Carbon Monoxide poisoning: A new incidence for an old disease.

N. B. HAMPSON[1], L.K. WEAVER[2]

Submitted - 2-15-07; accepted - 3-22-07

[1]*Center for Hyperbaric Medicine, Section of Pulmonary and Critical Care Medicine Virginia Mason Medical Center, Seattle, Washington;* [2]*Pulmonary and Critical Care Division, Department of Internal Medicine, LDS Hospital Center, Salt Lake City, Utah*

Hampson NB, Weaver LK. Carbon Monoxide Poisoning: A new incidence for an old disease. Undersea Hyperb Med 2007; 34(3):163-168. Purpose: While carbon monoxide (CO) poisoning is common in the USA, its incidence is uncertain. Fatal poisonings are counted with relative accuracy from death certificate data, but estimates of the more common nonfatal poisonings are either old or limited. This study was performed to estimate the number of emergency department (ED) visits annually in the USA for carbon monoxide poisoning. Basic Procedures: ED visit rates in five states (Idaho, Maine, Montana, Utah, and Washington) from three prior studies, each using different methodology, were used to extrapolate independent estimates of national ED visits. Main Findings: After correcting for regional differences in CO poisoning incidence, estimates of national ED visits per year ranging from 32,413 to 56,037 were obtained. Excluding the estimate derived from the Maine rate because it did not include intentional and fire-related poisonings, the national average is 50,558 $\pm$ 4,843 visits per year. Conclusions: There are approximately 50,000 ED visits for CO poisoning in the USA annually, 3-5 times the numbers previously estimated. As this disease can result in significant long-term morbidity even when treated, enhanced prevention efforts are warranted.

INTRODUCTION

As with any toxic insult, the manifestation of carbon monoxide (CO) poisoning can range from mild symptoms to death. The incidence of fatal cases can be determined with relative accuracy by coding on death certificates. In a 2002 study by the Centers for Disease Control and Prevention (1), it was reported that there were an average of 1,100 accidental and 2,400 intentional CO deaths in the United States (USA) from 1968 to 1998.

The number of nonfatal episodes of CO poisoning is more difficult to discern. For decades, it has commonly been written "10,000 people seek medical attention or lose one or more days of normal activity annually because of carbon monoxide intoxication" (2). This statement relates to a 1967 publication from the US Department of Health, Education, and Welfare (3). The figure originated from data collected by the Injury Control Program of the Public Health Service in the late 1960s and is now almost forty years old.

The vast majority of cases of CO poisoning are nonfatal. Because nonfatal CO poisoning may result in significant sequelae even when appropriately treated (4), prevention is extremely important. Without a valid estimate of the disease burden in this country, however, resources for education and prevention programs may be under allocated and preventable morbidity occurring.

Estimates of the rate of emergency department (ED) visits have been reported for five states, using three different methods (5-7). This study will attempt to use each to extrapolate a national figure for CO-related ED visits, compare the results, and then estimate a contemporary number for the incidence of nonfatal CO poisoning in the USA.

METHODS

Crude rates of ED visits for all types of CO poisoning in Washington, Idaho and Montana for calendar year 1994 were previously calculated from a postal survey of emergency departments in the three states (5). Compiled responses from 100% of the 178 EDs in the region regarding number of ED visits were then converted to rates per population using 1994 US Census Bureau state population estimates. Rates of 13.6, 22.4, and 40.4 visits per 100,000 resident population were reported for the three states, respectively, and are the rates used in this study.

Annual crude rates for the hospital ED visits for CO poisoning in Maine were calculated using ED billing records (6). Hospital billing records in Maine are housed by the Maine Health Data Organization and include record-level information for every patient visit to all non-federal acute care facilities. These data include records of patients seen in the ED and then discharged as outpatients, as well as those subsequently admitted as inpatients. The datasets include diagnostic information coded using the International Classification of Diseases, Version 9 - Clinical Modification (ICD-9 CM) (8). Codes selected for inclusion in the CO visit rate calculation included only acute, accidental, non-fire related cases for Maine residents. From 2000-2003, an average annual rate of 8.6 per 100,000 people was found and is the figure used in this study.

The crude rate of ED visits for CO poisoning in Utah in calendar year 1996 was previously calculated with information obtained from a statewide database of ED discharge diagnoses (7). Diagnosis information is coded in that database according to the ICD-9. The database was searched for discharge diagnoses of ICD-9 code 986 ("toxic effect of carbon monoxide") and the results converted to rate per population using US Census Bureau 1996 population estimates for Utah. Visits for all types of CO poisoning were included. The reported rate of 16.0 visits per 100,000 is the rate used in this study. These data did not include people who died pre-hospital or were directly admitted to the hospital without going through an ED.

Each of the five state visit rates were used to calculate an independent contemporary estimate of national ED visits for CO poisoning. US Census Bureau population estimates for 2005 were used (9). First, each state rate was applied to the 2005 population figure for that state to obtain a current estimate of in-state visits. Next, each state rate was applied to the remainder of the US population (excluding that state) to obtain an estimate of out-of-state visits. Adding these figures yielded five national estimates for CO-related ED visits, assuming that each state's visit rate was the same throughout the country.

Recognizing that the incidence of CO poisoning varies widely throughout the country and the likelihood that none of the five state rates represented the exact national average rate, each of the five estimates were then corrected for regional differences in CO poisoning death rate. To do this, it was assumed that ED visit rates would be approximately proportional to the death rate from CO poisoning in the same state. This presumes that the ratio of nonfatal to fatal poisonings is similar state-to-state. Number of deaths per state from unintentional, non-fire-related CO poisoning from years 1999 to 2002 were obtained from a current CDC estimate and converted into crude death rates by dividing by the state population (10). Because numbers of deaths per state are relatively small and the rate may change significantly from year to year, the combined rates for four years were used. Each estimate for ED visits outside of the state whose visit rate was being used for the calculation was corrected based upon the relationship of that state's death rate to the death rate in the rest of the country, excluding that state. That number was then added to the in-state visit estimate to yield a regionally corrected national visit estimate.

To illustrate, Idaho's ED visit rate was 22.4 per 100,000. Applying that rate directly to 2005 population figures yields 320 in-state and 66,076 out-of-state visits, totaling 66,396 nationally. Idaho's CO mortality rate from 1999 to 2002 was 2.10 per million and that of the rest of the country was 1.68 per million. Multiplying the out-of-state figure by 1.68/2.10 to correct for Idaho's increased incidence of CO poisoning reduces it to 52,861 and the national estimate to 53,181 visits.

Validity of the assumption that the ratio of ED visit rates to death rates from CO poisoning should be similar from state-to-state was tested by performing linear regression analysis of the data from the four states for which all types of CO visits were included in the ED rate (Idaho, Montana, Utah, Washington).

RESULTS

Using previously published state rates for ED visits for CO poisoning, direct extrapolation to the 2005 US population yielded national estimates of ED visits per year ranging from 25,492 to 119,486, with an average estimate of 59,822 (Table 1). When corrected for regional differences in CO poisoning incidence, the national estimates ranged from 32,413 to 56,037 ED visits for CO poisoning annually, averaging 46,929 visits. Excluding the estimate derived from the Maine rate because it did not include intentional and fire-related poisonings, the national average is 50,558 $\pm$ 4,843 visits per year.

By state, the ratio of CO ED visit rate to CO death rate was Idaho 97.4, Montana 90.9, Utah 100.0, and Washington 85.0 (Figure 1, see page 166; $R^2 = 0.9910$, $p = 0.0045$).

DISCUSSION

This study estimates that there are approximately 50,000 ED visits in the USA annually for diagnosed CO poisoning, significantly more than the commonly cited 1974 figure of 10,000 total nonfatal cases, which was intended to include both those who sought medical attention and those who did not (3). The number is also significantly higher

	ED Visits per 100,000 Population	Estimated 2005 In-state ED Visits	Estimated 2005 National ED Visits, Uncorrected	Estimated 2005 National ED Visits, Corrected
Idaho (ref 5)	22.4 (1994)	320	66,396	53,181
Maine (ref 6)	8.6* (2000-03)	114*	25,492*	32,413*
Montana (ref 5)	40.4 (1994)	378	119,486	47,064
Utah (ref 7)	16.0 (1996)	395	47,426	56,037
Washington (ref 5)	13.6 (1994)	855	40,312	45,949

* Includes only accidental, non-fire related CO ED visits.

Table 1. Number of emergency department visits annually for diagnosed CO poisoning, estimated from state rates, and then corrected for regional differences in CO poisoning incidence.

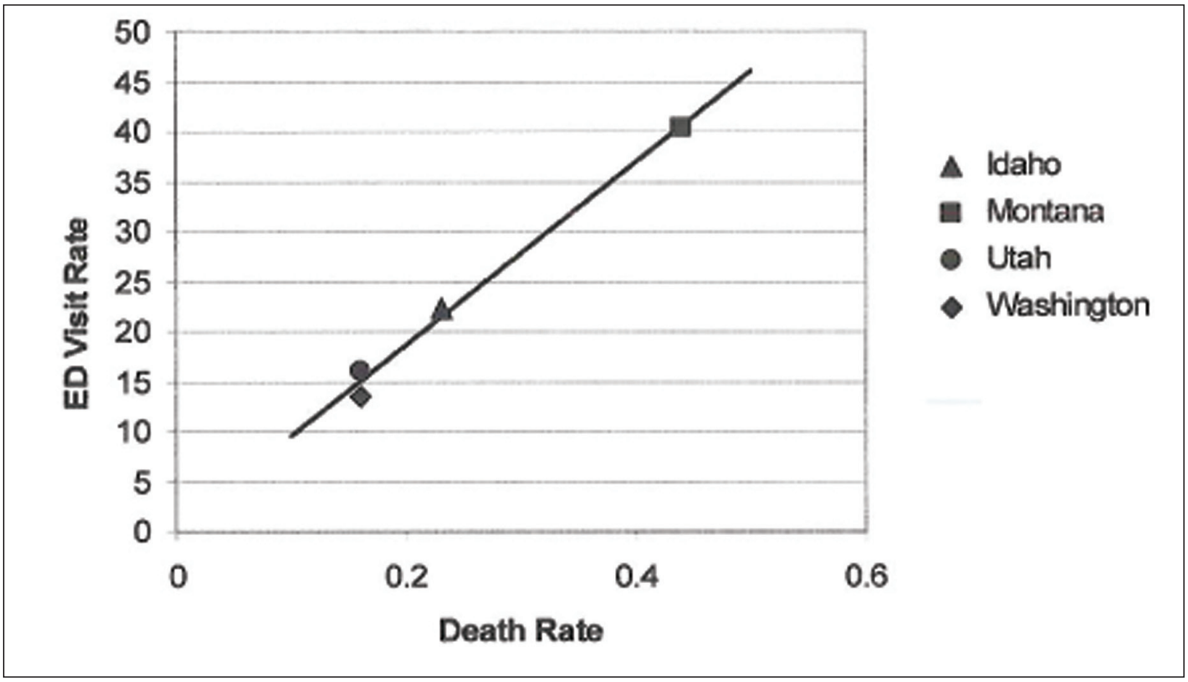

Fig 1. Correlation of state CO ED visit rates (per 100,000 population) with CO death rate (per 100,000 population).

than a 2005 estimate of 15,200 annual ED visits for CO poisoning (11).

It is not surprising that the number of poisoned patients would be greater than 10,000 cases annually, since that estimate was derived from data in the late 1960's. The US population at that time was approximately 200 million and has now increased to 300 million. Population growth, however, would explain only a 50% increase in the number of cases. In addition, automobiles have become safer since that time, with the addition of catalytic converters and reduced CO emissions. While the methodology from which the 10,000 estimate was made was not published, one must suspect that it was of limited quality. In the "Carbon Monoxide Program Action Kit" developed by the Public Health Service in 1969, the estimate of 10,000 cases per year is noted to be "based on the scant evidence available" and representative of "only a portion of the true number" (2).

The 2005 estimate of 15,200 visits was made from data collected by the National Electronic Injury Surveillance System All Injury Program (NEISS-AIP) (11). NEISS-AIP is operated by the US Consumer Product Safety Commission and collects data regarding ED visits for all types and causes of injuries (12). The estimate specifically excluded cases of intentional CO poisoning and also those resulting from fire, both significant proportions of the total population of CO poisoning victims. Furthermore, NEISS-AIP data were drawn from a group of approximately 100 hospitals selected as representative of US population demographics, not necessarily weighted for regional differences in CO poisoning incidence. Failure to account for regional differences has the potential to result in significant error, as state death rates from CO poisoning differ by over 10-fold (0.56 per million in California vs. 6.88 per million in Wyoming; 10).

Despite the fact that these new estimates of national annual ED visits for CO poisoning were calculated from rates derived from three different methods, the results are remarkably similar. In an earlier paper, the visit rates from Idaho, Montana and Washington were used to estimate 43,000 ED visits for CO poisoning in the US annually (5). Adoption of that estimate has been limited due to the fact that it was based on data from only three states, collected by one method. The current estimate of 50,000 ED visits annually is probably more reliable because it is consistent, despite being derived from different methodologies. It is also not surprising that the estimate derived from the Maine ED visit rate was lowest, since it excluded intentional and fire-related poisonings. The rates used for the other four states included visits for all types of CO poisoning. Excluding Maine, the estimates differ by a maximum of only about 20%.

While this new estimate of national ED visits for CO poisoning is 3-5 times greater than previous ones, it may still be an underestimate. Because symptoms of CO poisoning can be so nonspecific (e.g. headache, nausea, vomiting, dizziness), the condition is notorious for being underdiagnosed (13-16). The current estimate of US ED visits for CO poisoning was made using rates of diagnosed CO poisoning in five different states. Based upon studies examining under- or misdiagnosis of CO poisoning, it is reasonable to assume that many more cases go undiagnosed and the true number of ED visits due to CO poisoning is greater than estimated here.

Because the severity or details of poisoning of the patients included in this report are unknown, there is uncertainty about long-term outcomes. However, a prospective study showed that 33% of the patients not treated with hyperbaric oxygen had cognitive sequelae one year after poisoning and 18% had sequelae if treated with hyperbaric oxygen (4). Most patients are not treated with hyperbaric oxygen, so approximately one-fourth to one-third of poisoned patients may exhibit permanent brain-related sequelae after poisoning. In addition, 43% of poisoned patients exhibit affective problems one year following poisoning (17). It also appears that cardiac injury at the time of poisoning increases the risk for cardiovascular-related death in the following 10 years (18). These poisoning-related sequelae may be caused by inflammation, possibly independent of brain hypoxia (19), and may not require loss of consciousness for injury (17, 20). Therefore, we estimate that many thousands of poisoned patients per year in the USA are developing cognitive and affective sequelae from this preventable disorder.

An important potential limitation of this study is related to the assumption that the ratios of nonfatal to fatal cases of CO poisoning are similar from state to state. If exposures are less severe in some states than others or treatment more effective in some areas, the method used for national extrapolation of ED visit numbers would be compromised. However, such differences have never been reported. Treatment of CO poisoning has been proven to reduce long-term morbidity from the disease but has not been shown to affect mortality. Further, the states for which data are available are remarkably similar in this regard (Figure 1). Finally, the concept of correlating ED visit rates with death rates for a disease has been used previously for asthma and chronic obstructive pulmonary disease, in association with changes in air pollution levels (21).

A second potential limitation is that different age groups are represented in the death rate data and the ED visit data. Deaths from CO poisoning are more common in the elderly. This analysis presumes that the proportion of CO exposures among different age groups is similar state-to-state. Finally, it should be noted that the state ED visit rate data utilized were collected at different points in time. If nonfatal CO poisoning had changed over that period, the analysis could be affected. However, available data suggest that the incidence of nonfatal poisonings has been stable from 1992-2002 (22).

Almost all cases of accidental CO poisoning are preventable with appropriate public education, prevention programs and regulations on CO-emitting devices. It is hoped that this significantly larger estimate of 50,000 ED visits for CO poisoning annually in the USA will prompt an increase in emphasis and resource allocation to this effort.

REFERENCES

1. Mott JA, Wolfe MI, Alverson CJ, Macdonald SC, Bailey CR, Ball LB, Moorman JE, Somers JH, Mannino DM, Redd SC. National vehicle emissions policies and practices and declining US carbon monoxide-related mortality. *JAMA* 2002; 288(8):988-995.
2. Hampson NB. Incidence of carbon monoxide poisoning in the United States. *Undersea Hyperb Med* 1999; 26(1):47-48.
3. Schaplowsky AF, Oglesbay FB, Morrison JH, Gallagher RE, Berman W. Carbon monoxide contamination of the living environment: A national survey of home air and children's blood. *J Environ Health* 1974; 36(6):569-573.
4. Weaver LK, Hopkins RO, Chan KJ, Churchill S, Elliott CG, Clemmer TP, Orme JF Jr, Thomas FO, Morris AH. Hyperbaric oxygen for acute carbon monoxide poisoning. *N Engl J Med* 2002; 347(14):1057-1067.
5. Hampson NB. Emergency department visits for carbon monoxide poisoning in the Pacific Northwest. *J Emerg Med* 1998; 16(5):695-698.
6. Graber JM, Smith AE. Results of a state-based surveillance system for carbon monoxide poisoning. *Public Health Rep* 2007; 122(2):145-154.
7. Weaver LK, Mobasher H, Hopkins RO, Churchill S. Emergency department visits for CO poisoning in Utah in 1996. *Undersea Hyperb Med* 1999: 26(Suppl):51.
8. U.S. Department of Health and Human Services. International Classification of Diseases 9th Revision, Clinical Manifestation (ICD-9-CM). Hyattsville, MD: National Center for Health Statistics, 2004.
9. U.S. Census Bureau. Population Estimates by Race, Hispanic Origin and Age for States and Counties. http://www.census.gov/Press-Release/www/releases/archives/population/007263.html (accessed December 8, 2006).
10. King M, Bailey C.. Unintentional, non-fire, carbon monoxide-related death rates-United States, 1999-2002. Unpublished data. Air Pollution and Respiratory Health Branch, Centers for Disease Control and Prevention , 2007.
11. Centers for Disease Control and Prevention. Unintentional non-fire-related carbon monoxide exposures--United States, 2001-2003. *Morb Mortal Wkly Rep* 2005; 54(2):36-9.
12. Centers for Disease Control and Prevention. National Estimates of Nonfatal Injuries Treated in Hospital Emergency Departments --- United States, 2000. *Morb Mortal Wkly Rep* 2001; 50(17):340-346.
13. Grace TW, Platt, FW. Subacute carbon monoxide poisoning: Another great imitator. *JAMA* 1981; 246(15):1698-1700.
14. Barret L, Danel V, Faure J. Carbon monoxide poisoning, A diagnosis frequently overlooked. *Clin Toxicol* 1985; 23(4-6):309-313.
15. Dolan MC, Haltom TL, Barrows GH, Short CS, Ferriell KM. Carboxyhemoglobin levels in patients with flu-like symptoms. *Ann Emerg Med* 1987; 16(7):87-91.
16. Turnbull TL, Hart RG, Strange GR, Cooper MA, Lindblad R, Watkins JM, Ferraro CM. Emergency department screening for unsuspected carbon monoxide exposure. *Ann Emerg Med* 1988; 17(5):478-483.
17. Jasper BW, Hopkins RO, Duker HV, Weaver LK. Affective outcome following carbon monoxide poisoning: a prospective longitudinal study. *Cogn Behav Neurol* 2005; 18(2):127-34.
18. Henry CR, Satran D, Lindgren B, Adkinson C, Nicholson CI, Henry TD. Myocardial injury and long-term mortality following moderate to severe carbon monoxide poisoning. *JAMA* 2006; 295(4):398-402.
19. Thom SR, Bhopale VM, Han ST, Clark JM, Hardy KR. Intravascular neutrophil activation due to carbon monoxide poisoning. *Am J Respir Crit Care Med* 2006; 174(11):1239-1248.
20. Weaver LK, Chan KJ, Hopkins RO, Churchill S. Risk factors in acute carbon monoxide poisoning. *Undersea and Hyper Med* 2004; 31(3):358-9.
21. Tobias GA, Sunyer DJ, Castellsague PJ, Saez ZM, Anto Boque JM. Impact of air pollution on the mortality and emergencies of chronic obstructive pulmonary disease and asthma in Barcelona. *Gaceta Sanitaria* 1998; 12(5):223-30.
22. Hampson NB. Trends in the incidence of carbon monoxide poisoning in the US. *Am J Emerg Med* 2005; 23(7):838-841.