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Biochemical parameters and clinical outcomes of carbon monoxide poisoning in special groups: children, pregnant women, and the elderly

A. VURAL[1], T. DOLANBAY[1], M. OZÇELIK[1], Z.Y. OZTORUN[2], N. ARDIC[3], A.B. VURAL[1], M.C. ALTAY[1]

[1]Emergency Medicine, Niğde Ömer Halisdemir University School of Medicine, Niğde, Turkey
[2]Pediatrics, Niğde Ömer Halisdemir University School of Medicine, Niğde, Turkey
[3]Obstetrics and Gynecology, Niğde Ömer Halisdemir University, School of Medicine, Niğde, Turkey

Abstract. – OBJECTIVE: Carbon monoxide (CO), a toxic gas, poses a significant threat to human health. Children, pregnant women, and elderly individuals are particularly vulnerable to this toxicity. This study aims to evaluate the demographic and clinical characteristics of pediatric, pregnant, and geriatric patients.

PATIENTS AND METHODS: The study included pediatric, pregnant, and geriatric patients with a confirmed diagnosis of CO poisoning, excluding those with complete file data and those with carboxyhemoglobin (COHb) levels below 5% (for children and pregnant patients) and 10% (for elderly patients). Patients aged < 18 years, > 65 years, and pregnant patients admitted to the adult and pediatric emergency departments were included in the study; statistical analyses were conducted using SPSS Inc., with a p-value of < 0.05 considered statistically significant.

RESULTS: For pediatric patients, a statistically significant difference was observed between the two groups in terms of their main complaints, which were primarily attributed to neurological and general symptoms. A positive correlation was found between follow-up time and several factors, including white blood cell (WBC) count and troponin, lactate, lactate dehydrogenase (LDH), and COHb levels. For pregnant patients, no in-hospital mortality was observed in the patients included in this study. A significant negative correlation was identified between age and both COHb and hemoglobin (Hb) levels. A strong positive correlation was found between the COHb levels and hospital follow-up time. For elderly patients, no significant differences were found between the two treatment modalities. Notably, higher COHb levels on admission were associated with a more fatal in-hospital course, with COHb levels > 40% of all patients requiring intubation.

CONCLUSIONS: Vulnerable populations are at increased risk of exposure to CO, and the study results emphasize the necessity of heightened awareness and preventive measures to safeguard these individuals from CO poisoning.

Key Words:
Carbon monoxide (CO) poisoning, Children, Clinical outcome, Pregnant women, Elderly, Hyperbaric oxygen (HBO), Normobaric oxygen (NBO), Mortality.

Introduction

Carbon monoxide (CO) is a gas that is difficult to detect because of its lack of color and odor[1]. Despite its deceptive appearance, CO is highly toxic and poses a serious threat to human health. It is primarily produced through the incomplete or inadequate combustion of organic matter[1,2]. CO toxicity arises from the ability of CO to displace oxygen molecules in the oxygen transport system of the body when inhaled. CO binds to hemoglobin more readily than oxygen, reducing the capacity of the blood to transport oxygen to tissues and organs, causing global hypoxia[3]. The heart and brain are particularly vulnerable to hypoxia because they are highly oxygen-dependent and sensitive[4]. Although tissue hypoxia plays a significant role in the toxic effects of CO, it is not the sole mechanism through which CO exerts its toxicity. CO also causes oxidative stress, inflammation, endothelial dysfunction, and mitochondrial dysfunction[5-7].

The relationship between hypoxia, oxidative stress, and inflammation has been identified as a possible contributor to the aging process and the emergence of age-related diseases[8]. Consequently, the three pathophysiological events that

Corresponding Author: Abdussamed Vural, MD; e-mail: abdussamedvural@gmail.com; abdussamedvural@ohu.edu.tr

occur in elderly individuals with CO poisoning are of great significance. In non-smokers, the carboxyhemoglobin (COHb) ratio generally does not exceed 5%; however, in smokers, the ratio can increase to 10%[9,10].

The manifestations of hypoxia can vary depending on the severity and duration of CO exposure[11]. The symptoms associated with CO poisoning are non-specific and can range from mild effects such as dizziness and headaches to more severe consequences, including loss of consciousness and, in extreme cases, fatality[12]. Children, pregnant individuals, and the elderly are particularly vulnerable to the cardiovascular and neurovascular effects of CO exposure[13,14]. A report[15] from the United States National Poison Data System in 2020 revealed that a quarter of single CO exposures occurred in children and adolescents under the age of 20. Furthermore, the risk of fatality increased with age, highlighting the importance of preventive measures to avoid CO poisoning[16].

The binding affinity of CO to fetal hemoglobin is greater than its affinity for adult hemoglobin. As a result, the levels of CO in fetal or neonatal blood are higher than those in maternal blood, which increases the risk of toxicity. Additionally, in pregnant patients, even when maternal CO levels are not toxic, the elimination time of CO gas between the mother and fetus is approximately five times longer, suggesting that the fetus is at risk of hypoxia[17].

For individuals suspected of or diagnosed with CO poisoning, prompt initiation of treatment is recommended by providing high-flow (100%) normobaric oxygen (NBO) through a non-rebreathing face mask. The half-life of COHb in a person breathing normal air is estimated to range from 250 to 320 min. However, when a patient receives high-flow oxygen at a rate greater than 15 L/min through a non-rebreathing mask, the duration is reduced to 75-90 min[18]. Hyperbaric oxygen therapy (HBOT) is a topic of ongoing debate, and there is currently no conclusive evidence regarding its use in children. However, scholars[19] have suggested that this treatment may be beneficial in preventing delayed neurological sequelae (DNS) in pediatric patients. Current data on pregnant individuals experiencing CO poisoning and the effectiveness of HBOT is limited. Nonetheless, it is advisable for these individuals to receive HBOT, particularly when therapy is likely to lead to optimal outcomes[20]. It is crucial to note that HBOT is primarily suggested for severe cases of CO poisoning accompanied by complications such as pregnancy-related issues, neurological or cardiac manifestations, or significant acidosis[21].

This study aimed to conduct a retrospective analysis of the demographic, clinical, and biochemical characteristics of special populations, including children, pregnant women, and the elderly, who were admitted to our adult and pediatric emergency departments for CO exposure. This study aimed to increase knowledge of the demographic and clinical profiles of these patients, to provide valuable insights into the management of CO exposure in these populations, and to develop strategies to prevent CO exposure.

Patients and Methods

Study Design

This retrospective observational study was conducted with the aim of analyzing data from pediatric, pregnant, and elderly patients who were diagnosed with acute CO poisoning and admitted to Niğde Ömer Halisdemir Training and Research Hospital between November 1st, 2021, and July 1st, 2023. The study was conducted in accordance with the Declaration of Helsinki, as revised in 2013, and was approved by the Non-Interventional Ethics Committee of Niğde Ömer Halisdemir University Faculty of Medicine dated (24/08/2023 and numbered 2023/54). Permission to use patient data was granted by the ethics committee. However, due to the retrospective design of the study, the requirement for informed consent was waived.

Patient Selection

The data used in this study were obtained through the hospital's automation system, Karmed, and recorded using an Excel-based dataset. This dataset contained demographic information, including age and sex, as well as clinical details, such as the season and month of admission, source of exposure, administered treatments, discharge status, total follow-up time, and in-hospital mortality. Additionally, this study evaluated whether neurologic and cardiologic complications developed after exposure to carbon monoxide (CO) in elderly patients. This study also assessed in-hospital mortality and clinical outcomes at 1 and 3 months. The prognosis was based on whether the elderly patients were diagnosed with cardiac diseases, such as acute coronary syndrome, arrhythmia, and heart failure. The study also analyzed cognitive deficits, motor disorders, hallucinations, depression, and clinical symptoms resembling Parkinson's disease, as well as diagnoses of neurovascular disorders such as stroke or transient ischemic attack. The clinical outcomes of patients who received normobaric oxygen (NBO) and hyperbaric oxygen (HBO) therapy were compared. Laboratory findings, including COHb levels upon admission, cardiac markers such as troponin, creatine kinase (CK), creatine kinase myocardial band (CK-MB), lactate dehydrogenase (LDH), liver and kidney function test results, hemogram values [white blood cell count (WBC) and hemoglobin levels], and blood gas parameters [pH, bicarbonate (HCO_3), and lactate] were also examined. All patients were administered 100% oxygen using non-rebreathing face masks until they achieved an asymptomatic status and their COHb levels decreased below 5%. In the case of pregnant patients, obstetric consultation was sought for fetal evaluation, and all pregnant patients underwent non-stress testing.

Inclusion Criteria

This study included pediatric, pregnant, and elderly individuals with a verified diagnosis of the toxic effect of carbon monoxide (T58) as determined by the International Classification of Diseases-10 (ICD-10) code. Eligible participants were aged < 18 or ≥ 65 years and were admitted to either the adult or pediatric emergency department of our third-level hospital.

Exclusion Criteria

Patients who lacked data in our hospital's automation system or had erroneous diagnostic codes were excluded from the study. Furthermore, individuals whose medical records could not be retrieved retrospectively or whose prognostic data remained ambiguous were also excluded. The study excluded pediatric patients with COHb levels < 5% and elderly patients with COHb levels < 10% to eliminate smoking bias. However, all expectant mothers with a history of CO exposure were included in the study for fetal assessment, regardless of clinical presentation or COHb level.

Statistical Analysis

For all patients

Qualitative categorical variables were expressed as numbers and percentages in the descriptive statistics. For quantitative continuous data, if they were normally distributed, they were expressed as mean and standard deviation (SD), and if they were not normally distributed, they were expressed as median and range (minimum-maximum). The Kolmogorov-Smirnov test was used to assess data normality. Pearson's Chi-square or Fisher's exact test was used for comparisons of categorical groups. Pearson correlation analysis was used for normally distributed continuous variables, and Spearman correlation analysis was used for non-normally distributed variables for correlation analysis. All data were analyzed at a 95% confidence level, and a p-value < 0.05 was considered statistically significant. Data were entered into an Excel database (Microsoft Office 2010, Redmond, WA, USA), and statistical analyses were performed using SPSS (IBM SPSS Statistics Version 22, SPSS Inc., Armonk, NY, USA).

For elderly Patients

In this study, patients were further divided into two subgroups based on their COHb levels and Glasgow Coma Scale (GCS) scores to compare late prognosis and in-hospital mortality. Correlation analysis using Spearman's correlation was conducted to assess the relationships between quantitative data.

Results

The results of this research are given separately for all groups.

Pediatric Patients

This study involved 57 pediatric patients who were selected based on predetermined inclusion criteria. The average age (in months) of these patients was 102.05 ± 58.51 years, with a female sex ratio of 52.6% (n = 30) and a male sex ratio of 47.4% (n = 27). Analysis of the seasonal distribution revealed that the peak frequency of admissions occurred during the winter months (Figure 1) (61.4%, n = 35). Moreover, it was observed that February, a single month, accounted for the highest frequency of admissions (47.4%, n = 27). The results of this study indicated that the primary source of exposure for poisoning was natural gas from water heaters and stoves, which accounted for 87.7% (50 cases) of the cases. Weakness, malaise, nausea, and vomiting were the most commonly reported symptoms, comprising 87.7%

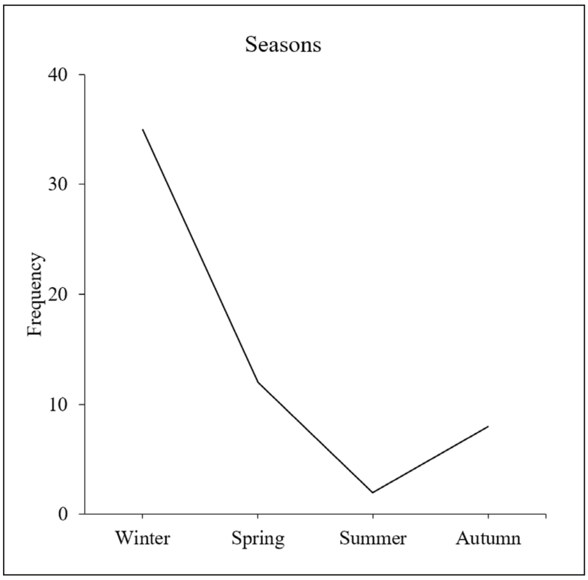

Figure 1. Seasonal distribution of acute CO poisoning in children.

of the cases. Additionally, five patients (8.8%) reported symptoms of chest tightness and pain, while two patients (3.5%) experienced altered consciousness or syncope. Amongst the two patients, one had a GCS score of 14, while the other had a score of 13. Analysis of the qualitative data pertaining to HBOT and normobaric oxygen therapy (NBOT) for these individuals revealed no statistically significant differences in terms of age, sex, or mode of exposure ($p > 0.05$). Nonetheless, a statistically significant difference was observed between the two groups in terms of the main complaints. This difference was primarily attributed to neurological and flu-like symptoms, as indicated by the multiple Chi-square analysis ($p < 0.001$). The demographic and clinical data of the patients are provided in Table I. Of the entire patient population, four individuals (7%) were sent to an external center that possessed the closest hyperbaric oxygen unit for HBO treatment. When we excluded patients who were referred for HBO treatment from the calculation, the emergency discharge rate was 91.2%. The average length of in-hospital follow-up was 7.57 ± 5.34 days.

When comparing the length of in-hospital follow-up based on the treatment received, a statistically significant difference was observed between the HBOT and NBOT groups ($p < 0.001$). Consequently, patients who underwent HBOT had a longer in-hospital follow-up period. However, in-hospital mortality was not observed among the patients included in this study. The correlations between the continuous variables of the patients are presented in Table II. According to the findings, there was a positive correlation between follow-up time and several factors, including WBC, tro-

Table I. Demographic and clinical characteristics of the patients.

Variables	Patients with CO poisonings (n = 57)			*p*-value
	Total (*n* = 57) n (%)	HBOT (*n* = 4) n (%)	NBOT (*n* = 53) n (%)	
Gender; n (%)				
Male	27 (47.4)	3 (75)	24 (45.28)	0.33*
Female	30 (52.6)	1 (25)	29 (54.72)	
Age (months); mean (SD)	102.05 ± 58.51	103.25 ± 60.57	101.96 ± 58.95	0.96**
¶Main symptoms; n (%)				
Cardiac	5 (8.8)	2 (50)	3 (5.66)	
Neurological	2 (3.5)	2 (50	0 (0)	**<0.001***
Flu-like	50 (87.7)	0 (0)	50 (94.34)	
CO source; n (%)				
Water heater- natural gas	26 (45.6)	2 (50)	24 (45.28)	
Stove	7 (12.3)	2 (50)	22 (41.5)	0.578*
Smoke	24 (42.1)	0 (0)	7 (13.22)	
In-hospital mortality				
n (%)	0 (0)	0 (0)	0 (0)	Constant
Total, n (%)	57 (100)	4 (100)	53 (100)	

¶Multiple Chi-square analyses were performed. The statistical significance between HBOT and NBOT is due to patients' neurological and flu-like symptoms. *Fisher's exact test, ***t*-test. HBOT: hyperbaric oxygen therapy; NBOT: normobaric oxygen therapy; CO: carbon monoxide; SD: standard deviation.

Table II. Correlation analysis of the laboratory values in pediatric patients.

	Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Age month	1													
2	Follow duration	-.028	1												
3	COHb (%)	-.132	.319*	1											
4	pH	-.077	-.292*	-.183	1										
5	HCO_3- (mmol/L)	0.155	-.115	-.101	.320*	1									
6	Lactate (mmol/L)	-.153	.531**	.454**	-.579**	-.320*	1								
7	LDH (U/L)	-.175	.407**	.070	.221	-.154	.214	1							
8	WBC (x10^3 cells/uL)	-.398**	.464**	.100	.008	-.203	.366**	.550**	1						
9	Troponin (ng/L)	.031	.420**	-.008	-.291*	-.259	.342**	.191	.390**	1					
10	AST (U/L)	-.537**	.159	-.029	.091	-.269*	.179	.566**	.382**	.080	1				
11	ALT (U/L)	-.299*	.107	-.203	-.150	-.106	.155	.072	.239	.013	.457**	1			
12	Urea (mg/dl)	.087	.049	.098	-.160	.109	.125	.129	.048	.033	.089	.039	1		
13	Creatinine (mg/dl)	.644**	.179	.253	-.222	.139	.191	.052	-.058	.119	-.362**	-.083	.212	1	
14	Hemoglobin (g/dL)	.379**	-.043	-.084	.052	.126	-.182	-.142	-.331*	.020	-.344**	-.084	.049	.424**	1

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). WBC: white blood cell; AST: aspartate aminotransferase; ALT: alanine aminotransferase; LDH: lactate dehydrogenase HCO_3-: bicarbonate.

ponin, lactate, LDH, and COHb levels, with correlation coefficients of r = 0.464, $p < 0.001$; r = 0.420, $p = 0.001$; r = 0.531, $p < 0.001$; r = 0.407, $p = 0.002$; and r = 0.319, $p = 0.015$, respectively. Furthermore, a positive correlation was detected between COHb and lactate levels, with a correlation coefficient of r = 0.454, $p < 0.001$. There were also positive correlations between lactate and WBC, troponin, LDH, and aspartate aminotransferase (AST) levels, with correlation coefficients of r = 0.366, $p = 0.005$; r = 0.342, $p = 0.009$; r = 0.550, $p < 0.001$; and r = 0.560, $p < 0.001$, respectively. On the other hand, a negative correlation was observed between follow-up time and pH, with a correlation coefficient of r = -0.292, p=0.028. Finally, no significant correlation was detected between the GCS score and COHb levels ($p > 0.05$).

Pregnant Patients

This study included five pregnant patients with acute CO exposure. The median age of the pregnant patients was 23 years (range: 20-29 years). Upon examining the seasonal distribution, it was observed that the majority of admissions occurred during the spring season, accounting for 80% of the cases (n = 4), with March being the most common admission month, comprising 40.4% of the cases (n = 3). The primary cause of poisoning was stoves, accounting for 60% of cases (n = 3). All patients reported non-specific symptoms, such as weakness, malaise, nausea, and vomiting. No neurological or cardiological complaints were noted. Notably, two of the five patients exhibited COHb levels exceeding 15%.

The demographic and clinical data of the patients are summarized in Table III. All patients received NBOT, and the mean in-hospital follow-up time was 9.6 ± 2.6 hours. No in-hospital mortality was observed among the patients included in the study. Correlation analysis revealed a significant negative correlation between COHb and hemoglobin levels (r = -0.90, $p = 0.037$). Additionally, a strong positive correlation was found between the COHb levels and hospital follow-up time (r = 0.905, $p = 0.005$).

Elderly Patients

This study comprised 31 individuals, with an average age of 73.68 years and a sex distribution of 54.8% female. This demographic was selected according to the specific inclusion and exclusion criteria. Considering the seasonal distribution, the most frequent admissions were in the winter (45.2%, n = 14) and spring (45.2%, n = 14). The highest frequency of application occurred in January. It was also found that most poisonings were caused by stoves (77.4%, n = 22). Most of the complaints (80.6%, n = 25) of our patients presenting to the emergency department had flu-like symptoms. The rates of neurological and cardiologic complaints were 12.9% (n = 4) and 6.9% (n = 2), respectively. The median GCS score was 15 (3-15). However, among a total of 7 people

Table III. Demographic and clinical characteristics of the pregnant patients.

Variables	Total (n = 5)
Age, median (min-max)	23 (20-29)
Gestational week, median (min-max)	27 (11-37)
Number of pregnancies, median, (min-max)	2 (1-4)
Seasonal distribution, n (%)	
Winter	2 (40)
Spring	3 (60)
Main complaint, n (%)	
Weakness, malaise, nausea, vomiting	5 (100)
Neurological	0 (0)
Cardiological	0 (0)
Hospital follow-up time (hours), mean (SD)	9.6 ± 2.6
COHb level, median (min-max)	13.60 (2.7-17.9)
Treatment administered, n (%)	
NBO	5 (100)
HBO	0 (0)
In-hospital mortality	
No	5 (100)

COHb: carboxyhemoglobin; NBO: normobaric oxygen; HBO: hyperbaric oxygen; SD: standard deviation.

(22.5%) with a GCS score below 15, the median GCS score was 5 (3-14). The percentage of patients who required intubation in the emergency department was 16.5% (n = 5). Four patients (12.9%) underwent HBO. The in-hospital mortality rate was 12.9% (n = 4). The sociodemographic and clinical data of the patients are presented in Table IV.

In the present study, five of the 31 patients required intubation. Intubated patients were excluded from comparisons that analyzed the effects of HBOT and NBOT on prognosis. Consequently, there were no statistically significant differences in 1-month and 3-month mortality and neurologic and cardiologic poor outcomes between patients who received HBOT and those who did not (p > 0.05). No mortality was observed among the patients who survived after CO exposure. Regarding the 1-month clinical outcome, only 1 of 22 patients who received NBOT (4.55%) developed acute coronary syndrome (ACS) (p = 0.846). However, no instances of arrhythmia or heart failure (HF) were observed. Regarding the 3-month clinical outcomes, two patients (9.09%) were diagnosed with ACS (p = 0.711). No delayed neurological sequelae (DNS) were observed in the 1-month prognosis, and only one patient (4.55%) developed DNS at the 3-month follow-up (p = 0.846). Cerebrovascular disease (CVD) was detected in one patient (4.55%) at the 3-month follow-up (p = 0.846). No complications were detected in any of the 4 patients who received HBOT.

When the study groups (n = 26) were compared according to COHb levels (patients who were intubated in the hospital were excluded from the analysis) (group 1: ≥ 10% to < 25%, group 2: ≥ 25% to < 40%), no statistically significant difference was found for DNS, ACS, CVD, arrhythmia, and HF endpoints (p>0.05). In this study, patients were divided into two groups according to their GCS scores. According to the analysis (n = 31), in-hospital mortality was significantly higher in patients with a GCS score of < 15 than in those with a GCS score of 15 (p = 0.001). When the patients were divided into two groups, < 40% and > 40%, in terms of COHb levels (n = 31), it was found that patients with COHb levels of 40% and above had a significantly more fatal prognosis (p = 0.003). These associations are presented in Table V.

Table VI displays the correlation analysis results for patients' continuous variables. Accordingly, there was a negative correlation between COHb levels and pH (r = -0.534, p = 0.002), and a posi-

Table IV. The demographic and clinical characteristics of the elderly patients.

Variables (n = 31)		Frequency (n)	Percent (%)
Gender	Male	14	45.2
	Female	17	54.8
Age, year	Median (min-max)	72 (65-86)	
	Mean (SD)	73.68 (6.76)	
Place of residence	City	24	71.0
	Rural	7	29.0
Source of exposure	Stove	22	77.4
Application time (time)	Wakefulness (08:00-22:00)	13	41.9
	Early Stage of sleep (22:00-04:00)	8	25.8
	Late stage of sleep (04:00-08:00)	10	32.3
Chronic diseases	DM	9	29.0
	CAD	4	12.9
	CVD	3	9.7
	HF	1	3.2
	COPD	5	16.1
Intubation need	Yes	5	16.1
Main symptoms at admission ED	Neurological	4	12.9
	Cardiological	2	6.5
	Non-specific	25	80.6
Hyperbaric oxygen therapy indication status	Yes	18	58.1
Treatment	Normobaric oxygen (NBO)	22	71.0
	Hyperbaric oxygen (HBO)	4	12.9
	Intubation	5	16.1
In-hospital mortality	Yes	4	12.9

ED: emergency department; DM: diabetes mellitus; CAD: coronary artery disease; CVD: cerebrovascular disease; HF: heart failure; COPD: chronic obstructive pulmonary disease.

Table V. Clinical outcomes for elderly patients according to COHb, GCS, and treatment modalities.

Dependent variables		Endpoints	*p*-value
COHb (%), (n = 26)	≥ 10- < 25	3- month ACS	1.000
	≥ 25-40	3-month DNS	1.000
Treatment (n = 26)	HBO	3- month ACS	0.711
	NBO	3-month DNS	0.846
COHb (%), (n = 26)	≥ 10- < 25	In-hospital mortality	0.486
	≥ 25-40		
COHb (%), (n = 31)	< 40	In-hospital mortality	0.003*
	≥ 40		
GCS (3-15), n = 31	15		0.001*
	< 15		

*Fisher's exact test, *p*-value is significant at 0.05 level. ACS: acute coronary syndrome; DNS: delayed neurologic sequelae; GCS: glasgow coma scale; COHb: carboxyhemoglobin; NBO: normobaric oxygen; HBO: hyperbaric oxygen.

tive correlation between lactate, troponin, creatinin kinase myoglobin band (CKMB), WBC, AST, and creatinine (r = 0.615, $p = 0.003$; r = 0.385, $p = 0.035$; r = 0.490, $p = 0.006$; r = 0.493, $p = 0.007$; r = 0.388; $p = 0.035$, r = 0.49; $p = 0.006$). A negative correlation was also found between pH, troponin, and CKMB (r = -0.473; $p = 0.008$, r = -0.389; $p = 0.034$). Additionally, a positive correlation was found between lactate and troponin levels and WBC count (r = 0.473, $p = 0.013$; r = 0.504, $p = 0.009$). Finally, a positive correlation was found between WBC count and ALT levels (r = 0.402, $p = 0.031$).

Discussion

For Pediatric and Pregnant Patients

The importance of conducting thorough evaluations and providing treatment for CO poisoning is particularly crucial for both children and pregnant women. Children are at a higher risk of CO poisoning because of their elevated metabolic demands and limited ability to articulate their symptoms. For example, the research by Meo et al[22] revealed a strong connection between air pollution and cognitive dysfunction in students who attended a school located in a heavily polluted area with particular matter PM2.5, PM10, CO, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3). The study[22] showed that students attending a polluted school experienced impairments in attention, thinking, and decision-making skills compared with those attending a school without pollution. Pregnant women are also more susceptible to CO poisoning because of the strong affinity of fetal hemoglobin for carbon monoxide and the prolonged duration of its binding to hemoglobin[19].

Hospitalization for CO poisoning is necessary under various conditions. These include the persistence of clinical symptoms for up to four hours after the start of treatment, COHb levels exceeding 25%, the appearance of indicators suggestive of cardiac involvement, pregnancy, the presence of treatment-resistant metabolic acidosis, the occurrence of seizures, syncope, and rhabdomyolysis. If there are no established criteria for hospitalization or if there is a decrease or absence of complaints or symptoms after 4 hours of observation, it may be appropriate to discharge the child[23]. In this study, pediatric patients were monitored for an average duration of 6-8 hours. All patients who exhibited complete resolution of their symptoms and had CO levels < 5% following treatment were discharged to their homes.

Various methods have been investigated to determine the prognosis of pediatric CO poisoning. A study by Seçilmiş et al[24] found no significant correlation between COHb levels and clinical severity, GCS scores, or need for intensive care. However, high COHb levels, especially those exceeding 30%, have been associated with cardiac damage and neurological symptoms, although they do not cause permanent sequelae. Consistent with the literature, no significant correlation was found between prognosis and COHb levels in this study ($p > 0.05$). However, we found a significant correlation between COHb levels and the length of hospital stay in pregnant and pediatric patients (r = 0.975 and r = 0.319, respectively).

The need to administer HBO to children and pregnant women can be a topic of debate. While HBOT has shown potential benefits in CO poisoning, it is essential to carefully weigh the potential disadvantages, such as oxidative dam-

Table VI. Correlation analysis of the elderly patients' laboratory data.

Variables	COHb	Ph	Lactate	Troponin	CKMB	Hemoglobin	WBC	AST	ALT	Creatinie	Urea
COHb (%)	1,000										
Ph	-.534**	1.000									
Lactate (mmol/L)	.615**	-.544**	1.000								
Troponin (ng/L)	.385*	-.473**	.473*	1.000							
CKMB (ug/L)	.490**	-.389*	.259	.515**	1.000						
Hemoglobin (g/dL)	.066	.049	-.345	-.167	.089	1.000					
WBC (x10^3 cells /uL)	.493**	-.239	.504**	.252	.211	.086	1.000				
AST (U/L)	.388*	-.330	.276	.149	.624**	.119	.314	1.000			
ALT (U/L)	.261	-.161	.208	.044	.331	.362	.402*	.678**	1.000		
Creatinine (mg/dl)	.490**	-.301	.370	.359	.431*	.113	.167	.293	.067	1.000	
Urea (mg/dl)	.223	-.112	.192	.317	.374*	-.071	-.059	.151	.077	.646**	1.000

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed). COHb: carboxyhemoglobin; CKMB: creatinin kinase myoglobin band; WBC: white blood cell; AST: aspartate aminotransferase; ALT: alanine aminotransferase.

age, safety concerns in children, misconceptions about risks, and the need for more evidence on its use in pregnancy.

This cautious approach will seek to balance the potential benefits of HBOT with the severity of the condition and associated risks, ensuring that the therapy is administered judiciously, with the advantages outweighing any potential drawbacks. In this study, we performed HBOT on a total of four pediatric patients with end-organ damage. Two patients had syncope and were referred for HBOT. Significant troponin elevation was observed in two of the five patients with cardiac complaints, and these patients were referred for HBOT. An international multicenter study conducted by Arslan[20] demonstrated that 120 minutes of HBO treatment at 2.4 atmospheric pressure was both safe and effective for pregnant women. In a study by Mutluoglu et al[28], HBO use was recommended in pregnant women with COHb levels ≥ 20%. However, in our study, all pregnant patients exhibited mild clinical complaints, had no signs of end-organ damage, and had COHb levels < 20%; therefore, they received NBOT instead. This decision may have been influenced by mild clinical symptoms and the absence of end-organ damage. Although the application of HBOT in pediatric practice shares many similarities with its use in adults, there are currently no formal recommendations from scientific or professional committees. To establish a strong scientific and clinical basis, supported by legislation, for the prudent use of HBOT in pediatric patients and pregnant women, it is necessary to develop strategies to prevent malpractice and protect physicians from potential legal consequences[29].

It has been suggested in the literature that assessing the severity of acute CO poisoning based solely on the COHb level may not be accurate[30]. In our study, we did not observe a statistically significant correlation between the COHb level and GCS score, which is an indicator of clinical severity in both pregnant women and children.

Correlation analysis in cases of acute CO poisoning revealed statistically significant positive or negative correlations between CO levels and laboratory values, such as lactate, troponin, urea, creatinine, AST, ALT, and pH[31,32]. In our study, we also found a positive correlation between follow-up time and various factors, such as WBC, troponin, lactate, LDH, and COHb levels in pediatric patients; however, there was a negative correlation between follow-up time and pH. Pregnant patients showed a significant negative correlation between COHb and hemoglobin levels and a positive correlation between COHb levels and hospital follow-up time. We attributed the deterioration in laboratory values to cellular and tissue hypoxia due to CO poisoning. The duration required for tissue hypoxia to subside depends on the half-life of CO in blood[18]. Therefore, patients with high CO levels were followed up in the hospital for a longer period, which is consistent with the literature.

Epidemiologically, CO poisoning is more prevalent globally during the winter months. Studies[33,34] conducted in our country have shown that exposure to CO occurs most frequently during winter, with water heaters and stoves being the most common sources of CO emissions. This finding is consistent with those reported in the literature.

For Elderly Patients

Aging can result in a decrease in cognitive abilities and a weakening of the cardiovascular system. This is a result of the natural physiological changes that occur with aging[35]. Clinical outcomes such as morbidity, mortality, and length of hospitalization are influenced by patient-specific variables such as age, general health status, and presence of comorbidities[36]. Therefore, the global hypoxic state in acute CO poisoning affects elderly patients more severely due to increased frailty with aging, and higher morbidity and mortality rates are observed in this patient group[37]. In our study, intubation was required in approximately 17% of patients and mortality was observed in approximately 13%. Various studies[38,39] in the literature have shown that HBOT is an effective modality for increasing arterial and tissue oxygen levels in acute CO poisoning. In addition, HBO treatment has been shown to significantly reduce the incidence of neurological and cardiovascular problems.

However, in the current study, no statistically significant difference was found between the HBOT and NBOT groups in terms of 1-month and 3-month mortality, delayed DNS, ACS, CVD, arrhythmia, and HF. Although most delayed neurological sequelae develop several weeks after full recovery from CO exposure, DNS can occur up to 1 year after exposure[40]. In this context, the small sample size of our study and the insufficient follow-up period in terms of prognosis may have prevented the detection of possible neurological and cardiovascular complications. In cases of acute poisoning, COHb levels may not correlate consistently with the presence of clinical symptoms and predicted outcome[41]. An article by Grieb et al[30] presented contrasting results in two individuals with similar COHb levels. In this study, a 28-year-old woman experienced severe clinical symptoms, including loss of consciousness, respiratory failure, and the need for endotracheal intubation. Despite similar COHb levels, a 22-year-old man had no critical symptoms and fully recovered after mild symptomatic treatment[30]. Patients with COHb levels of 25% and above exhibited more neurological symptoms, according to a study by Doğruyol et al[14] on elderly patients. However, this study showed a statistically significant difference between high COHb levels and poor clinical outcomes in the hospital. In particular, all patients with CO levels of 40% or above were intubated. We found that most died in hospital within the first 48 months. We believe that this situation is actually a good example of the effects high COHb levels have on clinical outcomes in the elderly. Laboratory parameters such as troponin, urea, creatinine, WBC, AST, ALT, pH, and lactate were positively or negatively correlated with CO levels in studies of acute CO intoxication[31,32,42,43]. In this study, positive and negative relationships between COHb levels and such blood parameters were found. We suggest that the increase in these values can be attributed to the damage caused to end organs, such as the brain and heart, as a result of CO-induced global hypoxia.

Potential Approaches to Reduce CO Exposure-Related Intoxications

Various effective approaches to reduce poisoning and deaths associated with CO exposure have been identified in recent research[16]. Engineering innovations that have successfully reduced the emission of CO from different sources have led to a reduction in CO poisoning fatalities. Urban and rural central heating renovation, which has been shown to be a powerful way to reduce the burden of CO poisoning further, has been proposed[44]. Practical knowledge regarding safety measures during the installation of heaters, controlling CO production systems, and using sensitive alarms has been suggested as a key component for reducing mortality and morbidity resulting from CO poisoning[45]. Several studies[46,47] have demonstrated that the successful application of CO detectors in homes has resulted in a significant reduction in CO exposure, leading to morbidity and mortality[46]. An inclusive national CO poisoning surveillance network is proposed as a basis for such preventive measures and to augment the reliable figures of the CO poisoning burden[47].

In other words, a set of complex strategies that include engineering innovations, policy improvements, education, and surveillance are vital for decreasing the number of poisonings and deaths caused by CO exposure. By adopting these measures, CO distribution and epidemiological management can be improved, thus enhancing public health safety.

Study Strengths and Limitations

We would like to point out some of the strengths of our paper. For example, in this article, acute carbon monoxide poisoning in children, pregnant women, and the elderly is studied simultaneously. In general, these groups have been studied separately in the literature. However, this study is subject to several notable limitations. Firstly, this study encompasses a relatively limited sample. The small sample size, particularly within the pregnant population, may have increased the likelihood of a type 2 error, where we might incorrectly conclude that there is no difference or association when, in reality, such differences or associations exist. Secondly, this study does not allow for an evaluation of the consent process for patients for whom HBO is recommended as part of their treatment plan. In other words, even if there are patients within this specific population who should ideally receive HBO, the retrospective nature of the study precludes us from shedding light on this aspect. Additionally, some values that should be known and may be important for the study could not be determined satisfactorily in terms of the clarity of the data. For example, the periods during which patients were exposed to CO were excluded from the study for the reasons mentioned above. By including these periods, changes in COHb levels can be more accurately assessed. Consequently, there is a need for prospective clinical randomized studies to provide a more comprehensive understanding of the distinctions between groups and the efficacy of treatment.

Conclusions

Assessing and treating CO poisoning in pediatric and pregnant patients is crucial because of their increased vulnerability. Hospitalization is necessary for patients with persistent symptoms, high COHb levels, cardiac involvement, pregnancy, and other complications. This study found that pediatric patients were usually monitored for 6-8 hours before discharge. Although COHb levels may not directly indicate clinical severity, they can affect the length of hospital stay. High COHb levels, particularly above 30%, may indicate cardiac damage and neurological symptoms. HBOT may be necessary in specific cases such as loss of consciousness, neurological disorders, signs of end-organ ischemia, and pregnancy with COHb levels exceeding 20%. This study supports the use of HBOT in pediatric patients with end-organ damage and pregnant patients with severe symptoms. Pregnant patients with mild symptoms and COHb levels below 20% received normobaric oxygen therapy (NBOT) in this study, which is in line with the literature recommendations. The correlation between COHb levels and GCS score was not significant, emphasizing the need for individualized approaches to managing CO poisoning based on symptoms and severity.

The main findings in the elderly with carbon monoxide poisoning are as follows: (I) Severe hypoxia may occur due to age-related diseases, leading to serious disorders in sensitive organs, such as the brain and heart. (II) HBOT may not be more effective than NBOT for reducing mortality and late complications. (III) Patients with higher COHb levels at presentation to the emergency department and lower GCS scores had higher in-hospital mortality rates. (IV) All intubated patients had COHb levels above 40%. (V) Positive correlations were mostly found between COHb, pH, lactate, troponin, CKMB, AST, ALT, and creatinine levels, as expected from acute CO poisoning.

To safeguard vulnerable groups, it is crucial to adopt additional measures to prevent CO exposure. This involves installing CO detectors in living spaces and facilities, regularly maintaining heating and combustion appliances, and promptly seeking medical attention upon displaying symptoms suggestive of CO poisoning. Educating caregivers, family members, and healthcare workers about the heightened risk and potential indicators of CO poisoning in these populations is essential for tackling this significant public health hazard.

Conflict of Interest

The authors declare that they have no conflict of interest to disclose.

Ethics Approval

This study was conducted in accordance with the Declaration of Helsinki of 1975 (as revised in 2013), and the protocol was reviewed and approved by the Non-Interventional Ethics Committee of Niğde Ömer Halisdemir University Faculty of Medicine, dated 24/08/2023 and numbered 2023/54.

Informed Consent

Permission to use patient data was granted by the ethics committee. However, due to the retrospective design of the study, the requirement for informed consent was waived.

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Authors' Contributions

Conception and design: Abdussamed Vural, Mustafa Özçelik, Asaf Burak Vural, Mustafa Cihan Altay, Turgut Dolanbay; acquisition of data: Mustafa Özçelik, Asaf Vural Burak, Mustafa Cihan Altay, Zeynep Yılmaz Öztorun, Nazan Ardıç; data analysis and interpretation: Abdussamed Vural, Turgut Dolanbay; writing: Abdussamed Vural; critical revison: Zeyney Yılmaz Öztorun, Nazan Ardıç, Turgut Dolanbay; final reading, validation and approval: all authors.

ORCID ID

Abdussamed Vural: 0000-0003-4506-916X
Turgut Dolanbay: 0000-0002-4092-1192
Mustafa Özçelik: 0000-0003-1029-1043
Zeynep Yılmaz Öztorun: 0000-0001-8017-3048
Nazan Ardıç: 0000-0001-6777-1967
Asaf Burak Vural: 0000-0002-5503-5169
Mustafa Cihan Altay: 0000-0003-0919-4967

Data Availability

All data generated or analyzed during this study are included in this published article.

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