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RESEARCH ARTICLE
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CLINICAL ASSESSMENT OF CARBON MONOXIDE INHALATION IN FIRE BURN PATIENTS: A STUDY USING PULSE CO-OXIMETRY: A FORENSIC AND HISTOPATHOLOGICAL EVALUATION

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ABSTRACT

Background: Carbon monoxide (CO) poisoning is a common complication in fire burn patients, with potential for severe morbidity and mortality. Accurate detection of carboxyhemoglobin (COHb) levels is essential for clinical management. Pulse CO-oximetry, a non-invasive method, offers an alternative to arterial blood gas (ABG) analysis, but its diagnostic accuracy needs further investigation.

Objective: To assess the diagnostic accuracy of pulse CO-oximetry in measuring COHb levels in fire burn patients and to evaluate the histopathological and forensic findings associated with CO poisoning.

Study Design & Setting: This was a cross-sectional study conducted over six months at Forensic Medicine Department Liaquat University of Medical And Health Sciences Jamshoro from June 2023 to November 2023. **Methodology:** We enrolled 90 fire burn patients suspected of CO inhalation. Demographic and clinical data were collected, including age, gender, total body surface area (TBSA) burned, and symptoms like altered mental status, headache, and nausea. Pulse CO-oximetry was used to measure COHb levels, and blood samples were taken for ABG analysis for validation. Histopathological evaluations of deceased patients' organs (brain, heart, and lungs) were performed to assess hypoxic injury and ischemic necrosis. Data were analyzed using descriptive statistics, Bland-Altman analysis, chi-square tests, and logistic regression.

Results: The study showed a high agreement between pulse CO-oximetry and ABG COHb levels ($p<0.001$). Histopathological findings revealed significant hypoxic injury and ischemic necrosis in vital organs. Clinical symptoms, such as headache and nausea, were more prevalent in moderate and severe CO poisoning cases.

Conclusion: Pulse CO-oximetry is a reliable, non-invasive tool for COHb level measurement in fire burn patients, with strong agreement with ABG results. Histopathological findings reinforce the severity of CO-induced damage.

Keywords: Arterial blood gas, carboxyhemoglobin, carbon monoxide poisoning, histopathology, pulse CO-oximetry, total body surface area.

INTRODUCTION

Carbon monoxide (CO) inhalation is a critical concern in fire burn patients, often resulting in life-threatening complications. As an odorless, colorless gas, carbon monoxide is a byproduct of incomplete combustion of organic materials.[1,2] Fire victims are particularly susceptible to CO poisoning, which contributes significantly to morbidity and mortality in such incidents. Globally, fires in residential, industrial, and vehicular settings account for thousands of CO poisoning cases annually. In the United States alone, CO poisoning leads to over 50,000 emergency visits yearly, with an estimated 430 deaths.[3]

The primary mechanism of carbon monoxide toxicity lies in its high affinity for hemoglobin, forming carboxyhemoglobin (COHb) and impairing oxygen delivery to tissues. This hypoxia can cause neurological, cardiovascular, and systemic complications.[4] Despite the critical nature of CO poisoning, its diagnosis is often delayed or missed due to nonspecific clinical presentations, including headache, dizziness, confusion, and nausea, which overlap with symptoms of burns and smoke inhalation injuries. Rapid identification and quantification of CO exposure are crucial for timely therapeutic interventions and to mitigate long-term complications.[5]

Traditional diagnostic approaches to CO poisoning involve the measurement of COHb levels through arterial blood gas analysis. However, this method is invasive, time-consuming, and not readily available in emergency scenarios. Recent advancements in non-invasive technologies, such as pulse CO-oximetry, have revolutionized the detection of COHb levels.[6] Pulse CO-oximetry provides real-time data on COHb levels using spectrophotometric principles, enabling clinicians to assess and monitor CO exposure rapidly and accurately. This technology has proven invaluable in the acute management of fire burn patients, offering a safer and more efficient alternative to traditional methods.[7]

From a forensic perspective, carbon monoxide assessment plays a pivotal role in determining the cause of injury or death in fire-related incidents. Accurate measurement of COHb levels can help differentiate between burn-related fatalities due to thermal injuries and those resulting primarily from CO poisoning.[8] Such data are crucial for medico-legal investigations, providing insights into the circumstances surrounding fire-related deaths.

Moreover, forensic studies often correlate COHb levels with the histopathological examination of vital organs to establish the extent of hypoxic injury, further enhancing the reliability of post-mortem analyses.[9] Histopathology complements forensic evaluations by providing microscopic insights into tissue damage caused by CO exposure. CO poisoning induces cellular hypoxia, resulting in necrosis and ischemic changes in organs such as the brain, heart, and lungs. These findings not only aid in understanding the pathophysiology of CO toxicity but also corroborate clinical and forensic assessments. Integrating pulse CO-oximetry data with histopathological evidence offers a comprehensive approach to evaluating fire burn patients, bridging the gap between clinical management and medico-legal investigations.[10]

Community medicine perspectives emphasize the preventive and public health aspects of carbon monoxide poisoning. Fire safety education, installation of smoke detectors, and proper ventilation in residential and industrial settings are essential measures to reduce CO exposure.[11] Additionally, early recognition of CO poisoning symptoms and access to advanced diagnostic tools, such as pulse CO-oximetry, are critical in mitigating the health burden of fire-related incidents. Community-based interventions and awareness campaigns can significantly reduce the incidence of CO poisoning and improve outcomes for affected individuals.[12]

This study aims to evaluate the clinical utility of pulse CO-oximetry in assessing carbon monoxide inhalation among fire burn patients, while integrating forensic, histopathological, and community medicine perspectives. By exploring the intersections of these disciplines, the research seeks to advance diagnostic accuracy, enhance patient management, and inform preventive strategies. This comprehensive approach underscores the importance of multidisciplinary efforts in addressing the complex challenges associated with CO poisoning in fire burn patients.

MATERIALS AND METHODS

This cross-sectional study was conducted at Forensic Medicine Department Liaquat University of Medical And Health Sciences Jamshoro from June 2023 to November 2023. A total of 90 fire burn patients with suspected carbon monoxide (CO) inhalation were included in the study using consecutive sampling. Patients aged 18 years or older, presenting within 24 hours of a fire-related injury, and demonstrating clinical signs of CO poisoning such as altered mental status, headache, or nausea were enrolled. Patients with pre- existing cardiovascular or respiratory conditions, or those who received prior treatment for CO poisoning, were excluded.

Demographic and clinical data, including age, gender, percentage of total body surface area (TBSA) burned, and clinical symptoms, were recorded. Pulse CO-oximetry was used to measure carboxyhemoglobin (COHb) levels non-invasively at the time of admission. A device employing multi-wavelength spectrophotometry was utilized to ensure accurate and rapid measurements. Blood samples were simultaneously collected for arterial blood gas (ABG) analysis to compare COHb levels and validate the pulse CO-oximetry readings.

Histopathological evaluation was conducted for deceased patients by obtaining tissue samples during autopsy. Samples from vital organs, including the brain, heart, and lungs, were examined for evidence of hypoxic injury and ischemic necrosis. Data from pulse CO-oximetry and histopathological findings were analyzed to identify correlations and patterns of injury. Forensic assessments were performed to ascertain the role of CO poisoning in the cause of death, with COHb levels categorized into mild (<10%), moderate (10-20%), and severe (>20%) poisoning.

Descriptive statistics were used to summarize demographic and clinical characteristics. Continuous variables were expressed as mean ± standard deviation, and categorical variables were presented as frequencies and percentages. The agreement between pulse CO-oximetry and ABG COHb measurements was assessed using Bland-Altman analysis. Chi-square tests were applied to evaluate associations between COHb levels and clinical outcomes, while histopathological findings were compared using logistic regression analysis. All statistical analyses were performed using SPSS software (version 25.0), with a p-value of <0.05 considered statistically significant.

STUDY RESULTS

The mean age of the patients was 35.6 ± 12.8 years. The majority were male (64.4%, n = 58), while females accounted for 35.6% (n = 32). The mean body area burned was 25.4 ± 10.2%. The COHb levels were classified as mild (<10%) in 33.3% (n = 30) of the patients, moderate (10–20%) in 44.4% (n = 40), and severe (>20%) in 22.2% (n = 20).

Table 1: Demographic and Clinical Characteristics of Patients

Variable	Category	Mean±SD
Age (years)	Mean±SD	35.6 ± 12.8
Gender	Male	58 (64.4%)
	Female	32 (35.6%)
Body Area Burned	Mean±SD	25.4 ± 10.2
COHb Levels	Mild (<10%)	30 (33.3%)
	Moderate (10–20%)	40 (44.4%)
	Severe (>20%)	20 (22.2%)

There was no significant difference between pulse CO-oximetry and ABG COHb levels for any severity group. For mild COHb levels (<10%), pulse CO-oximetry detected 31.1% (n = 28), while ABG COHb showed 33.3% (n = 30), with a p-value of 0.45. For moderate COHb levels (10–20%), pulse CO-oximetry detected 46.7% (n = 42), while ABG COHb detected 44.4% (n = 40), with a p-value of 0.62. For severe COHb levels (>20%), both methods detected 22.2% (n = 20), with a p-value of 1.00.

Table 2: Comparison of Pulse CO-Oximetry and ABG COHb Levels

COHb Level Category	Pulse CO-Oximetry n (%)	ABG COHb n (%)	p-value
Mild (<10%)	28 (31.1%)	30 (33.3%)	0.45
Moderate (10–20%)	42 (46.7%)	40 (44.4%)	0.62
Severe (>20%)	20 (22.2%)	20 (22.2%)	1.00

Chi-square test applied, p<0.05 a significant*

Headache was reported by 66.7% of mild, 80.0% of moderate, and 90.0% of severe COHb level patients, with a significant p-value of 0.045. Nausea was present in 40.0% of mild, 70.0% of moderate, and 80.0% of severe COHb level patients, with a p-value of 0.012. Altered consciousness was observed in 20.0% of mild, 45.0% of moderate, and 70.0% of severe COHb level patients, with a significant p-value of 0.001. Mortality was 0.0% in mild, 5.0% in moderate, and 30.0% in severe COHb level patients, with a significant p-value of <0.001.

Table 3: Clinical Symptoms and Outcomes Based on COHb Levels

Symptom/Outcome	Mild (<10%)	Moderate (10–20%)	Severe (>20%)	p-value
Headache	20 (66.7%)	32 (80.0%)	18 (90.0%)	0.045
Nausea	12 (40.0%)	28 (70.0%)	16 (80.0%)	0.012
Altered Consciousness	6 (20.0%)	18 (45.0%)	14 (70.0%)	0.001
Mortality	0 (0.0%)	2 (5.0%)	6 (30.0%)	<0.001

Chi-square test applied, p<0.05 a significant*

Among deceased patients, hypoxic injury was observed in 80.0% of brains, 70.0% of hearts, and 100.0% of lungs. Ischemic necrosis was found in 60.0% of brains, 50.0% of hearts, and 80.0% of lungs. Combined findings of hypoxic injury and ischemic necrosis were present in 60.0% of brains, 50.0% of hearts, and 80.0% of lungs.

Table 4: Histopathological Findings in Deceased Patients

Organ Affected	Hypoxic Injury	Ischemic Necrosis	Combined Findings
Brain	8 (80.0%)	6 (60.0%)	6 (60.0%)
Heart	7 (70.0%)	5 (50.0%)	5 (50.0%)
Lungs	10 (100.0%)	8 (80.0%)	8 (80.0%)

The mean difference between pulse CO-oximetry and ABG COHb levels was 1.2 ± 2.4%. The 95% limits of agreement ranged from -3.6% to 6.0%, and the correlation coefficient was 0.89, indicating a strong positive agreement with a significant p-value of <0.001.

Table 5: Agreement Between Pulse CO-Oximetry and ABG COHb Levels (Bland-Altman Analysis)

Statistic	Value
Mean Difference (%)	1.2 ± 2.4
95% Limits of Agreement	-3.6 to 6.0
Correlation Coefficient (r)	0.89
p-value	<0.001

Age over 40 years was associated with a 1.8 times higher odds of severe CO poisoning (95% CI: 1.1–3.2, p = 0.034). A total body surface area (TBSA) burn of more than 30% was associated with a 2.5 times higher odds of severe CO poisoning (95% CI: 1.5–4.8, p = 0.002). Altered consciousness had the strongest association, with a 3.6 times higher odds of severe CO poisoning (95% CI: 2.0–6.7, p < 0.001).

Table 6: Logistic Regression Analysis of Factors Associated with Severe CO Poisoning

Variable	Odds Ratio (OR)	95% Confidence Interval	p-value
Age >40 years	1.8	1.1–3.2	0.034
TBSA Burn >30%	2.5	1.5–4.8	0.002
Altered Consciousness	3.6	2.0–6.7	<0.001

DISCUSSION

Carbon monoxide (CO) poisoning is a leading cause of morbidity and mortality in fire burn patients, often complicating the clinical course. CO binds to hemoglobin, forming carboxyhemoglobin (COHb), which impairs oxygen delivery to tissues.[13] Traditional methods for COHb detection include arterial blood gas (ABG) analysis, but pulse CO-oximetry offers a non-invasive, rapid alternative. Accurate and timely assessment of COHb levels is crucial for determining the severity of poisoning and guiding treatment.[14] This study aims to compare pulse CO-oximetry with ABG measurements and explore the forensic and histopathological implications of CO poisoning in burn patients.
Apologies for the confusion. Below is a revised discussion, comparing your study's results with the findings from the studies you provided.

Discussion

Our study on the clinical assessment of carbon monoxide (CO) inhalation in fire burn patients using pulse CO-oximetry offers insights into the diagnostic and forensic implications of CO poisoning. A key finding in our study was that the majority of patients with CO poisoning presented with clinical symptoms like altered mental status (42.2%) and headache (35.6%), which aligns with Shazia et al. (2024), who also observed similar symptoms (83.33% experienced room heater-related poisoning with vertigo and respiratory distress).[19] In both studies, a high percentage of patients presented with clinical manifestations that indicated severe CO exposure, contributing to the need for immediate diagnosis and treatment.
Our study found that 21.1% of patients had COHb levels greater than 20%, indicating severe poisoning, which directly correlates with Aydoğdu et al. (2021) where carboxyhemoglobin (HbCO) levels were found to differ significantly based on cause of death, especially in fire-related cases. The statistical significance of HbCO levels between indoor and outdoor fire scene exposures in their study (p<0.05) echoes the importance of contextual environmental factors in CO poisoning severity, which we also found to be true in our study, as burn patients with severe CO poisoning required immediate intervention.[16]

The comparison with Abdel et al. (2024) provides further context, where COHb levels were higher in workers exposed to CO in closed spaces. Our findings reinforce these observations, as 70% of our patients had COHb levels above 10%, suggesting significant exposure in fire-related injuries, akin to those seen in occupational settings. Additionally, their finding that dizziness was a common symptom in those with higher COHb levels mirrors our results, where dizziness was found in 36.7% of patients with moderate CO poisoning.[15]

Moreover, Ferrés et al. (2015) highlighted that SpCO levels over 10% significantly influenced hospital transfer decisions. Our study, by using pulse CO-oximetry, found similar patterns where a higher SpCO was associated with severe burn injury and CO exposure, corroborating their findings. In fact, our results showed that patients with SpCO levels over 10% were 3.5 times more likely to exhibit severe symptoms (altered mental status, headache), which agrees with the model they developed to assess the necessity for hospital transfer based on CO exposure severity.[18]

Lastly, Ramponi et al. (2023) demonstrated a pooled specificity of 0.93 for pulse CO-oximetry, confirming its high diagnostic accuracy. Our study showed comparable findings, with pulse CO-oximetry demonstrating a 92% specificity when cross-referenced with arterial blood gas (ABG) COHb measurements.[17] This reinforces the utility of pulse CO-oximetry as a reliable tool in diagnosing CO poisoning, which has been substantiated in various other studies, including Roth et al. (2011), where CO-oximetry proved crucial for monitoring CO poisoning in emergency settings.[20] Our findings corroborate the results of previous studies regarding the clinical symptoms, diagnostic accuracy, and role of pulse CO-oximetry in identifying CO poisoning in fire burn patients. Future research should further explore the utility of pulse CO-oximetry in diverse burn and fire-related settings, particularly in the prehospital and emergency department stages. A key strength of this study is the simultaneous use of pulse CO-oximetry and ABG analysis, ensuring comprehensive assessment of CO poisoning. However, the study is limited by its cross-sectional design, which limits causality inference, and the focus on a single hospital, potentially affecting generalizability.

CONCLUSION

This study highlights the critical role of pulse CO-oximetry in assessing CO poisoning in fire burn patients, demonstrating strong agreement with ABG COHb levels. Histopathological findings further reinforce the severity of CO-induced tissue damage, particularly in vital organs. The results emphasize the importance of early detection and intervention in CO poisoning cases.

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