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Carbon monoxide poisoning deaths in the United States, 1999 to 2012☆,☆☆

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Abstract

Background—Unintentional, non-fire related (UNFR) carbon monoxide (CO) poisoning deaths are preventable. Surveillance of the populations most at-risk for unintentional, non-fire related (UNFR) carbon monoxide (CO) poisoning is crucial for targeting prevention efforts.

Objective—This study provides estimates on UNFR CO poisoning mortality in the United States and characterizes the at-risk populations.

Methods—We used 1999 to 2012 data to calculate death rates. We used underlying and multiple conditions variables from death records to identify UNFR CO poisoning cases.

Results—For this study, we identified 6136 CO poisoning fatalities during 1999 to 2012 resulting in an average of 438 deaths annually. The annual average age-adjusted death rate was 1.48 deaths per million. Fifty four percent of the deaths occurred in a home. Age-adjusted death rates were highest for males (2.21 deaths per million) and non-Hispanic blacks (1.74 deaths per million). The age-specific death rate was highest for those aged ≥85 years (6.00 deaths per million). The annual rate of UNFR CO poisoning deaths did not change substantially during the study period, but we observed a decrease in the rate of suicide and unintentional fire related cases.

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☆☆Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention.

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Conclusion—CO poisoning was the second most common non-medicinal poisonings death. Developing and enhancing current public health interventions could reduce ongoing exposures to CO from common sources, such as those in the residential setting.

1. Introduction

Carbon monoxide (CO) is a toxic, colorless, odorless gas that is a product of combustion [1] Common symptoms of CO exposure include headache, dizziness, fatigue, nausea, vomiting, and chest pain. CO is particularly dangerous because it is imperceptible with a non-specific symptomatic presentation; victims can become sick or die before realizing they are exposed. However, CO poisoning related deaths are preventable.

CO poisoning causes approximately 50,000 people to visit the emergency department per year [2]. Of these, unintentional, non-fire related (UNFR) CO poisonings cause an estimated 21,000 people to visit an emergency department each year and result in hospitalization for more than 2300 [3]. Many CO poisoning cases occur in the home [4]. The most common sources of CO poisonings in homes are the use of gasoline-powered engines, such as electric generators, and malfunctioning heating and cooking appliances [1].

Several factors have affected CO poisoning death rates. Engineering innovations that decrease the amount of CO released from a source have been successful in reducing deaths from CO-poisoning. From 1968–1999, CO poisoning deaths declined due to advances such as the installation of catalytic converters in motor vehicles and the enforcement of standards set by the 1970 Clean Air Act [6,7]. Conversely, previous studies have shown that circumstances that lead to greater use of CO-emitting sources, such as winter storms, increase the number of CO poisoning deaths. Loss of electric power and increased cold weather during winter storms or disasters promotes an increased use of gasoline-powered generators in unventilated areas and indoor use of alternative heating sources, such as charcoal grills, consequently increasing the number of deaths [4,8–12].

Studies have postulated that interventions such as the installation of CO alarms can also reduce the number of deaths, possibly by half [13]. However, although many states have laws requiring CO alarms in new construction homes, older houses may not have a unit installed. Past studies have noted only 30% of households use CO alarms [14]. Even when homes have CO alarms, residents must remember to change batteries in the units regularly for them to work properly.

Although both unintentional and suicide related CO poisonings are preventable, public health intervention strategies differ. Interventions to prevent suicide-related poisonings focus on the sources of suicidal thoughts, while interventions to prevent unintentional poisonings focus on the source of the CO. For example, in unintentional fire-related CO poisoning, the fire is the source of the CO and therefore, fire prevention education and the use of flame retardant material are the focus. Unlike fire-related CO poisonings, UNFR CO poisoning victims do not sense the presence of a poisonous gas unless a CO alarm alerts them. Outreach and education for UNFR CO poisoning can range from increasing the use of CO alarms to educating consumers on the proper use of and care for related equipment and early sign and symptoms of CO poisoning. This analysis focuses on UNFR CO poisoning.

The objective of this study is to more comprehensively characterize the burden of CO poisoning-related mortality in the U.S and to characterize the populations most at-risk. Understanding the factors associated to UNFR CO poisoning death is a necessary component in the burden of both fatal and non-fatal CO poisoning cases and therefore a critical part for successful public health planning and prevention efforts.

2. Methods

To identify fatalities from CO poisoning, we used mortality data for multiple causes of death in the United States from the National Center for Health Statistic's National Vital Statistics System for the years 1999 through 2012. The dataset for this period is a compilation of all death certificate data without any personal identifiers. Fatalities were limited to those who resided and died in the 50 states and the District of Columbia.

We calculated the frequency of death due to non-medicinal poisonings listed on the death record and defined by *International Classification of Diseases, Tenth Revision* (*ICD-10*) codes T51–T65, "Toxic effects of substances chiefly non-medicinal as to source."

Table 1 presents the definitions for the CO poisoning deaths. T58, toxic effect of CO, can only be a contributory cause of death and not an underlying cause. Therefore, we used code X47 (accidental poisoning by exposure to gases and vapors) to denote poisoning as either an underlying or contributory cause [15]. The manner of death, along with the *ICD-10* code, distinguishes unintentional deaths ("accidental") from suicides ("suicides" or "self-harm"). We calculated annual crude rates for suicides, UNFR, and unintentional fire and vehicular-related CO poisoning deaths.

We adjusted death rates (DRs) for age using the direct standardization-method and the US standard age population for year 2000 [16]. Denominator data for calculated rates came from the US Census population with bridged-race census counts or intercensal or postcensal estimates of the US resident population for July 1, 1999–July 1, 2012. For years 2000 and 2010, we used the census population count, and for all other years (1999, 2001–2009, 2011–2012) we used the intercensal or postcensal estimates [17]. We calculated all annual rates in units of deaths per one million persons (deaths per million); we did not present rates based on 10 or fewer deaths.

We stratified age-adjusted UNFR CO poisoning DRs by sex, race/ethnicity, educational attainment, marital status, urban/rural county of death classification, state, region, and year of death. For educational attainment analysis, we limited the population to persons 18 years and older and for marital status analysis, we limited the population to persons 15 years and older. Those categorized as "Widowed," "Never married, single," and "Divorced"were considered not married. In addition, we calculated age stratified rates and analyzed the average number of deaths per day by season, month, and day of the week. Finally, we computed frequencies for place of death and place of CO exposure.

We calculated 95 percent confidence intervals (95% CI) using the gamma method [18] and conducted analyses using SAS software (version 9.3; SAS Institute, Inc., Cary, NC). To determine if there was a statistical difference in the average number of deaths per day of the week, we used Poisson regressions using an alpha of 0.05.

3. Results

Among US residents in the 50 states and the District of Columbia, 34,215 CO poisoning deaths (*ICD-10* code: T58) occurred from 1999 to 2012. CO poisoning is the second most frequent poisoning listed on death certificates (Table 2).

The annual average age-adjusted UNFR CO poisoning DR for the study period (1999–2012) was 1.46 deaths per million (Table 3). Age-adjusted DRs were the highest for males (2.28 deaths per million) and non-Hispanic blacks (1.74 deaths per million). By age group, DRs were highest for those aged 85 years or greater (6.00 deaths per million) and lowest for those aged 5 to 14 years (0.25 deaths per million). Among decedents 18 years and older, 66% had a high school education or less. Finally, in 65% of the cases, UNFR CO decedents were not married (Table 3).

Forty-nine states had a sufficient number of deaths to permit calculation of age-adjusted death rates by state (Fig. 1). The Western region had the highest DR (2.05 deaths per million [95% CI: 1.96, 2.15]) and the Northeast had the lowest DR (0.91 deaths per million [95% CI: 0.85, 0.98]). The three states with the highest age-adjusted UNFR CO poisoning DR were Wyoming (5.14 deaths per million [95% CI: 3.62, 7.08]),Montana (3.66 deaths permillion [95% CI: 2.70, 4.84]), and Alaska (3.77 deaths per million [95% CI: 2.66, 5.18]) (Fig. 1). Among States with more than 10 deaths, the lowest age-adjusted DRs per million persons were Massachusetts (0.49 deaths per million [95% CI: 0.36, 0.65]), New Jersey (0.82 deaths per million [95% CI: 0.67, 0.99]) and California (0.68 deaths permillion [95% CI: 0.60, 0.75]). Further geographic analysis revealed that age-adjusted rates of UNFR CO deaths were higher in rural counties (2.28 deaths per million [95% CI: 2.18, 2.38]) than in urban counties (1.24 deaths per million [95%CI: 1.20, 1.27]) (Table 4).

Over half of the fatalities (54%, n = 3341) occurred in the decedent’s home (Table 4), rather than in a medical center (18%, n = 1104. (Table 4) In 3744 (61%) of the deaths, the place of CO exposure was the home. In 549 (8%) of CO fatalities, exposure occurred in trade and service areas; 118 (1%) occurred in streets and highways, and 58 (1%) occurred in industrial and construction areas. Three percent (n = 193) of deaths were reported to be related to occupation.

Fig. 2 shows the number of CO poisoning cases by year and manner of death. CO poisoning from suicides and unintentional fire cases decreased during 1999 to 2012, while UNFR CO poisoning cases remained consistent over this period. The annual age-adjusted DR ranged from 1.21 deaths per million in 2010 to 1.68 deaths per million in 2005. The average daily number of deaths was 1.68 deaths for the entire period. The average daily number of deaths by month ranged from 0.99 deaths per day in July to 2.74 deaths per day in January. Analysis by day of the week showed that the daily average number of deaths was lower on weekdays (1.59 deaths per day) than on weekends (1.90 deaths per day) ($P < .0001$) (Table 4). Specifically, the average daily number of CO deaths was highest on Sundays (2.00 deaths) and lowest on Thursdays (1.53 deaths) ($P < 0.0001$).

4. Discussion

From 1999 to 2012, CO poisoning was the second most common cause of death among non-medicinal poisonings (Table 2). The annual rate of UNFR CO poisoning deaths did not change substantially during this time, but we observed a decrease in the rate of suicide and unintentional fire related cases. The demographic groups with the highest age-adjusted DRs were among those who were 85 years or older, males, and non-Hispanic blacks.

In this study, we did not observe similar declines in UNFR CO poisoning fatalities as reported in previous studies [6,7]. In 1968, the crude death rate for all unintentional CO poisonings was 7.06 deaths per million and the majority of deaths were due to motor vehicle exhaust [6]. In 1998, the rate dropped to 1.81 deaths per million [6]; from 1968 to 1998, deaths due to motor vehicle exhaust experienced the greatest decline. In our study, the average age-adjusted UNFR CO death rate plateaued at 1.52 deaths per million over the 12 years.

Suicides and unintentional fire-related CO poisoning deaths continue to decline, and vehicle-related CO deaths have the lowest rate of all categories. The decline in suicides by CO poisoning is consistent with other studies [30]. Successes in fire safety may have caused the decline in unintentional fire-related deaths [29]. The rapid declines that were once seen with engineering changes in motor vehicles, including the use of the catalytic convertor and resulting increased fuel efficiency and compliance with standards in the Clean Air Act, reached a plateau [7].

Since 1999, the average annual rates of UNFR CO mortality did not change. Poisonings as a group remains a leading cause of residential deaths in the US [33]. As demonstrated in this study, most (64%) UNFR CO poisonings deaths occurred in the home. Residential settings contain many common CO sources, including poorly maintained or unventilated heating and cooking appliances, or motor vehicles running in an enclosed space. CO alarms in homes are, therefore, an important secondary prevention strategy. However, according to national estimates during the study period, only 29% to 33% of American households reported having a working CO alarm [19,20].

Our characterization of the at-risk population for UNFR CO poisoning fatalities is largely consistent with previous studies [8]. Studies have found that both male and elderly population subgroups have the highest rates of UNFR CO related hospitalization [5]. Males also typically represent a larger proportion of those who are severely poisoned. Males may experience a higher dose of CO poisoning exposure due to the frequency of use of CO emitting equipment. For example, males may have higher DRs due to the increased likelihood of using fuel-burning equipment [8]. In contrast, females are more likely to receive medical treatment for less severe poisonings, such as those that result in a visit to an emergency department [5].

Elderly population subgroups may be associated with other factors such as comorbid conditions and misdiagnoses which leads to repeated exposure. These factors may explain their higher death rate. For example, CO poisoning may exacerbate preexisting cardiopulmonary disease, even at low levels [31]. CO poisoning may be misdiagnosed, as symptoms are nonspecific, which could result in the return of those exposed to a hazardous location [33]. Seeking medical care and rapid diagnosis and treatment increase the chance of a successful outcome [21,22] and may be why death is less frequent once CO poisoning victims are in the hospital [6].

Geographically, the US West and Midwest had the highest age-adjusted DRs, a finding that is consistent with other studies [5,6,23]. These regional distributions may be a reflection of the increase of UNFR CO deaths during winter. Although the Northeastern US has severe winters, it has the lowest geographical age-adjusted DR. Studies of CO morbidity have found higher regional rates of non-fatal UNFR CO poisoning in the Northeast [5,23] suggesting that residents leave the CO poisoned area and seek help. Another finding consistent with previous literature is that the incidence of CO poisoning for rural areas was higher than urban areas' UNFR CO poisoning DR [5,24].

Temporally, our study found that the highest average daily number of CO related deaths occurred during the winter months, similar to observations in previous studies [5,24,25]. Increases in such high-risk behaviors as "warming up" motor vehicles, improperly maintaining home heating systems, using cooking equipment for heating, and using generators during winter storms leads to a greater rate of CO poisoning during winter months [25]. In addition, CO related deaths due to disaster situations, such as hurricanes, may be attributable to factors such as extended power outages that can lead to increased use of generators and alternative heating and cooking methods [4,26,27].

Higher UNFR CO poisoning DRs on the weekend may be caused by prolonged exposure to CO, as compared to weekday exposure. During the weekends, people may be likely to engage in more leisure time behaviors that could increase exposure to CO, such as using motorized equipment for home improvement or engine repair. More weekend hours may be spent at home than during the weekdays when many are at work. In addition, individuals may be more likely to consume alcohol on the weekend. In fact, previous studies have found that up to 42% of those with unintentional, fatal CO poisoning were under the influence of alcohol [13], which impaired their ability to recognize symptoms and seek treatment.

While some of our demographic and temporal trends in mortality have been consistent with previous studies, we also examined previously unpublished findings on populations potentially at-risk for UNFR CO mortality. We found that 69% of the fatalities had a high school education or less, suggesting that public health outreach needs to focus on this educational level. Furthermore, we found that 65% of those with fatal UNFR CO exposures were not married. One possibility is that no one was present to assist in recognizing the hazard and intervening or seeking help among the non-married individuals with fatal CO exposures.

Overall, maintaining a high index of suspicion is important to help recognize and identify CO cases that go to the emergency department, especially among those most at-risk, and during the winter season and around disaster events. The emergency department not only can play an important role in the early recognition of CO poisoning cases, but can also serve as an opportunity for intervention. For example, if an patient arrives at the emergency department with altered mental status, checking the patient's carboxyhemoglobin level in addition to other factors may provide additional insight on their condition. There may also be an opportunity to educate a patient on the potential source of the CO and steps that need to be taken to ensure that it is safe to return to the area, as well as the importance of CO alarms. [28,29,32]

This study is subject to a few limitations. While the main purpose of this paper is to more comprehensively characterize the burden of CO poisoning-related mortality in the US, some cases are missed. For example, among cases that die in the emergency room or hospital setting, if the CO poisoning is not recognized before death, the case can be misdiagnosed and missed, leading to an underestimation of the DR. In addition, because we based the case definition largely on *ICD-10* coding, some intentional and fire related cases may be included in the UNFR analysis through reporting and coding errors or vice versa. However, this misclassification may be minimal.

One strength of this study is that poisoning deaths are likely to be reviewed by a medical examiner and an autopsy is conducted, thus increasing confidence that the event was related to CO [7]. Because of current vital statistics practices, the number of missing cases should be minimal. Additionally, the case definition in this study requires both *ICD-10* codes T58 and X47, thereby increasing the likelihood that the cases captured in the analysis were truly UNFR CO cases.

5. Conclusions

The findings of this analysis do not demonstrate a decreasing trend in UNFR CO poisoning deaths since 1999. Opportunities to reduce these deaths can include public health programs focused on populations with the highest rates of UNFR CO mortality and emphasizing the importance of properly installing CO alarms; these approaches have shown to be an effective use of prevention resources and reduce the severity of CO exposure and prevent UNFR CO deaths [13,24]. Furthermore, as the majority of American households do not have a working CO alarm [19], this is an area where public health interventions can have significant impact.

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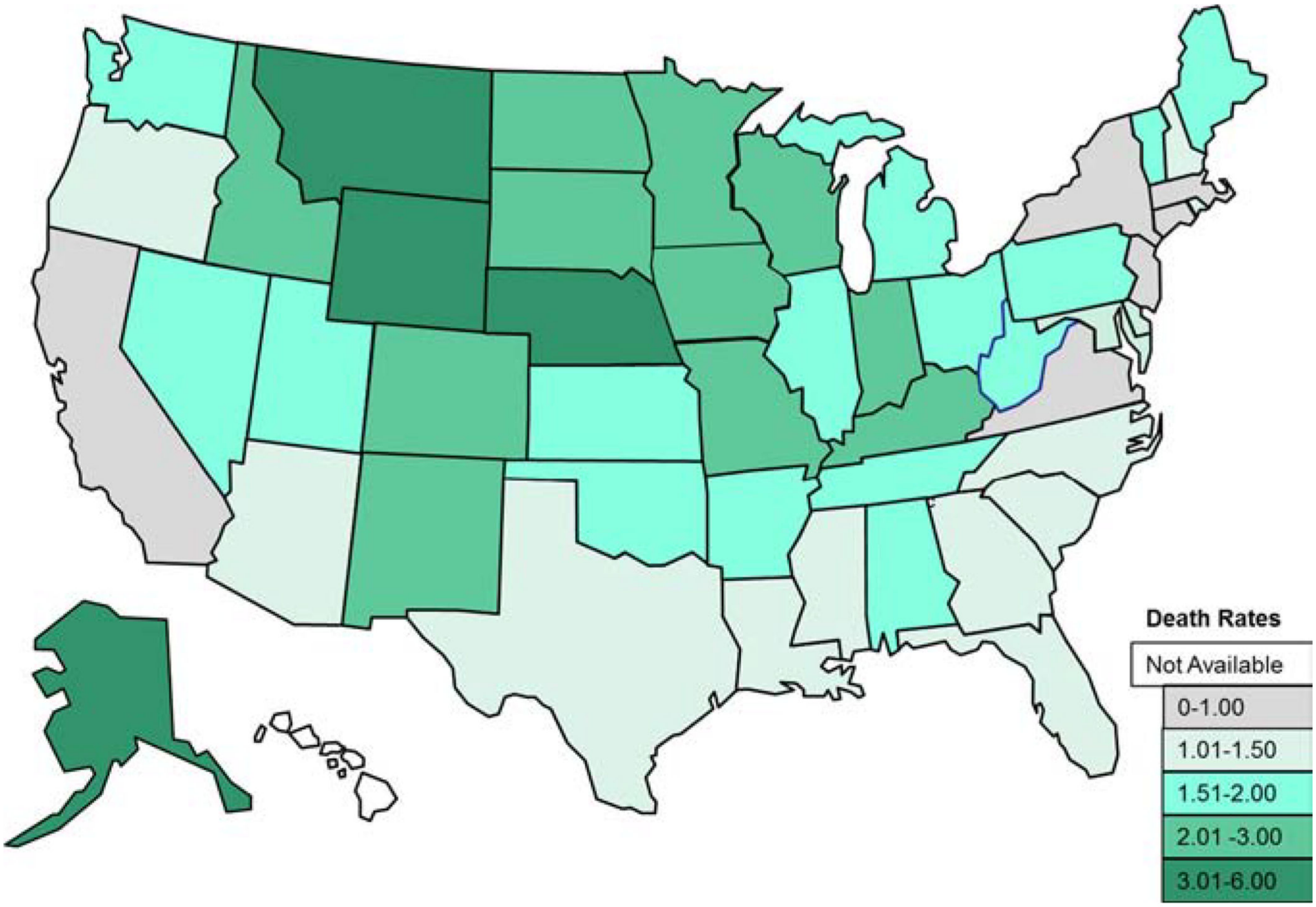

*Rates based on ≤10 deaths in the numerator not presented(Hawaii and District of Columbia).
Per million

Fig. 1.

Age-adjusted UNFR CO Poisoning by state, 1999–2012, United States*. *Rates based on ≤10 deaths in the numerator not presented (Hawaii and District of Columbia). Per million.

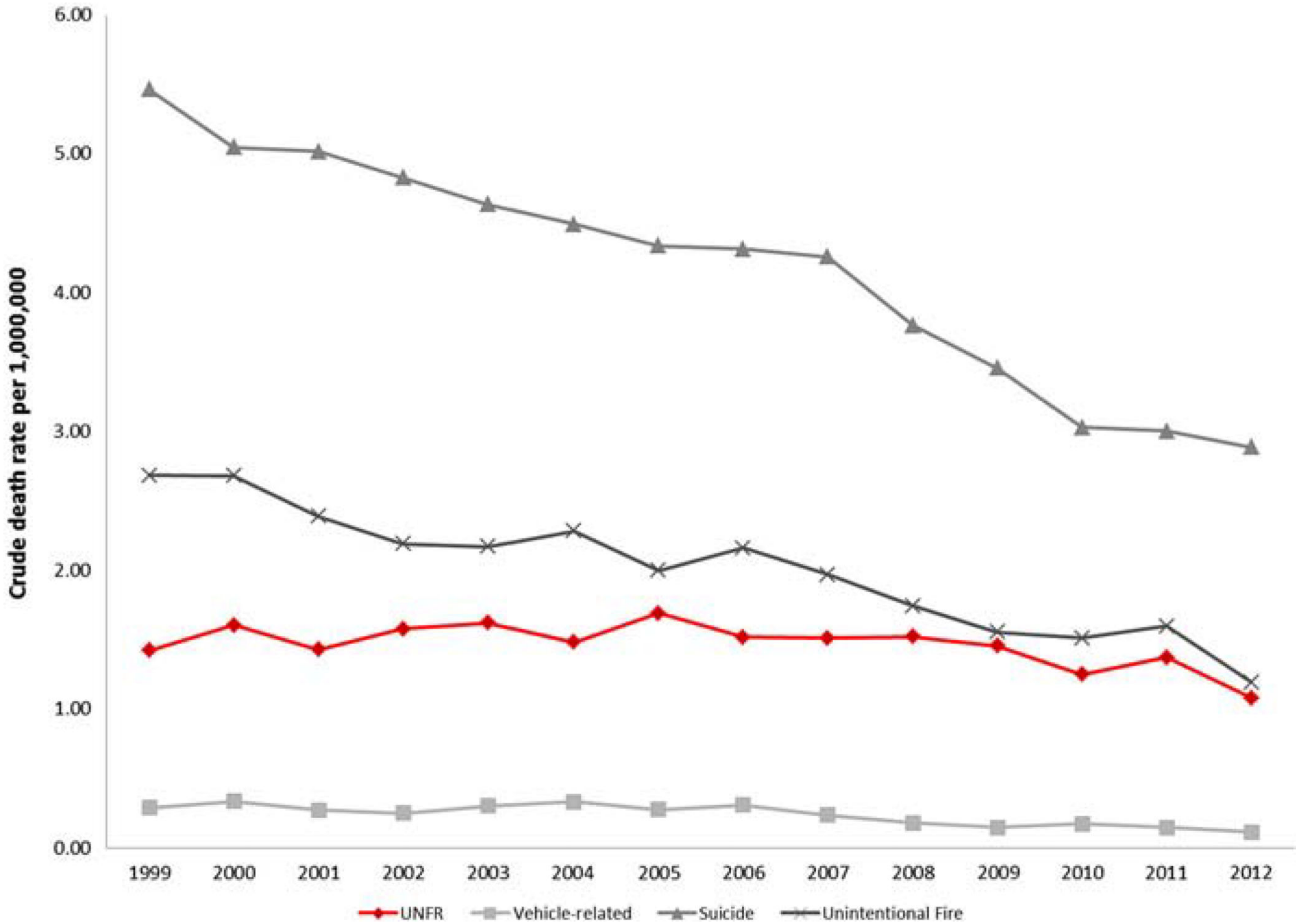

Fig. 2.

Crude rate of CO poisonings by intent, fire-, and vehicular-relatedness. Trend from 1999 to 2012, United States.

Table 1

Definitions for UNFR, unintentional fire and vehicular and suicide carbon monoxide related death. Each death definition combines a Manner of Death code and an *ICD-10* code

	ICD-10 **codes (either underlying or contributory cause)**
UNFR	T58 & X47 Exclude: X00-X09, X76, X97, Y26, and Y17
Unintentional vehicular	T58& at least one from V01 to V99
Unintentional fire	T58 & at least one from X00-X09
Suicide	T58 & least one from X60 to X84

Table 2

Frequency of poisonings (Toxic effects of substances chiefly non-medicinal as to source) on the death certificates, 1999 to 2010

Poisons	Number of deaths	CO poisoning
Toxic effects of alcohol (*ICD-10* code: T51)	77,082	704 (0.9%)
Toxic effects of CO poisoning (*ICD-10* code: T58)	34,215	
Smoke inhalation excluding tobacco smoke (*ICD-10* code: T598)	34,037	5897 (17%)

Table 3

Characteristics of persons with fatal, unintentional, non-fire related carbon monoxide poisoning, United States, 1999 to 2012. N = 6136

Variable	n (%)	Average annual crude rate*	Average annual age-adjusted rate*	95% Confidence Interval
Total (N)	6136 (100)	1.48	1.46	1.42–1.49
Age group (years)				
<5	97 (1)	0.35	-	-
5–14	141 (2)	0.25	-	-
15–24	567 (9)	0.96	-	-
25–34	715 (11)	1.27	-	-
35–44	1038 (16)	1.72	-	-
45–54	1157 (18)	1.96	-	-
55–64	836 (13)	1.92	-	-
65–74	557 (9)	2.00	-	-
75–84	618 (10)	3.42	-	-
≥85	410 (6)	6.00	-	-
Sex				
Male	4518 (73)	2.21	2.28	2.21–2.34
Female	1618 (26)	0.77	0.72	0.69–0.76
Race/ethnicity				
White, non-Hispanic	4427 (72)	1.59	1.46	1.42–1.50
Black, non-Hispanic	828 (13)	1.58	1.74	1.62–1.85
Other, non-Hispanic	203 (3)	0.88	0.90	0.78–1.03
Hispanic	656 (10)	1.07	1.17	1.08–1.26
Unknown	22 (<1)	-	-	-
Educational attainment** (n = 5792)				
Less than high school graduate	1273 (22)			
High school graduate	2534 (44)			
Some college	1025 (18)			
College or more	682 (12)			
Unknown	278 (5)			
Marital status**** (n = 5898)				
Married	2023 (34)			
Not Married	3807 (65)			
Unknown	68 (1)			

*Rates per 1 million persons.

**Educational attainment only for those persons ≥18 years.

****Marital status only for those ≥15 years.

Table 4

Exposure circumstances for cases of fatal, unintentional, non-fire related CO poisoning, United States, 1999 to 2012. N = 6136

Variable	n (%)	Age adjusted ten year average annual rate*	95% Confidence Interval	Daily average number of deaths
County				
Urban	4355 (71)	1.24	1.20–1.27	-
Rural	1781 (29)	2.28	2.18–2.38	-
Region				
Northeast	733	0.91	0.85–0.98	-
Midwest	1581	1.68	1.59–1.76	-
South	1486	0.97	0.92–1.02	-
West	1932	2.05	1.95–2.25	-
Place of death				
Decedent’s home	3341 (54)	-	-	-
Medical center	1104 (18)	-	-	-
Other/unknown	1691 (28)	-	-	-
Place of CO exposure				
Home	3744 (61)	-	-	-
Other specified places	697 (11)	-	-	-
Trade and service area	549 (8)	-	-	-
Street and highway	118(1)	-	-	-
Industrial and construction area	58 (1)	-	-	-
Farm	39 (0)	-	-	-
Other/unknown	931 (0)	-	-	-
Death at work**, n = 5898				
Yes	193 (3)	-	-	-
No	4885 (83)	-	-	-
Unknown	820 (14)	-	-	-
Season***		-		
Winter	2383 (39)	-	-	2.64
Spring	1324 (22)		-	1.44
Summer	952 (16)	-	-	1.03
Autumn	1477 (24)	-	-	1.62
Day of the week****		-		
Weekday	4149 (68)	-	-	1.59
Weekend	1984 (32)	-	-	1.90

***** $P < .0001$

* Average adjusted rate per 1 million persons.

** Occupational relation only for those ≥15 years.

*** Winter is defined as December, January, February; Autumn is defined as September, October, November; Spring is defined as March, April, May; Summer is defined as June, July, August.