	Percent
Non-Latino white	128	51.2	1,082,049	71.5
Non-Latino black	20	8.0	56,347	3.7
Latino	51	20.4	177,410	11.7
Asian	15	6.0	75,553	5.0
Other/Multi-racial/ Unknown	36	14.4	122,484	8.1

1) n=250 for the study sample and N=1,513,843 for Washington State
2) Chi squared test P<0.001.

The US census data generally reflect increases in the minority populations compared with the non-Latino white population for Washington State from 1990 and earlier (9). The average carboxyhemoglobin level was 19.0 $\pm$ 10.3% (range 0.3% to 57.6%). Loss of consciousness occurred in 50% of patients, 7.6% of patients were intubated during HBO_2 therapy, and overall, six patients died.

Table 3 summarizes the intent and source of CO poisoning. The vast majority was unintentional in nature (94%) and evenly split between boys and girls. The most common sources were motor vehicles (34%), followed by charcoal briquettes (24%), then fire (11%). All motor vehicle poisoning cases occurred after the U.S. introduction of catalytic converters in automobiles in 1975. The leading source of CO for girls was charcoal briquettes (28%); in contrast boys were most often poisoned by motor vehicle exhaust (41%).

Table 3. Reason and source of CO poisoning cases among children.

	All cases		Females		Males	
	Number	Percent[2]	Number	Percent[3]	Number	Percent[3]
Reason						
Unintentional	236	94.4	118	50.0	118	50.0
Intentional	14	5.6	4	28.6	10	71.4
Source						
Motor vehicle	84	33.6	31	36.9	53	63.1
Charcoal briquettes	60	24.0	34	56.7	26	43.3
Fire	28	11.2	11	39.3	17	60.7
Generator	11	4.4	7	63.6	4	36.4
Furnace	23	9.2	17	73.9	6	26.1
Boat	18	7.2	9	50.0	9	50.0
Other	26	10.4	13	50.0	13	50.0

1) Other source includes: natural gas leak, indoor swimming pool heater, propane heater, kerosene heater, propane lantern, wood stove, or gas powered compressor
2) Percent indicates percent of total cases
3) Percent indicates percent for each reason or source

Source of CO also differed by age (Table 4). The most common source for 0-2 year olds was charcoal briquettes (40%). While charcoal briquettes remained an important source of CO, motor vehicles predominated for the remaining age categories.

Table 4. Source of CO poisoning cases by age category among children.

	Motor Vehicle	Charcoal	Fire	Generator	Furnace	Boat	Other	Total
0-2 years	9	17	2	2	5	3	4	42
3-5 years	17	7	11	0	5	8	6	54
6-10 years	25	21	7	0	6	4	6	69
11-13 years	14	6	3	3	3	3	4	36
14-17 years	19	9	5	6	4	0	6	49
Total	84	60	28	11	23	18	26	250

Table 5 summarizes the source of CO by race/ethnicity. In contrast to non-Latino white children who were most often poisoned by motor vehicles (32.8%), non-Latino black (55.0%) and Latino children (70.6%) had significantly higher proportions of CO poisonings by charcoal briquettes (P<0.001). The multinomial logistic regression model did not reveal confounding by age or gender when considering CO source as predicted by race/ethnicity (data not shown).

Table 5. Number of all CO cases by sources of CO and race/ethnicity (% of cases of each race/ethnicity category are given in parentheses).

Race/ethnicity	Motor Vehicle	Charcoal	Other	Total
Non-Latino white	42 (32.8%)	7 (5.5%)	79 (61.7%)	128 (100%)
Non-Latino black	3 (15.0%)	11 (55.0%)	6 (30.0%)	20 (100%)
Latino	13 (25.5%)	36 (70.6%)	2 (3.9%)	51 (100%)
Asian	2 (13.3%)	5 (33.3%)	8 (53.3%)	15 (100%)
Other/ Unknown	24 (66.7%)	1 (2.8%)	11 (30.6%)	36 (100%)
Total	84 (33.6%)	60 (24.0%)	106 (42.4%)	250 (100%)

1. Fisher's Exact Test P<0.001.
2. Sources other than motor vehicle and charcoal were generally infrequent and were therefore collapsed into the "Other" category.

Figure 1 summarizes the leading source of CO by month. The greatest numbers of CO poisoning cases were treated during the winter months of November (15%), December (12%), and January (14%). In general, motor vehicle exhaust predominated in every month, except for October and November when charcoal briquettes were the leading source of CO exposure.

Figure 2 gives the trends in CO poisoning by 2-year epoch. Cases increased in frequency in 1985-1986 from five to over 20 cases per 2 years. The number of cases peaked in 1995-96 with over 40 cases and has declined since then. This trend for Washington State is similar to the peak in calls to US poison control centers regarding cases of carbon monoxide exposure in 1995-1996 (10).

The source of unintentional CO exposure differed among racial/ethnic groups (Table 6). The leading source of CO was motor vehicles for Non-Latino whites, charcoal briquettes for Non-Latino blacks and Latinos, and furnaces for Asians.

Table 6. Leading sources of unintentional CO poisoning by race/ethnicity.

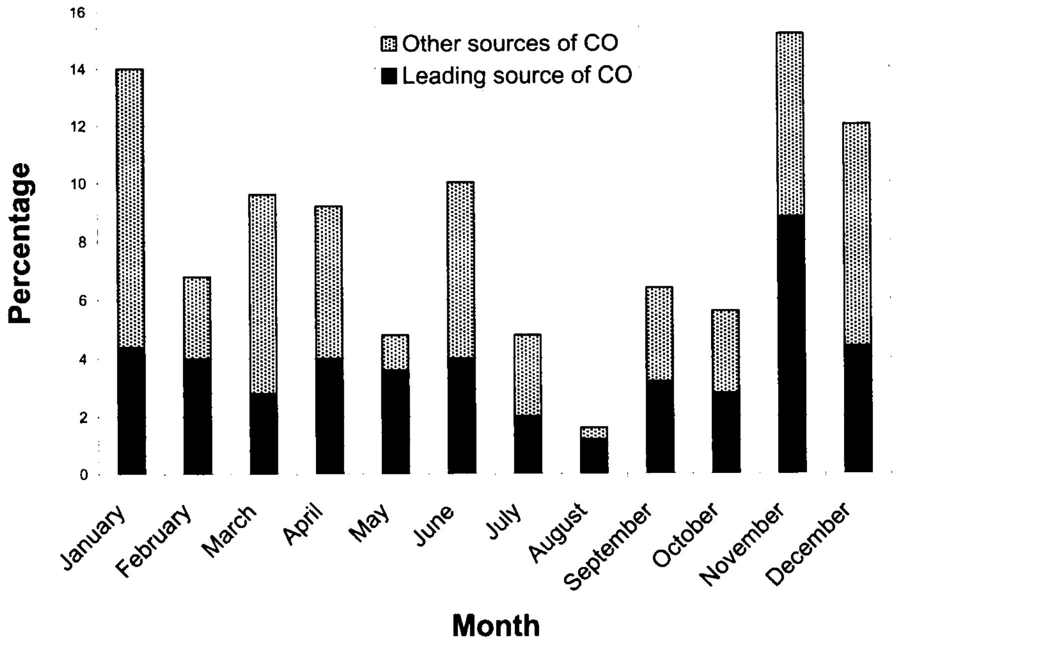
	Number	Percent	Source
Non-Latino white	42	32%	Motor vehicle
Non-Latino black	11	55%	Charcoal briquettes
Latino	36	71%	Charcoal briquettes
Asian	6	40%	Furnace
Other/ unknown	24	67%	Motor vehicle

Of the 14 intentional poisoning cases, the CO sources were motor vehicle exhaust (11), charcoal briquettes (2) and propane heater (1). All intentional CO poisoning occurred in adolescents aged 15-17 years and the majority were male (10 of 14 cases, 71%) (Table 3) and non-Latino white (12 of 14 cases, 86%) (Table 7). With regard to season, 6 of the 14 (43%)

Table 7. Leading sources of intentional CO poisoning by race/ethnicity

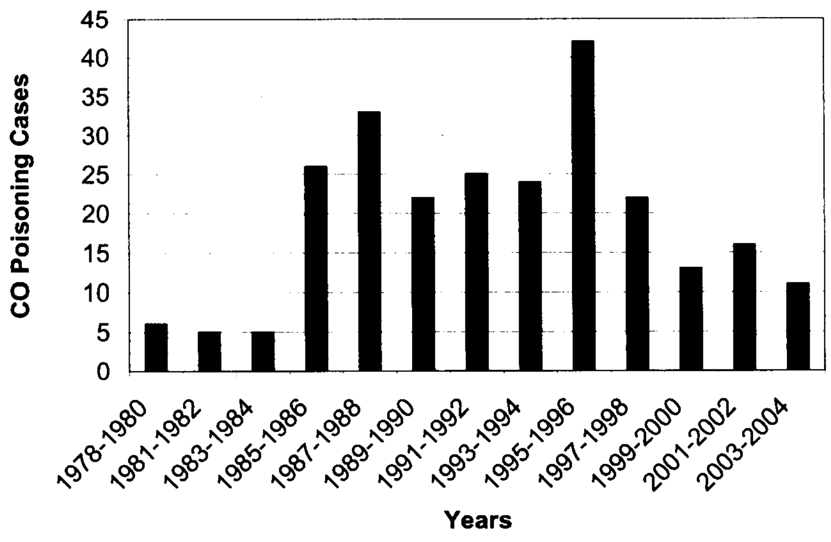
	Number	Percent	Source
Non-Latino white	12	83%	Motor vehicle
Non-Latino black	0	0	Not applicable
Latino	0	0	Not applicable
Asian	1	100%	Charcoal briquettes
Other/unknown	1	100%	Motor vehicle

Fig. 1. Percentage of CO poisoning cases by month.



1) The leading source of CO was by motor vehicle for January, March-July, September, and December.
2) The leading source of CO was by charcoal briquettes for October and November.
3) The leading source of CO was equally split by motor vehicles and furnaces in February.
4) The leading source of CO was equally split among motor vehicles, fires, boats, and other in August.

Fig. 2. Number of CO poisoning cases by epoch.



1) The first epoch is 26 months. The final epoch is 23 months long.

intentional CO poisoning cases occurred during December and January.

DISCUSSION

We report on an approximate 26-year experience of treating severe pediatric carbon monoxide poisoning at a single institution in Seattle, Washington that serves as the primary HBO_2 treatment center in Washington state and as a primary referral center for Idaho and Montana. During one 10-year period studied (1987-1997), 88% of the individuals in Washington state who received HBO_2 for CO poisoning were treated at VMCHM.[3] Over 95% of the cases treated at VMCHM are referred from within Washington state and a majority of those (79%) from within Western Washington.[3]

Unintentional CO poisoning predominated in the present experience, accounting for 94% of cases. Similar to national data, CO poisoning followed a seasonal pattern with 41% of cases occurring in November through January (2,11). This finding was not surprising since this 4-state region has a 4-season climate with the winter heating season starting in October, leading to greater exposure to faulty furnaces, charcoal briquettes improperly used as indoor heating/ cooking sources, and automobile exhaust from vehicles "warming up".

Consistent with previous reports, motor vehicles were the most common source of CO poisoning, although the proportion in our series was smaller (1,6). The leading source of CO exposure differed by race/ethnicity. Overall, minority children were disproportionately affected by severe CO poisoning from any source. Consistent with Washington state data on unintentional, severe CO poisoning in adults and children combined, our data indicate that Latinos and non-Latino blacks had significantly higher proportions of poisonings by charcoal briquettes in contrast to non-Latino whites in which motor vehicles accounted for the highest proportion (3). These data may reflect the increased use of charcoal briquettes for cooking or heating among recent immigrants or a limitation of the charcoal briquette warning labels for a multicultural population in which some persons may not understand the English-language warning labels. We also report gender differences by source of CO such that females predominated in charcoal briquette poisonings, also similar to previous Washington state data.[3] Notably, the youngest children (0-2 years old) were most often poisoned by charcoal briquettes, likely because they spend more time at home or indoors, as compared to motor vehicles for the older children and adolescents who likely spend more time in motor vehicles than the youngest children.

Finally, we found that most intentional CO poisoning cases occurred in adolescent males by motor vehicle. In contrast to national data on adults and children in which intentional deaths occurred uniformly throughout the year with slight increases in the spring (11), our intentional cases followed a seasonal pattern predominating in the winter months of December and January.

This study has several limitations including: 1) Reporting on a single institution's experience which limits general applicability—especially to regions of the country that lack a 4-season climate. 2) The need for cases to be referred to this institution for hyperbaric oxygen treatment, which likely has led to an underestimation of the total number of poisoning cases. For instance, CO poisoning leads to non-specific symptomatology resulting in under-diagnosis of poisoning (12). 3) Lack of more complete socioeconomic or demographic data—particularly with regard to income level which may influence use of charcoal briquettes for cooking or heating. 4) COHb levels (range

0.3% to 57.6%) were obtained at widely varying times in each of the subject's initial management due to the multiple referral sites that include a four-state area. Although nine of the subjects had a COHb level ≤ 3%, these levels typically reflected a longer than average interval for obtaining a blood sample rather than the cases being of mild severity. Indeed, 8 of these 9 subjects had loss of consciousness, and two of these nine subjects died. Despite these limitations, this report helps to fill important gaps in the pediatric CO poisoning literature with regard to race/ethnicity, seasonality, and intentional CO poisoning.

As with most CO poisoning, the majority of the 250 severe pediatric cases were likely preventable. These cases represent only a fraction of the total CO poisonings in this region and do not account for mild to moderate cases of CO poisoning or patients in whom CO poisoning is misdiagnosed. In a previous report, Cobb and Etzel proposed that the decline in unintentional CO-related deaths from 1979 to 1988 is at least partially attributable to prevention efforts by state and local health departments (11). Accordingly, health care providers and public health practitioners should provide adequate education in order to prevent CO poisoning. We have shown that severe pediatric CO poisoning demonstrates a seasonal pattern with key sources of exposure varying by gender, age, and race/ethnicity. These unique characteristics should be taken into account in order to design culturally competent prevention programs that efficiently target the populations at greatest risk for CO poisoning. Some examples of prevention programs include: 1) increasing CO detector use in residential and commercial garages, 2) CO detection shutoff switches or warning indicators for automobiles, 3) multilingual or visual-based warning labels on charcoal briquettes, 4) awareness campaigns for CO poisoning during and prior to the peak heating season, and 5) targeted awareness campaigns for Latinos and non-Latino blacks around charcoal briquette use.

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