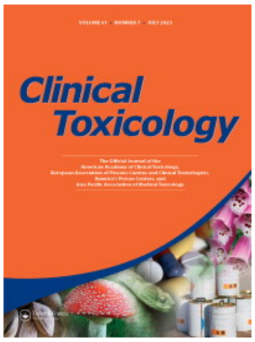

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CLINICAL RESEARCH

Carbon monoxide poisoning mortality in the United States from 2015–2021

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ABSTRACT

Introduction: Most carbon monoxide poisoning is preventable. Tracking of longitudinal trends in carbon monoxide-related mortality is needed to guide public health efforts. This study sought to describe mortality in the United States from carbon monoxide poisoning, examine the epidemiology of unintentional ("accidental") and intentional exposures, and identify trends in both.

Methods: The Centers for Disease Control and Prevention's Wonder databases were utilized to extract online data from National Center for Health Statistics files containing mortality data in the United States from 2015-2021. Extracted were deaths, crude death rates, intent of exposure, and demographics of persons dying from carbon monoxide poisoning, excluding cases related to fires. Also extracted was the number of suicidal deaths of all types. Carbon monoxide deaths related to consumer products were obtained from the Consumer Product Safety Commission. Information on state legislation mandating residential carbon monoxide alarms was obtained from online resources.

Results: Total carbon monoxide deaths decreased from 1,253 in 2015 to 1,067 in 2021. An increase in accidental poisoning deaths was offset by a larger decrease in intentional deaths, despite an increase in suicides of all types in the country. For the first time in the United States, accidental carbon monoxide deaths (543) outnumbered intentional deaths (524) in 2021. The increase in accidental deaths is consistent with those recently reported from carbon monoxide-emitting consumer products by the Consumer Product Safety Commission. Furthermore, even though over one-half of accidental deaths occurred at home, no evidence of a protective effect of state laws requiring residential carbon monoxide alarms was seen.

Conclusions: Accidental carbon monoxide poisoning deaths increased from 2015-2021 for the first time in four decades. Exploration of the possibility they are due to consumer products warrants attention and prevention efforts. We were unable to demonstrate the preventive effect of residential carbon monoxide alarm legislation.

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Introduction

Carbon monoxide poisoning is responsible for hundreds of deaths and thousands of emergency department visits in the United States annually [1–4]. Unintentional exposures account for most nonfatal poisonings [5], with the greatest number of deaths resulting from intentional exposures [6]. Unintentional carbon monoxide poisoning is estimated to result in societal costs of over $1 billion annually [7]. When this topic was reviewed with a comparison of unintentional and intentional carbon monoxide poisoning mortality data from 1999–2014 [3], the death rates of both types of poisoning were declining and intentional poisoning deaths outnumbered unintentional by a factor of approximately two to one.

It is important to continue to track the epidemiology of a preventable condition like carbon monoxide poisoning for several reasons. First, knowing disease incidence over time allows the effectiveness of ongoing prevention programs to be assessed. Second, it allows one to evaluate the impact of the introduction of a new prevention intervention. Third, one can identify the characteristics of the group being poisoned and modify targeted education appropriately. In a 2007 issue of *Morbidity and Mortality Weekly Report,* [6] the editorial comment regarding a study examining carbon monoxide poisoning deaths from 1999–2004 read, "As additional years of data become available, tracking of longitudinal trends in carbon monoxide related mortality should continue to guide public health measures aimed at preventing deaths from carbon monoxide poisoning." [6]

This report will describe unintentional and intentional US carbon monoxide poisoning mortality from 2015–2021, extending previously published data summarizing the years from 1999–2014 [3]. Direct extension of trends will be possible because data have been extracted in a similar fashion from similar databases. In addition, an attempt will be made to explain any trends in various subsets of carbon monoxide poisoning recognized, including by intent of poisoning and geographic locale. Further, the impact of legislation requiring residential carbon monoxide alarms in most states will be examined. It is hoped that these analyses will identify productive areas for further research to assist in the planning,

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financing, development, and implementation of ongoing and future prevention efforts.

Methods

Annual data from the fifty US states and the District of Columbia for the years 2015–2021 including the number of carbon monoxide poisoning deaths, crude death rates with 95% confidence intervals, exposure intent, and victim demographics (location by state, place of death, age group, gender, race, ethnicity) were obtained from the National Center for Health Statistics (NCHS) multiple causes of death files. Online files were queried using US Centers for Disease Control and Prevention Wonder (CDC) databases [8], an open-access search program offered by the CDC for dissemination of public health data.

The files "Multiple Cause of Death 1999–2020 and 2018–2021" were utilized for this report [9]. They contain mortality data drawn from all death certificates filed in the US. States provide coded data from death certificates to the National Center for Health Statistics or coding is done by the National Center for Health Statistics from copies of state death certificates. Coding is performed using a standardized method [10]. Underlying and multiple causes of death are indexed by the tenth version of the International Classification of Diseases (ICD-10) codes, 113 selected causes of death, injury causes, and drug/alcohol-induced causes of death. Each death certificate record contains a single underlying cause of death, up to 20 additional multiple causes, and demographic data [8].

The CDC Wonder database calculates crude death rates using population estimates from the US Census Bureau [8]. To obtain the crude death rate for any year or group of years, the user selects the cause of death of interest and the time period. The CDC Wonder database then divides the number of deaths from that cause by the number of the specified population in the US during those years. The system suppresses sub-national data representing fewer than 10 persons for confidentiality reasons. Rates are labelled "unreliable" when the death count in a category is fewer than 20. Death rates were expressed per 100,000 people provided by CDC Wonder.

Carbon monoxide poisoning deaths were identified using the Underlying Cause of Death terms "Accidental" or "Suicide" for the field Injury Intent, plus "Poisoning" for Mechanism, and then ICD-10 code T58 (Toxic effect of carbon monoxide) plus code X47 (Accidental poisoning by and exposure to carbon monoxide and other gases and vapors, excluding carbon monoxide from smoke and fumes due to fire) or codes T58 and X67 (Intentional self-poisoning by and exposure to carbon monoxide other gases and vapors, excluding carbon monoxide from smoke, fire and flames and excluding metal fumes and vapours) for Multiple Cause of Death. Codes related to fires were not included in this analysis. A small number of homicidal poisonings and deaths of undetermined intent were also excluded from the analysis.

Cases of suicide of all types were identified from the CDC Wonder database using the Underlying Cause of Death terms Injury Intent = "Suicide" and Underlying Cause of Death Injury Mechanism = "All Causes of Death." This yielded the total number of suicide deaths and crude death rates irrespective of the method of suicide. Data on the number of deaths due to carbon monoxide poisoning from consumer products was obtained from the Consumer Product Safety Commission [11]. Non-consumer product sources of carbon monoxide include fires, automobiles, and work-related exposures.

State requirements for residential carbon monoxide alarms were obtained from several online resources [12–14]. Almost every US state has a different law, with each identifying some combination of (1) type of residence covered by the law (e.g. one and two-family homes, townhouses, townhomes of three stories or less, apartments, dormitories, adult family homes), (2) conditions under which a residence is included (e.g., new construction, existing construction, at the time of transfer of ownership, when a permit is issued for a specified type of repair or remodel), and (3) particular features of the homes requiring alarms (presence of a fireplace, fossil fuel-burning appliance, or attached garage). There are only nine states requiring a carbon monoxide alarm in all dwellings (California, Illinois, Massachusetts, Minnesota, New York, Rhode Island, Utah, Washington, Wisconsin). Details of a specific state's law can be seen in reference [12].

Data were analyzed using descriptive statistics [15], linear regression to evaluate trends [16], and a calculator of the difference of slope between two lines [17]. In. the latter, the user provides the sample size, slope, and standard error for each of the two lines and the program calculates the probability value, the *t*-value for the significance test, and degrees of freedom. A probability value of less than 0.05 indicates that the slopes are different from each other.

Results

From 2015 to 2021, there were a total of 8,168 carbon monoxide poisoning deaths in the US (3,189 accidental and 4,979 intentional), averaging 1,167 per year (Table 1). Over this time, combined annual carbon monoxide deaths decreased from 1,253 in 2015 to 1,067 in 2021. This decrease of approximately 200 annual deaths was entirely accounted for by a decline in intentional carbon monoxide deaths.

Annual unintentional carbon monoxide poisoning deaths increased from 393 in 2015 to 543 in 2021 (Table 1,

Table 1. Annual US deaths and crude death rate per 100,000 for accidental and intentional carbon monoxide poisoning, and carbon monoxide poisoning of all types from 2015–2021.

	All		Accidental		Intentional	
	Deaths	Crude death rate	Deaths	Crude death rate	Deaths	Crude death rate
2015	1,253	0.39	393	0.12	860	0.27
2016	1,246	0.39	389	0.12	857	0.26
2017	1,131	0.35	403	0.12	728	0.22
2018	1,174	0.36	441	0.14	733	0.22
2019	1,228	0.37	529	0.16	699	0.21
2020	1,069	0.33	491	0.15	578	0.18
2021	1,067	0.35	543	0.16	524	0.16
Total	8,168		3,189		4,979	

Figure 1). Accidental deaths were 75% male (Table 2). Age groups accounting for the greatest number of deaths were 45–54 and 55–64 years. Whites accounted for 79%. Hispanic or Latino origin was identified in 14% of the total. The elderly (age 85+ years) had the highest accidental death rate. Death rates for Asian/Pacific Islanders were lower than the other racial groups, with a crude death rate of approximately one-half that of blacks/African Americans, American Indians/Alaska natives, and whites. Consumer products accounted for 1,815 accidental carbon monoxide deaths from 2009–2019 [11]. Using that as a numerator and accidental death counts from this study as a denominator, consumer products resulted in 42% of unintentional carbon monoxide poisoning mortality during that period.

In the 2023 Consumer Product Safety Commission report, accidental non-fire related carbon monoxide deaths resulting from consumer products appear to have begun rising in 2013, increasing from 137 in 2012 to 250 in 2019. Figure 2 compares the number of accidental carbon monoxide deaths due to consumer products and non-consumer product poisoning in the US annually. As the number of total deaths has increased, so has the number of deaths from carbon

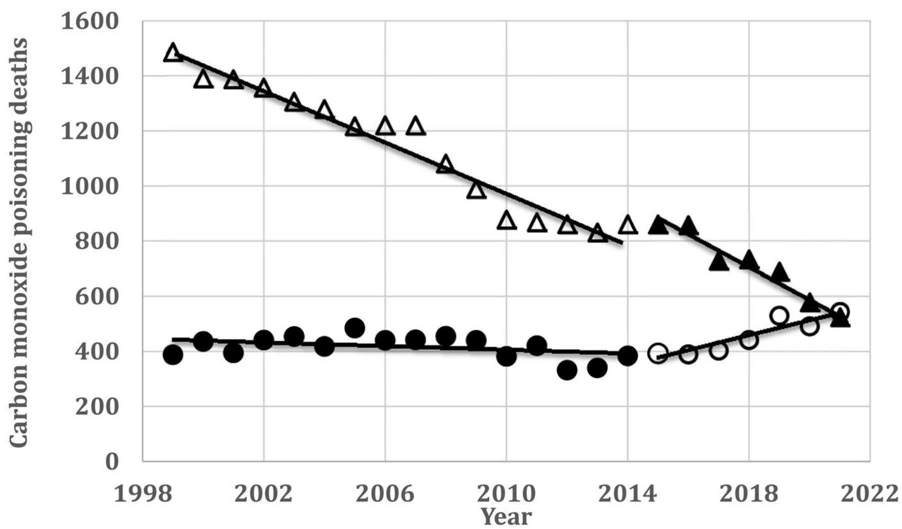

Figure 1. A number of US deaths from carbon monoxide poisoning. Intentional cases from 1999–2014 are represented by open triangles and accidental cases by filled circles. Intentional cases from 2015–2021 are represented by filled triangles and accidental by open circles. Cases from 1999 to 2014 are from reference 3 and cases from 2015–2021 are from the current study.

Table 2. Total US deaths and crude death rates per 100,000 from carbon monoxide poisoning for the period 2015–2021 by demographic group and divided into accidental and intentional poisoning.

		Accidental		Intentional	
		Number	Crude death rate	Number	Crude death rate
Gender					
	Female ($n = 1,159,907,050$)	803	0.07	1,105	0.10
	Male ($n = 1,127,143,286$)	2,386	0.21	3,874	0.34
Age	< 1 y ($n = 26,818,241$)	Suppressed		Suppressed	
	1-4 y ($n = 110,470,525$)	30	0.03	Suppressed	
	5-14 y ($n = 288,041,028$)	60	0.02	Suppressed	
	15-24 y ($n = 301,192,905$)	249	0.07	306	0.10
	25-34 y ($n = 317,360,053$)	393	0.08	581	0.18
	35-44 y ($n = 290,412,387$)	457	0.16	840	0.29
	45-54 y ($n = 291,910,962$)	554	0.19	1231	0.42
	55-64 y ($n = 294,264,535$)	556	0.19	1084	0.37
	65-74 y ($n = 214,055,562$)	372	0.17	462	0.22
	75-84 y ($n = 106,885,127$)	280	0.26	292	0.27
	85+ y ($n = 44,919,805$)	232	0.52	182	0.40
Race/ethnicity					
	American Indian/Alaska Native ($n = 28,321,031$)	46	0.16	19	Unreliable
	Asian/Pacific Islander ($n = 147,980,922$)	96	0.07	135	0.09
	Black/African American ($n = 321,158,365$)	512	0.16	168	0.05
	White ($n = 1,774,569,224$)	2,520	0.14	4,649	0.26
	Hispanic or Latino Origin				
	Yes ($n = 624,013,372$)	444	0.11	168	0.04
	No ($n = 1,600,389,120$)	2,737	0.15	4,793	0.27
Place of death					
	Decedent's home	1,677	51%	3,098	62%
	All other	1,619	49%	1,916	38%

Footnote: The "*n*" number following the title of each subgroup is the population at risk for death over the total seven-year period. The Centers for Disease Control and Prevention Wonder database suppresses subnational data representing fewer than 10 persons for reasons of confidentiality and labels rates as unreliable when the death count in a category is less than 20.

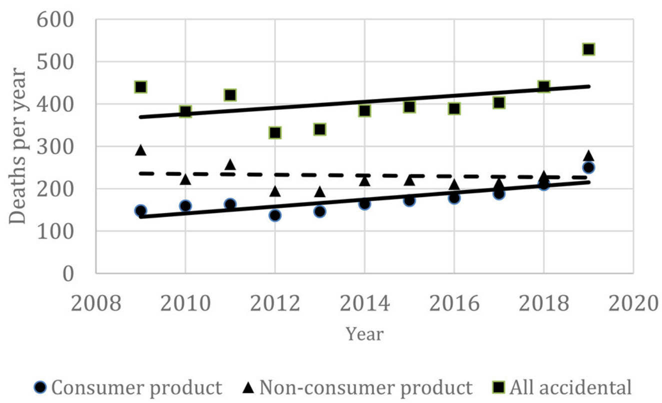

Figure 2. Deaths per year from consumer product carbon monoxide sources (circles with sol;id line) non-consumer product sources (triangles with dashed line) and all accidental carbon monoxide deaths in the US (squares with solid line). Linear regression lines are shown.

monoxide produced by consumer products. The slopes of the two linear trend lines, and therefore increase in number of deaths, are almost identical ($P = 0.9864$).

The location of death was the decedent's home in 51% of accidental poisonings. As of May 2023, 47 states and the District of Columbia had enacted regulations requiring carbon monoxide alarms in at least one major category of residence [12–14]. The implementation year of the initial requirement in each state is listed in Table 3. Three states, Hawaii, Kansas, and Missouri, have no statewide residential carbon monoxide alarm requirements. Accidental carbon monoxide poisoning crude death rates (± standard deviation) per 100,000 from 2015–2021 were not statistically different in states with laws requiring alarms in all domiciles vs. those that do not (0.18 ± 0.07 vs. 0.18 ± 0.18 respectively; two-tailed *t*-test $P = 0.8577$). Figure 3 compares the fraction of unintentional carbon monoxide poisoning deaths that occurred in the home with the fraction of states which have enacted laws requiring residential carbon monoxide alarms. No clear relationship is seen.

As they had in prior years, the number of intentional carbon monoxide deaths continued to decline (Figure 1). There were 860 suicidal carbon monoxide deaths in 2015, decreasing to 524 in 2021. Compared with the years immediately preceding this study [3], the crude death rate decreased by one-third among females and one-half among males (Table 2). In every ten-year age group from "25–34 years" through the age group "85+ years," the crude death rate decreased by 31–55%. The characteristics of intentional poisoning deaths (Table 2) included males outnumbering females by a factor greater than three-fold and the greatest number of deaths and the highest death rate among middle-aged individuals aged 45–64 years. Carbon monoxide suicides were uncommon among minority races and Hispanic groups, with over 90% occurring in non-Hispanic whites. Suicidal deaths of all types increased from 2015 to 2021, with deaths increasing from 44,193 to 48,183 annually. Table 3 lists the number of deaths, crude death rate, and rank order by state for accidental and intentional carbon monoxide poisoning over the years 2015–2021. It also shows the rank order of states for all types of suicide combined and the year residential carbon monoxide alarms were first required by each state.

Discussion

Unintentional carbon monoxide poisoning deaths

In 2021, US accidental carbon monoxide deaths exceeded the number of suicidal carbon monoxide deaths for the first time. This was due both to a continued decline in intentional poisonings and to a newly recognized increase in accidental carbon monoxide deaths. In 1991, Cobb and Etzel [18] published an analysis of US carbon monoxide-related deaths from 1979–1988. They focused on unintentional poisoning mortality and reported a steady decline, with deaths decreasing from 1,513 in 1979 to 878 in 1988. Death data coding at that time included carbon monoxide sources, with motor vehicles responsible for 57% of unintentional deaths. Mott and colleagues [19] examined the issue from 1968–1998 to study the effect of automobile emission regulations, finding 33,836 unintentional carbon monoxide-related deaths during those three decades and a steady decrease in unintentional carbon monoxide deaths with 1,417 deaths in 1968 dropping to 491 deaths in 1998.

In 2016, Hampson [3] reported on accidental and intentional carbon monoxide deaths from 1999–2014 using CDC Wonder database to examine the National Center for Health Statistics databases. He found that males predominated in accidental non-fire related deaths, non-Hispanic blacks were the ethnic/racial group with the highest death rate and those over 85 years had the highest death rate relative to age. Geographically, the states with the highest accidental carbon monoxide death rates were Wyoming, Alaska, and Montana. States with the lowest accidental death rates were Massachusetts, California, and New Jersey. Hampson [3] reported a slight overall decline in the accidental carbon monoxide death rate from 1999–2014.

In the present study examining 2015–2021, the demographics of those poisoned accidentally do not qualitatively change from previous reports of Sircar and Hampson [2,3]. The state rankings are similar to those reported for 1999–2014. The notable finding regarding unintentional carbon monoxide deaths is their increase in number for the first time in over four decades.

It is widely believed that unintentional carbon monoxide poisoning can largely be prevented with public education, consumer product warning labels, residential carbon monoxide alarms, and engineering advances minimizing carbon monoxide emissions [2,19]. That appeared to be the case while accidental carbon monoxide poisoning deaths were declining from 1968 to 2014. Now that they are increasing, it is important to determine the reason.

The Consumer Product Safety Commission is charged with protecting the public from unreasonable risk of injury or death associated with the use of thousands of types of consumer products. The Consumer Product Safety Commission tracks accidental carbon monoxide deaths related to consumer products and publishes an annual summary. Their 2023 summary [11] included the years 2009–2019, the latter of which was the year with the highest number of deaths from generators and the greatest number of deaths overall from products for which they are responsible. Figure 2 is

Table 3. State-specific data on accidental and intentional carbon monoxide deaths from 2015–2021, including number of deaths, crude death rates per 100,000, and ranking of crude death rates by state.

	Deaths	Accidental crude death rates	Rank	Carbon monoxide alarm mandate Year enacted	Deaths	Intentional crude death rates	Rank	All suicides Rank
Alabama	47	0.14	27	2012	56	0.16	37	24
Alaska	33	0.64	1	2005	Suppressed			3
Arizona	42	0.08	39	2013	115	0.23	32	14
Arkansas	40	0.19	16	2012	53	0.25	29	13
California	227	0.08	40	2013	358	0.13	43	47
Colorado	105	0.26	8	2009	163	0.41	7	5
Connecticut	36	0.14	26	2005	89	0.36	14	45
Delaware	Suppressed			2017	Suppressed			43
Dist of Columbia	Suppressed			2017	Suppressed			51
Florida	177	0.12	31	2008	350	0.24	31	27
Georgia	75	0.10	34	2009	105	0.14	41	36
Hawaii	Suppressed			None	Suppressed			39
Idaho	25	0.20	12	2011	47	0.38	9	6
Illinois	139	0.16	24	2007	233	0.26	25	44
Indiana	94	0.20	13	2017	134	0.29	22	28
Iowa	57	0.26	9	2010	97	0.44	4	29
Kansas	48	0.24	10	None	62	0.30	17	19
Kentucky	52	0.17	23	2011	81	0.26	27	21
Louisiana	44	0.13	28	2011	41	0.13	44	31
Maine	Suppressed			2009	38	0.40	8	15
Maryland	34	0.08	42	2008	75	0.18	35	26
Massachusetts	42	0.09	38	2006	124	0.26	28	48
Michigan	137	0.20	14	2010	200	0.29	21	34
Minnesota	108	0.28	7	2007	145	0.37	11	20
Mississippi	26	0.12	30	2013	24	0.12	46	35
Missouri	80	0.19	17	None	127	0.30	19	17
Montana	22	0.30	6	2009	48	0.64	1	2
Nebraska	51	0.04	3	2011	56	0.42	5	37
Nevada	25	0.12	32	2017	52	0.24	30	7
New Hampshire	Suppressed			2010	50	0.53	3	38
New Jersey	56	0.09	37	1996	102	0.16	38	50
New Mexico	47	0.32	5	2011	31	0.21	33	4
New York	129	0.09	36	2003	172	0.13	45	49
North Carolina	76	0.10	33	2010	126	0.17	36	40
North Dakota	24	0.45	2	2011	22	0.41	6	18
Ohio	170	0.21	11	2013	213	0.26	26	33
Oklahoma	53	0.19	15	2011	73	0.26	24	8
Oregon	38	0.13	29	2011	109	0.37	10	12
Pennsylvania	158	0.18	21	2010	247	0.28	23	32
Rhode Island	Suppressed			2002	25	0.34	15	46
South Carolina	52	0.15	25	2013	57	0.16	39	23
South Dakota	Suppressed			2012	22	0.36	12	9
Tennessee	87	0.18	18	2011	93	0.20	34	22
Texas	192	0.10	35	2022	208	0.10	47	42
Utah	26	0.18	22	2006	79	0.36	13	10
Vermont	Suppressed			2005	13	0.30	20	16
Virginia	48	0.08	41	2011	82	0.14	42	41
Washington	93	0.18	19	2011	161	0.30	18	25
West Virginia	41	0.33	4	1998	19	0.15	40	11
Wisconsin	72	0.18	20	2008	133	0.33	16	30
Wyoming	Suppressed			2008	25	0.61	2	1

Footnote: Ranking of states by crude death rate for suicide of all types over the same time period is provided for comparison. Also provided is the first year that each state-mandated residential carbon monoxide alarm. The Centers for Disease Control and Prevention Wonder database suppresses sub-national data representing fewer than 10 persons for reasons of confidentiality and labels rates unreliable when the death count in a category is less than 20.

strongly supportive of the concept that the increase in total accidental carbon monoxide deaths in the US is due to consumer products. Prevention efforts need to focus on those consumer product groups that demonstrate increasing mortality in the Consumer Product Safety Commission data such as heating systems, engine-driven tools, and water heaters [11].

The effectiveness of residential carbon monoxide alarms to prevent unintentional carbon monoxide poisoning is problematic. A majority (51%) of all US accidental carbon monoxide poisoning deaths from 2015–2021 occurred in the decedent's home. Similarly, 69% of consumer product-related carbon monoxide deaths from 2009–2019 occurred within the home.

It is logical to assume that residential carbon monoxide alarms would prevent poisoning. Two studies are often cited in support of carbon monoxide alarm effectiveness. In one [20], 136 New Mexico carbon monoxide deaths over 16 years were retrospectively reviewed, and study investigators determined one-half might have survived the exposure had an operational carbon monoxide alarm been present in the residence. In the other [21], a North Carolina ice storm resulted in extensive power outages and a subsequent outbreak of carbon monoxide poisonings in a

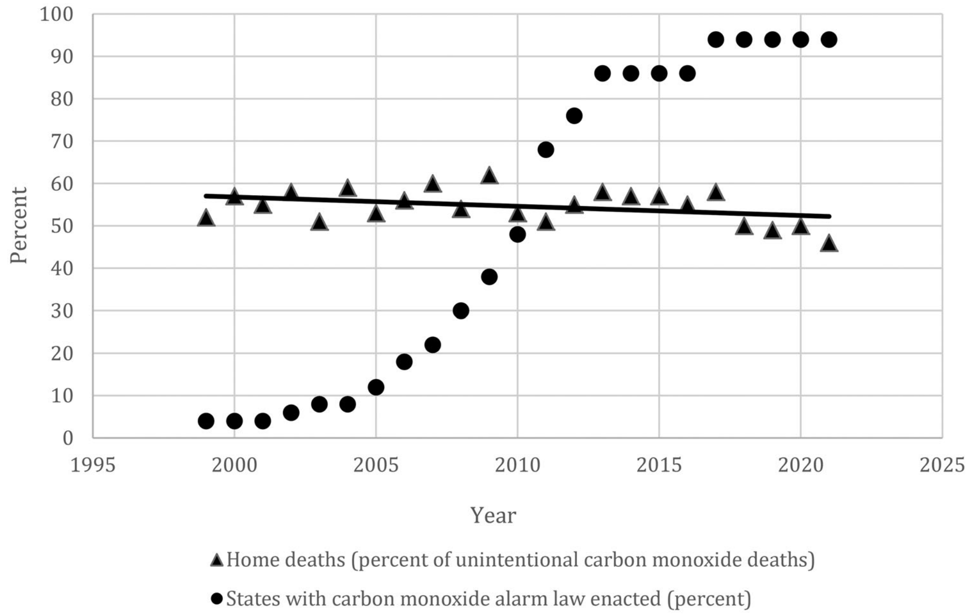

Figure 3. Fraction (percent) of unintentional carbon monoxide poisoning deaths occurring at home 1999–2021 (triangles) vs. fraction of states that have enacted legislation requiring residential carbon monoxide alarms in some type of domicile (circles). Death data 1999–2014 from reference 3, data on alarm laws from reference 11.

county that had required carbon monoxide alarm installation in a subset of residences two years earlier. Of 124 individuals subsequently diagnosed with symptomatic carbon monoxide poisoning, 109 came from homes without reported functional carbon monoxide alarms. This included 25 of 26 with poisoning deemed to be severe, with one death. It is unknown how many undiagnosed carbon monoxide poisonings occurred or how many homes actually had functioning alarms.

There are no large population-based studies demonstrating the effectiveness of carbon monoxide alarms in the prevention of fatal or nonfatal poisoning. It has been calculated that universal installation of residential carbon monoxide alarms would be cost-effective if they prevented as few as 10% of poisonings [22]. The long history of smoke alarm use has allowed the collection of extensive data regarding their performance. The death rate per 1,000 home structure fires is 55 per cent lower in homes with working smoke alarms [23].

When the report on US carbon monoxide deaths from 1999–2014 was published in 2016, 19 states had laws requiring carbon monoxide alarms in at least some form of domicile and 31 did not [3]. The accidental death rates were compared between the two groups and there was no difference. One possible explanation was the laws had been enacted too recently to have an effect. Today, all US states except three have such regulations. Figure 3 compares the fraction of states with enacted residential carbon monoxide alarm laws vs. the fraction of accidental carbon monoxide deaths that occurred in the home from 1999–2021. No clear relationship is apparent.

One possible reason it has been difficult to prove carbon monoxide alarms prevent poisoning is that alarms have been installed but they are nonfunctional due to dead or missing batteries or age. It should be recognized that proper maintenance includes periodic device replacement, as the sensors have limited lifespans [24,25]. Ryan and Arnold [24] tested 30 alarms in household use and found about one-half failed to work properly. Those that failed tended to be 10 years old or older, despite the manufacturer's recommendations that they be replaced after 5–7 years.

A second reason could be that requirements for alarm installation have been ignored and the true prevalence of alarms within homes is low. In a 2008 survey of [26] residents of Washington State (where residential carbon monoxide alarms were not required at the time) and Utah (where they had been required in new construction since 2006), the prevalence of alarm presence was 41% and 59%, respectively. When the survey was repeated in Washington State in 2016 [27], three years after residential carbon monoxide alarms became mandatory, usage had risen to 78%. This was similar to 68% reporting having a home carbon monoxide alarm in a 2009 survey performed eight years after a mandate was passed in a North Carolina county [28]. More information is needed on alarm prevalence in homes after the enactment of legislation requiring them. If the rate of installation is low, five years may be insufficient to expect a recognizable effect.

A third reason for failing to see an effect of alarms could be limitations inherent in the state laws. As noted, the laws are extremely variable regarding residences covered. This undoubtedly introduces a significant amount of noise into any attempt to measure an effect. Fourth, carbon monoxide alarms may be preventing nonfatal poisonings but not carbon monoxide deaths. It is much harder to track nonfatal carbon monoxide poisoning as no reliable national surveillance system is currently available [4,29]. Current estimates of nonfatal poisonings are compiled from multiple sources and could be missing an effect that alarms are having.

A nationwide surveillance program [30] operating from 2008–2011 collected data on 1,601 unintentionally poisoned patients treated with hyperbaric oxygen. Of those, 1,164 (73%) were poisoned in a residential setting. Only 117 (10%) reported that a carbon monoxide alarm was present in the residence and among the cases with an alarm, only 71 (60%) reported hearing it go off. This certainly raises issues of both market penetration and functionality.

A fifth and final reason that carbon monoxide alarms may not be preventing carbon monoxide poisoning deaths is that a certain fraction may not be preventable with alarms [19]. As Yoon and colleagues pointed out [20], since carbon monoxide poisoning is often associated with intoxication, individuals sedated with alcohol or other drugs may not respond to an alarm.

In 2007, the CDC said, "Because persons are relying on carbon monoxide alarms to prevent carbon monoxide poisoning, additional research regarding their effectiveness is needed" [6]. Unfortunately, that remains the case in 2023. Proving that residential carbon monoxide alarms are effectively preventing unintentional carbon monoxide poisoning is a prime area for further research.

Intentional carbon monoxide poisoning deaths

The number of accidental carbon monoxide deaths in the US exceeded the number of intentional carbon monoxide deaths for the first time in 2021. This was a function of both the decrease in intentional and the increase in unintentional carbon monoxide deaths (Table 1, Figure 1).

In the study by Mott and colleagues [19], intentional carbon monoxide deaths decreased from 2371 in 1968 to 1747 in 1998, about 1% per year over 31 years. There was a transient increase from 1981–1987, but a subsequent steady decline. Nonetheless, for every unintentional carbon monoxide death that occurred (33,836), there were 2.2 carbon monoxide-related suicides (73,940) [19]. Suicidal carbon monoxide poisoning continued to decrease from 1,486 cases per year in 1999 to 831 in 2014, approximately 3% per year over 16 years [3]. In 2014, suicidal carbon monoxide poisoning still resulted in twice the number of deaths as unintentional exposures. The additional decrease in this study to 524 cases in 2021 shows an even more rapid rate of decline at approximately 6% annually.

As noted, suicide from all causes has continued to increase over the past 40 years while carbon monoxide-related suicide declined. The latter has been felt to be largely the result of the introduction of catalytic converters in 1975 and more stringent automobile emission standards [31]. Mott and colleagues [19] reported that 1,330 of 1,747 (76%) carbon monoxide suicides from 1968–1998 were automobile related [19]. Automobiles manufactured prior to 1975 continue to disappear from the road and emissions engineering continues to advance, both contributing to reduction in carbon monoxide production. As of 2023, only 2% of automobiles manufactured prior to 1985 are still on the road [32].

Carbon monoxide emissions from late-model cars with catalytic converters are so low that committing suicide with one requires running the engine in a tightly sealed enclosure for a very long time [31,33]. In addition to the lack of available old cars, websites discussing suicide methods discourage the use of automobile carbon monoxide to commit suicide because of its general ineffectiveness and slowness of death [34].

State-by-State carbon monoxide poisoning deaths

Northern latitude and high-altitude states tended to have the highest death rates from accidental carbon monoxide poisoning (e.g. Alaska, North Dakota, Nebraska) (Table 3). This is similar to prior studies and felt to be driven largely by wintertime home heating incidents [2]. However, states with the lowest accidental crude death rates (e.g. Maryland, California, Virginia) are not those with the warmest climates. Their accidental death rates are probably low as a result of poisoning prevention programs such as stringent vehicle emissions controls and aggressive public education.

States with high intentional carbon monoxide death rates (e.g. Montana, New Hampshire) also have colder winter climates, as do states with the highest death rates from suicide of all types (e.g. Wyoming, Montana, Alaska) (Table 3). The association of cold climate with high death rates in all three categories, such as is seen in Idaho, Montana, and Wyoming, raises the possibility that those attempting suicide in colder climates choose carbon monoxide poisoning as a method because more carbon monoxide sources are available. Additional investigation is warranted.

Limitations

The major limitation to this study relates to death certificate coding, specifically the inability to identify carbon monoxide sources from certificates coded with ICD-10 since 1999, the potential misassignment of the intent of poisoning, and the inability to differentiate multiple poisoning incidents from single events. All of these would help answer questions raised about US carbon monoxide poisoning mortality and likely aid in prevention efforts. Further, compliance with US state laws requiring residential carbon monoxide alarms is not known, so the effect of such alarms is not known.

Conclusions

The accidental death rate from carbon monoxide is increasing in the US, possibly in direct relation to poisoning by consumer products. The major categories of products causing this increase in deaths need further investigation and intervention. It is likely that the Consumer Product Safety Commission will take the lead in this.

Residential carbon monoxide alarms have very little data supporting their effectiveness in preventing carbon monoxide poisoning, fatal or non-fatal. This needs additional attention so that support for the expansion of their use can be justified. As a part of this, the uptake of alarms after legislation is passed mandating their installation should be determined. If low, barriers to installation must be identified and addressed.

Only when a high utilization rate has been achieved will it be possible to determine how effectively alarms impact unintentional carbon monoxide mortality. Further investigation of the rate of malfunctioning detectors is also needed.

Third, the reasons that some US states simultaneously have high rates of accidental carbon monoxide poisoning, intentional carbon monoxide poisoning, and suicide, in general, should be explored. This will likely require much better surveillance of carbon monoxide sources causing poisoning than currently exists. It is possible that further analysis could yield a clue to overall suicide prevention.

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