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Forensic and Epidemiological Evaluation of Carbonmonoxide-Related Deaths: A Ten-Year Autopsy Study from Southern Turkiye

Karbonmonoksit ile İlgili Ölümlerin Adli ve Epidemiyolojik Değerlendirilmesi: Türkiye'nin Güneyinden On Yıllık Otopsi Çalışması

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Öz

Amaç: Karbonmonoksit (CO) zehirlenmesi, dünya genelinde önemli ve önlenebilir bir ölüm nedeni olmaya devam etmektedir. Bu çalışmanın amacı, Antalya, Türkiye'de otopsisi yapılan ölümcül CO zehirlenmesi vakalarının epidemiyolojik, toksikolojik ve adli özelliklerini değerlendirmektir.

Gereç Ve Yöntem: 2011 ile 2020 yılları arasında Antalya'da gerçekleştirilen 8.649 otopsi arasında, CO zehirlenmesi tanısı konulan 105 olgu retrospektif olarak incelenmiştir. Olgulara ait yaş, cinsiyet, mevsimsel dağılım, olayın gerçekleştiği yer, COHb düzeyleri, otopsi bulguları ve toksikolojik analiz sonuçları değerlendirilmiştir. COHb düzeyleri, moleküler absorbsiyon spektrofotometrisi yöntemiyle ölçülmüştür. İstatistiksel analizlerde Mann–Whitney U, Fisher's Exact ve Spearman korelasyon testleri kullanılmıştır.

Bulgular: 105 olgunun 68'i (%64,8) erkek, 37'si (%35,2) kadındı. Ölümlerin çoğunluğu kış mevsiminde (%56,2) ve konut ortamında (%71,4) gerçekleşmiştir. Katı yakıtla çalışan sobalar, CO maruziyetinin en yaygın kaynağı olarak saptanmıştır (%30,5). Ortalama COHb düzeyi %56,5 olup, yaşlı bireylerde ve kronik hastalığı bulunanlarda anlamlı olarak daha düşük seviyeler tespit edilmiştir ($p<0,05$). Olguların %19,1'inde CO zehirlenmesine geniş yanıklar da eşlik etmiştir. COHb düzeyleri, yaş ile ters yönde korelasyon göstermiş; eşlik eden hastalığı veya termal yaralanması olan olgularda daha düşük bulunmuştur.

Sonuç: Ölümcül CO zehirlenmesi, özellikle yetersiz havalandırılan ortamlarda kullanılan katı yakıtlı sobalarla ilişkili olarak hâlâ büyük ölçüde önlenebilir bir halk sağlığı sorunu olmaya devam etmektedir. Postmortem COHb tayini, tanı açısından en güvenilir yöntemdir. Kamu spotları, yapısal güvenlik önlemlerinin iyileştirilmesi ve multidisipliner iş birliği, CO'ya bağlı ölümlerin azaltılmasında temel unsurlardır.

Anahtar Kelimeler: Karbonmonoksit zehirlenmesi, Karboksihemoglobin, Adli otopsi, Postmortem bulgular, Toksikoloji, Halk sağlığı

Abstract

Aim: Carbon monoxide (CO) poisoning remains a significant and preventable cause of accidental deaths worldwide. This study aims to evaluate the epidemiological, toxicological, and forensic characteristics of fatal CO poisoning cases that underwent autopsy in Turkiye.

Methods: A retrospective review was conducted on 105 autopsy cases diagnosed with CO poisoning among 8,649 autopsies performed between 2011 and 2020 at the Antalya. Data regarding age, sex, seasonality, origin of the incident, COHb levels, autopsy findings, and toxicological results were analyzed.

Results: Of the 105 cases, 68 (64.8%) were male and 37 (35.2%) were female. The majority of deaths occurred in winter (56.2%) and within residential settings (71.4%). Solid-fuel stoves were the most common source of CO exposure (30.5%). The mean COHb level was 56.5%, with significantly lower levels observed in elderly individuals and those with chronic illnesses ($p<0.05$). In 19.1% of cases, CO poisoning was accompanied by extensive burns. COHb levels correlated inversely with age and were lower in cases with comorbid conditions and thermal injury.

Conclusion: Fatal CO poisoning remains a largely preventable public health concern, particularly associated with solid-fuel stoves in poorly ventilated environments. Postmortem COHb quantification remains the most reliable diagnostic tool. Public education, structural safety improvements, and multidisciplinary collaboration are essential to reduce CO-related fatalities.

Keywords: Carbon monoxide poisoning, Carboxyhemoglobin, Forensic autopsy, Postmortem findings, Toxicology, Public health

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INTRODUCTION

Carbon monoxide (CO) is a toxic gas composed of one carbon (C) and one oxygen (O) atom joined by a triple bond. It is colorless, odorless, tasteless, and non-irritating (1,2). It is typically produced as a result of the incomplete combustion of carbon-containing materials (3).

The toxicity of carbon monoxide is primarily related to its ability to rapidly diffuse into erythrocytes and bind to hemoglobin. Its affinity for hemoglobin is approximately 300 times greater than that of oxygen (4). This leads to the formation of carboxyhemoglobin (COHb), which impairs oxygen delivery to tissues and results in tissue hypoxia. The consequent reduction in oxygen-carrying capacity can cause inadequate oxygenation at the tissue level, potentially leading to death by asphyxiation (5). CO exposure may occur through the combustion of fuels such as liquefied petroleum gas (LPG), natural gas, wood, and coal used for heating, cooking, or lighting in enclosed spaces, by inhalation of smoke during fires, or through exposure to exhaust fumes (6).

When the proportion of carboxyhemoglobin (COHb) to total hemoglobin remains below 10%, symptoms are generally absent. In fatal cases of CO poisoning, however, COHb levels are typically reported to range between 30% and 80% (7). Among individuals with pre-existing respiratory or cardiovascular conditions, as well as in older adults, death may occur at lower COHb levels and within a shorter timeframe. This is attributed to the lower prevalence of comorbidities in younger individuals and their greater ability to tolerate tissue hypoxia (5,8).

In cases of carbon monoxide poisoning, certain macroscopic findings observed during forensic examination and autopsy may provide diagnostic clues. These include the presence of soot and smoke residues in the nasal passages, mouth, and airways, as well as the characteristic bright red or 'cherry-red' discoloration of the skin and internal organs. However, such findings are not specific and therefore cannot definitively confirm CO poisoning. The absence of soot or smoke does not necessarily indicate that death occurred before the onset of a fire, nor does their presence alone confirm carbon monoxide exposure. Consequently, in all cases where CO poisoning is suspected, the most reliable diagnostic method is the quantitative toxicological analysis of blood carboxyhemoglobin (COHb) levels (9,10).

This study retrospectively evaluated the socio-demographic characteristics, seasonal and monthly distribution, origin of death, as well as autopsy and toxicological findings of carbon monoxide-related fatalities that underwent forensic autopsy in Council of Forensic Medicine, Antalya Group Administration Türkiye between 2011 and 2020. Based on the findings, the study aims to highlight critical considerations for forensic medical practice and to draw attention to legal, societal, and structural measures necessary for the prevention of carbon monoxide-related deaths.

METHODS

This study retrospectively examined all autopsies conducted between January 1, 2011, and December 31, 2020, at the Council of Forensic Medicine, Antalya Group Administration Türkiye . Among the 8,649 autopsy cases reviewed, 105 were determined to have died due to carbon monoxide (CO) poisoning and were included in the analysis.

In all cases, a systematic autopsy was performed, during which the trachea and main bronchi were longitudinally opened and examined macroscopically for evidence of soot deposition or mucosal injury. In addition, representative lung tissue samples were collected for histopathological examination to further assess the effects of smoke inhalation and pulmonary injury.

Carboxyhemoglobin (COHb) analyses were performed at the Toxicology Laboratory of the Council of Forensic Medicine, Antalya Group Administration using postmortem femoral venous blood samples and molecular absorption spectrophotometry (11).

The cases were evaluated in terms of age, sex, time of death (year, month, season, day), origin of the incident, scene of the event, COHb level, medical history, autopsy findings, toxicological results, and presence of traumatic findings. Additional case characteristics, including the circumstances of the incident, were obtained through review of autopsy reports and relevant forensic investigation files.

The data obtained from the cases were digitized and transferred to the Statistical Package for the Social Sciences (SPSS) version 23.0, through which all statistical analyses were conducted. Fisher's Exact Test, Mann–Whitney U Test, and Spearman correlation analysis were used for data analysis. A p-value of less than 0.05 was considered statistically significant.

Ethical and administrative approval for the present study was obtained from the Council of Forensic Medicine Education and Scientific Research Commission (Approval No: 2021/313; March 30, 2021).

RESULTS

Of the 105 cases included in the study, 68 (64.8%) were male and 37 (35.2%) were female, yielding a male-to-female ratio of 1.83. The overall mean age of the cases was 51.8 years (min: 1, max: 95, SD: 25.4); the mean age was 51.6 years for males (min: 2, max: 91, SD: 23.7) and 52.2 years for females (min: 1, max: 95, SD: 28.6). When the distribution by age group was examined, the highest number of cases occurred in the 70–79 age group (19.1%; n=20), followed by the 50–59 (13.3%; n=14), 40–49 (12.4%; n=13), and 80–89 (12.4%; n=13) age groups. No statistically significant difference was found between males and females in terms of age distribution.

An analysis of the monthly and seasonal distribution of deaths due to carbon monoxide poisoning revealed a clear predominance in the winter months. The majority of cases occurred during winter (n=59, 56.2%), followed by spring (n=20, 19.1%), autumn (n=18, 17.1%), and summer (n=8, 7.6%). In the monthly distribution, January accounted for the highest number of cases (n=30, 28.6%), followed by December (n=15, 14.3%) and February (n=14, 13.3%). No cases were observed in July or September, while only 2 cases (1.9%) occurred in June and 3 (2.9%) in May. The monthly distribution of cases is illustrated in Figure-1.

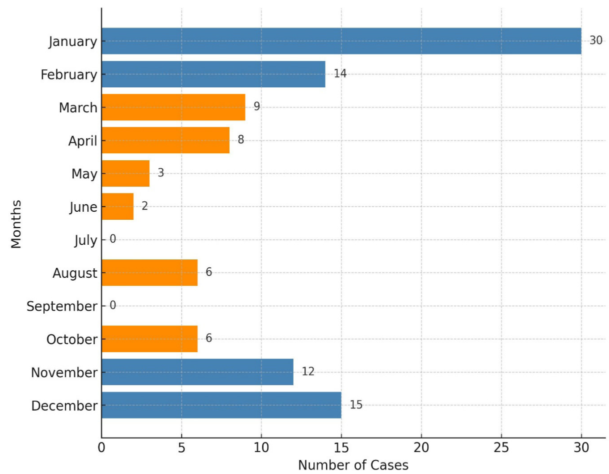

Figure 1. Monthly Distribution of Carbon Monoxide Poisoning Cases

It was determined that the most common location for CO poisoning incidents was residential settings, with 71.4% of the cases (n=75) occurring in homes. A detailed breakdown of the locations where the poisonings took place is presented in Table 1.

The most common source of CO leading to death was identified as solid-fuel heating stoves, which were responsible in 32 cases (30.5%). The distribution of CO sources responsible for exposure is presented in Figure-2.

Table 1. Locations Where Carbon Monoxide Poisoning Occurred

Location of Incident	n	%
Home	75	71.4
Workplace	5	4.8
Tent	5	4.8
Inside a car	4	3.8
Shack	3	2.8
Mine	2	1.9
Water well	2	1.9
Unknown	2	1.9
Others	7	6.7
Total	105	100.0

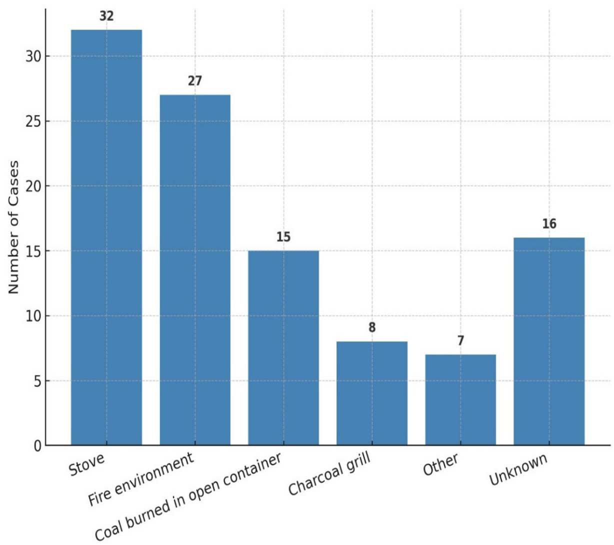

Figure 2. Distribution of Carbon Monoxide Sources Leading to Poisoning

In one case within the study population, COHb measurement could not be performed due to technical reasons. Among the remaining 104 cases, COHb levels ranged from a minimum of 15.4% to a maximum of 84.3%, with a mean level of 56.5% (SD: 16.07). When evaluated by sex, the mean COHb level was 52.6% in females (min: 17.4%; max: 76.4%; SD: 15.6) and 58.6% in males (min: 15.4%; max: 84.3%; SD: 16.04). This difference was found to be statistically significant ($p = 0.04$).

When COHb levels were compared across age groups, the highest mean level was observed in the 20–29 age group (68.4%), while the lowest was found in individuals aged 90 years and older (42.4%). A statistically significant inverse correlation was identified between age and COHb level, indicating that COHb levels decreased with increasing age ($p = 0.026$). When COHb values were categorized into defined intervals, the highest number of cases was concentrated in the 61–70% range ($n = 36$). Further details regarding this distribution are presented in Figure-3.

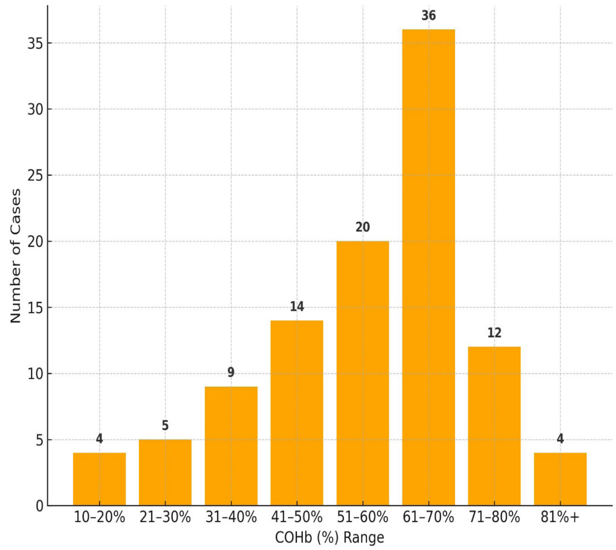

Figure 3. Distribution of Cases by COHb (%) Range

According to data obtained from autopsy reports, a total of 16 incidents involving multiple fatalities were identified in this study. Among these, 13 incidents involved two victims each, two incidents involved three victims, and one incident involved four victims, resulting in a total of 36 individuals who died in these 16 events. Notably, in 9 of these 16 multi-fatality incidents, the source of CO exposure was identified as solid-fuel stove use.

In 83 cases (79.1%), death occurred solely in association with carbon monoxide poisoning. Additionally, 20 individuals (19.1%) presented with extensive burn injuries along with CO poisoning, and in 2 cases (1.8%), exposure to other toxic gases in combination with CO was also noted. Postmortem lividity was observed in 80 cases

(76.2%). In the remaining 25 cases (23.8%), lividity could not be evaluated—due to extensive burn injuries in 19 cases and advanced decomposition in 6 cases. Regarding the color of postmortem lividity, the most frequently observed hue was bright red-pink or cherry-red, recorded in 68 cases (64.8%). In addition, mildly light red lividity was observed in 3 cases (2.9%), while 9 cases (8.5%) exhibited varying shades of purple lividity. When the relationship between the color of postmortem lividity and COHb levels was evaluated, the mean COHb level in the 68 cases with bright red-pink lividity was calculated as 61%. In the 3 cases with mildly light red lividity, the mean level was 40.9%, while in the 8 cases falling into other color categories (excluding one case where measurement could not be performed due to technical reasons), the mean COHb level was found to be 51.9%.

When the cases were evaluated in terms of chronic disease status, no information could be obtained for 51 cases (48.6%). Among the remaining 54 cases, 31 (29.5%) had no chronic disease, while 23 (21.9%) had at least one chronic condition (e.g., cardiovascular or respiratory diseases, diabetes, hypertension, cancer, etc.). In these 54 cases with available data, the mean COHb level was 60.1% in individuals without chronic diseases, whereas it was 50.6% in those with at least one chronic condition. The difference between the two groups was found to be statistically significant ($p < 0.01$).

DISCUSSION

Poisonings are among the leading public health issues worldwide, causing substantial morbidity and mortality, and are largely preventable. One of the primary contributors to this problem is carbon monoxide (CO), a common environmental pollutant. Each year, CO is reported to be responsible for a significant proportion of accidental poisoning cases and poisoning-related deaths globally (12).

Studies conducted both in Türkiye and internationally have reported that deaths due to carbon monoxide poisoning account for approximately 1.06% to 3.5% of all forensic autopsies (12–21). In the present study, CO poisoning was identified as the cause of death in 105 out of 8,649 autopsies performed between 2011 and 2020, corresponding to a rate of 1.2%. This rate is lower than those reported in many studies in the literature and closely aligns with findings from a study conducted in Aydın, Türkiye (13). The relatively low rates observed in Antalya and Aydın may be attributed to the milder climate in both regions, which likely results in reduced use of CO-emitting heating sources.

The male predominance detected in our study may be associated with a greater likelihood of men being employed in industrial and technical sectors, taking an active role in activities such as heating or vehicle maintenance, and spending time alone in enclosed spaces. Other studies have also reported a higher representation of males in CO poisoning-related deaths, supporting our findings (13, 16, 17, 22–24). These patterns suggest that gender roles and behavioral tendencies may be important risk factors in carbon monoxide exposure.

Numerous studies have reported that deaths due to carbon monoxide poisoning most frequently occur during the winter months (25–27). Similarly, in our study, 56.2% of the cases occurred in December, January, and February, confirming that the highest seasonal concentration of cases was during winter. This finding is attributed to the increased use of heating devices such as solid-fuel stoves and water heaters—which have the potential to produce carbon monoxide—during colder months.

Various studies have reported that CO-related deaths typically occur in residential and other enclosed living spaces (17, 21–23). These include homes, annexes, tents, shacks, and containers—structures commonly used for habitation and often characterized by limited air circulation. Similarly, in the present study, the vast majority of CO poisoning cases occurred in domestic settings. It is well known that carbon monoxide commonly originates from heating devices, and that it can accumulate rapidly in enclosed, poorly ventilated environments, leading to toxic effects. These findings support the consistency of our results with existing literature and underscore the strong association between CO poisoning and confined living spaces. Numerous studies in the literature have identified stoves as the most common source of carbon monoxide poisoning, with reported case proportions ranging from 37.5% to 78.6% (18, 25, 27). Similarly, in our study, solid-fuel stoves were determined to be the most likely source of CO in approximately one-third of the cases (30.5%). This finding highlights that coal- and wood-burning stoves, which are still widely used in Türkiye, continue to pose a significant public health risk—particularly in residences lacking adequate ventilation and proper chimney systems. In certain cases, carbon monoxide exposure was attributed to sources such as indoor fires, charcoal grills, or open fires ignited in outdoor areas. Nevertheless, these types of exposures tend to be situational and do not constitute a public health threat of the same magnitude as stove-related CO poisoning, which remains more prevalent and persistent in the general population.

In one case, COHb measurement could not be performed due to technical limitations; the diagnosis of CO poisoning had been confirmed based on the COHb level documented in the patient's medical records. As this value could not be verified through postmortem analysis, it was excluded from the statistical evaluation. Studies conducted in various regions have shown that COHb levels in fatal carbon monoxide poisoning cases most commonly fall within the 40–70% range. For example, a study from Bursa, Türkiye reported that the majority of cases had COHb levels between 31–50%, whereas in Eskişehir, Türkiye, the most frequent range was 51–70% (17, 21). Similarly, studies from Denmark and Elazığ, Türkiye indicated that COHb levels were predominantly above 50% (18, 28). In our study, the most frequently observed COHb range was 61–70% (n=36), followed by 51–60% (n=20) and 41–50% (n=14). These findings are largely consistent with the literature and support the observation that lethal COHb concentrations in fatal CO poisonings typically fall within the 40–70% range. However, as cases with COHb levels below 20% or above 80% have also been documented, it is evident that the lethal threshold may vary depending on individual susceptibility. Factors such as age, comorbidities, duration of exposure, and the environmental conditions of the incident may all influence this variability. Additionally, differences in calibration among toxicological measurement devices and postmortem changes should be considered when interpreting COHb levels.

Among the 54 cases with available information on chronic disease status, the mean COHb level was significantly higher in the 31 individuals without chronic diseases compared to the 23 individuals with at least one chronic condition. This finding suggests that individuals with chronic diseases may succumb to carbon monoxide poisoning even at lower COHb levels. Additionally, a statistically significant inverse correlation was observed between age and COHb level, indicating that COHb levels tend to decrease with increasing age. Similarly, a study conducted in Eskişehir, Türkiye reported that 58.3% of cases with COHb levels below 50% were individuals aged over 60 (21). When these two findings are considered together, it appears that the burden of chronic illness, which increases with age, may heighten individual susceptibility to carbon monoxide and raise the risk of death at lower COHb concentrations. The reduced physiological reserve in elderly and comorbid individuals may lead to a more rapid deterioration under hypoxic conditions, resulting in fatal outcomes at COHb levels as low as 20% (28). Therefore, forensic toxicological assessments should consider not only COHb concentration but also the individual's age and medical history to ensure accurate interpretation.

The mean COHb level in the 82 cases in which death was attributed solely to carbon monoxide poisoning was found to be 60.1%. In two cases involving combined gas poisoning (CO plus other gases), the mean COHb level was 69.2%. In contrast, among the 20 cases with both CO poisoning and extensive burn injuries, the mean COHb level was markedly lower at 40.5%. Although these cases involved significant thermal injury, they were included in the CO poisoning group based on autopsy findings and toxicological analyses indicating a contributory role of CO exposure in the fatal outcome. This finding suggests that COHb levels do not increase postmortem and instead reflect the amount of carbon monoxide absorbed at the time of death. In burn cases, it is plausible that thermal injury and systemic physiological stress caused by the burns may have led to death before COHb levels could reach higher concentrations. Therefore, the lower COHb levels observed in these cases indicate that death may have occurred earlier due to the combined effects of burns and CO exposure, rather than from CO alone.

Similar to our findings, other studies in the literature have reported that the most common sources of carbon monoxide in multi-fatality incidents are coal-burning stoves or coal fires ignited in open containers used for heating purposes (17, 18, 21). Key contributing factors include the presence of multiple individuals in enclosed living spaces such as houses or tents, and the fact that carbon monoxide is colorless, odorless, and non-irritating—making it difficult to detect before symptoms occur. Notably, the likelihood of exposure occurring during sleep further increases the risk of simultaneous poisoning among multiple individuals, helping to explain the occurrence of such fatal clusters.

In our study, cherry-red or bright red-pink lividity was observed in the vast majority of carbon monoxide–related deaths, and similar discoloration was frequently noted in the blood, muscles, and internal organs. In contrast, soot deposits in the respiratory tract and esophagus were observed in a more limited number of cases. These findings are largely consistent with the existing literature. For instance, a study by Nielsen et al. reported cherry-red livor mortis in 73.6% of cases, while another study from Trabzon, Türkiye noted similar discoloration and internal organ hyperemia in over 80% of cases (16, 28). Although such color changes are considered important diagnostic clues in carbon monoxide poisoning, they are not specific findings. As noted in previous reports, similar discoloration may also be seen in cases of hypothermia, cyanide poisoning, postmortem cooling, or when the body is covered with wet clothing (9). Likewise, the presence of soot in the nostrils, mouth, trachea, or bronchi—often encountered in individuals exposed to smoke inhalation—does not, on its own, confirm CO poisoning. The absence of soot does not necessarily indicate death prior to the onset of fire, and its presence merely demonstrates that these anatomical regions were exposed to smoke, not that death resulted from carbon monoxide toxicity (9). Therefore, while macroscopic findings can support the suspicion of CO exposure, quantitative determination of carboxyhemoglobin remains the most reliable method for confirming the diagnosis (29).

In our study, the origin of the incident could not be determined in 17 out of 105 carbon monoxide–related deaths. However, among the 88 cases with known origins, 80.9% were attributed to preventable causes. This finding highlights that the majority of CO-related deaths are, in fact, avoidable. In line with previous literature, most of the

CO sources identified in our study were solid-fuel stoves. Regular inspection of heating devices and fuels, ensuring proper ventilation and chimney systems, and increasing public awareness about safe usage are essential strategies for preventing such poisonings. Carbon monoxide detectors can serve as effective secondary prevention tools, particularly in enclosed spaces, by providing early warnings (30). Promoting their use through legal regulations in both residential settings and public spaces could significantly reduce the number of incidents. In contrast, in temporary or high-risk shelters such as tents or rural cabins, where technical infrastructure may be lacking, increasing individual awareness becomes even more critical. In this context, age specific educational programs, curricular integration in schools, and sustained media-based awareness campaigns could all contribute to fostering a broader culture of prevention across society.

Limitations

This study possesses multiple limitations intrinsic to its retrospective design. The precision and comprehensiveness of data are dependent upon the quality of autopsy reports and forensic investigation records, which may differ among cases. Specifically, information concerning the duration and circumstances of CO exposure, along with the existence of preexisting chronic conditions, was not readily available for all subjects. Moreover, the study was performed in a singular forensic institution within a defined geographic area, potentially constraining the applicability of the results to other populations or environmental settings. Despite these limitations, the study provides significant insights into the forensic attributes and public health implications of fatal carbon monoxide poisoning cases.

CONCLUSION

In conclusion, this study demonstrates that a significant portion of carbon monoxide–related deaths are preventable, with coal stoves and similar heating sources identified as primary risk factors. The inverse correlation between COHb levels and age/comorbidity status indicates that elderly and medically vulnerable individuals are at increased risk, even at lower exposure levels. From a forensic medicine perspective, CO poisoning should be considered in suspicious deaths occurring in enclosed spaces, particularly during winter months, and all potential CO sources (e.g., stoves, water heaters, grills) should be carefully examined during scene investigations. Routine COHb analysis is essential in autopsies, especially for deaths occurring in collective living spaces such as hotels or dormitories.

In terms of public health policy, enhancing individual awareness and promoting technical measures such as device maintenance, proper ventilation, and widespread use of CO detectors are critical. The mandatory installation of carbon monoxide detectors in all rental residences and temporary shelters, supported by public subsidies where necessary, is recommended. A multidisciplinary approach involving forensic, medical, and social collaboration is essential to reducing the burden of CO-related mortality.

Declarations

Conflict of Interest

The authors declare that they have no conflict of interest related to this article.

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