Suicidal carbon monoxide poisoning has decreased with controls on automobile emissions

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ABSTRACT

Background: Highway vehicle CO emissions have decreased 85% since introduction of the catalytic converter in 1975. We sought to examine whether morbidity and mortality from intentional motor vehicle-related CO poisoning have also changed.

Methods: Vehicle CO emissions data from 1970-2013 were obtained from the U.S. Environmental Protection Agency. U.S. Centers for Disease Control and Prevention data were used for the suicide crude death rate (CDR) from CO poisoning from 1999-2010. Data on non-fatal intentional CO poisonings treated at a regional hyperbaric treatment center from 1981-2013 were analyzed with regard to numbers treated and presenting carboxyhemoglobin (COHb) levels.

Results: Since 1985, the CDR for suicidal motor vehicle-related CO poisoning has decreased in parallel with CO emissions (R^2=0.985). Non-fatal motor vehicle-related intentional CO poisoning cases decreased 63% over 33 years (p=0.0017). COHb levels decreased 35% in these patients (p<0.0001).

Conclusions: There has been a decrease in both fatal and non-fatal intentional CO poisoning from motor vehicle exhaust since the 1980s. This correlates with reductions in vehicle CO emissions and is a likely result of the U.S. Clean Air Act of 1970 and the application of catalytic converters since 1975.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) first established specific environmental standards for carbon monoxide (CO) in 1971, one year following release of the initial version of the United States Clean Air Act [1,2]. Subsequent development of the catalytic converter and mandating its installation on automobiles built after 1975 led to large drops in CO emissions. The catalytic converter oxidizes CO to carbon dioxide in the chemical equation $(2)CO + O_2 = (2)CO_2$. Its use dramatically reduces the automotive output of CO and is largely responsible for the decrease in environmental ambient CO that has been seen across the country since 1970.

Anecdotal reports have suggested that reduced motor vehicle carbon monoxide CO emissions resulting from improved engineering and installation of catalytic converters have made committing suicide by breathing exhaust gas from a low-emission vehicle more difficult or even impossible [3,4,5]. Studies have shown inconsistent correlation between suicidal deaths related to motor vehicle CO and levels of CO emissions from automobiles. Data in this regard were last updated in the medical literature in a 2002 paper that encompassed the years up to 1998 [6].

CO poisoning accounts for approximately 450 unintentional, non-fire related deaths and 1,750 intentional deaths annually in the United States [6,7]. Of 61,129 individuals committing suicide by CO poisoning from 1968-1998 in whom a CO source was identified, 99% were motor vehicle-related [6]. Among 433 patients treated at one U.S. hyperbaric oxygen therapy facility for non-fatal intentional CO poisoning from 1980 to 2005, 94% used motor vehicles as the CO source [8].

This study will extend data on national motor vehicle-related suicidal CO deaths. In addition, it will examine the experience of a regional referral center for CO poisoning treatment over the past 33 years. If reducing automobile emissions has made intentional CO poisoning from automobile exhaust more difficult, both the number of deaths in the United States as well as

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non-fatal poisonings treated should have decreased. Associated with this, one would predict a decline in blood carboxyhemoglobin (COHb) levels among those treated due to the reduction in automobile CO production and, therefore, individual exposure.

METHODS

Total CO emissions from highway vehicles (cars and light trucks, heavy trucks, buses, engines, and motorcycles) from 1970-2013 were obtained from the U.S. Environmental Protection Agency (EPA) [9].

Data on the crude death rate (CDR) per year from 1981-1998 for suicide from motor vehicle exhaust were obtained from reference 4, then extended from 1999-2010 using "CDC Wonder," an online system for disseminating public health data and information by allowing the search of selected U.S. Centers for Disease Control and Prevention (CDC) data files [10]. Database "Multiple Cause of Death 1999-2010" was searched using year, suicide, toxic effects of carbon monoxide, and intentional self-poisoning by and exposure to other gases and vapors parameters. Due to a change from ICD-9 to ICD-10, it was not possible to search the 1999-2010 database for source of CO. Therefore, suicidal CO deaths from all sources are contained in the counts shown starting in 1999.

Information on patients treated with hyperbaric oxygen for moderate to severe CO poisoning at the Virginia Mason Center for Hyperbaric Medicine, a regional referral center, was obtained from an Institutional Review Board-approved research database. Data extracted included number of total CO-poisoned patients treated per year from 1981-2013, number of intentional motor vehicle-related and non-related cases treated and the initial COHb levels of the patients.

Statistical analysis included descriptive statistics, as well as linear regression.

RESULTS

From 1970 to 2013, total CO emissions from highway vehicles decreased 85% from 163,421 to 24,796 tons per year [9].

When the rate of vehicle CO emissions produced per year is compared to the CO suicide crude death rate from 1985 to 2010, the two are highly correlated ($y = 0.0594x + 1.2655$; $R^2 = 0.98546$; $p = 0.00008$) (Figure 1).

The regional referral center treated 1,875 patients for acute CO poisoning from 1981-2013, accidental and intentional combined. As is illustrated in Figure 2, a total of 461 (25%) of these were treated for intentional CO poisoning by motor vehicle exhaust inhalation. From 1981-2013, there has been a 63% decrease in such patients treated ($y = -0.4472x + 906.86$; $R^2 = 0.28292$; $p = 0.0017$).

Initial blood COHb levels for the 461 patients treated for intentional motor vehicle exhaust CO poisoning demonstrate a decrease in the annual average level over 33 years from 29.1% to 19.1% ($y = -0.2478x + 517.07$; $R^2 = 0.0234$; $p < 0.001$) (Figure 3). Conversely, for 48 intentional CO poisonings of non-motor vehicle sources treated from 1981-2013, no significant change in COHb levels was seen ($y = -0.1358x + 296.05$; $R^2 = 0.01295$; $p = 0.4412$).

DISCUSSION

In 1969, the average new car in the United States emitted 13.99 gm CO/minute at idle [11]. By 1989, that figure had fallen to 0.22 gm CO/minute. Prior to 1970, automobile exhaust CO concentrations in the range of 7-12% were not uncommon. Most regions that require emissions testing now use 1% (100,000 PPM) as an upper limit for passing, although new cars may have CO emissions as low as 0.1% (10,000 PPM) [3].

A previously reported unanticipated benefit from the reduction of CO in automobile exhaust has been a significant decline in accidental CO poisoning deaths in the U.S. In 1991, Cobb and Etzel from the CDC reported that the annual number of all accidental CO-related deaths decreased 42%, from 1,513 in 1979 to 878 in 1988 [12]. They noted that CO from automobile exhaust was responsible for 57% of accidental poisoning deaths. Accidental automobile-related CO deaths decreased about 45%, from approximately 850 in 1979 to approximately 475 in 1988. Cobb and Etzel speculated that a major factor was compliance with EPA regulations, lower automobile CO emissions and less likelihood for death related to exposures to high levels of CO from activities such as vehicle operation in enclosed spaces.

In 2002, Mott and co-workers from the CDC and the EPA expanded upon Cobb and Etzel's work [6]. They examined the time period from 1968 to 1998, with regard to rates of both accidental and intentional motor vehicle-related CO deaths, comparing them to contemporaneous light-duty vehicle CO emissions. Their results were reported largely by decade, 1968 to

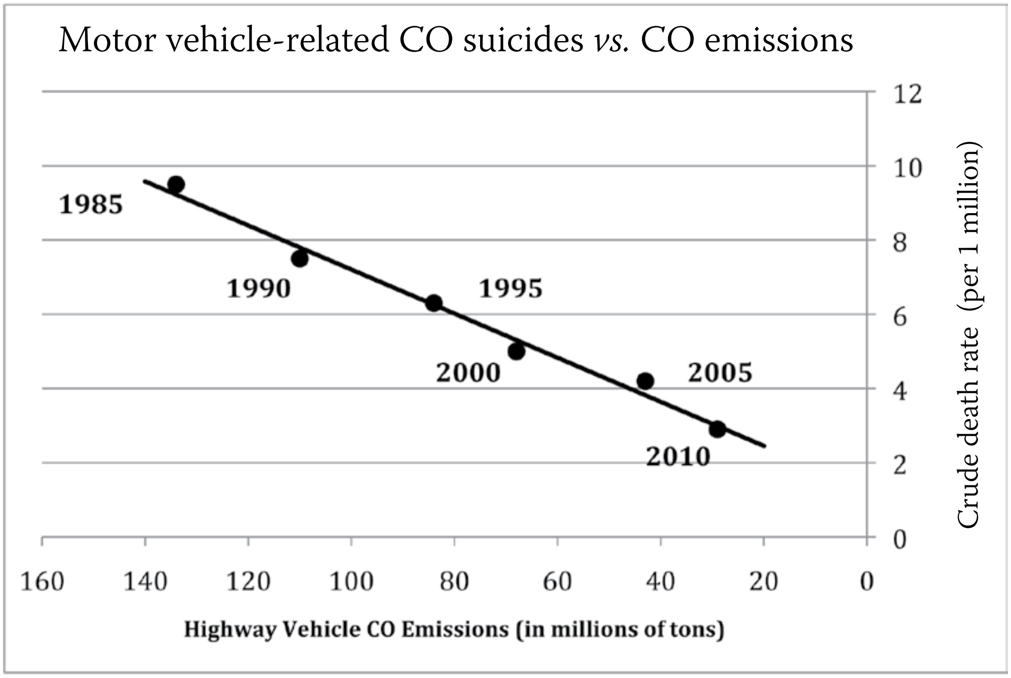

Figure 1. The rate of motor vehicle CO suicides has decreased linearly in relationship to vehicle CO emissions since 1985 (r = 0.99; p = 0.0008).

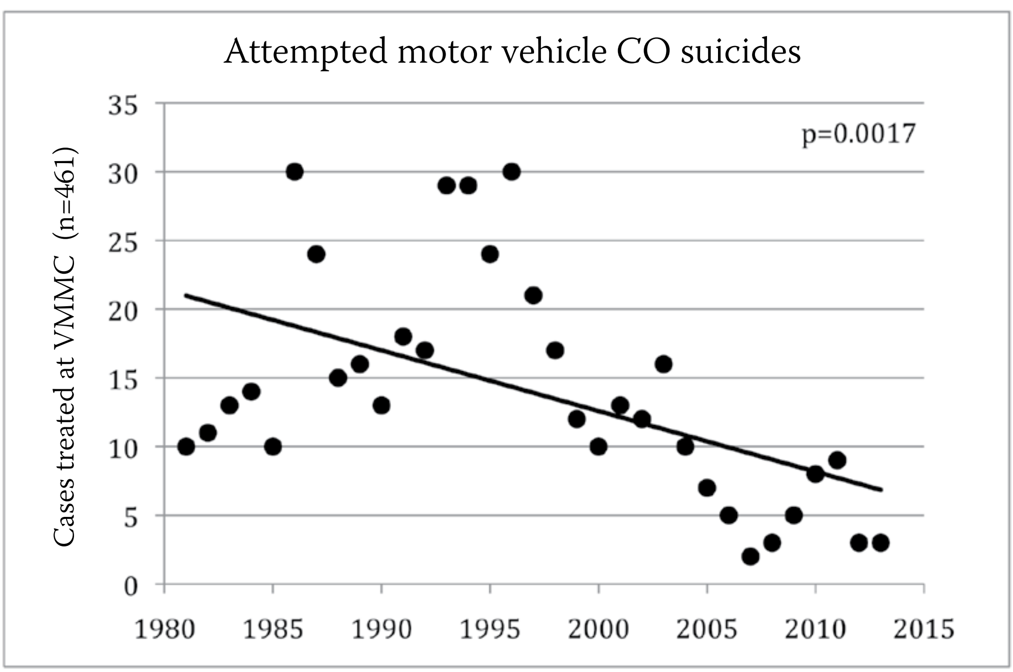

Figure 2. Number of intentional, motor vehicle-related CO-poisoned individuals treated per year from 1981 to 2013 at Virginia Mason Medical Center in Seattle, Washington.

1978, 1979-1988 and 1989-1998. The unintentional motor vehicle-related CO crude death rate did not change from 1968-1978, then decreased 48% from 1979-1988 and another 28% from 1989-1998. Overall, the accidental crude death rate decreased from 3.86 per million person years in 1968 to 0.88 in 1988. In the Mott, et al. paper, a graphic shows that the decline in the crude death rate began about 1978, near the time that average CO emissions from automobiles began to drop. Further decreases in the accidental motor vehicle CO crude death rate generally correlated with declining average CO emissions through 1996.

In the case of suicidal CO poisoning deaths from motor vehicles, their findings were less clear. Mott and colleagues reported that the intentional crude death rate fell over 30 years from 9.53 per million person years in 1968 to 4.92 in 1998. By decade, it did not change from 1968-1978, increased from 1979 to 1988, then fell from 1989 to 1998 (Figure 4). Following an increase from 1983 to 1987, the crude death rate has decreased almost linearly from 1987 to 2010 in parallel to ongoing declines in automobile CO emissions, using new data from CDC Wonder to extend the annual rates beyond 1998 (Figure 1).

While the correlation between CO production and suicide crude death rate is extremely strong (R^2=0.99), we cannot state that other variables would not also correlate because we tested CO production only.

Another potential limitation would appear to be the fact that a switch to ICD-10 coding was accompanied by the inability to search death databases for the CO source after 1998, making it impossible to identify only motor vehicle-related suicides. However, the crude death rate for all suicidal CO poisoning continued to fall lower throughout the decade following 1988, strongly suggesting that the predominant source of CO for such suicide attempts continued to be motor vehicles, as discussed earlier. CO emissions technology has continued to improve, while pre-1975 automobiles have continued to disappear as available modes for suicide.

While none of the three case reports cited are overwhelmingly convincing of increased difficulty to commit suicide by motor vehicle [3,4,5], it nonetheless seems likely that this is the case. When the crude death rate from intentional motor vehicle-related CO poisoning is compared to the tons of CO produced by vehicles annually from 1985 to 2010 (Figure 1), the two form a virtual line of identity.

Further support comes from the data on intentional, non-fatal motor vehicle-related poisonings. The number of such patients treated annually at a regional referral center decreased significantly from 1981-2013, from approximately 38 per year to approximately 14 per year (Figure 3). It should be noted that this decline reflected a decreasing proportion of the overall CO poisoning treatment volume being comprised of suicidal motor vehicle-related cases and was not simply due to a reduction in total CO poisoning cases.

Simultaneous with this has been a 34% drop in initial COHb levels in motor vehicle-related suicide attempt patients. We speculate that attempted suicide using motor vehicle exhaust is terminated in one of three ways. First, someone can discover the event in progress and intervene. Second, the vehicle can run out of gasoline and stop producing CO. Third, the individual can change his/her mind and terminate the exposure. There is no reason to think that the time from the start of exposure to any of these occurrences would have changed. Therefore, since the exposure time is likely unchanged and the CO production less, the COHb level would be expected to be lower. While COHb level does not correlate with clinical presentation [13], it is a marker of exposure, related to time and CO exposure concentration. As noted, the parallel group of 48 individuals who attempted suicide with CO from sources other than motor vehicles did not demonstrate a decrease in COHb levels over the same time period.

Now that more data are available, it seems that the preliminary observation in 2002 by Mott of a decreasing death rate due to suicidal motor vehicle-related CO poisoning is correct. While it is still possible to commit suicide by CO poisoning from breathing motor vehicle exhaust gas, it is clearly not as easy as it was pre-emissions controls [11]. While one could certainly use a pre-1975 automobile, they are rapidly becoming less available. Suicide can also be accomplished by running an emission-controlled vehicle in a tightly sealed space for a very long period of time [11]. As oxygen is depleted by combustion, the engine becomes less efficient and begins to produce more CO as hypoxia develops. Compounding this is the fact that catalytic converters require oxygen to oxidize CO. In a sufficiently hypoxic environment, the engine will produce more CO and the catalytic converters remove less of it.

There are books and websites providing instructions for successful suicide. One of these is a website, "Lost all Hope" [14]. In the section on carbon monoxide it is

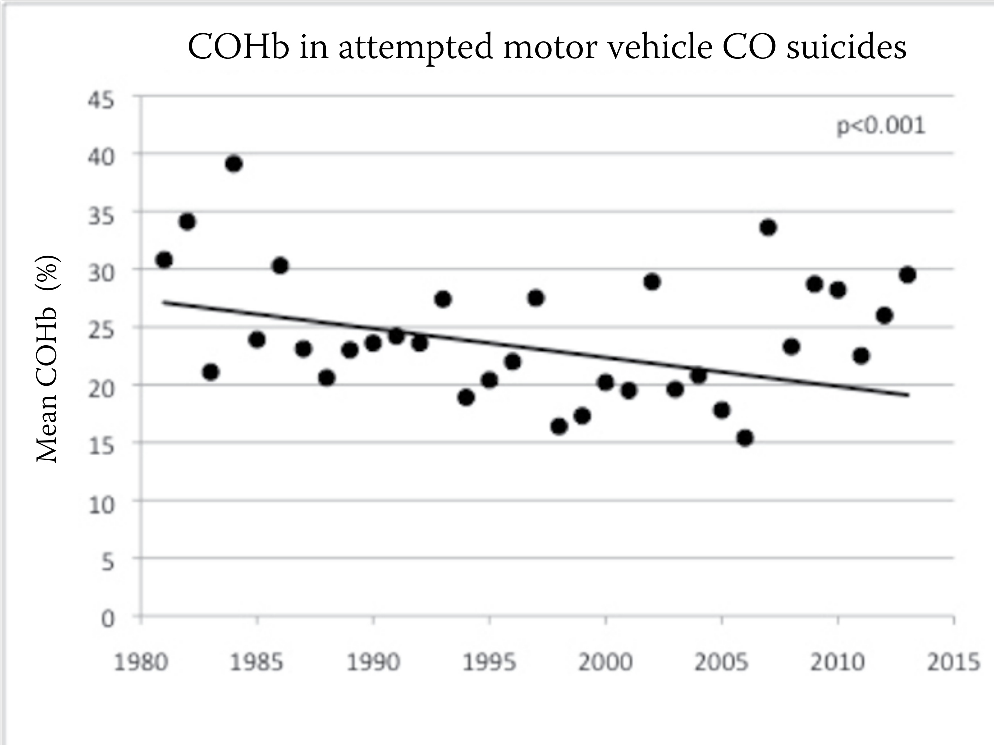

Figure 3. Mean COHb levels from patients treated each year from 1981 to 2013 for intentional self-inflicted motor vehicle-related CO poisoning at Virginia Mason Medical Center in Seattle. Total n = 461; each closed circle represents 3-30 patients.

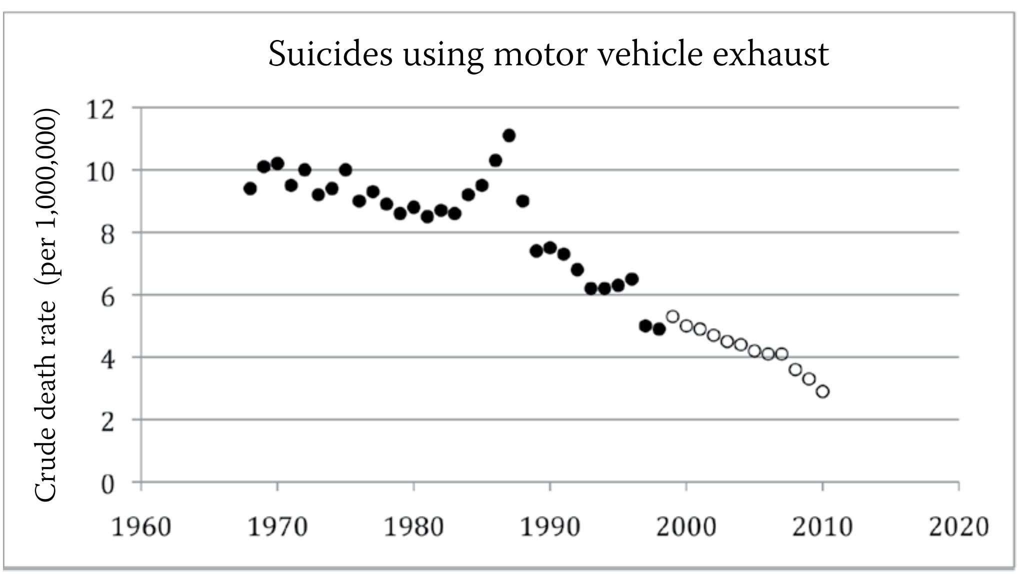

Figure 4. U.S. crude death rate per year due to suicidal CO poisoning related to motor vehicles. Solid circles are data from the Centers for Disease Control and Prevention (CDC), adapted from reference 6. Open circles are data from CDC Wonder (difference described in text) (reference 10).

stated: ”In the past, using car exhaust fumes to commit suicide was a well known method . . . But that was before the days of emissions controls on cars which now emit much lower levels of CO than previously. While it is possible to achieve death using his method, it does generally require older cars. The method is susceptible to a number of things that can go wrong, and for this reason it is no longer cited as an effective method to commit suicide especially in places like the US . . . . where car emissions are more tightly controlled.”

In summary, the incidence of both fatal and non-fatal intentional CO poisoning related to motor vehicle exhaust have decreased since the 1980s. These declines correlate temporally and quantitatively with reductions in vehicle CO emissions and are in large part due to the U.S. Clean Air Act of 1970 and the widespread introduction of automotive catalytic converters in 1975.

Conflict of interest

The authors have declared that no conflict of interest exists with this submission. ■

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