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REVIEW ARTICLE

Carbon monoxide poisoning: pathophysiologic principles underlying good treatment

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Carbon monoxide (CO) poisoning is the most common form of gas poisoning in Spain. Most cases are household accidents due to incomplete combustion of gases by room heaters, water heaters, braziers and similar devices, or the result of smoke inhalation, where CO and cyanide poisoning account for most deaths. CO toxicity is a result of its binding to 2 heme molecules. Binding to hemoglobin causes hypoxia, anoxia, and the majority of acute symptoms. Binding to cytochromes in the mitochondrial respiratory chain leads to consequent inhibition of respiration at the cellular level, contributing to the differential signs and symptoms seen in some patients. The most frequent are headache (96.9%), nausea (66.1%), vomiting (35.8%), unstable gait (32%), loss of consciousness (29.2%), and tachycardia (20%). Children, pregnant women, the elderly, and individuals with a history of heart disease are at risk of severe poisoning. A diagnosis is confirmed by a blood test or pulse oximetry result indicating that CO is bound to hemoglobin or by the detection of CO in expired air. If CO poisoning is suspected, further exposure must be prevented by removing the victim from the source of inhalation, while also protecting rescuers and medical caregivers, and by ventilating the premises. Oxygen should be administered immediately at a normal pressure and at the highest concentration possible (through a high-flow mask or at 100% if the patient is intubated) even before laboratory findings confirm the diagnosis. This review includes a discussion of the use of hyperbaric oxygen to treat CO poisoning. [Emergencias 2010;22:451-459]

Key words: Carbon monoxide. Poisoning. Hyperbaric chamber. Mitochondria. Toxicology.

Introduction

The gas carbon monoxide (CO) is colorless, odorless and non-irritating for the airways. It easily enters pulmonary alveoli and, depending on its concentration in ambient air and exposure time, can rapidly induce a combination of harmful effects which may even cause death within minutes or irreversible neurological damage[1]. Due to its physical and chemical characteristics and toxic capacity, CO has been called the silent invisible killer[2]. CO is produced when combustion occurs with a paucity of oxygen in the ambient air; stoves, heaters and water boilers in badly ventilated kitchens and bathrooms are a frequent source of poisoning at home, sometimes in an epidemic and catastrophic way as has happened repeatedly in our country[3]. CO is also found in the smoke from fires, along with other harmful gases and particles, which is a possible cause of death in fire victims[4].

Clinical manifestations of CO poisoning (COP) is multi-factorial and non-specific, and a reason for visits to the emergency department (ED). This diagnosis should be considered, especially in the winter months, when faced with unexplained neurological symptoms and particularly when involving two or more people who live together in the same household. Treatment with oxygen therapy is mandatory, but the form of administration, with normobaric or hyperbaric oxygen remains controversial.

Epidemiology

COP is considered an under-diagnosed entity, given its non-specific clinical manifestations and absence of pathognomonic signs or symptoms, and medical staff awareness on this issue and a greater availability of analytical methods have been shown to lead to increased diagnosis and therefore epidemiological information[5].

In our context, COP is the most frequent type of poisoning by gas, and the cause is habitually domestic accidents involving fumes from incomplete combustion of gases in stoves, heaters, boilers etc., so the number of victims rises in the winter months. It affects equally men and women, adults and children[6,7]. Substitution of so-called town gas by natural gas in the 1980s last century represented a turning point in COP casuistry since it prevented suicides at home by this method, although CO from other sources is still used in many countries to attempt suicide[8,9].

Inhalation of smoke from fires is another known source of COP and, together with cyanide poisoning, is the main cause of fatal outcome[10,11].

CO poisoning also occur due to exposure to gas combustion engines (cars, motorcycles, boats, pneumatic compressors, power generators and others) and in some published series, up to 20% of COP cases were directly associated with occupational exposure to CO[12].

In the United States, COP has been estimated to generate 25,000 ED visits per year, 500 accidental deaths and about 1,700 suicidal deaths[13]. In Switzerland, COP causes about 130 hospitalizations and 23 deaths per year[14]; in France, about 20 deaths per year[15] and in Spain, some hospitals record 75 cases of COP per year[16]. As a general reference figure, the surveillance section of the Spanish Association of Clinical Toxicology, involving 15 hospitals in various regions, has reported an average of 175 cases of COP per year (2004-2008), with an average of 3 deaths each year among those who reach the hospital alive[17]. From these data, it is estimated that there are in Spain about 2,000 cases of COP per year, with a mortality rate of about 4%.

Pathophysiology

The toxicity of CO depends essentially on the ability of this molecule to bind to heme groups which contain some proteins. Its interaction with two of them is of special importance from the physiological point of view.

First, hemoglobin (Hb) for which CO has an affinity 230 times greater than for oxygen. This means that with partial blood pressure 230 times less than that of oxygen (i.e. 0.4 mmHg instead of 100 mmHg), CO has the same percentage of Hb saturation as oxygen (i.e. 100%, Figure 1). In addition to this greater affinity, CO also produces a shift to the left of the dissociation curve of oxygen with Hb, so the little oxygen transported by Hb is transferred to tissue with greater difficulty. This effect on Hb, long known and described[18,19], results in anoxic tissue hypoxia which is responsible for most of the acute symptoms in COP. In fatal cases, death occurs due to tissue hypoxia by reversible and competitive binding of CO to the heme group of Hb, displacing oxygen. Normal values of COHb are below 3% in non-smokers (and less than 10% in smokers); on reaching 50% or higher, death is virtually inevitable. In contrast, when the degree of CO poisoning does not actually cause death of the individual, CO binding to Hb slowly reverses with time (assuming no further exposure to CO), since the elimination half-life of COHb is 320 minutes. The rate of this process can be accelerated by the administration of 100% oxygen (which reduces the half-life of COHb to 80 minutes) and / or by administering 100% oxygen above atmospheric pressure (COHb half-life may be reduced to 23 minutes at 3 atmospheres of pressure)[20,21].

The noxious effects of CO on other proteins are an additional pathophysiological mechanism. In fact, the harmful effects of CO at the extravascular level by a mechanism which is independent of Hb was reported by Haldane in 1927[22]. In 1939, CO was shown to bind to other heme-proteins apart from Hb, and in vitro to cytochrome a3 of the cytochrome c oxidase (complex IV of the mitochondrial respiratory chain) causing inhibition[23]. More recently in vivo inhibition was

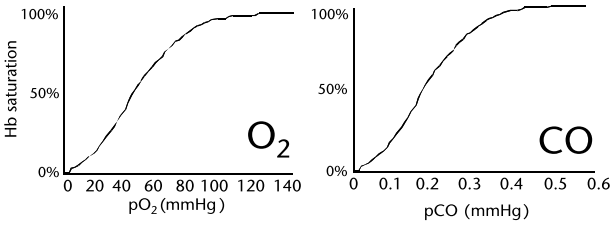

Figure 1. Schematic representation of the dissociation curves of hemoglobin (Hb) for oxygen (O_2) and carbon monoxide (CO). Note that the partial pressure of CO needed to saturate 100% of the Hb in the form of carboxyhemoglobin is about 0.4 mmHg, 230 times lower than the partial pressure of O_2 required to saturate 100% of hemoglobin as oxyhemoglobin.

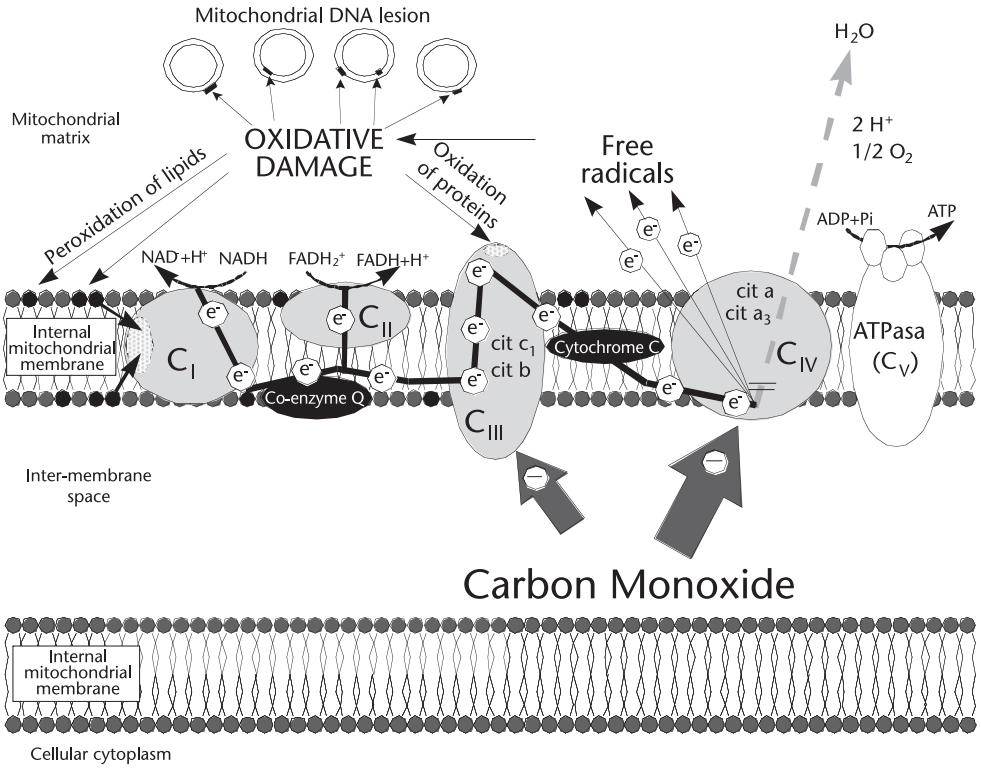

Figure 2. Schematic representation of the effects of carbon monoxide on mitochondrial respiratory chain cytochromes. Interrupting the flow of electrons (e^-) in the mitochondrial respiratory chain by blocking the complex IV (C_{IV}, which contains the cytochrome aa_3) means that the high reducing potential of these e- is not neutralized by oxygen and the free radicals generated cause the reduction of proteins, membrane lipids and mitochondrial DNA, altering or blunting their function.

found to be caused by the binding of CO to myoglobin in the skeletal muscle of dogs[24] and CO binding to mitochondrial cytochrome c oxidase in the brain of rats[25]. In he 1990s, several animal studies stressed the relevance of this mechanism of action. Thus, Brown and Piantadosi observed that, in rats, intracellular uptake of CO interferes with brain metabolism, even after elimination of all COHb from the blood[26], and Zhang and Piantadosi in an animal model demonstrated that free radicals generated during exposure to CO can contribute to neuronal damage during re-oxygenation after severe CO poisoning[27]. However, in humans with severe CO poisoning, this has not been shown. We only know that isolated human mitochondria show sensitivity to increasing concentrations of CO in laboratory studies[28].

During recent years it has been shown that lymphocytes of COP patients have reduced oxidative activity of the mitochondrial respiratory chain, especially due to inhibition of complex III enzymatic activity (containing cytochrome bc1) and of complex IV (containing the cytochrome aa3) in the chain, and that this inhibition is still detectable 14 days after the acute episode[29,30].

This inhibition of mitochondrial function could play a pathogenic role in late signs and symptoms. Hypothetically, they may be due to free radicals which increase oxidative damage in other neighboring molecules of particular biological relevance. In effect, blocking the transit of electrons with high reducing power of cytochromes of the mitochondrial respiratory chain would divert these towards the reduction of proteins and other molecules instead of reducing oxygen, which is what happens in situations of normal function (Figure 2). In this regard, increased peroxidation of lymphocyte membranes in COP has been described, which would be in line with this hypothesis[31].

Clinical manifestations

As mentioned, tissue damage and late effects of COP depend primarily on alterations in the respiratory mitochondrial respiratory chain and liberation of intracellular free radicals[32]. However, the clinical manifestations of acute poisoning are due to tissue hypoxia caused by CO occupying the Hb, with diminished oxygen transport.

Depending on the degree of intoxication, the clinical picture may vary, from mild nonspecific symptoms to death due to serious damage of the central nervous system (CNS) and / or cardiovascular system[33].

The acute symptoms depend on the target organ affected by hypoxia in each case. CNS involvement results in headache, syncope and fainting, reduced level of consciousness from disorientation to coma, seizures, ataxia, behavioral disturbances, dizziness and loss of balance, and general weakness. Cardiovascular system involvement results in palpitations, chest tightness, abnormal cardiac rhythm and ischemic cardiac alterations in any form of presentation, especially in patients with coronary artery disease[34]. Cardiorespiratory arrest may occur due to severe cardiac hypoxia or to brainstem alteration. Systemic symptoms may include nausea, vomiting, diarrhea, fatigue, impotence, muscle weakness and rhabdomyolysis. In pregnant women, severe COP can induce miscarriage or fetal defects. However, the most common signs and symptoms are headache (96.9%), dizziness (66.1%), nausea (35.8%), unsteady gait (32%), loss of consciousness (29.2%) and tachycardia (20%). Children, pregnant women, the elderly and patients with coronary artery disease are considered at risk of being more severely affected.

Some days or weeks (and up to three months) after acute intoxication, a late neurological syndrome may appear[35]. It presents with one or more of the following symptoms: higher function disorders (apraxia, agnosia, aphasia, calculation deficit, memory lapses, disorientation), character disorders (aggressiveness, irritability, apathy), myalgia, fatigue, poor vision or parkinsonism. These are late manifestations of intracellular damage in nervous tissue, because of peripheral intracellular effects of CO (other than Hb). Therefore, COP patients should be given outpatient appointments for follow up about 15-30 days after the intoxication, to rule out this possibility by means of a neurological examination.

Diagnosis

COP should be suspected in patients with similar non-specific flu-like syndromes without fever (fatigue, myalgia, headache). Also, COP may mimic food poisoning (nausea, vomiting, diarrhea). Environmental anamnesis (potential sources of CO) may help and information on possible collective involvement should be sought.

Differential diagnosis should be made with entities presenting with similar clinical manifestations in any of the areas affected by COP: transient stroke, epilepsy, arrhythmia and chest pain associated with other etiologies. Likewise, one should always rule out the presence of other toxins, particularly benzodiazepines, antidepressants, neuroleptic drugs and alcohol in cases of attempted suicide and cyanide poisoning in patients exposed to fire in confined areas with synthetic materials[36-38].

Given the nonspecific clinical symptoms, a high index of suspicion is required to diagnose COP. The suspected diagnosis is based on two pillars: acute symptoms and the presence of a possible source of poisoning (vehicle engines, boilers, braziers, fire, etc.) in the context of domestic or occupational/industrial accidents, or suicide attempts. Diagnosis is guided by collective involvement, improvement of symptoms on removing the victim from the scene of the accident and response to oxygen administration.

Diagnostic confirmation is analytical: determining blood Hb occupied by CO (carboxyhemoglobin, COHb) or detection of CO in expired air (CO-E). The blood sample required for gasometry is 2 ml of blood. No significant differences exist between venous or arterial samples. Conventional pulse oximetry is unable to differentiate oxyhemoglobin from COHb, so percentages of oxyhemoglobin are falsely elevated, although non-invasive pulse coximeters are now available (Figure 3) and provide acceptable estimates of COHb, which is very useful when there is no analytical equipment available[39]. The detection of CO in expired air is also possible. In any case, COHb levels gradually descend with time since cessation of exposure and the application of any type of oxygen therapy, so these two factors must be taken into account when assessing the result of COHb determination.

CO enters the body solely by inhalation, but the physiological catabolism of Hb in normal conditions results in a COHb concentration of 1-3%.

No other biological system generates CO. Smokers inhale CO and their COHb levels can reach 10% or more. Workers exposed to CO (garages, car parks, car workshops, metal industry) or chemicals (methylene chloride) that are metabolized to CO may also have elevated COHb. With these exceptions, high levels of COHb or CO-E offer a definite diagnosis of COP. However, these determinations can give false negatives, and the concentration of COHb decreases rapidly on non-exposure or oxygen therapy. Despite the de-

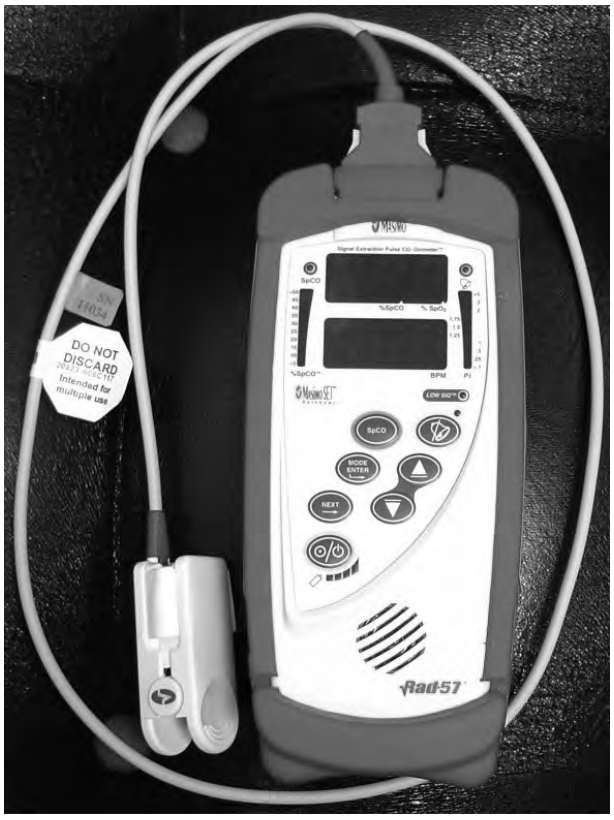

Figure 3. Device used to estimate the concentration of carboxyhemoglobin by pulse oximetry.

crease in COHb, intracellular CO persists, and this is what may cause clinical alterations due to respiratory mitochondrial disturbance and the release of free radicals. Therefore, high COHb is diagnostic of COP, but low COHb does not rule it out.

Other possible laboratory test abnormalities include: leukocytosis with left shift, increased creatine kinase due to rhabdomyolysis, alterations in cardiac enzymes (troponin) due to myocardial ischemia, and lactic acidosis, usually slight, due to CO interference with cellular respiration. If severe acidosis is found, mixed poisoning by hydrocyanic acid (HCA) or other toxins must be ruled out. Other complementary tests include an ECG to monitor possible ischemic alterations or heart rates associated with COP and a chest X-ray to rule out pulmonary lesions, especially in cases of smoke inhalation or bronchoaspiration in patients with impaired levels of consciousness.

Estimating the severity of intoxication

Severe clinical damage can coexist with relatively low levels of COHb and CO-E, because of the time lapse between intoxication and analytical determinations and/or the administration of oxygen therapy. However, elevated COHb or significantly increased CO-E always indicate severe poisoning, even in asymptomatic patients or those with few symptoms. But, apart from these extreme cases, the initial levels have no predictive value regarding initial clinical severity or the possibility of developing late neurological symptoms. It is therefore necessary to consider other laboratory and clinical criteria to establish the severity of the intoxication and decide on the appropriate therapy in cases of normal or nearly normal laboratory results (Table 1).

Table 1. Criteria of Severity in carbon monoxide poisoning (COP)

Laboratory criteria:
– More than 20% COHb, regardless of symptoms. High levels always indicate massive exposure.
– More than 10% COHb in children and pregnant women due to greater clinical susceptibility of immature central nervous system.
– Metabolic acidosis.

Clinical criteria:
– Neurological symptoms, even when brief and transient. Loss of consciousness, seizures, etc.
– Cardiovascular symptoms, even when brief and transient. Alterations of repolarization, arrhythmia, angina, etc.
– Cardiopulmonary arrest reversed.

Notes:
– Consider hyperbaric oxygen therapy in children and pregnant women, despite the absence of severity criteria and COHb values below 10%.
– It is advisable to contact the Hyperbaric Unit of reference for decisions on therapy in all cases.

General treatment

Suspecting COP in situ, the victim must be removed from further exposure, with rescuers protected and the site well ventilated. There is no CO purification system in the body, except physiological elimination of the gas by exhalation. Treatment of COP is mainly by oxygen therapy under normobaric or hyperbaric conditions, as appropriate. Oxygen displaces the CO of COHb, accelerating elimination and reducing the amount of CO arriving at the cells via blood flow. It also enhances the dissociation of CO with extravascular proteins (Hb, myoglobin, cytochromes) and decreases the production of free radicals. Because oxygen therapy under normobaric conditions has no side effects, it should be administered without waiting for laboratory confirmation. If the patient requires intubation and mechanical ventilation, the FiO_2 value to use is 1, and if not, the patient should receive the highest concentration possible via face mask with high-flow reservoir.

Table 2. Management of patients with carbon monoxide poisoning (COP)

Place of care	Diagnostic process	Therapeutic management
At the scene of accident (initial medicalized attention).	Evaluate neurologic & cardiac symptoms. Environmental history: possible sources of CO, other victims. Monitoring. 12-lead ECG: rule out arrhythmias and ischemic signs. Obtain blood gas sample to measure initial COHb. CO in expired air also useful. CO saturation by conventional pulse oximetry is not useful, but pulse CO oximetry devices measuring COHb are currently available.	Remove the victim from the source of poisoning. Rescuer self-protection. CPR if needed. OTI & ventilation with $FiO_2 = 1$. If patient is breathing, maximum possible concentration of O_2. Via peripheral vein. Arrhythmias and ischemic changes usually revert with O_2 treatment. If not, symptomatic treatment. Seizure: diazepam iv. Symptomatic and supportive treatment. In fires involving synthetic materials and a severely ill patient, consider possible poisoning by hydrocyanic acid and administer hydroxocobalamin.
Primary transfer.	Monitoring of cardiac & neurological status.	If patient is breathing, maximum possible concentration of O_2. Symptomatic and supportive treatment.
Hospital ED.	Anamnesis. Physical examination with special attention to cardiovascular system and CNS. Blood COHb determination (sample taken in initial treatment, if any). Laboratory tests: blood count and formula, CK, Troponin I, acid-base balance. Determine severity criteria. Repeat 12-lead ECG. Evaluate changes. Toxicological analysis of other suspected toxic agents.	CPR & OTI if necessary. If patient is breathing, maximum possible concentration of O_2. Symptomatic and supportive treatment. ECG monitoring. With possible poisoning by hydrocyanic acid, consider administering hydroxocobalamin if not already done. Specific treatment for poisoning by any other toxic agents.
Secondary transfer to a medical hyperbaric unit	No.	Oxygen therapy at maximum FiO_2. Monitoring.
Transfer to ICU (Patient OTI)	No.	Treatment protocols.
At discharge	No.	Appointment for neurological control at 1 month after poisoning.

CNS: central nervous system, CPR: cardiopulmonary resuscitation; OTI: orotracheal intubation, ECG: electrocardiogram; ICU: intensive care unit.

After initial care and confirmation of the diagnosis of COP, the level of severity should be assessed to decide on the need for treatment in a hyperbaric chamber. If normobaric oxygen therapy is selected, this should be maintained for a minimum of 8 hours, preferably 12 hours.

The half-life of COHb is much shorter than the time required for the intracellular elimination of CO and neutralization of oxidative damage caused. Traditionally, the treatment goal was to normalize COHb to restore tissue oxygenation, but currently this therapeutic approach is considered insufficient, so the treatment of choice is hyperbaric oxygen therapy or prolonged normobaric oxygen[40,41].

Other therapeutic measures are general and supportive, including CPR if necessary, cardiac monitoring in severe cases or in patients with a history of coronary artery disease, symptomatic treatment of nausea, vomiting, palpitations, etc., with the usual drugs. Most symptoms reverse or improve with oxygen therapy alone. We should not forget to seek, diagnose and treat other possible types of associated intoxication. The therapy indicated for each stage of care is shown in Table 2.

Treatment in the hyperbaric chamber

This consists of administering oxygen at an air pressure above atmospheric pressure to achieve an FiO_2 (fraction of inspired oxygen) greater than 1, and a hyperbaric chamber is used for this purpose. Pressures normally reach 2.2 to 2.5 times atmospheric pressure. Since the patient breathes pure oxygen at intervals of 30 minutes, he/she receives an absolute pressure of oxygen from 2.2 to 2.5 ATA. This increases the amount of oxygen circulating in the blood. The optimal number of sessions, duration and the pressure to be achieved in the chamber have not been clearly defined because COHb is rapidly reversed with hyperbaric treatment and there are no useful markers in clini-

Table 3. Mechanisms of action of hyperbaric oxygen therapy (HBO) in carbon monoxide poisoning (COP)

Mechanisms of action:
– Accelerates the dissociation of CO and CO Hb bound to extravascular proteins (myoglobin, cardiomyoglobin, cytochromes, guanylate cyclase, nitric oxide synthase).
– Accelerates the dissociation of CO from the mitochondrial cytochrome c oxidase, normalizing oxidative phosphorylation, and decreases the production of free radicals.
– Improves cerebral edema caused by disruption of the blood-brain barrier.
– Reduces the inflammation dependent on free NO (peroxidation of lipid membranes, polymorphonuclear diapedesis, Cerebrovascular oxidative damage). Diapedesis is inhibited by HBO but not by normobaric O_2 therapy.

CO: carbon monoxide, Hb: hemoglobin. NO: nitric oxide.

Table 4. Criteria for hyperbaric oxygen indication and contraindications

Indications:
– Coma (assuming necessary care available in the medical hyperbaric unit).
– Loss of actual or recovered consciousness.
– Seizures. Neurological disorders.
– COHb >20% (>10% in children and pregnant women).
– Signs of cardiac ischemia or arrhythmias.
– History of ischemic heart disease with COHb >15%.
– Persistent symptoms after 4-6 hours of treatment with normobaric oxygen.
Contraindications:
– Impossible to guarantee a safe transfer (mobile ICU with adequate equipment and a qualified physician).
– Hemodynamic instability, neurological or other non-controlled conditions.
– Center and / or HBO unit unequipped to resolve medical "complications".

COHb: carboxyhemoglobin; HBO: hyperbaric oxygen therapy.

cal practice that allow monitoring of the cellular effects (Table 3).

COP treatment with hyperbaric oxygen (HBO) remains a controversial issue in the literature. Among the supporters are the Undersea and Hyperbaric Medical Society and the European Consensus Conference (2004) that provide criteria for the selection of patients most likely to benefit from HBO. These criteria are reflected in Table 4. The recommendations are based on studies showing a decreased frequency of late neurological syndrome compared to patients treated with normobaric oxygen, and improved recovery of neurological tissue[42-44]. In addition, exploratory studies have shown more rapid restoration of mitochondrial function in COP patients treated with OHB[45,46].

A meta-analysis published by the Cochrane Foundation in 2005, which reviewed all studies then available, comparing normobaric with hyperbaric treatment only found 6 valid studies. Assessed together, the results showed a tendency to fewer neurological deficits in HBO, but the differences were not statistically significant (odds ratio for neurological deficit 0.78 [CI 95%, 0.54 to 1.12][47]. The results of this review have been discussed from different points of view[48].

The American College of Emergency Physicians (ACEP) believes that the use of HBO is not mandatory and that there are no clinical or laboratory criteria to identify subgroups of patients who should benefit from this treatment[49]. However, these views have also been challenged from within the same organization[50].

The controversy extends to the task of establishing national policies. Thus, the Health Systems in France[51] and Belgium[52] are in favor of HBO in certain circumstances while those of Germany[53] and Australia[54] are not.

In a recent review published in the New England Journal of Medicine on the clinical management of patients with COP, the author recommends the use of HBO, based on available data from both human and animal studies[55]. We believe that these recommendations are applicable to patients who meet some of the criteria listed in Table 4.

If HBO is indicated but the delay exceeds 6 hours, its potential benefits are reduced, but nevertheless exist. In selected patients who meet the severity and safety criteria, HBO should be administered. A decisive factor is distance from the hyperbaric chamber and ensuring that the transfer does not involve clinical destabilization. COP patients requiring ICU care are priority cases for HBO treatment.

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Intoxicación por monóxido de carbono: claves fisiopatológicas para un buen tratamiento

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En España, la intoxicación por monóxido de carbono (ICO) es la intoxicación por gases más frecuente. Su causa más habitual son los accidentes domésticos debidos a la combustión incompleta de gases en estufas, calentadores, calderas, braseros y otros, así como la inhalación del humo de los incendios donde la ICO, junto al cianuro, constituyen la principal causa de víctimas mortales. La capacidad tóxica del monóxido de carbono (CO) depende, esencialmente, de su unión a dos moléculas que contienen el grupo heme: la hemoglobina, que como resultado causa hipoxia anóxica y la mayor parte de la sintomatología aguda, y los citocromos de la cadena respiratoria mitocondrial, con el consiguiente bloqueo de la respiración celular y a la que se atribuye la sintomatología diferida que se produce en algunos pacientes. Los signos y síntomas más frecuentes son cefalea (96,9%), mareo (66,1%), náuseas (35,8%), inestabilidad a la marcha (32%), pérdida de conciencia (29,2%) y taquicardia (20%). Los niños, embarazadas, ancianos y pacientes con coronariopatía previa se consideran población de riesgo de afectación severa. La confirmación diagnóstica es analítica: determinación sanguínea de la hemoglobina ocupada por CO mediante una analítica o con un pulsioxímetro y/o la detección de CO en aire espirado. Ante la sospecha de ICO, se debe evitar la entrada de más CO en el organismo, y retirar a la víctima de la fuente de inhalación, con autoprotección del personal de rescate, asistencia y ventilación del local. Debe administrarse de inmediato oxígeno en condiciones normobáricas a la mayor concentración posible (mascarilla de alto flujo o al 100% si está intubado) ante cualquier diagnóstico de sospecha, sin esperar la confirmación analítica. Se discute en esta revisión el uso de oxígeno hiperbárico en la ICO. [Emergencias 2010;22:451-459]

Palabras clave: Monóxido de carbono. Intoxicación. Cámara hiperbárica. Mitocondria. Toxicología.