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ORIGINAL RESEARCH

QT interval prolongation during carbon monoxide poisoning is a predictor of late cardiac and neurological complications

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Abstract

Background: Carbon monoxide (CO) poisoning late complications and deaths are mainly associated with myocardia and central nervous system damage. The aim of this study was to examine how serum carboxyhemoglobin levels relate to acute QT interval prolongation (QTc) on electrocardiograms, delayed cardiac syndrome (DCS), delayed neuropsychiatric issues (DNS), and death in acute carbon monoxide poisoning. **Methods**: In this retrospective analysis, 1924 patients who presented to the emergency department with a preliminary diagnosis of CO poisoning between 2018 and 2023 were included in the study. Patients' QTc, serum carboxyhemoglobin, and late complications of CO poisoning were recorded. Additionally, DNS, DCS, and 30-day and one-year mortality rates were assessed. **Results**: The mean (standard deviation) age of the 1924 patients included in the study was 45 (14.7) years, and 837 (43.5%) were female. Troponin I was 0.3 (0.6) ng/dL, glucose was 125.1 (37.0) mg/dL, and the mean carboxyhemoglobin was 31.0 (10.5%) ($p < 0.001$). The QTc was 404.4 (38.3) ms in the group without complications of CO poisoning, 494.9 (23.9) ms in the DCS group, 481.2 (16.3) ms in the DNS group, and 497.0 (15.4) ms in the patients who died ($p < 0.001$). All-cause 30-day mortality rate was 127 (6.6%) ($p = 0.006$), while the 180-day mortality rate was 179 (9.3%). At a multivariate regression analysis, the QTc was an independent predictor of late complications and mortality due to CO poisoning, ($p < 0.001$). The ability to correctly identify DCS, DNS, and death in patients with a prolonged QTc was 90.3–92.7 (Area Under Curve (AUC): 0.93, 95% CI: 0.91–0.95), 89.6–90.8 (AUC: 0.87, 95% CI: 0.85–0.89), and 94.1–96.4 (AUC: 0.94, 95% CI: 0.92–0.95), respectively ($p < 0.001$). **Conclusions**: QTc in the acute phase of carbon monoxide poisoning may be an important in predicting late cardiac complications and neuropsychiatric sequelae.

Keywords

Carbon monoxide poisoning; Emergency department; Cardiac complications; Neuropsychiatric sequelae; QT interval prolongation

1. Introduction

Carbon monoxide (CO) poisoning is one of the most common causes of respiratory toxicity. A global epidemiological assessment determined an incidence of 137 per million and a mortality risk of 4.6 [1]. Although this rate is low in developed countries, it is still high in developing countries. Öz *et al*. [2] reported a mortality rate of 8.4% in Türkiye in 2023 due to CO poisoning. They reported that 346 people died from 3078 CO poisonings in Iran, and the mortality rate was 11.24% [3]. Carbon monoxide binds to hemoglobin to form carboxyhemoglobin (COHb), which has 200 to 250 times greater affinity for hemoglobin than oxygen. COHb formation reduces the oxygen-carrying capacity of hemoglobin and leads to cellular hypoxia [4]. Carbon monoxide causes harm by attaching to myoglobin, mitochondrial cytochrome C oxidase, and other proteins with heme in the heart and muscles. Thus, it activates platelets, neutrophils, and myeloperoxidase, increasing inflammatory effects. Elevated myeloperoxidase and reactive oxygen species facilitate lipid peroxidation [5]. Activated mediators cause irreversible deterioration or death in hypoxia-sensitive organs and tissues such as the brain and heart [6].

Delayed cardiac syndrome (DCS) complications are typical of CO poisoning. Even low levels of carboxyhemoglobin can exacerbate myocardial ischemia, and cardiac necrosis can develop in the absence of obvious symptoms [7]. Being exposed to carbon monoxide can lead to higher levels of heart-related markers [8] and dangerous heart rhythm problems, even if the heart's arteries are fine and there is some level of

heart dysfunction, depending on how much carbon monoxide is in the blood and how long the exposure lasts [9]. The corrected QT interval (QTc) measured on electrocardiography may increase the risk of individuals developing ventricular arrhythmias. QTc measures the heterogeneity of ventricular repolarization [10]. Higher levels of heart-related substances, like natriuretic peptide, creatine kinase, troponin, and creatine kinase myocardial band (CK-MB), are often seen more often with heart rhythm problems such as ST-segment elevation, changes in T waves, early heartbeats from the atria, and fast heart rate [7]. They have also been demonstrated at the case level in individuals with non-ST-segment elevation myocardial infarction [11]. Early diagnosis and management, including oxygen therapy, are critical to reduce these diverse and potentially life-threatening outcomes [12].

The most obvious clinical manifestations of CO poisoning are neurological deficits [13]. Headache, usually characterized as throbbing in the acute phase, is the presenting symptom in up to 84% of cases [14]. Long-term effects and loss of consciousness in the acute phase are associated with age over 36 years and carboxyhemoglobin levels greater than 25% [15]. The lack of standard diagnostic criteria for carbon monoxide poisoning makes it difficult to accurately assess the occurrence of delayed neuropsychiatric sequelae (DNS). Reported incidence rates vary between 7% and 40% in various studies [5, 16]. According to increasing evidence, mitochondrial oxidative stress and protein oxidation of the central nervous system are the primary causes of brain damage caused by CO poisoning [17]. A study found higher levels of basic myelin protein in the cerebrospinal fluid of patients with CO poisoning who later experienced delayed neurological problems, one month after exposure, compared to those without severe symptoms [18]. Brain imaging often shows abnormalities in the basal ganglia (especially the globus pallidus) and atrophy of the corpus callosum in severe cases [19]. In 2018, Liao *et al*. [20] found that a Glasgow Coma Scale score below 9, temporary loss of consciousness, a long delay between carbon monoxide exposure and getting to the emergency room, and QTc prolongation on the electrocardiogram (ECG) could be important signs of delayed neurological sequelae in patients with carbon monoxide poisoning. DNS resolves without specific treatment in approximately 75% of cases, while hyperbaric oxygen (HBO) therapy has been used to prevent or manage them with varying degrees of effectiveness [19].

Early diagnosis is vital to prevent long-term complications of CO poisoning. Therefore, the study aimed to determine the intrapatient mortality rates of QTc and serum carboxyhemoglobin levels in the acute period. The other aim was to determine the late-period DCS, DNS, and mortality rates within one year.

2. Materials and method

2.1 Study design and population

This retrospective study included 1924 patients over the age of 18 who were admitted to the Emergency Medicine Clinic due to CO poisoning between 01 January 2018, and 31 December 2023. In addition, 7117 individuals without CO poisoning were followed as a control group. We followed both the patient group and the control group for 30 days and one year using hospital automation and "e-nabiz" systems. Thus, the mortality status of patients with CO poisoning and one-year DCS and DNS changes in survivors were compared with the control group. The period from the patient's admission to the emergency department to discharge was accepted as 30 days. In addition, the clinical changes, intubations, and blood parameters of the patients were followed. Cardiology, neurology, and psychiatry outpatient clinic applications, clinical and laboratory results, and diagnoses of the patient and control groups were followed for one year. The hospital automation system contains patients' demographic, clinical, and laboratory data, as well as their diagnoses, hospitalization dates, and contact information.

2.2 Data collection

Patients were divided into three groups: non-complication, DCS, and DNS, within one year after acute CO poisoning. Patients were grouped as ST elevation myocardial infarction (STEMI) and non-ST elevation myocardial infarction (NSTEMI) according to DCS. STEMI cases were classified as inferior myocardial infarction (MI) and anterior MI groups. The comorbidity and mortality status of the cases were recorded. Age, gender, blood sugar, lipid profiles, pH, carboxyhemoglobin, ECG, and lactate levels of the patients were recorded at the first admission. The results of the cases were communicated via the "e-pulse" system in our country, the hospital automation system, and rarely by phone if necessary. In all cases included and excluded from the study, it was required that there was no COVID-19 infection, or the polymerase chain reaction test was negative.

2.3 Inclusion and exclusion criteria

2.3.1 Patient group

We included subjects over 18 years of age and those with carboxyhemoglobin concentrations of 15% or more in arterial blood gas in the study. Two unbiased emergency medicine specialists blindly assessed all parameters. Some discrepancies in interpretation were resolved by consensus through dialogue between the assessors. Our exclusion criteria included patients under 18 years of age, patients with insufficient laboratory and record data, and patients whose blood sugar levels were not assessed within the first 24 hours. The study also excluded subjects with chronic inflammatory conditions, malignancies, hematological disorders, chronic liver diseases, mental disorders, and cerebrovascular diseases. The study also left out people who had low potassium, low magnesium, low calcium, a history of heart failure, high pressure in the brain, congenital long QT syndrome, and those taking certain medications that can lengthen the QTc interval for various reasons.

2.3.2 Control group

The control group was randomly selected with power analysis on the specified dates from cases with similar age, gender, and comorbidity to the patient group. For this purpose, 3–4 control cases were determined for each selected patient.

Cases without CO poisoning, acute coronary syndrome, and neuropsychiatric disease were included in the control group. The same acceptance and rejection criteria were applied in both the control group and the patient group. The reason for keeping the number of cases high in the control group was to evaluate the changes in the year after the specified dates more objectively.

2.4 Definitions

2.4.1 Delayed Cardiac Syndrome (DCS)

ST elevation myocardial infarction (STEMI) [21] and non-ST elevation myocardial infarction (NSTEMI) [22] were defined according to relevant references. Patients diagnosed with DCS had an ECG performed during their emergency department visits. The cardiology team was consulted, and echocardiograms were performed. STEMI patients were taken to the angiography laboratory without waiting, while NSTEMI patients underwent angiography within the first 0–24 hours of their clinical presentation. The international classification of diseases (ICD) codes for acute coronary syndrome were I-21-I21.9 and I40-I40.9.2.4b.

2.4.2 Delayed Neuropsychiatric Sequelae (DNS)

Patients who did not have any previous neurological or psychiatric problems but later experienced delayed neurological issues, changes in personality, psychosis, cognitive problems, or changes in awareness days to months after CO exposure were categorized this way [23]. DNS was diagnosed upon admission to neurology and psychiatric outpatient clinics, rather than in the emergency department. Diagnoses were validated using data obtained from the hospital and the "e-nabiz" system. ICD codes F05.0-F05.1, G30-G30.9, F00-F01, G20, G21-G21.9, G46-G46.2, I66-I66.2, I65-I65.9, F90.0, F30, F31-31.2, F20-F20.9, and F23.2 were utilized.

2.4.3 e-nabiz

A patient-specific system requires a secret password established after receiving ethical permission from the Ministry of Health in our country, ensuring that all data remains confidential. This system enables patients to monitor all their information, encompassing hospitals, polyclinics, laboratories, and imaging services.

2.4.4 Other definitions

Hypertension: Defined as blood pressure equal to or greater than 140/90 mmHg on more than two occasions during office measurements or while receiving antihypertensive therapy. Diabetes mellitus: Defined as fasting blood sugar being 126 mg/dL or above or receiving antidiabetic treatment. CO exposure time: Defined as the time of possible exposure to carbon monoxide according to information received from the patient or relatives.

2.5 Laboratory design

All blood parameters and ECG utilized in the study correspond to the values recorded at the initial admission to the emergency department. The biochemistry results were examined within 45 to 60 minutes. Troponin I levels were assessed within a reference range of 0–0.05 ng/mL. Carboxyhemoglobin, pH, and lactate concentrations of the patients were acquired via arterial blood gas analysis. Blood was dispatched to the laboratory immediately after collection, and the findings were examined within 5 to 10 minutes. The standard range for carboxyhemoglobin is 0.5–1.5%, pH 7.35–7.45, and lactate concentration 0.5–1.6 mmol/L. Values beyond these ranges were deemed abnormal.

2.6 Electrocardiography and QT interval assessment

The QTc interval was measured on electrocardiograms taken within the first 10 minutes of the patients' first admission to the emergency room, before they received treatment. Patients' ECGs were acquired at the bedside with a 12-channel Cardiofax electrocardiography-9132K (Nihon Kohden, Tokyo, Japan). Upon the patient's admission to the emergency room, recordings were conducted utilizing a standard 12-channel ECG apparatus, set at a calibration of 1 mV/10 mm and 25 mm/s paper speed. We referred to the interval from the onset of the QRS complex to the conclusion of the T wave as QTc. The QT interval was assessed across multiple derivations, with the highest recorded QT interval utilized from any derivation. The DII lead was predominantly utilized; however, in instances where measures like distinctly flat T waves were unattainable, the V5 lead was also favored. Two seasoned specialist physicians assessed the QTc and RR intervals by looking at five consecutive pulses in DII. The automated system and manual techniques were employed to conduct the measurement. In cases where there was disagreement, the average of the two values was determined. The measurements included minor U waves (<25% of the T wave) that are either merged with the T wave or exhibit bifid characteristics. Consequently, the QTc interval was adjusted based on the heart rate. The predominant technique for computing QTc is the Bazett formula (QTc = QT/RR1/2) [24]. Typically, the QTc exceeds 360 ms, and it is considered extended when it exceeds 450 ms in men and 460 ms in women [25].

2.7 Statistical analysis

The universe size was determined by determining all intoxications applied to the emergency department between the dates specified in the study. During this period, it was determined that 4984 people applied to the emergency department for various poisoning reasons. Then, G*Power (Version 3.1.9.7, Heinrich Heine University, Düsseldorf, NRW, Germany) analysis was used to determine the population of the study [26]. In the power analysis of 4984 poisoning patients applied to the emergency department, it was determined that 1924 patients should be used in the study at a minimum of 5% acceptable error margin and 95% confidence interval. While performing the power analysis, calculations were made by minimizing the effect size, alpha, and beta error risk. Cases with drug, chemical, herbal, or alcohol types, non-CO respiratory poisonings, and COHb values below 15% were excluded from the universe size at presentation. 1924 patients were randomly selected from the remaining patients and included in the study.

To evaluate the data from this inquiry, the SPSS 26.0 software application was used (SPSS Inc., Chicago, IL, USA). The Kolmogorov-Smirnov test was used to evaluate whether all variables were normally distributed separately. It was determined that not all variables were normally distributed. Therefore, the Kruskal-Wallis H Test was used for the CO poisoning group, and the Mann-Whitney U Test was used in the mortality groups. We used chi-square analysis to look for patterns of correlation among the nominal variable sets. We used Spearman's *rho* analysis to find out which CO categories were associated with mortality. Using data collected after an acute CO overdose, a Kaplan-Meier survival analysis was run on DCS and DNS. The factors were also subjected to univariate and multivariate analysis using binary logistic regression. We used a method that adds important variables one by one to identify key factors that predict patient groups and death rates based on earlier analysis. After looking at how changes in QTc relate to carboxyhemoglobin levels, we evaluated how well DCS, DNS, and mortality could be identified using Receiver Operating Characteristic (ROC) curve analysis. All other factors in the data analysis were considered statistically significant at $p < 0.05$.

3. Results

3.1 Clinical characteristics of patients hospitalized in the pre-hospital emergency department

Our hospital is the region's tertiary education and research hospital and hyperbaric oxygen treatment center. Therefore, the ambulance control center brought 98.3% (n = 1891) of our cases directly from the scene to our emergency department. The remaining 1.7% (n = 33) were sent from the surrounding secondary and primary hospitals. Since all patients were oxygenated before entering the hospital, it was not possible to determine how much change there was in the cases. Therefore, the values at the time of admission to the emergency department were accepted as the first detected parameters. The patients and their relatives were asked about their state of consciousness, and the duration of CO exposure was recorded approximately. When the patients were brought to the emergency department, 67 of them were intubated, and their coma scores were around 3–4. In addition, the coma scores of 418 cases were between 9 and 12. A total of 127 cases with intubation and low coma scores were detected in the emergency department. Patients with poor general condition and coma scores below 10 points were admitted to the intensive care unit, and those with coma scores between 10 and 14 were admitted to the ward. Patients with good general condition, no change in consciousness, and high coma scores were admitted to emergency observation. Patients monitored for an average of 24 hours in the emergency observation unit were discharged after recovering. Patients admitted to the ward and intensive care unit were monitored for 3–29 days, depending on their clinical condition.

3.2 Baseline and laboratory characteristics of patient and control groups

The mean age of the CO poisoning group included in the study was 45.4 (14.7) years, 837 (43.5%) were female, and the age distribution range was 19–78 years. The mean age of the control group was 49.1 (11.8) years, and 3917 (41%) were female ($p = 0.549$). QTc interval was 404.4 (38.3) ms in patients without complications, 494.9 (24) ms in DCS, 481.2 (16.3) ms in DNS patients, and 393.8 (29.5) ms in the control group ($p < 0.001$). Carboxyhemoglobin was found to be 27.5% (8.2), 45% (6.2), and 44.4% (4.5), respectively ($p < 0.001$). In addition, the CO's possible exposure period, which was not studied in the control group but could be examined in the CO poisoning group, was remarkable in DCS and DNS patients ($p < 0.001$). Apart from this, pH was low, and lactate levels were significantly high in DCS and DNS patients ($p < 0.001$). The average troponin I level was 0.3 (0.6) ng/mL and the glucose level was 125.1 (37) mg/dL for all cases, while in the control group, these levels were 0.1 (0.1) ng/mL and 103.5 (28.1) mg/dL, respectively ($p < 0.001$). Table 1 presents the diabetes, hypertension, and tobacco-cigarette product use status of both the CO poisoning and control groups. At the end of a one-year follow-up, DCS was detected in 167 (8.7%) of the poisoning group. Of these, 130 (77.8%) were STEMI and 37 (22.2%) were NSTEMI ($p = 0.001$). However, 17 (0.2%) DCS patients were detected in the control group. The 30-day in-hospital mortality rate of the patients was determined as 127 (6.6%) in the poisoning group, while there was no death in the control group ($p = 0.006$). The one-year mortality rate of both groups was found to be 179 (9.3%) in the CO group and 9 (0.1%) in the control group ($p < 0.001$, Table 1). The distribution of patients in the study is given in Fig. 1.

3.3 Mortality rates in carbon monoxide poisoning within one year

When the mortality rates of the CO poisoning group were examined, the mean age of the living was 44.5 (14.3) years, while the mean age of the deceased was 62.2 (12.8) years ($p < 0.001$). Although there was no significant difference between the genders, the mortality rates were twice as high in males as in females ($p = 0.089$). In addition, the duration of exposure to CO poisoning was found to be 8.7 (1.3) hours higher in the deceased ($p < 0.001$). The QT interval was 497 (15.4) ms, carboxyhemoglobin was 49.5 (4.6), pH was 7.11 (0.08), lactate was 8.5 (1.8) mmol/L, glucose level was 170 (34.9) mg/L, and troponin I was 1.3 (1.0) ng/dL, and these levels were much higher in those who died compared to those who lived ($p < 0.001$). These values were significantly higher than the group without mortality ($p < 0.001$). In addition, mortality was seen in 27 (41.2%) of the patients who developed DCS ($p < 0.001$) and in 8 (4.5%) of the patients who developed DNS ($p = 0.002$). Data are available in Table 2.

One-year Kaplan-Meier survival analysis and log-rank analysis were performed for those exposed to CO poisoning. The estimated survival in patients without complications within one year after CO poisoning was 341 (2.3) days (95% confidence interval (CI): 336.6–345.5). In DCS patients, it was estimated at 165.6 (16.5) days (95% CI: 133.3–197.9), and in DNS cases,

TABLE 1. Basic characteristics of carbon monoxide poisoning and analysis of laboratory results according to late cardiac and neuropsychosis groups.

	Carbon Monoxide Poisoning Group				Control Group	
	All Patients n (%)	Non-complication n (%)	DCS n (%)	DNS n (%)	Control n (%)	*p*-value
Gender						
Female	837 (43.5)	668 (43.1)	72 (43.1)	97 (47.1)	3917 (41.0)	0.549
Male	1087 (56.5)	883 (56.9)	95 (56.9)	109 (52.9)	4200 (59.0)	
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Age, yr	45.4 (14.7)	43.1 (13.8)	63.3 (7.8)	64.2 (4.2)	49.1 (11.8)	<0.001
Corrected QT interval (QTc), ms	420.5 (48.4)	404.4 (38.3)	494.9 (24.0)	481.2 (16.3)	393.8 (29.5)	<0.001
Exposure time, h	3.65 (2.0)	3.23 (1.9)	5.7 (1.9)	5.07 (1.02)	-	<0.001
Laboratory						
Carboxyhemoglobin, %	31 (10.5)	27.5 (8.2)	45 (6.2)	44.4 (4.5)	-	<0.001
pH	7.3 (0.1)	7.4 (0.1)	7.2 (0.1)	7.3 (0.1)	-	<0.001
Lactate, mmol/L	3.3 (2.5)	2.5 (1.9)	7.1 (1.7)	6.2 (1.8)	-	<0.001
Triglyceride, mg/dL	95.2 (31.5)	93.3 (29.5)	110.7 (41.8)	112.0 (41.1)	89.3 (27.6)	0.001
Cholesterol, mg/dL	158.5 (43.2)	157.4 (42.5)	168.5 (49.8)	167.2 (44.5)	143.8 (39.7)	0.009
High Density Lipoprotein, mg/dL	34.4 (9.2)	34.5 (9.1)	34.5 (8.8)	33.2 (9.1)	38.5 (10.4)	0.359
Low-Density Lipoprotein, mg/dL	101.4 (34.3)	100.9 (34.1)	104 (32.5)	107.2 (40.11)	97.2 (29.7)	0.275
Glucose, mg/dL	125.1 (37.0)	115.4 (29.7)	159.4 (31.9)	170.1 (40.0)	103.5 (28.1)	<0.001
Troponin I, pg/dL	0.3 (0.6)	0.2 (0.5)	1.1 (0.9)	0.8 (0.5)	0.1 (0.1)	<0.001
Comorbidity						
Diabetes Mellitus	285 (26.1)	150 (52.6)	83 (29.1)	52 (18.2)	1729 (24.3)	<0.001
Hypertension	181 (16.5)	84 (46.4)	60 (33.1)	37 (20.4)	1309 (18.4)	<0.001
Tobacco/Cigarette	629 (57.4)	583 (92.7)	36 (5.7)	10 (1.6)	3815 (53.6)	<0.001
	n (%)	n (%)	n (%)	n (%)	n (%)	
Delayed Cardiac Syndrome						
STEMI	130 (77.8)	Inferior MI Groups	41 (31.5)		13(76.5)	0.001
		Anterior MI Groups	89 (68.5)		4 (23.5)	
NSTEMI	37 (22.2)					
Mortality (30 days)						
No	1797 (93.4)	1452 (75.5)	140 (7.3)	205 (10.7)	7117 (100.0)	0.006
Yes	127 (6.6)	99 (5.1)	27 (1.4)	1 (0.1)	0	
Mortality (One-year)						
No	1745 (90.7)	1444 (93.1)	103 (61.7)	198 (96.1)	7108 (99.9)	<0.001
Yes	179 (9.3)	107 (6.9)	64 (38.3)	8 (3.9)	9 (0.1)	
Total	n: 1924 (100.0%)	n: 1551 (80.6%)	n: 167 (8.7%)	n: 206 (10.7%)	n: 7117 (100.0%)	

DCS: Delayed Cardiac Syndrome; DNS: Delayed Neuropsychiatric Sequelae; SD: Standard Deviation; STEMI: ST elevation myocardial infarction; NSTEMI: non-ST elevation myocardial infarction; MI: Myocardial infarction; p: Statistical significance (<0.05).

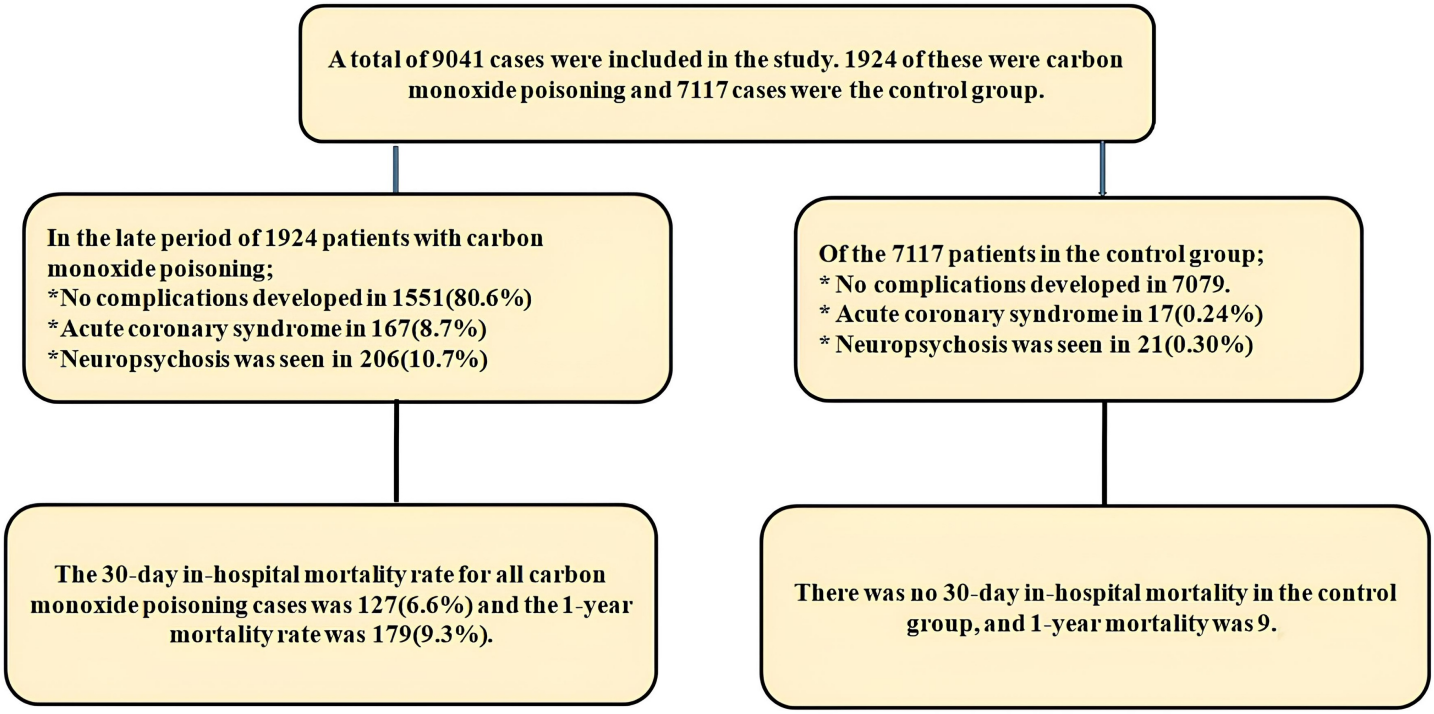

FIGURE 1. Distribution of patients in the study.

TABLE 2. Basic and laboratory analysis of carbon monoxide poisoning according to one-year mortality.

Mortality		No Mean (SD) n: 1797 (93.4%)	Yes Mean (SD) n: 127 (6.6%)	*p*-value
Age, yr		44.5 (14.3)	62.2 (12.8)	<0.001
Gender				
Female, n (%)		793 (44.1)	44 (34.6)	0.089
Male, n (%)		1004 (55.9)	83 (65.4)	
Corrected QT interval (QTc), ms		415.1 (45.2)	497.0 (15.4)	<0.001
Exposure time, h		3.3 (1.5)	8.7 (1.3)	<0.001
Laboratory				
Carboxyhemoglobin, %		29.3 (9.54)	49.5 (4.6)	<0.001
pH		7.7 (0.1)	7.1 (0.1)	<0.001
Lactate, mmol/L		2.9 (2.1)	8.5 (1.8)	<0.001
Blood Sugar, mg/dL		121.9 (35.0)	170.2 (34.9)	<0.001
Troponin I, ng/dL		0.3 (0.5)	1.3 (1.0)	<0.001
Delayed Neuropsychiatric Sequelae				
No		1547 (88.7)	171 (95.5)	0.002
Yes		198 (11.3)	8 (4.5)	
Delayed Cardiac Syndrome				
No		1657 (94.3)	100 (5.7)	<0.001
STEMI	Inferior MI Groups	34 (82.9)	7 (17.1)	
	Anterior MI Groups	70 (78.6)	19 (21.4)	
NSTEMI		36 (97.3)	1 (2.7)	

SD: Standard Deviation; STEMI: ST elevation myocardial infarction; NSTEMI: non-ST elevation myocardial infarction; MI: Myocardial infarction; CO: Carbon monoxide; p: Statistical significance (<0.05).

it was 296.8 (26.9) days (95% CI: 244–349.6). For all patients, it was estimated 334.2 (2.2) days (95% CI: 329.8–338.5), and the log-rank ratio was 241.6 days ($p < 0.001$). The distribution of cases is given in Fig. 2.

3.4 CO groups and mortality correlation analysis

Correlation analysis of CO poisoning groups and mortality with variables was performed. Age, glucose, QTc, carboxyhemoglobin, troponin I, and lactate showed a moderate to strong positive correlation between CO poisoning groups and mortality. Moderate to strong negative correlation was found with pH in both groups (Table 3).

3.5 Carbon monoxide poisoning groups and mortality variables with uni/multivariate regression analysis

Mortality, DNS, and DCS univariate and multivariate regression analyses were performed. DNS was found to be significant in univariate regression analysis with all variables used as parameters. After adjustment for multivariate regression, insignificant values were detected with the pH value, but significant values were detected with other parameters. All values were found to be significant in univariate analysis performed with DCS. However, age, QTc, blood sugar, and troponin were found to be predictive values in multivariate analysis. All parameters were also significant in the univariate analysis performed for mortality. However, age, pH, lactate, and troponin I were found to be significant values in multivariate analysis (Table 4).

3.6 Receiver operating characteristic (ROC) curve analysis

Receiver operating characteristic (ROC) curve analysis was performed with QTc and carboxyhemoglobin to predict CO poisoning groups and mortality development. According to this analysis, DCS sensitivity and specificity variables are given in Fig. 3, DNS in Fig. 4, and mortality in Fig. 5. Their distributions are also in Table 5. ROC curve analysis could

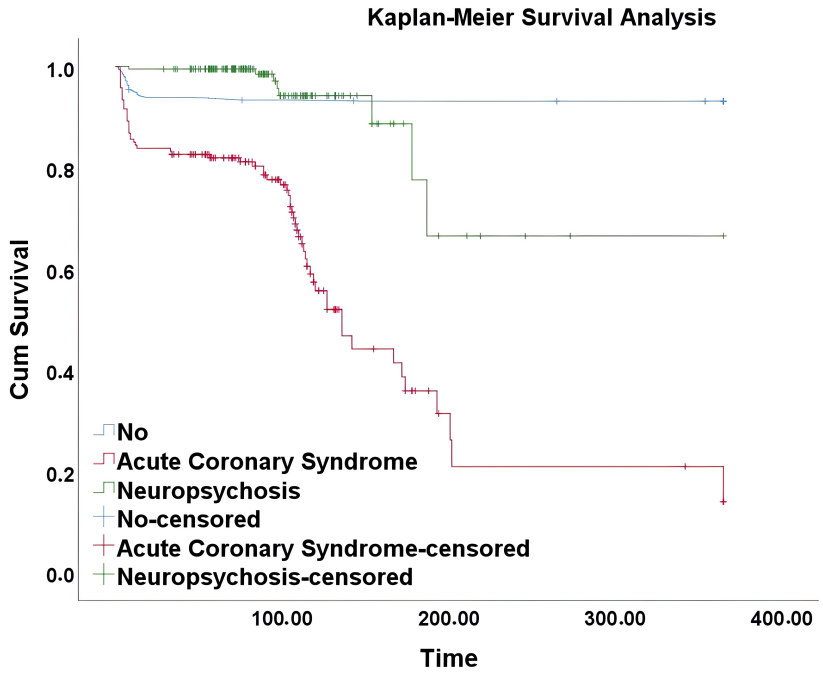

FIGURE 2. Kaplan-Meier Survival analysis in carbon monoxide poisoning.

TABLE 3. Correlation analysis of carbon monoxide poisoning groups and mortality with variables.

	Carbon monoxide Poisoning Groups		Mortality	
	r	*p*	*r*	*p*
Age, yr	0.53	<0.001	0.29	<0.001
Blood sugar, mg/dL	0.41	<0.001	0.33	<0.001
Carboxyhemoglobin, %	0.62	<0.001	0.47	<0.001
Exposure time, h	0.37	<0.001	0.67	<0.001
Corrected QT interval (QTc), ms	0.62	<0.001	0.42	<0.001
Troponin I, ng/dL	0.42	<0.001	0.44	<0.001
pH	−0.31	<0.001	−0.64	<0.001
Lactate, mmol/L	0.59	<0.001	0.58	<0.001

TABLE 4. Carbon monoxide poisoning groups and mortality by univariate and multivariate analysis of variables.

Carbon Monoxide Poisoning Groups and Mortality	Univariate			Multivariate		
	OR	95% CI	*p*	OR	95% CI	*p*
CO poisoning groups						
Age, yr	1.14	1.12–1.16	0.001	1.09	1.05–1.12	<0.001
Carboxyhemoglobin, %	1.15	1.13–1.18	<0.001	1.13	1.08–1.19	<0.001
QTc, ms	1.04	1.03–1.04	<0.001	1.02	1.01–1.03	<0.001
Blood sugar, mg/dL	1.03	1.03–1.03	<0.001	1.01	1.01–1.02	0.005
pH	1.16	1.35–1.97	<0.001			
Lactate, mmol/L	1.54	1.46–1.63	<0.001	1.26	1.12–1.41	0.001
Troponin I, ng/dL	2.53	2.09–3.04	<0.001	0.59	0.42–0.82	0.002
Mortality						
Age, yr	1.11	1.09–1.13	0.001	0.96	0.92–0.99	0.023
Carboxyhemoglobin, %	1.06	1.05–1.07	<0.001			
QTc, ms	1.31	1.25–1.37	<0.001			
pH	1.49	1.41–1.57	<0.001	0.87	0.75–0.99	<0.001
Lactate, mmol/L	2.73	2.35–3.19	<0.001	1.80	1.45–2.24	<0.001
Blood sugar, mg/dL	1.03	1.02–1.03	<0.001			
Troponin I, ng/dL	5.58	4.38–7.10	<0.001	2.01	1.35–3.00	0.001

OR: Odds Ratio; CI: Confidence Interval; QTc: Corrected QT interval; CO: Carbon monoxide; p: Statistical significance (<0.05).

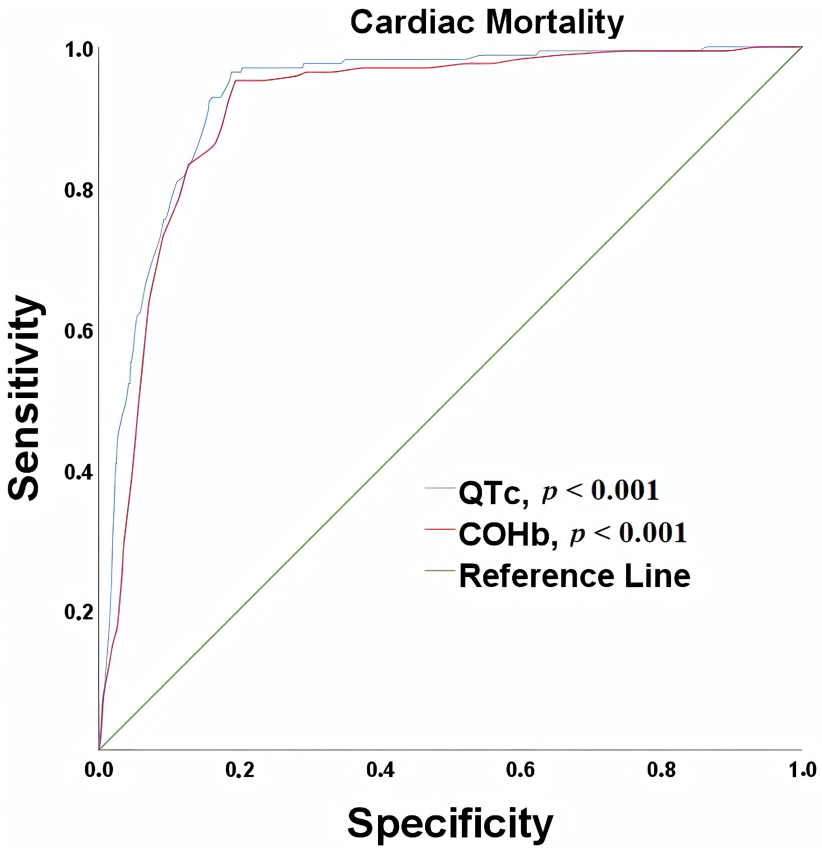

FIGURE 3. Receiver Operating Characteristic (ROC) Curve analysis; the relationship between QTc and carboxyhemoglobin levels and late cardiac effects. QTc: Corrected QT interval; COHb: Carboxyhemoglobin.

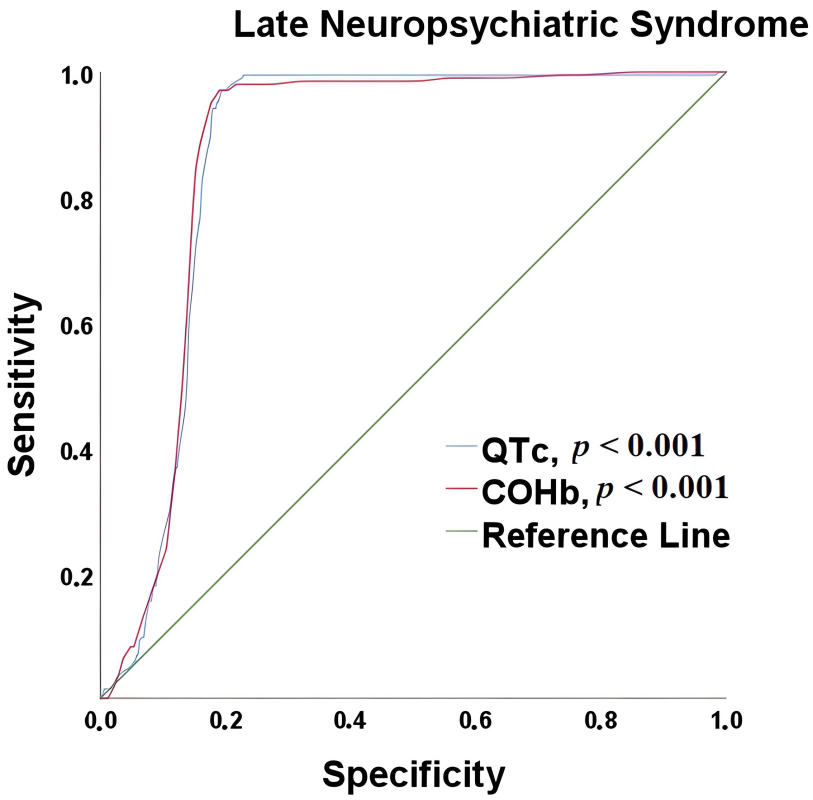

FIGURE 4. Receiver Operating Characteristic (ROC) Curve analysis; the relationship between QTc and carboxyhemoglobin levels and late-stage neuropsychiatric events. QTc: Corrected QT interval; COHb: Carboxyhemoglobin.

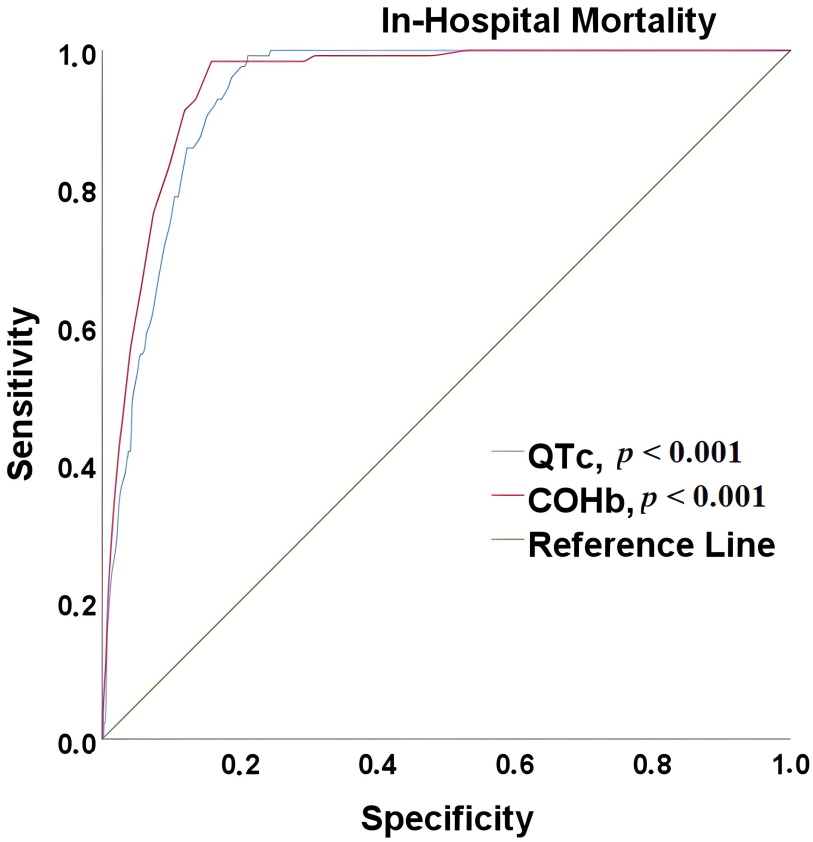

FIGURE 5. Receiver Operating Characteristic (ROC) Curve analysis; relationship between QTc and carboxyhemoglobin levels and mortality. QTc: Corrected QT interval; COHb: Carboxyhemoglobin.

TABLE 5. Receiver operating characteristic (ROC) curve analysis of carbon monoxide poisoning groups and mortality.

Carbon Monoxide Poisoning Groups and Mortality	AUC	95% CI	*p*	Sensitivity (%)	Specificity (%)
Delayed Cardiac Syndrome					
QTc	0.93	0.91–0.95	<0.001	92.7	90.3
COHb	0.91	0.89–0.93	<0.001	91.4	90.1
Delayed Neuropsychiatric Sequelae					
QTc	0.87	0.85–0.89	<0.001	90.8	89.6
COHb	0.87	0.85–0.89	<0.001	90.3	88.9
Mortality					
QTc	0.94	0.92–0.95	<0.001	96.4	94.1
COHb	0.95	0.94–0.96	<0.001	95.7	93.6

AUC: Area under the curve; CI: Confidence Interval; QTc: Corrected QT interval; COHb: Carboxyhemoglobin; p: Statistical significance (<0.05).

be performed with all parameters in this table. However, in previous studies, age, pH, blood sugar, lactate, and troponin I were used very frequently and found to be significant. Therefore, since carboxyhemoglobin value is used as a diagnostic tool in CO poisoning and QTc is used in rare studies, these two parameters were preferred in the study.

4. Discussion

Quantitative studies exist on carbon monoxide poisoning. Despite the substantial volume of research examining DNS and DCS in carbon monoxide poisoning, investigations into their correlation with QTc in acute poisoning remain scarce. This circumstance compelled us to investigate possible complications in the advanced phases of acute carbon monoxide poisoning. We assessed the incidence of CO poisoning in the study group compared to the normal population in the control group. Upon comparison of the complications arising from carbon monoxide poisoning with those in the control group, it was observed that the incidence of DNS was 9.81, the incidence of DCS was 9.82, and the fatality rates were 19.9 times elevated. The extension of QTc during the acute phase indicates a correlation with the severity of the prognosis in carbon monoxide poisoning. The inclusion of carbon monoxide poisoning among the risk variables present in the general population may have substantially contributed to these increases. This study is notable as it is one of the few investigations assessing the 30-day and one-year death rates and the emergence of comorbidities associated with QTc and carboxyhemoglobin in instances of carbon monoxide poisoning.

4.1 Mechanism and frequency of DCS and DNS development after carbon monoxide poisoning

Carbon monoxide is recognized for its cardiotoxic effects, inducing electrical, functional, and structural alterations in the heart. In carbon monoxide poisoning, there have been increases in heart-related markers like brain natriuretic peptide and troponin, as well as heart rhythm problems such as ST elevation, changes in T waves, early heartbeats from the atria, and fast heart rate [27]. Acute myocardial infarction (AMI) and cardiogenic shock, along with acute pulmonary edema, have been associated with CO poisoning [28]. Lippi *et al.* [29] reported similar results. Due to its higher affinity for hemoglobin compared to oxygen, carbon monoxide induces hypoxia by generating carboxyhemoglobin. Carbon monoxide induces harmful consequences in tissues particularly susceptible to hypoxia, including the brain and heart [30]. The etiology of heart injury in carbon monoxide overdose can be elucidated through two mechanisms. The first type is injury caused by carboxyhemoglobin, which happens when carbon monoxide binds to heme proteins instead of oxygen, while the second type is damage caused directly by carbon monoxide [31]. Carbon monoxide inflicts direct toxic damage to mitochondria at the cellular level, resulting in the inhibition of cytochrome C oxidase and a reduction in glutathione levels [32]. This process triggers anaerobic metabolism in cardiac myocytes, leading to hypoxia, lactic acidosis, and apoptosis, along with endothelial damage [33]. Additionally, carbon monoxide increases the production of harmful free radicals by causing low-density lipoproteins to oxidize and by creating peroxynitrite in the blood [34]. Numerous studies and case reports indicate that carbon monoxide can induce venous, arterial, and stent thrombosis, exhibiting a prothrombotic impact. Recent reports show that it plays a role in the long-term buildup of plaque in arteries by attaching to specific genes and creating unbalanced microRNAs [35]. Consequently, it was demonstrated that carbon monoxide poisoning elevates the chance of long-term malignant arrhythmia, coronary artery disease, and heart failure [36]. DCS was observed in 167 (8.7%) of 1924 cases in the study. Out of these cases, 130 (77.8%) were identified as STEMI, with 41 (31.5%) showing signs of acute inferior myocardial infarction and its variations, while 89 (68.5%) showed signs of acute anterior myocardial infarction and its variations. The mortality rate in the STEMI group was 20%. We have not previously found a literature source that studies the subtypes of late-stage acute MI after

CO poisoning. NSTEMI was detected in 36 (21.5%) of the cases. Similar studies have reported that only DCS develops without considering the subtypes of MI. Comparable studies have indicated that DCS solely manifests without regard to the MI subtypes. Kaya *et al*. [37] identified DCS in 100 (9.8%) of 1013 patients with CO poisoning, although the specific forms were not detailed. Karaman *et al*. [38] documented decompression sickness in 35 (14.7%) patients following carbon monoxide poisoning among 237 cases. According to the literature, a significant reason for the relatively low number of DCS cases is that all patients included in the study were located in the city center. The study of Kaya and Karaman shows that stove use is frequent in the periphery, and the duration of exposure to CO poisoning is long [37, 38].

Following recovery, some individuals experience DNS, including cognitive impairment, Parkinsonism, motor abnormalities, and peripheral neuropathy [39]. On the other hand, DNS has been associated with deep white matter damage. Acute brain injuries are associated with elevated levels of biochemical markers such as neuron-specific enolase (NSE) and S100β, as well as increased cytokines, interleukins, and growth factors in patients who lose consciousness [40]. CO intoxication inhibits metabolism and reuptake while increasing release, resulting in dopamine overproduction and striatal lesions that mirror the neurotoxicity found in methamphetamine or 3,4-metilendioksimetamfetamin (MDMA) abuse [41]. In addition, toxic leukoencephalopathy, characterized by cerebral demyelination and structural abnormalities in deep white matter, has been described in CO-intoxicated patients; however, the specific cellular targets of CO are unknown [42]. However, there are proposed mechanisms. One of these involves the activation of nitric oxide and other oxygen-free radicals by CO poisoning [43]. Radicals induce endothelial damage [44], inhibit lipid peroxidation, and promote leukocyte sequestration, leading to significant increases in brain microvasculature and resulting in ischemic brain damage [20]. An additional mechanism is the heightened thrombotic tendency [45]. Free radicals may enhance platelet adhesion and induce alterations in the fibrinolytic pathway. Consequently, oxidative stress and hypoxia occur [46, 47]. In the iron-rich globus pallidus and substantia nigra regions of the brain, carbon monoxide binds to heme proteins, causing direct toxic effects [47]. These proteins include neuroglobin, cytochrome oxidase, cytochrome P-450, dopamine beta-hydroxylase, and tryptophan oxidase. In certain cases, it is possible to notice thalamic and hippocampal damage, atrophy of the cortex, loss of Purkinje cells in the cerebellum, and a reduction in the amount of material found in the internal granular layer. Demyelination, degeneration, and lesions in gray matter and cerebral white matter are symptoms of carbon monoxide intoxication [48]. The parietooccipital region is the most commonly afflicted area; however, white matter lesions can be found in many parts of the brain, including the frontal and parietal cortex, centrum semiovale, and brainstem [49]. Reports indicate that 4–40% of patients experience DNS following CO poisoning, which is primarily characterized by cognitive alterations, personality changes, parkinsonism, incontinence, dementia, and psychosis. Peripheral neuropathy was also noted in young adults [50]. Numerous studies have documented DNS rates following CO poisoning, presenting varying data. The DNS rate is influenced by the duration of carbon monoxide exposure, the time taken to reach the emergency room, and the distinction between rural and urban areas. DNS was identified in 206 patients, representing 10.7% of the study population. Our rate was slightly lower than reported in the literature. The utilization of natural gas was significantly elevated in the city where the study was conducted. Coskun *et al*. [51] reported a DNS rate of 17.6% in their study involving 216 cases. Caballero-Bermejo *et al*. [52] reported that DNS developed in 11 out of 240 cases, representing 4.6% of the cohort studied. Recovery was observed in 63% of cases that developed DNS, while permanent sequelae were noted in the remaining cases after one year.

4.2 Prognostic importance of QTc in carbon monoxide intoxication

Despite the selection of many metrics to characterize DCS and DNS in multiple CO research, QTc was seldom employed. Variations in QTc indicate the impact of therapies and complications in cardiac cell repolarization resulting from ion channel dysfunction [53]. The noted rise in heterogeneity among ventricular myocardial cells may lead to changes in QTc [54]. This syndrome arises from autonomic nervous system malfunction and cardiac electrical abnormalities caused by cellular necrosis and electrolyte imbalances [55]. Studies indicate that in instances of acute myocardial ischemia, factors contributing to an extended QTc interval encompass acidosis, alterations in impedance, a decrease in epicardial temperature, and electrical heterogeneity within the ventricular myocardium [56]. The exact way that carbon monoxide poisoning causes QTc prolongation is not completely clear, but Dallas *et al*. [57] proposed that carbon monoxide increases the late part of the inward sodium current, which extends the action potential and the time calcium stays inside the cells. Carbon monoxide exposure generated QTc prolongation and spontaneous ventricular tachycardias. The etiology of QT prolongation in DNS remains inadequately clarified, suggesting that the underlying mechanism may resemble that of DCS. However, no studies have established a connection between QTc prolongation and DNS prediction in patients with carbon monoxide poisoning. The degree of carbon monoxide poisoning is theoretically positively correlated with the risk of acquiring delayed neurological sequelae. QTc prolongation may more accurately indicate the severity of carbon monoxide intoxication than previously thought [20]. In the study on carbon monoxide poisoning, the QTc interval was found to be 404.4 (38.3) ms in 1551 uncomplicated cases, 494.9 (23.9) ms in 167 patients with decompression sickness, 481.2 (16.6) ms in 206 patients with delayed neurological syndrome, and 393.8 (29.5) ms in 7117 normal control cases. Carboxyhemoglobin, troponin, and lactate levels increased at the same time as QTc prolongation, while pH decreased, showing severe acidosis. Moreover, although often overlooked in numerous investigations, a rise in serum blood glucose was observed concomitantly with an increase in QTc prolongation. Olatunde *et al*. [10] reported a QT interval of 622 ms in their case study subsequent to carbon monoxide intoxication. Yelken *et al*. [58] reported in their investigation of 104 cases that the QT interval was extended at

24 hours, thereafter, decreasing after this duration compared to the initial day. Hancı *et al*. [59] demonstrated that QTc was significantly prolonged in the carbon monoxide poisoning cohort relative to the non-poisoned control group. Liao *et al*. [20] showed that 42.1% of the 466 examined patients had prolonged QTc, with 62 of these individuals experiencing DNS. The extended QT interval had predictive significance for both DCS and DNS in our study. We observed a positive, moderate to high correlation between these diseases and QTc. Furthermore, the sensitivity and specificity rates exceed 90% in both cohorts.

Carboxyhemoglobin levels are critical in detecting carbon monoxide poisoning, with typical values being less than 2% in nonsmokers and 5–10% in smokers [60]. Levels above 10–15% indicate poisoning, while levels above 25% are serious and potentially fatal. COHb values can help determine the severity of poisoning and guide treatment strategies [61]. Although QTc has rarely been used for late complications in CO poisoning, carboxyhemoglobin has been used frequently. The carboxyhemoglobin value was considered significant in some studies, while it was considered insignificant in others. In the study, the carboxyhemoglobin value was found to be significant for the DNS group, but it was not determined to be significant as a prognostic value in the regression analysis performed for DCS and mortality. It was found to be significant for DCS in the studies of Kaya [37] and Karaman [38]. While carboxyhemoglobin was not found to be significant for DNS in the studies of Choi [23] and Jung *et al*. [62], it was stated that it is an important parameter that can be used for late findings in the studies of Gao *et al*. [63], and Wen *et al*. [64], a positive connection observed between QTc prolongation and carboxyhemoglobin levels. With the increase of one metric, a corresponding elevation in the others was noticed. This increase posed a significant risk for both delayed complications and fatalities in cases of carbon monoxide poisoning. We believe these factors can serve as predictive parameters in research. Moreover, numerous research studies have employed various parameters. Szponar *et al*. [65] employed troponin, carboxyhemoglobin, pH, and lactate levels for the assessment of DCS in their research. Lactate and troponin were identified as significant factors. Karaman *et al*. [38] used troponin, carboxyhemoglobin, and procalcitonin to study DCS and found that these indicators were important. Coskun *et al*. [51] found that carboxyhemoglobin, troponin, mean platelet volume (MPV), and red cell distribution width (RDW) were important signs when evaluating DNS. Jung *et al*. [62] employed carboxyhemoglobin, troponin I, and brain natriuretic peptide for DNS and reported substantial findings. In our investigation, troponin, COHb, pH, and lactate levels were assessed for both syndrome groups, excluding QTc. These characteristics are critical for prognostication in carbon monoxide intoxication. Studies indicate that glucose levels are typically elevated in carbon monoxide poisoning, although hypoglycemia occurs infrequently. In our cases, hyperglycemia is manifested in accordance with the severity of carbon monoxide intoxication. This rise was significant regarding prognosis, similar to other measures. Patel *et al*. [66] documented adverse effects on hypertension, metabolic syndrome, cholesterol levels, and blood glucose in their research.

4.3 Mortality predictors in carbon monoxide poisoning

The mortality rate in the study can be considered high. While this rate is very low in developed countries, as in the study of Mattiuzzi *et al*. [1], it is still high in developing countries, such as Turkey [2] and Iran [3]. Numerous factors, including geographical location and stove heating, contribute to this situation. The study found that the prolonged QTc, compared to survivors, was the most significant determinant of 30-day and 1-year mortality. QTc, an important parameter in mortality prediction, can be easily calculated using a simple method, allowing for the determination of risk status. COHb, lactate, troponin, and glucose were positively and strongly related to QTc prolongation in mortality prediction. An increase in one of these parameters can be considered as an increase in all of them. However, pH was observed as a strong negative indicator. The more severely the other parameters increased, the lower the pH was, and it was seen that it caused an increase in mortality with severe acidosis. We believe these parameters were effective in both the 30-day and 1-year hospital follow-ups. Furthermore, despite the absence of significant gender differences, the mortality rate in males was twice that of females. Mattiuzzi *et al*. [1] indicated that while the incidence of CO poisoning was similar across genders, the mortality rate for men was twice that of women. Forés *et al*. [67] indicated that mortality from carbon monoxide poisoning is more prevalent in men than in women due to greater exposure levels among men. Factors associated with a higher chance of dying in similar studies include pH levels below 7.20, loss of consciousness, high carboxyhemoglobin levels, and the need for endotracheal intubation during hyperbaric oxygen therapy [5]. The average age of patients who died in the study was 62 years, with a 30-day mortality rate of 6.6% and a 1-year mortality rate of 9.3%. Mattiuzzi *et al*. [1] indicated in their study that the mortality risk from carbon monoxide poisoning is elevated in older adults and infants, with an increase in risk associated with advancing age. The current study observed the highest mortality rate among individuals aged 65 years and older, recorded at 65.5%.

The principal intervention for carbon monoxide intoxication is the administration of 100% oxygen. Oxygen facilitates the fast elimination of carbon monoxide from hemoglobin, enabling the blood to restore its standard oxygen-carrying capacity [68]. Oxygen expedites the elimination of carbon monoxide from the body through the lungs, with 70% of carboxyhemoglobin being removed within the initial hour of treatment [69]. Hyperbaric oxygen therapy (HBOT) may be advised for patients with severe poisoning, particularly those who are unconscious or exhibiting critical symptoms. It is also advised for patients exhibiting elevated carboxyhemoglobin levels (generally >25–30%), pregnant women due to the heightened risk for fetal hemoglobin, individuals with cardiac complications such as myocardial ischemia or arrhythmia, and those experiencing prolonged exposure or delayed symptoms, including DNS, even following initial normobaric oxygen therapy [70]. HBOT administers oxygen at elevated pressures, significantly expediting the elimination of carbon monoxide from the bloodstream and tissues [71]. The

primary objective of HBOT is to eliminate carbon monoxide from hemoglobin and replenish cellular oxygen levels, thereby mitigating hypoxic effects [72]. All patients were sent to the observation unit of the primary emergency department. Initially, 100% oxygen was delivered at a flow rate of 4–6 L/min. Patients with a coma score below 10 were admitted to the intensive care unit, and those with a favorable coma score were sent to the ward. Patients in stable general condition, with no alterations in consciousness and elevated coma scores, were admitted to the emergency observation unit. Patients admitted to the ward and intensive care unit were followed for a duration of up to 29 days based on their clinical circumstances. Initially, 100% oxygen was delivered at a flow rate of 4–6 L/min in the emergency room. Furthermore, oxygen was provided to patients with carboxyhemoglobin levels below 25%, while hyperbaric oxygen therapy was supplied to those with levels exceeding 25%, in conjunction with oxygen, according on the patient's condition. Moreover, in critical instances, plasma colloids were administered for hypotension, 20% mannitol and corticosteroids for brain edema, diuretics to avert renal failure in cases of rhabdomyolysis, and bicarbonate for profound metabolic acidosis. Efforts were made to sustain normal body temperature and blood pressure. Diazepam was administered for sedation in cases of convulsions and hyperexcitability. Mechanical ventilation assistance, both noninvasive and invasive, was administered as required.

4.4 Limitations

The present investigation exhibited certain limitations. The principal constraint of this study was its retrospective design. Secondly, notwithstanding the substantial sample size, challenges related to accessibility and follow-up emerged. Third, the precise quantity of oxygen delivered during transit to the emergency department remains uncertain, hence obscuring its impact on QTc, COHb, pH, lactate, and troponin levels. Fourth, we methodically removed medications that extend QTc, electrolyte imbalances, long QT syndrome, and associated disorders; however, it is conceivable that some were overlooked. Moreover, patients with aortic stenosis and valvular heart disease were infrequent and hence excluded from consideration. These variables could be a potential constraint. Fifth, efforts were made to ascertain potential exposure durations from patients and their families, although their accuracy remains uncertain. The origin of CO may influence the prognosis; however, comprehensive information was inaccessible. Sixth, carboxyhemoglobin levels in both the control and patient groups were unmeasurable during follow-up. The degree to which risk factors like smoking and environmental pollution were prevalent during this period could not be anticipated. Seventh, as all instances were transported by ambulance via the emergency system command control center, the oxygen treatment administered to the cases was deemed comparable. Consequently, the blood parameters of the subjects upon their initial arrival at the emergency room were utilized without accounting for their prehospital interventions. Furthermore, the laboratory data for the cases may have been maintained in a more comprehensive manner. We may have documented more alterations in electrocardiography beyond STEMI, NSTEMI, and QTc. QTc is influenced by several medications and electrolyte disturbances. Nonetheless, it was not feasible to assess the extent of QTc variation during the decrease/increase phase in carbon monoxide poisoning. Ultimately, had we acquired serial ECG tracings for each patient, we could have ascertained the dynamic QTc duration and offered more compelling data about the utility of QTc prolongation in forecasting DNS following carbon monoxide intoxication.

5. Conclusions

The research indicated that QTc prolongation on ECG in carbon monoxide poisoning could significantly influence the probability of mortality and subsequent cardiac and neuropsychiatric disorders. Furthermore, carboxyhemoglobin, glucose, pH, and lactate concentrations may constitute significant factors. Additional research may be required for estimating the long-term effects of carbon monoxide poisoning and to ascertain the importance of QTc prolongation during the acute phase.

AVAILABILITY OF DATA AND MATERIALS

All data is available on request without restriction.

AUTHOR CONTRIBUTIONS

MAA, AC and BD—performed the conception and design of the work. EA, MC and DO—carried out the acquisition of data. BB, MAA and AC—conducted the analysis and interpretation of data. BD, EA and MC—drafted the work. DO, BB and MAA—made critical revision for important intellectual content. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the institutional ethics committee of Bagcilar Training and Research Hospital (Date: 03 December 2024 and Decision No: 2024/12/05/091). Since the study was retrospective, informed consent was not obtained from the patients. However, permission was obtained from the hospital management board and the local ethics committee to use patient files and data records on the condition that the patients' identities and personal data remain confidential.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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