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Research Article

Analysis of forensic toxicology of carbon monoxide cases in Jeddah, Saudi Arabia

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Abstract
Carbon monoxide (CO) poisoning remains a leading source of morbidity and mortality across the world. It stems from the partial combustion of carbon-containing materials, and it can come from heating equipment, motor vehicle emissions, and the use of charcoal. CO poisoning in Saudi Arabia is most common during winter because of faulty heating equipment and lack of fresh air. Despite acknowledged public health significance, there is scarce case–specific forensic toxicological evidence of CO poisoning in Jeddah. The current study adopted a retrospective cross-sectional study involving data collected from the Jeddah Poison Control and Forensic Medical Chemistry Center from 2019 to 2021. Recorded data were derived from toxicology postmortem reports and the Forensic Toxicology Jeddah Reports & Requests Database. Descriptive analysis was used to determine the COHb level. Of the cases reviewed, fire had the highest COHb level at 60%, being above 50%, burning was 63%, and other sources other than fire, such as car exhaust and charcoal burning, were 59%. Seasonal trend COHb saturation levels were slightly higher during the autumn, summer, and winter months, with 41%, 39%, and 36%, respectively. Male cases were significantly higher in winter and summer, and females were in spring and autumn, with overall higher COHb levels in females. Most cases of CO poisoning incidents occurring in Jeddah were the outcome of fire accidents. Co-poisoning cases are well addressed by forensic toxicology, although better techniques are required. Therefore, public health measures, increased visibility, easier identification of cases, and better diagnostics are necessary components of combating CO poisoning in Jeddah.

Keywords: Carbon monoxide (CO) poisoning; forensic toxicology; carboxyhemoglobin (COHb); fire-related causes; burning incidents; non-fire sources; seasonal variation

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1. Introduction

Background Information

Carbon monoxide (CO) poisoning, which is known as the ''silent killer,'' is one of the leading modes of accidental poisoning all over the world and one of the most important sources of morbidity and mortality (Mureşan et al., 2019). This toxic gas, produced due to inadequate combustion of carbonaceous materials, is tasteless and odorless (Bleecker, 2015; Ouahmane et al., 2018). From a global view, sources of exposure to CO are associated with faulty heating and fridges, and automobiles: exhaust, industry emissions, and the use of charcoal. A study by Mattiuzzi and Lippi (2020) emphasized the fact that epidemiological literature points to worldwide apprehension about CO poisoning, and it revealed that it depends on geographical practices, climatic and the type of soil: factors, infective diseases, environmental conditions, and socio–demographic character. In Saudi Arabia, CO poisoning is accepted today as one of the growing health threats, even though it is more prominent during the chilly season because of the malfunctions in heating devices and inadequate ventilation systems. Al-Asmari et al. (2021) and Aldossary et al. (2015) described several CO-related

deaths in those cities and emphasized the need to enhance the existing prevention methods. Forensic toxicology is central in diagnosing and confirming CO poisoning, mainly through determining the COHb level (Prackop, 2007; Hampson, 2016); however, information is scarce concerning Jeddah.
Nonetheless, the sources and frequency of CO in Jeddah and its effects on people's health have not been studied in detail despite its global and regional representation. This knowledge of factors through forensic toxicology is crucial in reducing health risks, preventing occurrences of such cases, and offering up legal investigations. This research seeks to fill these gaps, highlighting the forensic and public health consequences of CO poisoning in Jeddah.

Statement of the Problem
According to the findings, carbon monoxide poisoning is a complicated healthcare and legal concern in Jeddah, Saudi (Aldossary et al., 2015). Although CO poisoning can be adequately diagnosed through carboxyhemoglobin analysis (COHb analysis), there needs to be more adequate information or data relating to the prevalence and contribution of forensic analysis for nonfatal incidents in Jeddah (Al-Asmari et al., 2021). Furthermore, the low level of the usage of other comprehensive diagnostic tools impedes the knowledge of prolonged neurological symptoms and other late complications of poisoning and the general health status of individuals after exposure (Al-Asmari et al., 2021). To address these research gaps, this study assessed the forensic toxicology data of cases related to CO poisoning, which is quite important for promoting public health and shaping health policies.

Research Objective
To establish the usefulness of forensic toxicology in identifying the cause and prevalence mortalities and injuries caused by exposure to CO poisoning in Jeddah

Research Question
What is the usefulness of forensic toxicology in determining the cause and prevalence of mortalities and injuries associated with CO poisoning in Jeddah?

Significance of the Study
The research is relevant because the topic of study has not received adequate attention – carbon monoxide poisoning in Jeddah, Saudi Arabia. It has a positive aspect in terms of the identification of trends, origin, and impacts of CO poisoning through the analysis of forensic toxicology results. The results will facilitate the process of adopting public health policies of non-toxicity when utilizing such appliances by regulating the receipt of appliances into homes and raising awareness among the public. Further, this study presents a far superior meaning about the forensic approach and sufficient analytical procedures like the integration of COHb along with the estimation of TBCO. Understanding derived from this study will also be useful for legal and forensic purposes since it will be possible to provide objective data on the difference between accidental and intentional cases of CO poisoning. Therefore, this study aims to produce more effective clinical and preventive interventions that can eventually lead to the reduction of the morbidity and mortality attributable to CO poisoning in Jeddah.

2. Literature Review
Carbon monoxide is one of the most common causes of accidental poisoning, whose forensic and health impacts are alarming. Also known as 'the silent killer,' CO is an invisible, non-colorful, tasteless, and non-odorous gas formed by incomplete combustion of carbon-containing items and, as such, is present in many homesteads and working places (Mureşan et al., 2019; Al-Matrouk et al., 2021). Hence, in forensic toxicology, identification and quantization of total carboxyhemoglobin (COHb) levels in the blood are crucial for the identification of CO and its levels causing death (Rose et al., 2017; Can et al., 2019). As a case study of CO poisoning, this review aims to assess the applicability of forensic toxicology in analyzing such cases. It reviews the incidence of reported cases as well as the primary source and way in which forensic approaches are applied to validate the identified cases, besides pointing out the possible gaps in knowledge that need to be closed in the future to enhance understanding as well as reduce the occurrence of the disease.

Major Sources of Carbon Monoxide Exposure
Hazardous gas poisoning, particularly carbon monoxide (CO), is mainly responsible for household-related accidents, followed by heating systems and inadequate ventilation in Jeddah. In their antemortem forensic analysis, Al-Asmari et al. (2021) found that CO emanation from malfunctioning domestic appliances remained the most common in Jeddah, particularly in the colder periods when household heating appliances are in frequent use. Aldossary et al. (2015) have also noted the major role of local sources in CO poisoning in Dammam, indicating the regional danger of both improperly serviced and incorrectly installed appliances. In other areas, the poisoning is caused by automobile exhaust and industrial release of poisonous gas. In a similar study in Portugal by Costa et al. (2019) and in Greece by Stefanidou et al. (2012), it was realized that the main cause of exposure to CO in such areas was vehicular emission within the urban areas.
Moreover, Ruas et al. (2014) highlighted threats associated with the use of charcoal, especially when the place is lightly ventilated, which is the case in some states like Saudi Arabia. Some families in the culture use charcoal for cooking, heating, and stirring indoors; this raises the risks of exposure to carbon monoxide. In Saudi Arabia, it has become worse since cultural practices dictate that such spaces are enclosed spaces within households. The study makes scientific evidence of the household and domestic sources of CO poisoning, but industrial and automobile emissions remain unknown in Jeddah. Consequently, there is a need for more in-depth research, which will allow for the collection of more detailed information concerning the threat of CO

exposure in the city and will allow the development of more specific preventive activities.

Carbon Monoxide Poisoning Cases Identified Through Forensic Analysis

CO remains one of the most dangerous factors affecting the health of people all over the world regarding the level of morbidity and mortality indicators. A cross-sectional study by Al-Asmari et al. (2021) is a forensic autopsy-based CO death investigation from Jeddah for three years. The study also paid much attention to carboxyhemoglobin (COHb) levels, where any concentration above 50%, and it was noted that this was a good predictor of fatal poisoning due to exposure to carbon monoxide. Out of all the findings stated in the report, most of the incidences occurred in places with bad ventilation or backward heating systems, particularly when it was cold. The same trends have been depicted in other regions of Saudi Arabia and affirmed by Aldossary et al. (2015) as well as Attaia et al. (2020) in the Dammam and Alqurayyate regions where advancement in winter is attributed to the elevated utilization of heating gadgets and CO poison occurrences. These studies conclude that leaders and environments are potential causes of CO poisoning. In Taiwan, Huang et al. (2017) argue that CO exposure is caused by the same process of urbanization and heating as found in Saudi Arabia, as do Li et al. (2015) in China. Inadequate research or intermittent forensic examinations hinder the possibility of detecting trends in time or designing properly targeted actions (Fan et al., 2019; Xiao et al., 2022; Ata et al., 2024). Thus, controlling this public health challenge requires the combined use of capacity development in local reporting systems, as well as good research.

Role of Forensic Toxicology in Confirming Cause of Death or Injury

CO Poisoning is best diagnosed through forensic toxicology with reference to Carboxyhemoglobin (COHB). COHb concentrations have been found to be optimal in detecting persons with CO poisoning; a level of COHb greater than 50 percent proves that the person was poisoned fatally by the substance, according to Al-Asmari et al. (2021). Besides COHb, there is the routine indication for the measurement of TBCO, which Oliverio and Varlet (2020 recognized) to enhance exposure diagnostic precision because, in contrast to infused doses, TBCO in conjunction with COHb would provide a broader view into doses that entered the body. Besides, other sophisticated techniques such as spectrophotometry and gas chromatography, expounded by Ohmori et al. (2019) and Janík et al. (2017), have also been advanced as regards the efficiency and reliability of toxicology testing. Besides proving the existence of CO exposure, forensic toxicology has an evident meaning in identifying whether it has been suicidal or accidental (Sircar et al., 2015; Liu et al., 2021). For example, Nielsen (2014) suggested that there is a requirement for forensic investigation in cases of charcoal burning, even if such cases could be out of homicide or suicide. Zhang et al. (2021) and Kitamoto et al. (2016) pointed out that delayed neurological sequelae are a clinical reality that has a forensic implication with regard to the period and the origin of CO poisoning, the diagnosis of which can be a challenging examination of blood samples in reference to Carboxyhemoglobin (COHB). Al-Asmari et al. (2021) identified COHb concentrations as ideal for identifying CO poisoning, where a concentration above 50% is evidence of a fatal poison dose. In addition to COHb, Oliverio and Varlet (2020) proposed using the measurement of total blood carbon monoxide (TBCO) to increase the diagnostic accuracy of exposure, as TBCO testing in combination with COHb would provide a more detailed perspective in doses that ultimately reached the body

Furthermore, Ohmori et al. (2019) and Janík et al. (2017) described complex testing methods like spectrophotometry and gas chromatography, with the sole purpose of enhancing accuracy and credibility of toxicology testing. In addition to establishing the fact of CO exposure, forensic toxicology has an undoubted meaning in differentiating between intentional or accidental poisoning (Sircar et al., 2015; Liu et al., 2021). For instance, Nielsen et al. (2014) pointed out that there is a need for forensic examination when dealing with cases of charcoal burning, despite the fact that such cases could just be owing to homicide or suicide. A study by Zhang et al. (2021) and Kitamoto et al. (2016) revealed that delayed neurological sequelae are a clinical entity that has a forensic significance when it comes to the timeline and the cause of CO poisoning, whose diagnosis may be hampered. In Jeddah, lacking developed toxicological practices hampers comprehension of non-fatality and health sequelae of CO exposure. To date, there is little research investigation on the effects of delayed brain damage and other neurological consequences or injuries from sub-lethal levels of CO poisoning, thus lacking in forensic literature (Bidaki et al., 2020). Enhancing the utilization of contemporary toxicological methods is crucial for improving the precision of diagnosis and the formulation of intervention strategies regarding public health issues within the area.

Research Gaps

The above review revealed important gaps of knowledge regarding the occurrence of CO poisoning cases. First, there needs to be more coordinated local descriptive epidemiological surveys to determine the prevalence and sources of exposure to carbon monoxide poisoning. Second, while it is well-understood that levels of carboxyhemoglobin are related to levels of exposure to CO, local practices exceedingly rarely incorporate additional sophisticated biomarkers like TBCO. Finally, not enough attention is paid to non-fatality cases and complications – these are nitty-gritty essential when it comes to the effects of CO poisoning, plus the main intent of developing strategies for its prevention. When research fills these gaps and forensic methods advance, the resulting information helps improve the nation’s health and legal endeavors.

3. Methodology

Research Design and Setting

This research used a retrospective cross-sectional chart review system to study the cases of carbon monoxide poisoning in Jeddah between 2019 and 2021. A retrospective research design was used to analyze patterns and trends in previously reported cases to understand the position of forensic toxicology in establishing CO-related deaths. For this study, only cases treated at the Jeddah Poison Control and Forensic Medical Chemistry Center (JPCC) were considered, as they are the most crucial facilities that conduct forensic tests in the area. This setting was chosen because of complete toxicological information and connection with CO poisoning cases. This study focused on this institution with the belief that it would provide detailed specifics of the postmortem cases and the methods that are used in this institution to ascertain CO poisoning as a cause of death positively.

Data Collection

Information was gathered from two main sources. The first was the postmortem records of JPCC, which comprised data on COHb and other toxicological results. The second was the Forensic Toxicology Jeddah Reports and Requests Database (FTRJ), a collection of documents and cases maintained by the Ministry of Health of the Kingdom of Saudi Arabia. This database offered further demographic, clinical, and toxicological data for each case to optimize the assessment.

Data Analysis

The collected data were analyzed descriptively. Microsoft Excel was used to assess trends in CO poisoning. Any sample with COHb levels higher than 5% saturation was deemed to have COHb, meaning possible CO toxicity. It was used to label the cases of death attributable to or associated with CO exposure as "CO poisoning." Results were generalized to point out diagnostic trends and possible deficiencies in forensic toxicology procedures.

4. Results

A total of 170 postmortem samples tested positive for COHb and accounted for about 4.1 percent of the autopsy cases done at the hospital during the study period. The average mortality rate from CO poisoning was equivalent to 0.346 per 100,000 persons in Jeddah, and the mortality trend in Jeddah matched that of the period. On average, the frequency of CO-related postmortem case estimates was between 12- 14.2 per year. Thus, the results presented below show that CO poisoning is a non-epidemic phenomenon in this region and underlines the problem in question as one of health concern. The findings indicate the necessity of using preventive measures and improving the quality of forensic work regarding CO-caused deaths.

Forensic Toxicology of the Sources of Carbon Monoxide Poisoning Cases and Deaths in Jeddah

Table 1: Distribution of CO Poisoning Sources

		Distribution of CO Poisoning Sources		
Sources of CO poisoning			**N=97**	**COHb(%)**
	Fire	CO_{Hb}(%) Greater than 50%	43	60.00%
		CO_{Hb}(%) Between 30% and 50%	36	39.00%
		CO_{Hb}(%) Less than 30%	18	18.00%
			N=54	**COHb(%)**
	Burning	CO_{Hb}(%) Greater than 50%	20	63.00%
		CO_{Hb}(%) Between 30% and 50%	18	42.00%
		CO_{Hb}(%) Less than 30%	16	17.00%
			N=73	**COHb(%)**
	Non-fire (Car exhaust, Charcoal briquettes, Heat Stroke, Smoking, Postmortem formation, etc)	CO_{Hb}(%) Greater than 50%	18	59.00%
		CO_{Hb}(%) Between 30% and 50%	4	40.00%
		CO_{Hb}(%) Less than 30%	51	11.00%

As given in Table 1 above and Figure 2 below, the distribution of different sources of carbon monoxide (CO) poisoning is measured by COHb saturation level in Jeddah. As shown, three major categories of CO poisoning in Jeddah were identified, and they include fire, burning, and non-fire related (such as car exhaust, charcoal briquettes, heat stroke, smoking, and postmortem formation). From the fire-related sources, it was established that fire accounted for the largest proportion of deaths (60%) with COHb above 50%, while 39% and 18% of the cases had COHb of 30–50% and less than 30% respectively. In burning cases (N = 54), the level of COHb also indicated a substantial percentage of subjects with COHb > 50%, accounting for 63% as opposed to 17 % COHb below 30%. Non-fire sources (N=73), such as car exhaust, charcoal briquettes, and heat stroke, had a smaller number of cases with more than 50% COHb (59%) compared to fire and burning, and fewer cases less than 30% COHb. This gives insight into the different exposure levels in the different source types, with burning being considered the greatest contributor to CO poisoning cases in Jeddah.

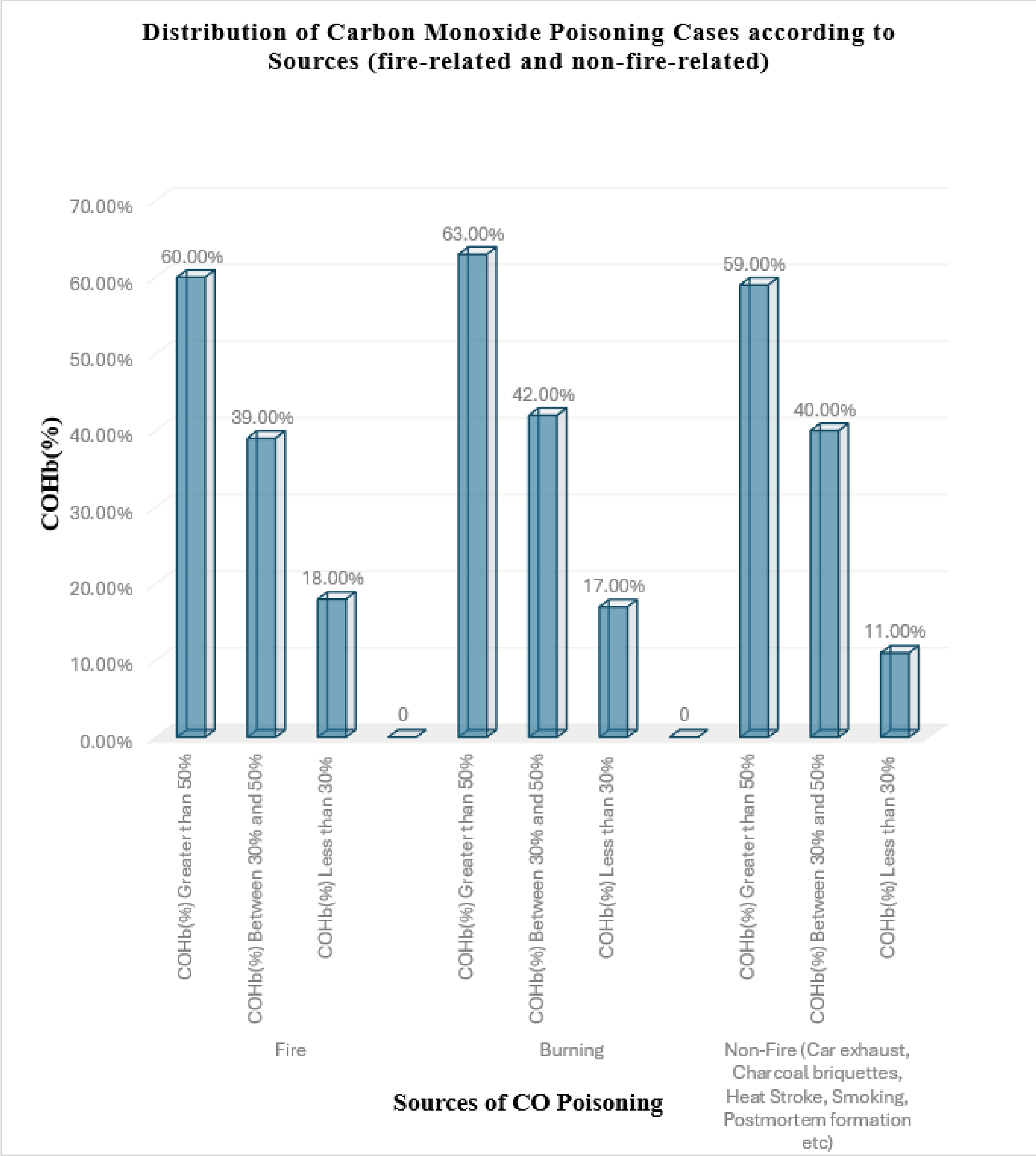

Figure 1: *Sources of carbon monoxide poisoning in Jeddah*

Table 2: Distribution of CO Poisoning Cases by Gender and Season

			Male		Female	Total Cases	
Season		**N**	**COHb%**	**N**	**COHb%**	**N**	**COHb%**
	Winter	23	46%	11	29%	34	36%
	Spring	40	26%	18	56%	58	30%
	Summer	23	39%	4	32%	27	39%
	Autumn	36	37%	15	48%	51	41%

As given in table 2 above details seasonal fluctuations in cases of CO poisoning by gender as well as by levels of COHb. As shown, 41% and 39% cases of CO poisoning were recorded during Autumn and Summer respectively while Winter (36%) and Spring (30%) accounted for the least number of CO poisoning cases respectively. During the summer, there were 27 cases, of which 23 cases were male patients, and the mean COHb level in summer (39%) was slightly higher compared to females (32%). During the autumn, 51 cases were reported, out of which males accounted for 37% of the COHb while the females accounted for 48% of the COHb.

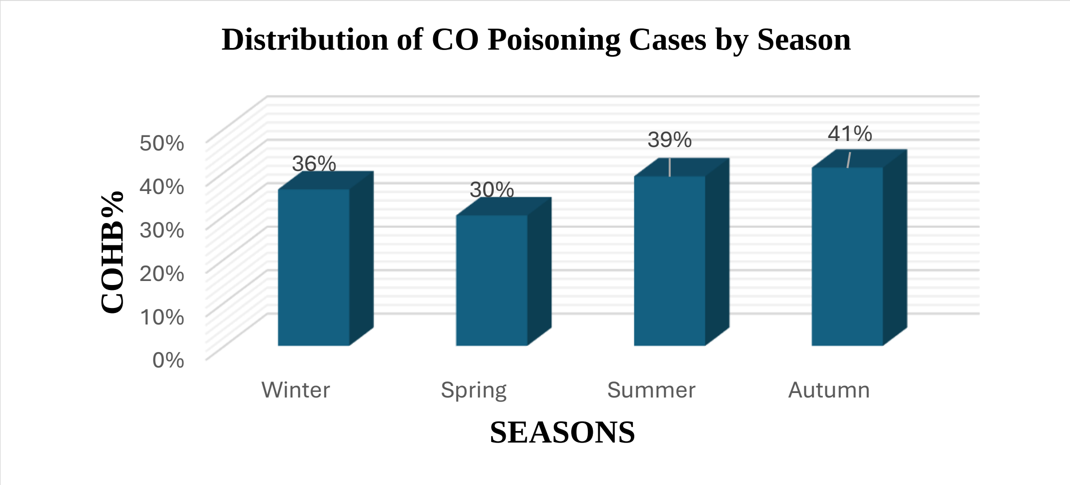

Figure 2: *CO Poisoning Cases by Season*

The bar chart (figure 2) shows the proportionality of CO poisoning cases by saturation percentages of COHb for the seasonal period. The average COHb level in organisms was determined by seasons: Autumn had the highest levels – 41%, followed by Summer (39%), Winter (36%) and finally Spring (30%). The discovered differences indicate certain trends: the elevation of the COHb level in the autumn and summer may result from specific seasonal factors, such as the utilization of heating or cultural practices during the cold or the transitional seasons. Winter also caused high COHb levels, which were presumably related to heating systems. Seasonality is evident in CO poisoning rates, with increased risks occurring during the winter seasons and vice versa during early Spring, thus calling for specific protective actions during colder seasons.

5. **Discussion**

The study establishes that CO poisoning in Jeddah arises from fire and other related causes, such as burning and fireless causes like car engine exhaust and charcoal briquettes. Most fire-associated incidents had COHb levels above 50%; in fact, COHb levels of 50% or above were present in 60% of those who died, as carbon monoxide exposure poses a death risk during fires. Burning incidents also resulted in raised COHb concentrations, with 63% of the cases above 50%. However, non-fire related deaths, though less overall, presented significant risk; 59 of the cases had COHb over 50%. These findings are also consistent with other research findings in other parts of the world. For example, Ruas et al. (2014) stressed the dangers of using charcoal in enclosed rooms, which is a cultural practice among families in KSA.

There was a clear cyclical trend with a slight elevation in COHb concentration in autumn and summer (41 percent and 39 percent, respectively) as compared to winter and spring (36 percent and 30 percent, respectively). Male cases were higher during winter and summer, maybe because of higher outdoor exposure and contact with heating systems, while females showed higher COHb percent during spring and autumn. These trends are similar to those identified by Al-Asmari et al. (2021), which attributed CO exposure in Jeddah to heating devices during winter months, as found in a previous study in Dammam by Aldossary et al. (2015). Internationally, the same phenomena were detected, too, particularly during the summer period. In Taiwan, Huang et al. (2017) concluded that CO poisoning is related to urbanization and heating, while Li et al. (2015) in China arrived at a similar conclusion—nonetheless, the minimum of studies on industrial and vehicular emissions in Jeddah hampers comprehension of their contribution.

The use of forensic toxicology is very important in establishing that CO. Drawing poisoned the victim from COHb levels, Al-Asmari et al. (2021) quantified fatal poisoning, encountering the 50% COHb threshold as legitimate. In their study, Oliverio and Varlet (2020) proposed the utilization of TBCO to improve diagnostic capability. Although some of the more sophisticated methods, such as spectrophotometry and Gas chromatography (Ohmori et al., 2019), enhance the accuracy of the tests, the use of such methods still needs to be improved in Jeddah. This limitation makes it difficult to differentiate between accidental deaths and intentional cases and to identify the delayed effects, such as neurological injuries months or years after the incident, as discussed by Zhang et al. (2021). The results of this study implicate the importance of improving procedures in forensic toxicology, better reporting CO cases locally, and developing specific approaches to eliminating CO poisoning in Jeddah effectively.

6. **Conclusion**

Carbon monoxide poisoning is still common in Jeddah and secondary to fire-related and burning causes and other non-fire causes such as exhaust from cars and the use of charcoal briquettes for cooking. From the study, the authors pointed out that there was a seasonal variation of the exposure to them with higher levels of COHb observed mostly in the Autumn and Summer, possibly due to cultural reasons and climatic conditions. Of the cases mentioned, the highest levels of COHb were detected in fire-related circumstances, indicating that exposure during a fire is deadly. The study also underlines the need for forensic toxicology since the COHb level above 50%Hb is considered to be lethal.

Nevertheless, restricted access to enhanced diagnostic technology in Jeddah restrains a general appreciation of a situation since it relates to not fatal cases and following neurological complications. There is a continued call for better CO poisoning prevention, such as Improvement of forensic procedures in CO deaths, reporting of CO cases, and public health measures, especially in the cold season, that can help to reduce needless loss of lives and incidences of the condition.

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