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REVIEW ARTICLE

The main aspects of carbon monoxide poisoning - a literature review

Os principais aspectos do envenenamento por monóxido de carbono - uma revisão da literatura

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ABSTRACT

Introduction: Carbon monoxide poisoning is a common occurrence in emergencies, usually with serious clinical conditions. Carbon monoxide is normally produced by the incomplete combustion of carbon compounds and is very commonly generated in fires and combustion machinery. **Objective:** This review aims to compile the main articles on carbon monoxide poisoning and thus synthesize the most updated information on the clinical aspects, diagnosis, and treatment of this hospital emergency. **Methods:** The PubMed and ScienceDirect databases were used for this purpose, using keyword searches and Boolean operators. **Results:** It was found that this intoxication has non-specific clinical aspects; the COHb level in the blood is the main diagnostic method, oxygen therapy is fundamental for reducing the half-life of COHb in the blood, and the prognosis is diverse, with neurological sequelae being one of the most important points. **Conclusion:** Carbon monoxide poisoning is a multifaceted emergency that requires well prepared professionals in hospitals to be correctly managed.

Keywords: Carbon monoxide poisoning; Carbon monoxide; Emergency service; Gas poisoning; Hyperbaric oxygenation.

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RESUMO

Introdução: A intoxicação por monóxido de carbono é uma ocorrência comum em emergências e geralmente com condições clínicas graves. O monóxido de carbono é normalmente produzido pela combustão incompleta de compostos de carbono e é muito comumente gerado em incêndios e máquinas de combustão. **Objetivo:** Esta revisão teve como objetivo reunir os principais artigos sobre intoxicação por monóxido de carbono e, assim, sintetizar as informações mais atualizadas sobre os aspectos clínicos, diagnóstico e tratamento dessa emergência hospitalar. **Métodos:** Foram utilizadas as bases de dados PubMed e ScienceDirect, por meio de buscas por palavras-chave e operadores booleanos. **Resultados:** Verificou-se que essa intoxicação tem aspectos clínicos inespecíficos; o nível de COHb no sangue é o principal método diagnóstico, a oxigenoterapia é fundamental para reduzir a meia-vida da COHb no sangue e o prognóstico é diverso, sendo as sequelas neurológicas um dos pontos mais importantes. **Conclusão:** A intoxicação por monóxido de carbono é uma emergência multifacetada que, para ser gerenciada corretamente em hospitais, exige que os profissionais estejam bem preparados para essa situação.

Palavras-chave: Intoxicação por monóxido de carbono; Monóxido de carbono; Serviço de emergência; Intoxicação por gases; Oxigenação hiperbárica.

INTRODUCTION

Carbon monoxide (CO) is a tasteless, odorless, and colorless gas, usually found in low concentrations in atmospheric air, approximately between 0.03 and 0.2 parts per million. It is mainly generated in the process of incomplete combustion of carbon-containing materials and may or not be a result of human activity[1].

Some of the main sources of CO in cases of poisoning by this substance are smoke from fires, burning coal indoors, and engine exhaust[2]. It is one of the most common forms of non-drug-related human poisoning[3].

CO is present in small quantities in human metabolism, however, it is toxic in high concentrations. Its toxicity is related to its high affinity for human hemoglobin (Hb), as the binding of Hb to CO is around 200 times more intense than the binding to O_2[4].

The physiologic concentration of carboxyhemoglobin (COHb) in healthy adult patients is less than 3% for non-smokers and 10% for smokers[5]. At levels higher than 10%, mild, moderate, or severe symptoms may appear[4].

Additionally, some patients develop late neurological sequelae and cardiac complications, such as acute myocardial infarction in patients with this predisposition[3]. It is also clear that the organs that are initially most affected are those with a high demand for oxygen, such as the brain and heart[6].

Throughout the patient management, it is also important to observe all the vital signs and establish venous acess[4]. To restore oxyhaemoglobin in the blood, oxygen therapy should be administered until symptoms disappear or COHb levels drop to physiologic concentration[4]. Hyperbaric oxygen therapy also could be used, although there is discussion about its use[6,7].

This review aims to provide an up-to-date description of the main clinical aspects, forms of diagnosis, and treatment of CO poisoning.

METHODS

A narrative review of the literature on exogenous poisoning caused by carbon monoxide was conducted. To do this, a search was conducted in the PubMed and Science Direct databases, including only articles published in the last 10 years, to select the most up-to-date work on the subject. The search used the main descriptors "Carbon Monoxide Intoxication", "Carbon Monoxide Poisoning," "Carbon Monoxide Exposure", and "Carbon Monoxide" and the secondary descriptors "Diagnosis", "Prognosis", "Treatment", "Hyperbaric Oxygen" and "Clinical Aspects", which were associated using the Boolean operators "AND" or "OR". All review articles, books, editorials, and letters were then excluded. The focus of the review was to select articles that addressed important aspects of carbon monoxide poisoning, including diagnosis, treatment, and prognosis. After the search, the exclusion criteria were applied, and a careful selection of the references found was conducted to choose articles relevant to the objectives of this review. It should be noted that because the review had a narrative nature, it followed no guidelines, as the study was conducted based on clinical experience.

Results

A total of 19 articles were ultimately selected for this review. The selected studies were carefully read and compiled into Table 1, outlining the objectives, results, and methodology of each study, highlighting the main aspects of the articles.

Table 1. Main works on carbon monoxide.

Author, year	Objective	Outcome	Methodology
Camacho et al. (2023)	Describe the occurrence of acute myocardial infarction (AMI) due to myocardial damage following carbon monoxide poisoning.	The possibility of AMI after CO intoxication was observed due to myocardial damage. More attention needs to be paid to cardiovascular findings as complications of intoxication.	Case report
Chi et al. (2022)	Verify the effectiveness of the FIRED score (fire rescue, CO poisoning, respiratory failure, reduced ECG score, and diabetes *mellitus*) in predicting unfavorable prognoses after CO poisoning.	The FIRED score is viable for predicting the prognosis of CO poisoning and can verify the mortality risks of these patients.	Retrospective cohort study
Cho et al. (2020)	Compare the risk of venous thromboembolism immediately after CO poisoning with the risk one year after poisoning.	The number of cases of venous thromboembolism was higher in the first 3 months after the diagnosis of CO poisoning than in the same period 1 year later.	Retrospective cohort study
Fukuda et al. (2020)	Determine COHb elimination rates and their differences in arterial and venous blood after inhalation injury to the airways in sheep.	Hyperventilation associated with PaCO2 may have caused an increase in hemoglobin's affinity for oxygen, resulting in faster elimination of COHb.	Experimental study
Huang et al. (2022)	Verify the occurrence of prognostic factors of hyperbaric oxygen therapy in patients with late encephalopathy caused by CO poisoning.	Hyperbaric oxygen therapy is a safe and effective treatment for late encephalopathy induced by carbon monoxide intoxication.	Retrospective cohort study
Ito et al. (2022)	Verify the incidence of rhabdomyolysis secondary to CO intoxication and the respective causative and prognostic factors.	Around 20% of the patients evaluated developed rhabdomyolysis after carbon monoxide poisoning. One possible explanation is the occurrence of hypoxia and consequent tissue necrosis in the muscle.	Retrospective cohort study
Jarman et al. (2023)	Determine the proportion of patients arriving at the emergency room with suspected CO poisoning who have increased COHb levels and evaluate the use of the COMA screening tool.	It is recommended to use the COMA strategy in conjunction with a test that measures COHb levels.	Prospective cross-sectional study
Liu et al. (2020)	Study the clinical findings, magnetic resonance imaging, and possible prognoses of late encephalopathy induced by carbon monoxide intoxication.	The patients had several neurological manifestations. Magnetic resonance imaging showed lesions in the cerebral white matter. The early use of hyperbaric oxygen therapy favors a better prognosis in these patients.	Retrospective cohort study
Mattiuzzi e Lippi (2020)	Present global epidemiological data on CO poisoning obtained from the Global Health Data Exchange Registry.	The overall incidence of CO poisoning practically remained constant over the last 25 years, while mortality has fallen by 36%.	Epidemiological study

continue...

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Author, year	Objective	Outcome	Methodology
Nakajima et al. (2019)	Evaluate cases of CO poisoning following the 2011 Great East Japan Earthquake using a national database of hospitalized patients.	The number of CO poisonings in the places hit by the earthquake has increased significantly.	Retrospective cohort study
Ouahmane et al. (2023)	Describe the clinical and epidemiological characteristics of CO intoxication and analyze the impact of hyperbaric oxygenation (HBOT) on the clinical progress and recovery of the patient's neurological signs.	OHB has a positive effect on the prevention and management of neurological sequelae resulting from CO intoxication, especially if administered early. However, more prospective studies are needed to prove the findings.	Single-center retrospective study
Pan et al. (2019)	Identify complication factors related to the prognosis of patients suffering from carbon monoxide poisoning.	Low scores on the Glasgow Coma Scale and high blood urea levels were identified as possible indicators of poor prognosis. There was also a relationship between the number of days of intubation and the unfavorable outcome of these patients.	Retrospective cohort study
Rhee et al. (2021)	To analyze the incidence of diseases of the neurological system in survivors of CO poisoning in South Korea.	Patients who have been affected by and survived CO poisoning have an elevated risk of developing diseases of the neurological system.	Retrospective cohort study
Rose et al. (2018)	Define the clinical profile of patients receiving OHB and analyze the effectiveness of this technique on acute and long-term mortality in CO poisoning.	Hyperbaric oxygen therapy for CO poisoning improves survival in both short- and long-term contexts; the need for more studies on the impact of HBOT on mortality was emphasized.	Retrospective cohort study
Rose et al. (2020)	Evaluate the use of Ngb-H64Q-CCC in carbon monoxide poisoning through an experimental study with rats.	Treatment with Ngb-H64Q-CCC increased the mice survival rate to 88%.	Experimental study
Simonsen et al. (2019)	Elucidate CO poisoning in terms of its scope, mortality, and the variables correlated with mortality.	Intoxication and mortality are intrinsically linked to comorbidities, especially those that can influence physical and cognitive function. Hyperbaric oxygen therapy, after adjusting for comorbidities and age, had no impact on survival in the short or long term.	Retrospective cohort study
Simonsen et al. (2021)	Explore the effects of mild and severe poisoning on metabolite and blood gas parameters.	The study added new knowledge to the mechanism of metabolites in cases of CO poisoning, including hypoxia, Ros formation, and peroxidation.	Experimental study
Villalba et al. (2019)	Address the limitations of previous studies and determine the performance of pulse oximeters in detecting high COHb values in emergencies.	The pulse oximeter was not as efficient as laboratory tests in quantifying CO intoxication.	Prospective cohort study
Yesiloglu et al. (2021)	Conduct a comparative analysis of the rate of reduction in COHb levels at consecutive times in CO-intoxicated patients who underwent oxygen therapy with a non-rebreathing face mask and a high-flow nasal cannula (HFNC).	Although there was no substantial disparity between the COHb decay curves between the two techniques, CNAF was more effective in reducing COHb half-life values, prompting further studies to gain a better understanding of the effects of this therapeutic technique.	Retrospective cohort study

Discussion

Concept

Carbon monoxide poisoning is a common and serious hospital emergency, which represents a serious health risk due to its potential lethality and the serious sequelae that it can cause.

This poisoning is one of the most common and most lethal causes of death from poisoning in the USA, as high COHb levels have significant effects on cardiopulmonary hydrodynamics, pulmonary mechanics oxygenation, and biochemical parameters[8].

The study by Simonsen et al. (2019)[9] assessed mortality and its contributing factors in the context of CO poisoning, evaluating around 23,000 patients, 92% of whom were hospitalized. They found that 9% of the patients evaluated died within the first 30 days after poisoning, 85% of whom were declared dead on the spot, and the other 15% were hospitalized. In addition, this study concluded that mortality and CO intoxication are highly associated with comorbidities that interfere with cognitive and physical functions.

In the Brazilian context, no data was found describing mortality from CO poisoning, which reveals the need for epidemiological studies that adequately detail this health parameter.

Diagnosis

CO poisoning is diagnosed based on three key factors: the history of the probable poisoning, the level of COHb in the blood, and the patient's clinical symptoms, with COHb levels being the most relevant for diagnosis (Figure 1)[8].

The study by Jarman et al. (2023)[10] evaluated the use of the "COMA" screening tool, which consists of a sequence of 4 questions, including questions about who was with the patient at the time of intoxication ("C"), whether the symptoms have improved outside the area of exposure ("O"), whether the ventilation equipment in the room is properly maintained ("M") and whether there is a carbon monoxide alarm in the room ("A"). The answers to questions "C" and "O" were found to be the ones that best indicate whether there is intoxication if combined with the COHb measurement.

Despite being invasive and depending on time and a laboratory to be conducted, the most accurate test for measuring COHb levels is venous gasometry. Thus, pulse oximetry is a plausible and less invasive alternative for monitoring patients in the pre-hospital period, although the use of pulse oximeters in hospital emergencies is controversial[11].

In clinical practice, COHb levels greater than 4% in non-smokers and greater than 10% in smokers are already considered to be outside the parameters of physiological normality. In order to diagnose CO intoxication, values greater than 10% are defined as the cut-off point for smokers and non-smokers[11].

Based on Simonsen et al. (2021)[2], mild signs and symptoms can occur with COHb of 3% to 24%; with values higher than 24%, there may be loss of consciousness, and contamination with higher values is potentially fatal. The same study states that the relationship between the current COHb level and the severity of symptoms is not necessarily related because, if the time interval between contamination and COHb measurement is long, the measured value can generate a discrepancy between the percentage of contamination and the symptoms presented. This conclusion about the low correlation between the symptoms presented and the COHb rate was also pointed out in the studies by Jarman et al. (2023)[10].

The increase in CO concentration, in addition to generating metabolic acidosis, can affect a range of metabolites, increasing or decreasing their levels. Among the metabolites that have their rates increased are lactate, pyruvate, and aromatic amino acids, with lactate being the one that has the most relevant changes and, among those that have a reduction, is acetate. Thus, tests that measure these rates may be relevant for a more accurate diagnosis[2].

The nonspecificity of the symptoms of CO intoxication is one of the factors that lead to misdiagnosis, as the most frequent symptoms, such as fatigue, headache, vertigo, nausea, vomiting, and mental confusion, are found in many patients who do not have CO intoxication[12].

Treatment

In the event of suspected poisoning, the recommended initial management step consists of immediately removing the patient from the source of CO exposure and conducting supportive care, such as airway control, respiratory function, and cardiac monitoring. After these measures are taken, supplementary oxygen should be administered, which can take place under normobaric or hyperbaric conditions. The oxygen therapy technique acts by reducing the blood concentration of COHb[13].

Thus, performing this therapy under high flow, with equipment adjusted for the application of 100% concentrated inhaled O_2, such as a face mask without reinhalation and, especially, a high-flow nasal cannula, is highly effective in reducing the half-life of COHb[14].

Hyperbaric oxygen therapy (HBOT) is a much-discussed therapeutic option in the scientific community for the treatment of CO poisoning. Although this procedure is widely accepted for its ability to reduce the half-life of COHb, there is controversy over its effectiveness, as there is little evidence to show that it has greater advantages compared to normobaric therapy in terms of reducing morbidity and improving survival from the sequelae of poisoning, such as late neurological damage[9].

The management of patients with HBOT presents logistical difficulties such as the limited number of hospital units that have a pressurized chamber and appropriately trained professionals, factors that influence the "Time-To-Chamber", an important predictor, defined as the time interval between the moment of intoxication and the start of HBOT[13,15].

The existing medical literature lists some situations in which HBOT may be indicated, which include altered mental status, syncope, cardiac complications, COHb blood levels greater than 25%, pregnant patients, and clinical scenarios that are commonly more serious[9,13].

Although the standard treatment of CO-intoxicated patients is limited to normobaric and hyperbaric oxygen therapy, which are based on increasing O_2 levels and the consequent faster elimination of COHb, these techniques have contraindications[13,16]. A supplementary pharmacological treatment approach based on an antidote is much needed, as it would enable faster management at the point of care and in hospital units. Antidotes based on high-affinity hemoproteins, such as neuroglobin H64-CCC, have been the subject of experimental studies in mice, given their mechanism of active sequestration and clearance of CO from the body[16].

It is common for CO poisoning to be accompanied by cyanide (CN) poisoning, given the similar physicochemical properties of the two compounds and the fact that both are products of incomplete combustion reactions, and, like CO, cyanide affects tissues with high energy demand[17].

Although the diagnosis of CN intoxication is difficult to distinguish from CO intoxication, there are some lines of treatment to be followed in this case. Initially, intubation and mechanical ventilation are essential for patients with reduced levels of consciousness (Figure 2). Pharmacological treatment varies in different countries, but the main antidotes are amyl nitrite, sodium nitrite, and thiosulphate in the United States — which produce an oxidation reaction whose product has preferential cyanide binding compared to cyanide binding by ferric ions located in the cytochrome oxidase enzyme and the electron transport chain — and dicobalt edetate in Europe. However, the use of hydroxocobalamin has become widespread in all countries, as this endogenous precursor of vitamin B has proved to be a useful antidote to CN[18].

Prognosis

Early diagnosis and treatment of carbon monoxide poisoning are essential to guarantee a good prognosis for the patient. Unfavorable prognoses may be related to the previous clinical characteristics of the affected patients since patients with diseases such as hypertension and diabetes mellitus (DM) showed unfavorable outcomes in the retrospective studies conducted by Chi et al. (2022)[7], a fact also concluded by the studies by Huang et al. (2022)[19]. This study also showed five factors that may be predictive of an unfavorable prognosis in CO poisoning: fire-related poisoning, intentional poisoning, respiratory failure, a lower score on the Glasgow Coma Scale, and DM.

Some of the possible complications related to CO intoxication concern rhabdomyolysis, myocardial damage, metabolic acidosis, and neurological dysfunctions, as well as kidney problems evidenced by elevated levels of urea and creatinine in the blood, all of which are related to unfavorable prognoses[6].

Table 2. Symptoms reported by 1096 patients after exposure to carbon monoxide[13].

Factor	N	%
Total	1096	100
Headache	604	55
Nausea/Vomiting	445	41
Dizziness	422	38
Altered mental status	279	25
Syncope	272	25
Fatigue	168	15
Chest pain	139	13
Shortness of breath	137	12
Neurologic deficit	122	11
Respiratory distress	67	6

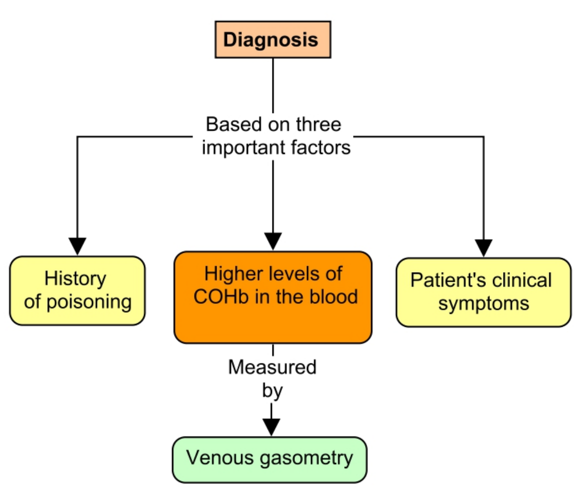

Figure 1. Diagram of diagnosis.

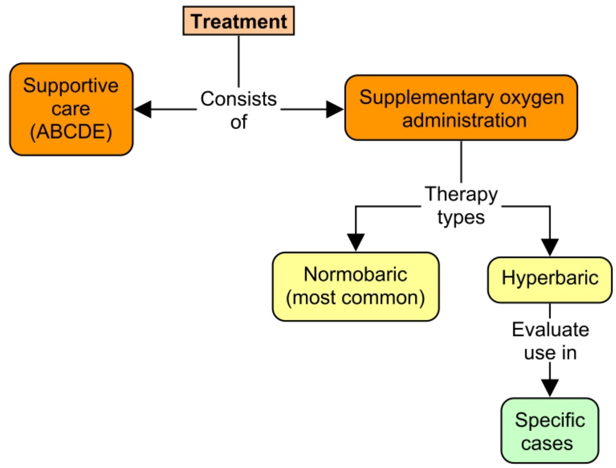

Figure 2. Diagram of treatment.

Complications related to rhabdomyolysis were observed in 20% of the patients studied by Ito et al. (2022)[20]. The onset of this condition may be related to greater exposure to carbon monoxide, which compromises the supply of oxygen to muscle cells and causes muscle necrosis. The literature also records the occurrence of myocardial infarction as a result of myocardial damage[21].

Cho et al. (2020)[3] analyzed that CO intoxication is considered a risk factor for thromboembolism, especially in the first 90 days. The risk of venous thromboembolism in the first 30 days was 13.6 times higher in the CO-intoxicated population than in the general population. These data from the study attest to the fact that, due to the elevated risk, CO-poisoned patients need constant medical monitoring in the first 90 days after poisoning. In critically ill patients, the use of heparin as prophylaxis for thromboembolism is recommended[22].

After acute CO poisoning, the occurrence of late neurological sequelae is an important complication in the prognosis[23]. According to the results of Rhee et al. (2021)[23], in a study carried out between 2012 and 2018, 86.2% of the patients evaluated were diagnosed with diseases of the neurological system. One of these late complications, which affects around 20% of CO poisoning patients, is carbon monoxide-induced late encephalopathy[24]. Although there is no consensus on its pathogenesis, it may be related to the degeneration of brain cells and the demyelination of oligodendrocytes, which corroborate the occurrence and progression of the disease[25].

How to prevent

The epidemiological study by Mattiuzzi and Lippi (2020)[1] attested that the dissemination of educational measures on the risks of CO poisoning and how to avoid them, the improvement in the effectiveness of detecting residential CO alarms, and the better management of poisoned patients are fundamental measures for reducing the mortality associated with CO poisoning.

Conclusion

CO poisoning has a variety and non-specific symptoms, which vary according to the rate of contamination and can progress from headache to a comatose state. Therefore, to avoid misdiagnosis, it is essential to conduct urgently tests such as venous gasometry, to measure the COHb level.

It was found that oxygen therapy, whether normobaric or hyperbaric, is extremely important for reducing the half-life of COHb; however, despite the notorious acceptance of HBOT, the scientific community still lacks studies that definitively attest to its efficacy and relevance in treatment.

Rhabdomyolysis, myocardial damage, and neurological sequelae are the main complications in the prognostic picture.

It is, therefore, of the utmost importance to have more scientific literature on CO poisoning to clarify the points of disagreement and thus draw up a diagnosis and treatment plan that is more effective in saving the patient.

Author's contributions

We describe contributions to the papers using the taxonomy (CRediT) provided above:

Conceptualization, Investigation, Methodology, Visualization & Writing – review & editing: CCFLM; CABN. *Project administration, Supervision & Writing – original draft*: GSC; MLB; DHSB. *Validation & Software*: CABN. *Data curation & Formal Analysis*: ALSA.

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