

High Flow Nasal Cannula Oxygen Therapy for Acute Carbon Monoxide Poisoning

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Abstract

Objective: Carbon monoxide (CO) poisoning is a globally prevalent and serious form of acute poisoning, frequently resulting from household fires, vehicle emissions, and incomplete combustion of fossil fuels. CO binds with hemoglobin to form carboxyhemoglobin (COHb), obstructing oxygen transport and leading to tissue hypoxia. Although hyperbaric oxygen (HBO) therapy is commonly used for severe CO poisoning, the efficacy of high-flow nasal cannula (HFNC) in the acute management of CO poisoning requires further investigation. This study evaluates the clinical impact of HFNC on CO poisoning patients.

Methods: This retrospective clinical series included five patients treated for acute CO poisoning in July 2024. All patients received immediate HFNC upon admission to the critical care unit. Treatment parameters, cognitive assessments, and biochemical indicators were closely monitored.

Results: HFNC demonstrated rapid efficacy, with some patients achieving normalized COHb levels within 1 hour and all patients recovering within 3 hours. Cognitive function, assessed through MoCA and MMSE, showed no significant long-term impairments in admission and 3-month follow-up. Biochemical analyses revealed a statistically significant decrease in neuronal specific enolase (NSE), hemoglobin (Hb), and red blood cell (RBC) counts. Normal MRI imaging showed no early abnormalities in all patients, perhaps advanced imaging techniques such as enhanced-MRI (e-MRI), functional-MRI (f-MRI) would show subtle changes.

Conclusions: HFNC provides a rapid, effective, and safe treatment for moderate CO poisoning. This study's detailed treatment parameters (60 L/min, 100% oxygen concentration) and offer valuable guidance for clinical application of HFNC, which is available in most hospital.

Key findings

- Immediate HFNC (60 L/min, FiO₂ 100%) rapidly reduced COHb in five moderate CO poisoning patients, with all levels normalizing within 3 hours.
- Cognitive performance remained preserved during hospitalization and follow-up, with normal MMSE/MoCA findings and no abnormalities on conventional brain MRI.
- NSE, hemoglobin, and red blood cell counts significantly decreased after HFNC, supporting improvement in hypoxia-related biochemical abnormalities.

Introduction

Carbon monoxide (CO) poisoning is a major global public health issue and a leading cause of acute poisoning deaths(1-3). Worldwide, tens of thousands of deaths annually are attributed to CO poisoning, with a notable seasonal peak in winter due to improper use of heating devices and inadequate ventilation(3, 4). CO is a colorless and odorless gas produced by the incomplete combustion of fossil

fuels such as coal, natural gas, and gasoline(4). It diffuses rapidly through alveolar membranes and binds to hemoglobin with an affinity 200–250 times greater than oxygen, forming COHb(4, 5). This process blocks oxygen transport and leads to widespread tissue hypoxia, resulting in multiple organ dysfunction(4-6).

The previous studies emphasized the importance of timely oxygen therapy to reduce mortality and improve outcomes(7). Domestic research has focused on the epidemiological characteristics of CO poisoning, emergency management, and the evaluation of long-term cardiovascular and neurological sequelae(1, 8). Internationally, studies have explored pathophysiological mechanisms, HBOT, and other therapeutic strategies. Although HBOT improves long-term prognosis in severe CO poisoning, its high cost, equipment requirements, and potential side effects limit widespread use.

Recently, The High-flow nasal cannula (HFNC) oxygen therapy has emerged as a promising non-invasive oxygen therapy for CO poisoning(9-11). HFNC can deliver high-concentration oxygen, so that rapidly lowering carboxyhemoglobin (COHb) levels, improving tissue oxygenation, and alleviating hypoxia(11, 12). Compared to HBOT and traditional mask oxygen therapy, HFNC is more accessible, safe, and operational(11-13). This study aims to evaluate the clinical efficacy of HFNC and its potential role in guiding treatment protocols for acute CO poisoning.

Methods

Patient Selection

In July 2024, five patients with moderate CO poisoning were admitted to Shanghai fourth people's hospital. They had been exposed to CO in an enclosed space. All patients presented with headache and nausea, without loss of consciousness or high level of lactate. In addition, the proportion of carboxyhemoglobin in the first arterial blood gas analysis after admission exceeded 30% in all cases. Therefore, they were diagnosed with moderate CO poisoning based on clinical presentation and arterial blood gas analysis. Although diagnosed with moderate carbon monoxide poisoning, the patients only had mild symptoms such as headache and nausea. Given the poor accessibility of hyperbaric oxygen therapy, high-flow oxygen was administered as the initial treatment when immediately transferred to the Intensive Care Unit (ICU). Written consent for data use and publication were obtained from all patients.

Treatment Protocol

High-flow oxygen therapy was initiated immediately upon admission using HFNC devices set at 60 L/min with an oxygen concentration of 100%. Arterial blood gas (ABG) analysis was performed hourly during HFNC to monitor COHb levels, and treatment continued until levels normalized ($\leq 3\%$)(1). Then, it was replaced with ordinary nasal cannula oxygen therapy which was maintained for an additional 4 days before discharge. During HFNC, daily attempts were made to transition patients to a normal nasal

cannula for oxygen delivery. Throughout the hospitalization period, vital signs, cognitive function, and biochemical parameters were continuously monitoring in real time to ensure patient stability .

Cognitive and Imaging Assessments

Cognitive Function: Cognitive performance was assessed using the Montreal Cognitive Assessment (MoCA) and Mini-Mental State Examination (MMSE). These assessments were conducted post-HFNC, during nasal cannula therapy, and at discharge.(We have acquired the copyright of MoCA and MMSE)

Imaging: Brain MRI, performed within 48 hours of admission and 3 month post discharge was used to detect neurological changes.

Biochemical Indicators Analysis and Statistical procedures

Serial tests of NSE, Hb, red blood cell count, and total carbon dioxide levels were obtained pre-treatment, post-HFNC, and before discharge. These blood indicators were analyzed to identify trends and statistical significance. Normally distributed continuous variables are expressed as mean±standard deviation and were analyzed using Student’s t-test. Non-normally distributed continuous variables are expressed as median (interquartile range) and were analyzed using the Mann–Whitney U test. For multiple timepoints, repeated-measures ANOVA would be more appropriate. Categorical variables are expressed as numbers and were analyzed with the χ^2 test. P<0.05 was considered a significant difference. Data analysis was performed in SPSS 27.0.

Results

Rapid Reduction in COHb Levels

Data were collected from 5 patients with acute CO poisoning. They had similar baseline data as the Table1 shows. Throughout the treatment period, we continuously monitored COHb levels via blood gas analysis. On the first day of treatment, blood gas tests were conducted per hour until COHb levels returned to normal. On days 2 and 3, blood gas analysis was performed per 5 hours to track changes in COHb levels. From days 4 to 9, blood gas analysis was conducted per 12 hours to follow the COHb content in the patient's arterial blood. For detailed results, refer to Table 2.

Table1 The baseline characteristics of patients

Variables	Patient-1	Patient-2	Patient-3	Patient-4	Patient-5
Sex(Male/Female)	Male	Male	Male	Male	Male
age (years)	22	23	24	23	25
BMI (kg/m ²)	28.97	27.17	23.67	23.14	20.22
Smoke☐Yes/No☐	Yes	Yes	Yes	Yes	Yes
History of chronic disease					
Hypertnesion☐Yes/No☐	No	No	No	No	No
Diabetes☐Yes/No☐	No	No	No	No	No
CNS Disease☐Yes/No☐	No	No	No	No	No

Table2 Changes of COHb in blood gas analysis during treatment

Treatment\Days\	Hour	Patient-1	Patient-2	Patient-3	Patient-4	Patient-5
1	0	32.2	35.4	31.8	32.7	30.6
	1	7.9	7.1	2	3	3.3
	2	4.5	4.4	5	2.4	1.4
	3	2.4	2.3	2.9	1.5	1.5
	4	2.4	2.2	2.3	1	0.6
	5	0.9	1.1	1.8	1.1	0.8
2	0	2	0.4	1.4	0.9	0.3
	5	1.5	0.6	1.3	1.5	2
	10	0.9	0	1.6	1.4	0.6
	15	1.3	0.5	1.5	1.4	1.4
	20	1.4	0.8	1.8	0.7	1.2
3	0	1.9	1.1	1.5	0.4	1.6
	5	2.1	0.7	1.8	1.9	0.9
	10	1.5	0.9	2	0.6	0.6
	15	1.6	1.9	0.7	0.9	0.7
	20	0.8	1.6	0.7	1.4	1.4
4	8	2.1	0.9	1.8	1.7	0.7
	20	2.2	0.8	0.1	1.7	1.3
5	8	1.3	1.2	0.8	1.8	0.8
	20	2.5	1.8	1.1	0.8	1.5
6	8	1.9	2	1.5	1.4	1.4
	20	1.1	1.5	1.2	1.2	0.9

7	8	1.7	0.9	0.4	1.7	1.5
	20	1.5	1	1.9	1.2	1.3
8	8	2.2	1.8	1.9	0.6	2
	20	2	1.2	0.9	2.1	1.7
9	8	2.4	0.9	1.3	1.5	1.1
	20	1.6	0.6	1.2	0.7	0.7

All patients experienced a rapid decline in COHb levels. HFNC demonstrated rapid effectiveness, with one patient normalizing COHb levels within 1 hour, and the COHb level of all patients were normal within 3 hours. Throughout the treatment period, no rebound or abnormal fluctuations in COHb levels were detected, highlighting the stability and reliability of the therapy. After 9 days of hospitalization, all five patients showed significant improvement and were discharged without complications (Table 3, Figure S1). This result not only confirms the effectiveness of high-flow oxygen therapy in the acute phase but also serves as a valuable reference for the clinical management of similar cases in the future.

Table 3 The clinical characteristics of patients

Variables	Patient-1	Patient-2	Patient-3	Patient-4	Patient-5
HFNC (days)	5	5	5	5	5
Ordinary nasal cannula oxygen therapy (days)	4	4	4	4	4
Time for COHb to return to normal (minutes)	<180	<180	<180	<60	<120
Pre-HFNC, COHb level (%)	32.2	35.4	31.8	32.7	30.6
Post-HFNC, COHb level (%)	2.5	1.8	1.1	0.8	1.5
COHb level at discharge (%)	1.6	0.6	1.2	0.7	1.7

Cognitive Function Outcomes

We conducted cognitive assessments using the Mini-Mental State Examination (MMSE) to evaluate the intellectual status and cognitive function of patients after high-flow oxygen therapy, on the 3rd and 5th and before discharge. The results indicated that all five patients had MMSE scores within the normal range throughout the observation period.

To gain a more detailed understanding of cognitive function, we also employed the Montreal Cognitive Assessment (MoCA), which evaluates 11 items across 8 cognitive domains, including attention and concentration, executive function, memory, language, visuospatial ability, abstract thinking, calculation, and orientation. Cognitive assessments revealed no significant impairments post-HFNC. Notably, one patient displayed mild cognitive impairment (MoCA score: 25) during normal nasal cannula therapy, who was recovery gradually after discharge.

These findings suggest that the intellectual status and cognitive functions of patients were well maintained during HFNC, with no significant cognitive decline observed. For detailed results, refer to Figure S2.

Biochemical Changes

We also collected and analyse the other laboratory biomarkers. We found that the level of neuronal specific enolase (NSE) (18.76 ± 7.14 vs 10.8 ± 1.35), Hemoglobin (Hb) (162.4 ± 8.85 vs 148 ± 8.31) and red blood cell (RBC) (5.31 ± 0.20 vs 4.87 ± 0.26) had a significant decrease after HFNC (Table4, Figure S3). In the early stages of CO poisoning, the brain and other organs of the body maybe suffered from hypoxia, resulting in elevated levels of serum NSE, Hb, and RBC.

Table 4 The laboratory biomarkers of patients with CO poisoning

Variables	Adimission	Pre-Discharge	<i>P</i> value
PO ₂ (kPa, mean±s)	15.36±3.84	16.42±3.71	0.6905
PCO ₂ (kPa, mean±s)	5.27±0.95	4.75±0.52	0.4206
Lactate (mmol/L, mean±s)	1.64±0.56	1.42±0.33	0.5397
RBC (×10 ¹² /L, mean±s)	5.31±0.20	4.87±0.26	0.0079*
Hb (g/L, mean±s)	162.4±8.85	148±8.31	0.0238*
PLT (×10 ⁹ /L, mean [IQR]▯	247(225.5, 296.0)	258.0(183.5, 260.5)	1.000
NSE(ng/mL, mean±s)	18.76±7.14	10.8±1.35	0.0159*

Imaging Findings

There were no abnormalities in normal MRI of all patients in eraly stage and 2-month follow-up▯Figure 1▯. Perhaps there may be some abnormal manifestations in enhanced-MRI (e-MRI) or functional-MRI (f-MRI).

Discussion

HBOT has been extensively studied and supported for treating CO poisoning, particularly in severe cases. HBOT can significantly enhance the long-term prognosis of patients with severe CO poisoning. However, its high cost, stringent equipment requirements, and potential side effects limit its widespread use(14, 15). HFNC, an non-invasive oxygen therapy, offers the benefits of delivering stable and high-concentration oxygen, ease of operation, and straightforward implementation, making it particularly suitable for the patients with different diseases(10-12). Compared to traditional mask oxygen supply and HBOT, HFNC is more flexible and safer for CO poisoning patients, making it especially useful in emergency departments and first aid settings(3, 10, 11, 15).

In this study, we found that HFNC (60 L/min, 100% oxygen concentration) could effectively and rapidly reduce COHb levels within 3 hours, improve tissue oxygenation, and alleviates hypoxia symptoms. After 5 days of HFNC, the patient showed no neurological impairment in 2-month follow-up. That's to say, for patients with CO poisoning, HFNC does not increase the risk of residual neurological damage(10-13). The finding was consistent with previous research results which found that HFNC significantly reduced the risk of neurological damage and complications in acute CO poisoning patients(3, 9, 16-18). Under the condition of no HBOT, the results of this study can guide the clinical treatment of patients with CO poisoning. These findings align with the results of previous studies and further underscore the potential value of HFNC in the acute CO poisoning.

Additionally, the study demonstrated HFNC's potential to improve patient prognosis through clinical data, supporting its application for acute CO poisoning. The results showed that there was a significant decrease in the level of NSE, Hb and RBC counts between pre-HFNC and post-HFNC. NSE is an enolase involved in the glycolytic pathway and also an acidic protease secreted by neurons and neuroendocrine cells in the human body(19-21). It is widely distributed in tissues such as lungs, brain, thymus, pancreas, etc., primarily derived from embryonic cells of the neuroendocrine system. Under normal circumstances, the concentration of NSE in the blood is relatively low(21-23). However, when the central nervous system is damaged, neurons are injured, leading to an increase in NSE levels(20-22, 24, 25). As for the decrease of RBC and Hb, it may be caused by hemolysis of RBCs damaged by carbon monoxide poisoning(1). In addition, no abnormalities were detected during the normal MRI examination in early stage and 3-month follow-up. Perhaps subtle pathological changes may be discovered during e- MRI or f-MRI examinations.

HFNC has been proven to be a rapid, effective, and safe treatment for moderate CO poisoning, significantly reducing COHb levels and improving clinical outcomes without increasing neurological impairment risks(9-13). This study provides critical evidence supporting the use of HFNC in acute management and identifies areas for future exploration, such as advanced imaging techniques and long-term outcomes. However, the study has certain limitations. First, the small sample size of only 5 patients may not adequately represent HFNC's effects across different CO poisoning cases. Future research should include larger, multicenter prospective studies to further validate HFNC's clinical efficacy and safety. Secondly, as a retrospective study, there may be information bias. Despite minimizing bias through systematic data collection and analysis, its influence cannot be entirely excluded. Thus, future studies should consider prospective randomized controlled trials to provide higher-quality evidence.

In conclusion, this the first study demonstrated that HFNC could rapidly lower the levels of COHb with in 3 hours. Besides, HFNC decrease NSE without increasing nerve damage risk. Early f-MRI perhaps help doctors better evaluate the patient's condition. However, future research should compare HFNC with other treatment options, such as HBOT, to establish a more robust scientific foundation for clinical application. These efforts are critical for reducing CO poisoning-related mortality and enhancing patient quality of life, carrying significant public health implications.

Declarations

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Authors' Contributions

Xiaoxiao Sun and Qingyu Sun prepared the manuscript of the article. Limin Yao revised the manuscript. Xiaoxiao Sun was responsible for statistical analysis. Fengrui Han offered the clinical data. Jian Song and Gang Bai participated in the whole treatment process. Lize Xiong designed the report. Zongping Fang revised the manuscript. All of authors consent to published the paper.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Disclosure statement

All of the authors had no any personal, financial, commercial, or academic conflicts of interest separately.

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Shanghai Fourth People's Hospital, School of Medicine, Tongji University. The research was carried out in accordance with the guidelines of the Ethics Committee and the Declaration of Helsinki. Written informed consent was obtained from all patients for data use and publication.

Availability of Data and Materials

The datasets analyzed in this study are available from the corresponding author upon request.

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Figure 1

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