CHAPTER 153

Inhaled Toxins

Lewis S. Nelson | Robert S. Hoffman

Inhalational exposure to systemic toxins can be covert and indolent (as in occupational exposure to irritant photochemical smog) or overt and fulminant. The circumstances of the exposure, the presence of combustion or odors, and the number and condition of victims assist in the management. Despite the array of possible toxic inhalants, identification of a specific inhalant is generally unnecessary because therapy is based primarily on the clinical manifestations (Table 153.1).

SIMPLE ASPHYXIANTS

Principles of Toxicity

Simple asphyxiants are inert and produce toxicity only by displacement of oxygen and lowering of the fraction of inspired oxygen (Fio_2). Exposed patients remain asymptomatic if the Fio_2 is normal. Carbon dioxide and nitrogen are exceptions in that both can produce narcosis at elevated partial pressures, even though their predominant toxicological effect is simple asphyxiation. Since the introduction of catalytic converters, most deaths from the intentional inhalation of automotive exhaust result from simple asphyxiation, due to hypoxia, and not from carbon monoxide (CO) poisoning.[1]

Clinical Features

Acute effects occur within minutes of onset of hypoxia and are the manifestations of ischemia. A fall in the Fio_2 from normal, 0.21 (ie, 21%), to 0.15 results in autonomic stimulation (eg, tachycardia, tachypnea, and dyspnea) and cerebral hypoxia (eg, ataxia, dizziness, incoordination, and confusion). Dyspnea is not an early finding, because hypoxemia is not nearly as potent a stimulus to the medullary respiratory center as are hypercarbia and acidemia. Lethargy from cerebral edema occurs as the Fio_2 falls below 0.1 (10%), and life is difficult to sustain at an Fio_2 below 0.06 (6%). Because removal from exposure terminates the simple asphyxiation and allows restoration of oxygenation and clinical improvement, most patients present with resolving symptoms. However, failure to improve suggests complications of ischemia (eg, seizures, coma, and cardiac arrest) and is associated with a poor prognosis.

Differential Diagnosis

Because the presenting complaints offered by most exposed patients are nonspecific (eg, dizziness, syncope, and dyspnea), the differential diagnosis is extensive. A consistent history, particularly of a setting in which asphyxia is expected to occur, an appropriate spectrum of complaints, and a rapid resolution on removal from exposure are generally sufficient to establish the diagnosis.

Diagnostic Testing

Minimally symptomatic or asymptomatic patients do not require chest radiography or arterial blood gas (ABG) analysis. There is no role for toxicology testing unless the asphyxiation was an act of deliberate self-harm, in which case we recommend selected screening for acetaminophen and any other relevant toxin implicated by history, physical examination, or observation. A definitive diagnosis ultimately requires scene investigation by a trained and suitably outfitted team. Determination of the exact nature of the gas is of limited clinical value but may have important public health implications.

Management

Management rarely requires specific therapy other than removal from exposure, supportive care, and administration of supplemental oxygen. Neurologic injury or cardiorespiratory arrest should be managed with standard resuscitation protocols. Psychiatric consultation is indicated when the exposure was an act of deliberate self-harm.

Disposition

Patients with manifestations of mild asphyxia who recover after removal from the exposure can be discharged after 6 hours of observation if they are asymptomatic or minimally symptomatic and improving. Patients at risk for complications of hypoxia, such as those presenting with significant signs or symptoms (eg, coma, chest pain, electrocardiogram [ECG] changes) or with exacerbating medical conditions (eg, cardiac disease), should be observed for 24 to 48 hours for the development or progression of post-hypoxic complications.

PULMONARY IRRITANTS

Principles of Toxicity

The pulmonary irritant gases are a large and diverse group of agents that produce a common toxicological syndrome when they are inhaled in moderate concentrations. Although many of these gases can be found in the home, significant poisoning from consumer products is uncommon because of restrictions designed to reduce their toxicity. However, catastrophes such as the 1984 release of methyl isocyanate in Bhopal, India, which resulted in more than 2000 fatalities and 250,000 injuries, remain as an environmental risk. On a different scale, industrialization has increased ambient concentrations of sulfur dioxide, ozone, and oxides of nitrogen. These irritant gases frequently exacerbate chronic pulmonary disease.

Irritant gases dissolve in the respiratory tract mucus and alter the air-lung interface by invoking an irritant or inflammatory response.[2] When these gases are dissolved, most of them produce an acid or alkaline product, but several generate oxygen-derived free radicals that produce direct cellular toxicity (Fig. 153.1). The clinical effects of pulmonary irritants can be predicted by their water solubility (see Table 153.1).

Clinical Features

Highly water-soluble gases rapidly impact the mucous membranes of the eyes (lacrimation) and upper airway (nasal burning, cough).

TABLE 153.1

Common Inhaled Toxins

INHALANT	SOURCE OR USE	PREDOMINANT CLASS
Acrolein	Combustion	Irritant, highly soluble
Ammonia	Fertilizer, combustion	Irritant, highly soluble
Carbon dioxide	Fermentation, complete combustion, fire extinguisher	Simple asphyxiant; systemic effects
Carbon monoxide (CO)	Incomplete combustion, methylene chloride	Chemical asphyxiant
Chloramine	Mixed cleaning products (eg, hypochlorite bleach and ammonia)	Irritant, highly soluble
Chlorine (Cl_2)	Swimming pool disinfectant, cleaning products	Irritant, intermediate solubility
Chlorobenzylidene malononitrile (CS), chloroacetophenone (CN)	Tear gas (Mace)	Pharmacologic irritant
Hydrogen chloride	Tanning and electroplating industry	Irritant, highly soluble
Hydrogen cyanide	Combustion of plastics, acidification of cyanide salts	Chemical asphyxiant
Hydrogen fluoride	Hydrofluoric acid	Irritant, highly soluble; systemic effects
Hydrogen sulfide	Decaying organic matter, oil industry, mines, asphalt	Chemical asphyxiant; irritant, highly soluble
Methane	Natural gas, swamp gas	Simple asphyxiant
Methylbromide	Fumigant	Chemical asphyxiant
Nitrogen	Mines, scuba diving (nitrogen narcosis, decompression sickness)	Simple asphyxiant; systemic effects
Nitrous oxide	Inhalant of abuse, whipping cream, racing fuel booster	Simple asphyxiant
Noble gases (eg, helium)	Industry, laboratories	Simple asphyxiant
Oxides of nitrogen	Silos, anesthetics, combustion	Irritant, intermediate solubility
Oxygen	Medical use, hyperbaric conditions	Irritant, free radical; systemic effects
Ozone	Electrostatic energy	Irritant, free radical
Phosgene	Combustion of chlorinated hydrocarbons	Irritant, poorly soluble
Phosphine	Hydration of aluminum or zinc phosphide (fumigants)	Chemical asphyxiant
Smoke (varying composition)	Combustion	Variable, but may include all classes
Sulfur dioxide	Photochemical smog (fossil fuels)	Irritant, highly soluble

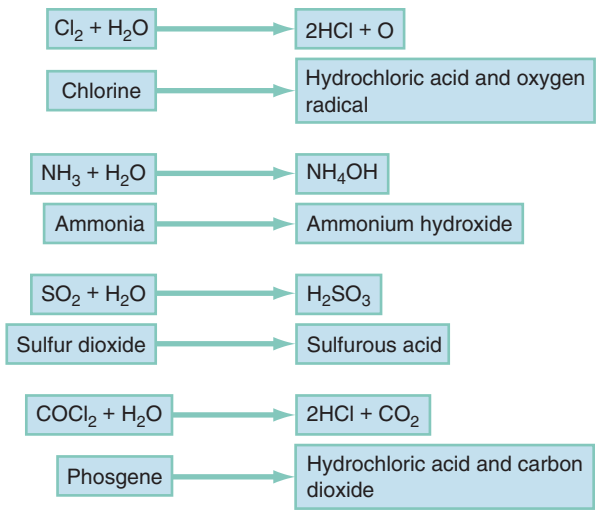

Fig. 153.1. Sample reactions of pulmonary irritants reacting with water in the lung. *Cl_2,* Chlorine; *CO_2,* carbon dioxide; *$CoCl_2$,* cobalt(II) chloride; *H_2O,* water; *H_2SO_3,* sulfurous acid; *HCl,* hydrochloric acid; *NH_3,* ammonia; *NH_4OH,* ammonium hydroxide; *O,* oxygen; *SO_2,* sulfur dioxide.

Although their pungent odors and rapid onset of symptoms tend to limit significant exposure, massive or prolonged exposure can result in life-threatening laryngeal edema, laryngospasm, bronchospasm, or acute respiratory distress syndrome (ARDS). In contrast, because poorly water-soluble gases do not readily irritate the mucous membranes at low concentrations and some have pleasant odors (eg, phosgene's odor is similar to that of hay), prolonged breathing in the toxic environment allows time for the gas to reach deep into the alveoli. Even moderate exposure causes delayed irritation of the lower airway, alveoli, and parenchyma after a 2- to 24-hour delay after exposure. Initial effects may be mild, only to progress to overt respiratory failure and ARDS during the ensuing 24 to 36 hours.[3] Gases with intermediate water solubility tend to produce syndromes that are a composite of the clinical features manifested with the other gases, depending on the extent of exposure. Massive exposure is most often associated with rapid onset of upper airway irritation and more moderate exposure with delayed onset of lower airway symptoms.

Differential Diagnosis

The typical symptoms of pulmonary exposure to irritant gas are bronchospasm, cough, a sensation of chest tightness, and acute conjunctival irritation, all of which may occur following allergen exposure, but the history generally confirms the exposure to the irritant. History may be particularly important if the patient

presents with severe or advanced findings, such as ARDS, which can occur after many physiologic insults, including trauma and sepsis.[4]

Diagnostic Testing

Inhalation of respiratory irritants may affect the upper airway, the lower airways and lungs, or both. Upper airway evaluation proceeds as described in the following Management section. Radiographic and laboratory studies are not useful in the evaluation of upper airway symptoms.

Oxygenation and ventilation are assessed by serial chest auscultation, pulse oximetry, and continuous capnography. Chest radiography is indicated for patients presenting with cough, dyspnea, hypoxia, or abnormal findings, such as rales or wheezes, on physical examination. ABGs are reserved for patients who are more severely symptomatic, have hypoxia, or do not improve readily with appropriate therapy.

In general, it is neither possible nor necessary to test for the specific agent. There are no clinical tests that will differentiate the irritant to which a patient was exposed, although testing at the site by public health authorities may be performed for epidemiologic purposes. Knowing that an agent was highly water soluble will shorten the observation period for symptom development, whereas patients exposed to poorly water soluble agents will require a more prolonged period of observation.

Management

Patients with no upper airway symptoms, normal voice, and no evidence of irritation (erythema) on examination of the oral pharynx require no further upper airway evaluation, but should be reexamined if symptoms or signs develop after the initial evaluation. Those with evidence of severe tissue irritation, such as oral or tongue edema, altered voice (raspy or muffled), or significant odynophagia or dysphagia should undergo early intubation, because progression of these injuries can be expected. Patients with significant erythema or pain in the oropharynx or nasopharynx and those with any evidence of alteration of voice, dysphagia or odynophagia, or stridor require early examination by laryngoscopy. Laryngoscopy may be performed using a flexible laryngoscope or rigid video or conventional laryngoscope with appropriate topical anesthesia and sedation as indicated (see Chapter 1). Patients with evidence of mild irritation of the larynx or supralaryngeal area (erythema, no edema, normal glottis) may be observed. Those with more severe findings considered not to require early intubation, such as erythema with mild edema, should undergo repeat examination 30 to 90 minutes after the initial examination or earlier, if symptoms or signs are worsening.

Bronchospasm generally responds to inhaled beta-adrenergic agonists in usual doses. There is no indication for ipratropium or a corticosteroid unless the patient has known underlying reactive airways disease.[3,5]

Patients exposed to chlorine or hydrogen chloride gas receive symptomatic relief from nebulized 2% sodium bicarbonate solution.[5] This solution is prepared by diluting a given volume of standard 8.4% sodium bicarbonate solution with three equivalent volumes of sterile water, and administering it with standard nebulizer equipment. There are no studies on the recommended dosing regimen, but if successful after its first use, providing it every 30 minutes as needed for symptom relief, for up to 6 hours, should be safe. Nebulized bicarbonate will not alter the inflammatory cascade, however, so it will not have significant effect on the progression of pulmonary injury.

ARDS, if identified, is managed as described in Chapters 22 and 67.

Disposition

Patients exposed to highly water-soluble gases (see Table 153.1) can be discharged if they are asymptomatic or symptoms are minimal and improving. After exposure to intermediate or poorly water-soluble gases, asymptomatic patients should be observed for increasing dyspnea for 6 hours before final disposition. Patients with prolonged gas exposure or exposure to highly concentrated gases, which may occur in a closed space, even if asymptomatic, or those in high-risk situations (eg, underlying pulmonary disease, extremes of age, and poor follow-up) should be observed in an inpatient setting or observation unit for 24 hours. Patients with upper airway findings on examination are observed in the emergency department (ED) or an intensive care unit (ICU) until there is clear evidence that the process is subsiding. All discharged patients should receive instructions for signs and symptoms of pulmonary deterioration.

SMOKE INHALATION

Principles of Toxicity

Annually, approximately 4000 people are injured or die in residential fires in the United States. Many of these casualties do not suffer serious cutaneous burns but rather die of smoke inhalation. This is a variant of irritant injury in which heated particulate matter and adsorbed toxins injure normal mucosa. In addition, CO and cyanide are systemic toxins often considered along with the smoke inhalation syndrome because of their common origin.

Even at temperatures between 350° and 500° C, air has such a low heat capacity that it rarely produces lower airway damage. However, the greater heat capacity of steam (approximately 4000 times that of air) or heated soot suspended in air (ie, smoke) can transfer heat and cause injury deep within the respiratory tract.

The nature of the fuel determines the composition of its smoke, and because fires involve variable fuels and burning conditions, the character of fire smoke is almost always undefined to the clinician. Irritant toxins produced by the fire are adsorbed onto carbonaceous particles that are deposited in the airways and damage the mucosa through mechanisms similar to those of the irritant gases.

Clinical Features

Thermal and irritant-induced laryngeal injury may produce cough, voice alteration, or stridor, but these findings are often delayed. Soot and irritant toxins in the airways can produce early cough, dyspnea, and bronchospasm. Subsequently, a cascade of airway inflammation results in ARDS with failure of pulmonary gas exchange. The time between smoke exposure and the onset of clinical symptoms is highly variable and dependent on the nature of the exposure. Deaths that occur rapidly after exposure are caused by asphyxia, airway compromise, or metabolic poisoning (eg, CO). Singed nasal hairs and soot in the sputum suggest substantial exposure, but significant exposure and injury can occur with neither of these being present.

Differential Diagnosis

With the obvious exposure history, the differential diagnosis is limited. Although it is often unclear whether inhalational injuries are thermal or irritant, the differentiation is clinically irrelevant. Concomitant physical injuries such as burns or trauma may complicate the metabolic picture.

Diagnostic Testing

Airway patency should be evaluated early. Airway management is as described earlier for inhaled pulmonary irritants. If evidence of significant airway exposure is present, such as carbonaceous sputum or hoarse voice, the airway should be examined by rigid or flexible laryngoscopy, and secured if signs of injury or compromise are noted. Pulmonary injury is assessed through auscultation and chest radiography for signs of alveolar filling or hyperinflation. Oxygenation should be assessed by co-oximetry, because blood gas analysis and pulse oximetry may be inaccurate in CO-poisoned patients (see discussion in the Carbon Monoxide section later). Co-oximetry will provide a blood carboxyhemoglobin (COHb) level, and we recommend testing for every patient, unless the smoke exposure was brief and in an open space. Metabolic acidosis, particularly when serum lactate concentration is greater than 10 mmol/L, suggests concomitant cyanide poisoning.[6]

Management

The acute management of smoke inhalation is identical to that of other irritant inhalational injuries. Early assessment of the airway and early intubation, as indicated, are critical because deterioration may be occult and rapid. Patients with no upper airway symptoms, normal oropharyngeal and nasopharyngeal examination, no voice alteration, and normal swallowing may be observed and reevaluated if symptoms, even mild symptoms, develop. Patients with symptoms or findings, though, are evaluated early by rigid or flexible laryngoscopy. Simply observing these patients for deterioration can result in airway compromise requiring rapid and, by then, difficult airway intervention. Despite a lack of evidence supporting their effectiveness, inhaled beta-adrenergics are widely used for patients with dyspnea or wheezing. Because these may provide benefit with little likelihood of harm, we recommend at least one dose of a beta-adrenergic agonist for patients with symptoms of bronchospasm. Both subjective (patient reported and findings on auscultation) and objective (respirometry) assessment may be used to determine whether these agents appear to benefit a particular patient and guide use of additional doses. Optimal supportive care and maintenance of adequate oxygenation (eg, suctioning and pulmonary toilet) are the most important aspects of care. Bronchoscopy with bronchoalveolar lavage is frequently recommended to clear debris and toxins from the distal airways. We do not recommend the use of corticosteroids, by inhalation or systemically, because there is no evidence of benefit and they are potentially harmful in patients with cutaneous burns. Ibuprofen, antioxidants, exogenous surfactant, and high-frequency ventilation yield variably improved survival in experimental and clinical trials; none is considered standard care.[7] Antibiotics should be used only in patients with suspected infection.

Disposition

Patients who are intubated should be admitted to the ICU or burn unit, depending on the extent of the cutaneous burns or respiratory tract injury. Patients with upper airway symptoms or signs, but without concerns for airway loss, should undergo repeat airway examination for 6 hours, preferably in an ICU. Patients with prolonged closed-space exposure or lower airway findings, such as rales or carbonaceous sputum, should be admitted to an ICU and observed for at least 24 hours while assessing for the development of signs of lower respiratory tract injury. Transfer to a higher level of care at another hospital or to a burn center should be based on local resources, consultation with the specialty center, an assessment of the risks of transfer, and existing protocols (see Chapter 56).

CYANIDE AND HYDROGEN SULFIDE

Principles of Toxicity

Instead of directly affecting the airway and lungs, these poisons cause effects at the cellular level. Hydrogen cyanide is a gas with many commercial uses, particularly in synthetic fiber manufacture and fumigation. Gaseous hydrogen cyanide is occasionally noted to have the odor of bitter almonds. Cyanide in its salt form (eg, sodium or potassium) is important in the metallurgy (eg, jewelry) and photography and is much safer to work with because of its low volatility. When cyanide salts are dissolved in water, hydrogen cyanide can leave the surface, particularly under acidic conditions. Cyanide is metabolically released in vivo from precursors (cyanogens) such as amygdalin, found in apricot and other *Prunus* species pits, and from nitriles, a group of chemicals with many commercial uses.

Hydrogen sulfide poisoning most often occurs in petroleum refinery and sewage storage tank workers. A recent Internet-derived means of suicide involves generation of hydrogen sulfide from sulfur-containing products, such as detergent, mixed with acids in an enclosed space, such as an automobile.[8] On occasion, well-intentioned but ill-prepared rescuers become victims, emphasizing the need for proper training and equipment. Hydrogen sulfide has a noxious odor similar to rotten eggs, which becomes unnoticeable with extremely high concentrations or prolonged exposure (a process called *olfactory fatigue*).

Gaseous cyanide is rapidly absorbed after inhalation and is immediately distributed to the oxygen-using body tissues. Inhibition of oxidative metabolism by binding to cytochrome c oxidase (or Complex IV) of the electron transport chain within mitochondria occurs within seconds. The poisoned tissue rapidly depletes its adenosine triphosphate reserves and ceases to function (Fig. 153.2). Cyanide has no evident effect on other oxygen-binding enzyme systems, most notably hemoglobin. This is probably explained by the oxidation state of its iron moiety; cyanide binds only to oxidized iron (Fe^{3+}), whereas deoxyhemoglobin contains reduced iron (Fe^{2+}).

Hydrogen sulfide exerts its toxic effects both as a pulmonary irritant and as a cellular poison.[9] Its deadly metabolic effects are produced by a mechanism identical to that for cyanide. However, hydrogen sulfide's spontaneous dissociation from the mitochondria is rapid, allowing many patients to survive after brief exposure.

Clinical Features

Tissue hypoxia occurs within minutes, with the exact onset dependent on the route, dose or concentration, and nature of the exposure. Dysfunction of the heart and the central nervous system—the organ systems most sensitive to hypoxia—is characteristic of cyanide poisoning, manifested as coma, seizures, dysrhythmias, and cardiovascular collapse. Metabolic acidosis develops as a result of diffuse cellular dysfunction and is associated with an elevated serum lactate concentration. Cyanosis is not a characteristic clinical finding. Given the extreme toxicity of cyanide, mild acute poisoning is uncommon. Patients with acute hydrogen sulfide poisoning have similar clinical manifestations, although many recover by the time of arrival in the ED.

Because cyanide and hydrogen sulfide prevent tissue extraction of oxygen from the blood, the oxygen content of venous blood remains high, approaching that of arterial blood. Clinically, this may appear as the "arterialization" or brightening of venous blood to resemble arterial blood. A comparison of the measured venous and arterial oxygen contents may assist in the diagnosis of cyanide poisoning. A low arterial-venous oxygen difference is suggestive

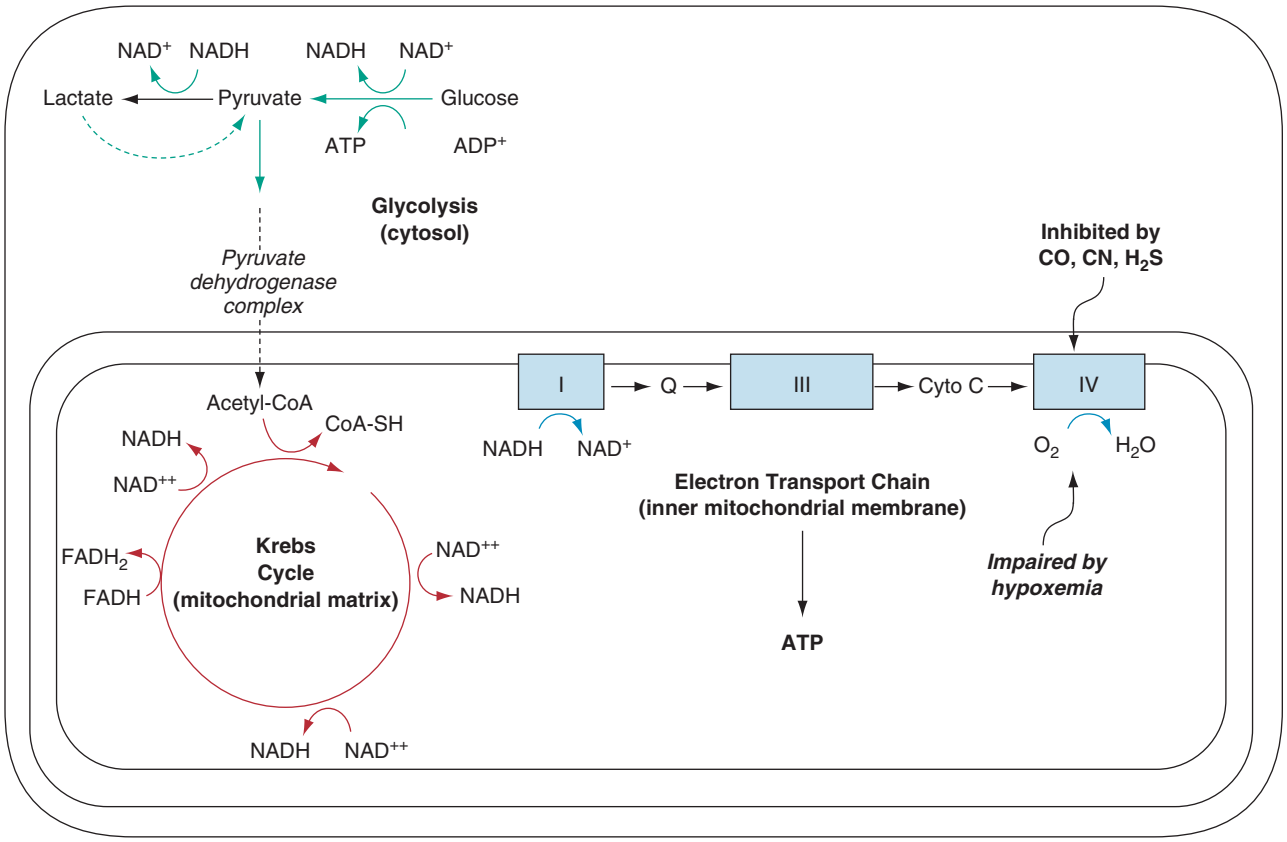

Fig. 153.2. The complete metabolism of a molecule of glucose to energy is complex but occurs in two broad steps. The first step, anaerobic glycolysis, which occurs in the absence of oxygen, generates pyruvate, nicotinamide adenine dinucleotide *(NADH),* and adenosine triphosphate *(ATP).* Pyruvate then enters the Krebs cycle to create potential energy in the second step, through the reduction of NAD^+ to NADH and flavin adenine dinucleotide *(FADH)* to $FADH_2$. Similarly, fatty acid metabolism and protein metabolism produce $FADH_2$ and NADH, which also requires conversion to ATP. These conversions occur in the mitochondrial membrane, where oxidative phosphorylation is linked to the electron transport chain, the last phase of which involves the transfer of electrons to molecular oxygen to form water. Cyanide *(CN),* hydrogen sulfide *(H_2S),* and carbon monoxide *(CO)* bind to and inhibit the last step, the Fe^{3+}-containing cytochrome-aa_3 oxidase in Complex IV, preventing further oxidation of NADH. This in turn hinders the Krebs cycle because the required regeneration of NAD^+ does not occur, and glucose metabolism is forced to end at pyruvate. For energy production to continue, NADH donates its electrons to pyruvate, creating lactate, and sufficient NAD^+ is regenerated for glycolysis to progress. Ultimately, energy failure and end-organ damage occur. *CoA,* Coenzyme A; *H_2O,* water; *IV,* intravenous; *O_2,* oxygen.

of cyanide poisoning but its absence is neither exclusionary nor its presence pathognomonic for the diagnosis.

Patients surviving cyanide or hydrogen sulfide poisoning may have persistent or delayed-onset neurologic syndromes identical to those noted in patients with CO poisoning or cardiac arrest.

Differential Diagnosis

In practice, rapid cardiovascular collapse, hypotension, bradycardia, ventricular dysrhythmias, and seizures in a fire victim should suggest cyanide poisoning, severe CO poisoning, or both.[6] In patients without an exposure history, the differential diagnosis is vast and includes CO poisoning, asphyxiants, cardiotoxins, cardiac dysfunction (dysrhythmia, myocardial infarction), and sepsis.

Diagnostic Testing

Unlike with CO poisoning, pulse oximetry and ABG analysis are accurate in cases of isolated cyanide or hydrogen sulfide poisoning. An increased anion gap metabolic acidosis and elevated serum lactate concentration are usually present. A lactate concentration greater than 10 mmol/L in a fire victim is highly predictive of cyanide poisoning.[6] CO and cyanide are fellow travelers, so an elevated COHb level in a fire victim warrants consideration of concomitant cyanide poisoning. The presence of severe clinical findings with a low COHb level is particularly concerning for cyanide poisoning. The result of a blood cyanide determination is usually too delayed to be of use in the ED, but it can be useful for confirmation and documentation purposes. Technology exists for immediate cyanide determination but is not widely available. Testing for hydrogen sulfide is not clinically available.

Management

The diagnosis of cyanide poisoning usually cannot be confirmed rapidly, and therapy is almost always empirical. Treatment should not be delayed pending the COHb level or other laboratory tests in patients with suspected acute cyanide poisoning. Patients removed from a fire environment who have cardiovascular instability, altered mental status, or a serum lactate greater than 10 mmol/L should receive cyanide treatment regardless of the COHb concentration.

Hydrogen Cyanide

The accepted goal of therapy is to reactivate the cytochrome oxidase system by providing an alternative binding site for the cyanide ion. There are two types of antidotal therapy for cyanide. The preferred antidote is hydroxocobalamin, which takes advantage of the high affinity of cobalt for cyanide. On binding of cyanide, cyanocobalamin, or vitamin B_{12}, is formed. The initial dose is 5 g intravenous (IV) over 15 minutes for adults and 70 mg/kg IV for children, up to an adult dose, and can be repeated once if an incomplete response is noted. Thiosulfate (see later), 12.5 g, can be administered concomitantly over 10 minutes through a separate IV. The known adverse effects of hydroxocobalamin are mild and include hypertension in those not cyanide poisoned and a bright red discoloration of the patient's skin. Inexperienced clinicians often mistake this side effect is as an "allergic" reaction to the drug. The drug's red color can interfere with certain spectrophotometric laboratory tests, including COHb and possibly serum lactate, and blood samples should be obtained before the administration of the first dose of hydroxocobalamin.[10]

The cyanide antidote kit is an alternative therapy for cyanide toxicity. The cyanide antidote kit produces a high-affinity source of ferric ions (Fe^{3+}) for cyanide to bind. The kit has three components (amyl nitrite, sodium nitrite, and sodium thiosulfate), and although the best results are likely to be attained when the entire kit is used, this may be impractical or dangerous, particularly for nonhospital providers. Because animal models and clinical evidence in humans demonstrate that sodium thiosulfate alone (the "third" component of the kit), in combination with oxygen, offers substantial protection, this should be the initial therapy administered by paramedics and during mass poisoning events in the absence of hydroxocobalamin. Antidotes should not completely replace other resuscitation measures, including high-flow oxygen and removal of the patient from the source of exposure.

Methemoglobin (MetHb) formation results from first two components of the kit. Inhaled amyl nitrite and IV sodium nitrite are both effective, but amyl nitrite should be administered to patients only before IV access. Caution should be taken to minimize the provider's exposure to the volatile amyl nitrite because dizziness, hypotension, or syncope may occur. The dose of sodium nitrite for a previously healthy adult is 300 mg (10 mL of a 3% solution) given during 2 to 4 minutes, and dosing instructions for anemic patients and children are supplied with the kit. Cyanide has a high affinity for MetHb and readily leaves cytochrome oxidase to form cyanmethemoglobin, which is metabolically inactive. Additionally, the nitrites are vasodilators, and this may be mechanistically important in their therapeutic effect by enhancing blood flow to the liver for clearance. However hypotension may complicate a rapid infusion.

Both free serum cyanide and cyanmethemoglobin are converted by sulfur transferase *(rhodanese)* to thiocyanate, which is renally eliminated. Because the rate of rhodanese function increases with the availability of sulfur donor, the third component of the antidote kit is the sulfur-containing compound sodium thiosulfate. The adult dose is 12.5 g IV, which is provided as 50 mL of a 25% solution (2 mL/kg of 25% sodium thiosulfate up to an adult dose in children). In general, few if any adverse effects are associated with proper doses. The nitrite components of the cyanide antidote kit should be avoided in fire victims with known or suspected simultaneous CO and cyanide poisoning because both CO and MetHb reduce oxygen delivery to the tissues. The use of the thiosulfate component alone in this subset of patients is recommended (Box 153.1).

There are insufficient clinical data to fully support the use of one cyanide antidote over the other. However, we recommend hydroxocobalamin, which is largely replacing the cyanide antidote kit because of its ease of use and presumed superior safety in CO-poisoned fire victims.[11] Direct comparison to thiosulfate alone in this population has not been and likely never will be performed, but animal models suggest that hydroxocobalamin is superior.[12] When possible, we recommend administering both hydroxocyanocobalamin and thiosulfate, with the priority given to hydroxocyanocobalamin, and never giving them through the same IV.

BOX 153.1

Cyanide Antidotes

HYDROXOCOBALAMIN*

Adults: 5 g IV over 15 minutes
Children: 70 mg/kg up to 5 g

CYANIDE ANTIDOTE KIT

1. MetHb inducers†
   Amyl nitrite (inhalational, prehospital) *or*
   Sodium nitrite ($NaNO_2$) 3% solution IV over 2 to 4 minutes IV
   Adults: 10 mL (300 mg)
   Children: See labeling information with kit
2. Cyanide detoxification
   Sodium thiosulfate (NaS_2O_3) 25% solution IV
   Adults: 50 mL (12.5 g)
   Children: 1.65 mL/kg up to 50 mL

IV, Intravenous; *MetHb,* methemoglobin.
*A second dose may be administered in patients with an incomplete response.
†Withhold nitrites if blood carboxyhemoglobin (COHb) is suspected to be present (eg, fire victims).

Hydrogen Sulfide

Because the bond between hydrogen sulfide and cytochrome oxidase is rapidly reversible, removal from exposure and standard resuscitative techniques are usually sufficient to reverse hydrogen sulfide toxicity. Use of the nitrite portion of the cyanide antidote kit is suggested to create MetHb for patients with severe or prolonged toxicity. Sodium thiosulfate is unnecessary because hydrogen sulfide is not detoxified by rhodanese. There is no defined role for hyperbaric oxygen (HBO) therapy in cases of hydrogen sulfide toxicity.

Disposition

Patients with symptomatic cyanide or hydrogen sulfide poisoning should be admitted to a critical care unit and observed for complications of tissue hypoxia. These patients should also be evaluated for delayed neuropsychiatric findings.

CARBON MONOXIDE

Principles of Toxicity

CO is the most common cause of acute poisoning death in developed nations and the most common cause of fire-related death.[13] CO is generated through incomplete combustion of virtually all carbon-containing products. Structure fires (eg, wood), clogged vents for home heating units (eg, methane), and use of gasoline-powered generators indoors are examples of the myriad means through which patients are poisoned by CO. Appropriate public health authorities (eg, fire department and Department of Health officials) should be informed immediately about any potential public health risks that are identified during the care of a CO-exposed patient.

CO interacts with deoxyhemoglobin to form COHb, which cannot carry oxygen. Hemoglobin binds CO tightly and forms a complex that is only slowly reversible. This allows the exposed individual to accumulate CO, even with exposure to low ambient concentrations. Although binding of hemoglobin is historically described as the mechanism of CO poisoning, it is relevant only in profoundly CO-poisoned patients because a simple reduction in oxygen-carrying capacity due, for example, to anemia would not cause similar symptoms. However, for pregnant patients, the fetus is at increased risk, because it is relatively hypoxic compared with the mother. Additionally, CO shifts the oxyhemoglobin dissociation curve to the left in such a way that even if oxygen is bound to hemoglobin, its unloading to tissues is impaired. In muscle, CO binds myoglobin, preventing its normal function, and this probably explains the development of atraumatic rhabdomyolysis.

Most importantly, CO affects cellular oxygen use at the tissue level. CO, similar to cyanide, inhibits the final cytochrome complex involved in mitochondrial oxidative phosphorylation. This results in a switch to anaerobic metabolism and ultimately in cellular death.

Delayed-onset neurologic complications may be a manifestation of the hypoxic insult, and reperfusion injury and lipid peroxidation related to platelet-induced nitric oxide release may play a significant role.[9] By alteration of the platelet-associated nitric oxide cycle, the microvascular endothelium of the central nervous system undergoes free radical–mediated injury, resulting in localized inflammation and dysfunction. Animal models and human reports suggest that loss of consciousness during CO exposure is a risk factor for the development of delayed neurologic sequelae.[14]

Clinical Features

Severe CO toxicity and cyanide poisoning have identical clinical presentations of chemical asphyxia: altered mental status, including coma and seizures; extremely abnormal vital signs, including hypotension and cardiac arrest; and metabolic acidosis. Unlike cyanide poisoning, however, mild CO poisoning occurs frequently, with headache, nausea, vomiting, dizziness, myalgia, and confusion as common presenting complaints. The neurological assessment in these patients may yield normal findings or may demonstrate focal findings or subtle perceptual abnormalities. The often-touted cherry-red skin color in patients with cyanide or CO poisoning is a postmortem finding and is not noted in living patients.

Delayed neurologic sequelae is a well-documented phenomenon after CO exposure; the frequency varies from 12% to 50%, depending on the definition and the sensitivity of the test used for their detection.[14] Patients have a variety of neurologic abnormalities after an asymptomatic period, ranging from 2 to 40 days. The delayed neurologic effects can be divided into those with readily identifiable neurologic syndromes (eg, focal deficits and seizures) and those with primarily psychiatric or cognitive findings (eg, apathy and memory deficits). Although the delayed neuropsychiatric sequelae require formal neuropsychiatric testing to be detected, the impact of these abnormalities on the patient's daily function may be significant. Risk factors that predict the development of delayed neurologic sequelae include extremes of age and loss of consciousness. Because most CO-poisoned patients reaching the ED survive with minimal intervention, prevention of delayed neurologic and neuropsychiatric sequelae is a major goal of therapy.

Differential Diagnosis

Mild to moderate CO poisoning is a difficult diagnosis to establish clinically, and patients are easily misdiagnosed as having a benign headache syndrome or viral illness. CO poisoning should be suspected in patients with persistent or recurrent headache, especially if a group of people have similar symptoms or if the headache improves soon after the person leaves an exposure site.

Patients with severe CO poisoning may present with coma or cardiovascular collapse, both of which have a broad toxicologic, metabolic, infectious, medical, and traumatic differential diagnosis. The medical history, physical examination, and standard laboratory testing are easily able to exclude many of these diagnoses. Given the relatively protean manifestations of CO poisoning and the potentially serious consequences of misdiagnosis, particularly if the patient returns to the contaminated environment, we recommend specific measurement of CO by co-oximetry of an arterial or venous blood sample when the clinician considers CO poisoning as a cause for the patient's presentation.

Diagnostic Testing

Suspicion of CO poisoning relies on the history and physical examination findings. Co-oximetry, an inexpensive and readily available spectrophotometric laboratory method that can distinguish between normal hemoglobin and COHb (and MetHb), confirms exposure to CO. Other laboratory tests only exclude other diagnoses. Severity of poisoning may not correlate with COHb levels because prolonged exposure to low levels can be fatal with a low measured COHb, but a brief, high-concentration exposure can produce a high COHb level with minimal symptoms.

The standard blood gas (ABG or venous blood gas [VBG]) analysis is a poor screening test for CO poisoning other than to identify the presence of a metabolic acidosis and a normal partial pressure of oxygen (Po_2). CO decreases oxygen bound to hemoglobin but does not affect the amount of oxygen dissolved in blood. Because the Po_2, a measure of dissolved oxygen, is normal in patients with CO poisoning, the calculated oxygen saturation will be normal even in the presence of significant CO poisoning. Most pulse oximeters are unable to detect CO poisoning because COHb essentially is misinterpreted as oxyhemoglobin. Newer pulse co-oximeters are capable of noninvasively detecting COHb as well as methemoglobinemia, but these instruments are not yet in common use.[15]

Management

Treatment begins with oxygen therapy, which serves two purposes. First, the half-life of COHb is inversely related to the Po_2; it can be reduced from approximately 5 hours on room air to 1 hour by providing supplemental 100% oxygen. HBO therapy (at 3 ATA) further reduces the half-life to approximately 30 minutes. Unfortunately, alteration of the kinetics of COHb is relevant only to patients with extremely elevated COHb levels (eg, 50%). Even then, only a minority of patients can be treated sufficiently rapidly for the HBO to be life saving. Second, a sufficient Po_2 can be achieved with HBO to sustain life in the absence of adequately functioning hemoglobin, but this is helpful only when the COHb is extremely elevated. Thus, the primary indication for HBO is not to prevent mortality but rather to prevent delayed neurologic sequelae.

There is controversy regarding the benefit of HBO because the effect is not immediate (as with life and death) and outcome assessment requires close follow-up and sophisticated testing. Several evidence-based reviews have asserted only a limited role for HBO, although this conclusion is disputed.[14,16] Evidence suggests that HBO helps prevent the development of delayed neuropsychiatric and neurologic sequelae after CO poisoning, with a decrease of delayed neurologic sequelae from approximately 12% to less than 1% with HBO. When HBO administration is delayed

BOX 153.2

Recommendations for Hyperbaric Oxygen

Carboxyhemoglobin (COHb) (varies by local standards) independent of clinical findings
- >25% with no clinical findings
- >15% in pregnancy or fetal distress

or an elevated COHb with one or more of the following findings:
- Syncope
- Coma
- Seizure
- Altered mental status (GCS <15) or confusion
- Abnormal cerebellar function
- Prolonged CO exposure with minor clinical findings ("soaking")

CO, Carbon monoxide; *GCS,* Glasgow Coma Score.

more than 6 hours after exposure, its efficacy appears to decrease, suggesting the need for rapid implementation. A randomized, double-blind study found that HBO therapy was superior to normobaric oxygen therapy at reducing the incidence of delayed neurologic sequelae at both 6 weeks and 1 year after poisoning.[17] However, another found no benefit of HBO on the development of delayed neurologic sequelae compared with extensive normobaric oxygen.[18] In the latter study, however, the majority of patients were suicidal and possibly depressed, which would interfere with performance on the neuropsychiatric testing needed to differentiate the two groups of patients. Another trial found that in comatose patients, one HBO session was superior to two sessions; however, in patients with transient loss of consciousness (ie, syncope), outcome after HBO therapy was equivalent to 6 hours of normobaric oxygen therapy.[13]

Given the implications of poor tissue oxygenation with COHb and the relative safety of HBO, a patient with a neurologic abnormality or cardiovascular instability (eg, syncope, altered mental status, myocardial ischemia, and dysrhythmias) is a candidate for HBO (Box 153.2). This should be tempered by the need for transport, often over long distances, for HBO therapy to be obtained. The decision about HBO therapy should not be strictly based on the COHb level, which correlates only weakly with toxicity. For example, patients with prolonged low-level exposure have a "soaking" phenomenon, in which extremely high tissue concentrations of CO occur with low COHb levels. Thus, patients with consequential clinical findings that are considered to be related to CO poisoning should receive HBO, even though their COHb level is relatively low.

In addition to use of HBO in patients with obvious signs of tissue hypoxia or syncope, we recommend referral for HBO for asymptomatic patients with a COHb level of 25%. The decision to perform HBO therapy should be made in the context of transport and other medical requirements, including need for transfer to a burn center. Where doubt remains, consultation with a medical toxicologist, poison center, or the HBO treatment specialist will guide decision-making. Because fetal CO poisoning is associated with dysfunction and death and HBO therapy appears to be safe in pregnancy, we recommend HBO therapy in a pregnant woman with a COHb level of 15% or greater regardless of symptoms. Further study is still needed to define the optimal duration, pressure, and frequency, as well as the cost-benefit and risk-benefit relationships of HBO therapy. At this time, discussion with a regional HBO center or poison control center is advisable. Patients with elevated COHb levels who do not require HBO should be treated with normobaric oxygen delivered by a tight-fitting non-rebreather face mask until the symptoms resolve and the COHb levels fall to normal.

Simultaneous Carbon Monoxide and Cyanide Poisoning (Fire Victims)

Concurrent toxicity from CO and cyanide is widely reported and a major factor in the mortality associated with smoke.[6] Smoke inhalation victims who present with coma and metabolic acidosis can have severe CO poisoning, cyanide poisoning, or both. Nitrite-induced methemoglobinemia, which further reduces the tissue oxygen delivery, may be detrimental to patients with elevated COHb levels or otherwise impaired oxygen delivery.

Sodium thiosulfate, administered without nitrites, or hydroxocobalamin should be given to all smoke inhalation victims with coma, hypotension, severe acidosis, or cardiovascular collapse in whom cyanide poisoning cannot be rapidly excluded.

Disposition

The decision to transfer a patient to an HBO facility should consider the time delay to therapy, patient issues (eg, burns and age), and potential transport-related complications. Patients with minor clinical effects that resolve can be discharged with follow-up, and those with signs of end organ effects, such as chest pain or altered mental status, if not transferred for HBO, should be admitted for observation. All patients exposed to CO require close follow-up for delayed neurologic sequelae.

KEY CONCEPTS

- An asphyxiant is any gas that displaces sufficient oxygen from the breathable air. Treatment consists of removal from exposure, supplemental oxygen, and supportive care.
- Highly water-soluble gases produce rapid irritation and predominantly upper respiratory tract symptoms, such as airway irritation. Poorly water-soluble gases often produce delayed lower respiratory tract findings, such as bronchospasm or acute respiratory distress syndrome (ARDS).
- CO poisoning is confirmed by co-oximetry measurement. Cyanide poisoning is treated empirically when cardiovascular instability (eg, hypotension), altered mental status, or a serum lactate greater than 10 mmol/L are present in a fire victim.
- Hydroxocobalamin is the preferred antidote for most cyanide poisoned patients due to its efficacy, ease of use, and safety in patient with concomitant CO poisoning. Sodium thiosulfate may be administered concomitantly and may provide additional benefit.
- Patients with hydrogen sulfide poisoning generally respond to removal from exposure and ventilatory support.
- Normobaric oxygen therapy is sufficient for many patients with CO poisoning, but we recommend consultation with a hyperbaric oxygen (HBO) facility, poison control center, or medical toxicologist for consideration of HBO therapy for patients with a COHb greater than 25% or any new neurologic or cardiovascular abnormality.

The references for this chapter can be found online by accessing the accompanying Expert Consult website.

REFERENCES

1. Studdert DM, Gurrin LC, Jatkar U, et al: Relationship between vehicle emissions laws and incidence of suicide by motor vehicle exhaust gas in Australia, 2001-06: an ecological analysis. PLoS Med 7(1):e1000210, 2010.
2. White CW, Martin JG: Chlorine gas inhalation: human clinical evidence of toxicity and experience in animal models. Proc Am Thorac Soc 7(4):257–263, 2010.
3. de Lange DW, Meulenbelt J: Do corticosteroids have a role in preventing or reducing acute toxic lung injury caused by inhalation of chemical agents? Clin Toxicol (Phila) 49(2):61–71, 2011.
4. ARDS Definition Task Force, Ranieri VM, Rubenfeld GD, et al: Acute respiratory distress syndrome: the Berlin definition. JAMA 307(23):2526–2533, 2012.
5. Vajner JE, Lung D: Case files of the University of California San Francisco Medical Toxicology Fellowship: acute chlorine gas inhalation and the utility of nebulized sodium bicarbonate. J Med Toxicol 9(3):259–265, 2013.
6. Baud FJ, Barriot P, Toffis V, et al: Elevated blood cyanide concentrations in victims of smoke inhalation. N Engl J Med 325(25):1761–1766, 1991.
7. Dries DJ, Endorf FW: Inhalation injury: epidemiology, pathology, treatment strategies. Scand J Trauma Resusc Emerg Med 21:31, 2013.
8. Centers for Disease Control and Prevention (CDC): Chemical suicides in automobiles—six states, 2006-2010. MMWR Morb Mortal Wkly Rep 60(35):1189–1192, 2011.
9. Thom SR: Carbon monoxide transport and actions in blood and tissues. Compr Physiol 1(1):421–446, 2011.
10. Livshits Z, Lugassy DM, Shawn LK, et al: Falsely low carboxyhemoglobin level after hydroxocobalamin therapy. N Engl J Med 367(13):1270–1271, 2012.
11. Streitz MJ, Bebarta VS, Borys DJ, et al: Patterns of cyanide antidote use since regulatory approval of hydroxocobalamin in the United States. Am J Ther 21(4):244–249, 2014.
12. Bebarta VS, Pitotti RL, Dixon P, et al: Hydroxocobalamin versus sodium thiosulfate for the treatment of acute cyanide toxicity in a swine (Sus scrofa) model. Ann Emerg Med 59(6):532–539, 2012.
13. Annane D, Chadda K, Gajdos P, et al: Hyperbaric oxygen therapy for acute domestic carbon monoxide poisoning: two randomized controlled trials. Intensive Care Med 37(3):486–492, 2010.
14. Hampson NB, Piantadosi CA, Thom SR, et al: Practice recommendations in the diagnosis, management, and prevention of carbon monoxide poisoning. Am J Respir Crit Care Med 186(11):1095–1101, 2012.
15. Touger M, Birnbaum A, Wang J, et al: Performance of the RAD-57 pulse CO-oximeter compared with standard laboratory carboxyhemoglobin measurement. Ann Emerg Med 56(4):382–388, 2010.
16. Buckley NA, Juurlink DN, Isbister G, et al: Hyperbaric oxygen for carbon monoxide poisoning. Cochrane Database Syst Rev (4):CD002041, 2011.
17. Weaver LK, Hopkins RO, Chan KJ, et al: Hyperbaric oxygen for acute carbon monoxide poisoning. N Engl J Med 347(14):1057–1067, 2002.
18. Scheinkestel CD, Bailey M, Myles PS, et al: Hyperbaric or normobaric oxygen for acute carbon monoxide poisoning: a randomised controlled clinical trial. Med J Aust 170(5):203–210, 1999.

CHAPTER 153: QUESTIONS & ANSWERS

153.1. A laboratory worker is brought to the emergency department (ED) after being found unconscious. His colleague reports that the patient was found with his oxygen mask off while working in a room filled with carbon dioxide. The patient is now awake but reports feeling tired and confused. He has no other complaints. His vital signs and physical examination are normal. What toxin-specific diagnostics test should be ordered for this patient?

A. Carboxyhemoglobin (COHb)
B. Chest radiograph
C. Electrocardiogram
D. Methemoglobin (MetHb)
E. No tests are indicated

Answer: E. Carbon dioxide is primarily a simple asphyxiant, meaning that its major consequential adverse effects stem from its displacement of oxygen in the lungs. Once patients are removed from the source, they generally recover completely. Patients should be observed until this time. COHb measurement would be indicated if there is a suspicion of carbon monoxide (CO) exposure. Chest radiographs should be ordered if patients have pulmonary complaints after an unknown exposure. Electrocardiograms should be ordered if patients are exposed to known cardiac toxins. MetHb levels should be checked when there is suspicion for oxidative stress on the red blood cells.

153.2. A 32-year-old woman presents following exposure to an irritant gas at her job site. She reports cough, burning eyes, and shortness of breath. She has mild tachypnea, with the remainder of her vital signs within normal limits. Her oxygen saturation is 96% on room air. She is noted to have stridor on physical examination. What is the preferred method to evaluate her upper airway symptoms?

A. Arterial blood gas (ABG)
B. Chest radiograph
C. Computed tomography of the neck
D. Fiberoptic laryngoscopy
E. Soft tissue neck radiograph

Answer: D. Fiberoptic or direct laryngoscopy is the preferred method to evaluate upper airway symptoms after exposures to irritant gases. Radiographs and laboratory tests have no role and should not influence the decision to provide a definitive airway. Symptoms can progress rapidly, so patients with upper airway symptoms require either placement of a definitive airway or close observation with frequent serial examinations.

153.3. A 52-year-old man is brought to the emergency department (ED) after being rescued from a house fire. He has not suffered any cutaneous burns. He complains of a sore throat, hoarse voice, and cough. Vital signs are normal. Physical examination reveals soot in his oropharynx and carbonaceous sputum. What therapy should be instituted first?

A. Endotracheal intubation
B. Intravenous (IV) methylprednisolone
C. Nebulized albuterol
D. Nebulized sodium bicarbonate
E. Saline bronchoalveolar lavage

Answer: A. Endotracheal intubation should be performed early in patients with signs and symptoms of significant airway burns (as this patient has). Corticosteroids are not beneficial and can worsen associated injuries. Inhaled beta-agonists are commonly used, but there is no evidence of improved outcome. Inhaled sodium bicarbonate plays no role in the management of smoke inhalation. Bronchoalveolar lavage can be performed if there is suspicion of inhaled debris or toxins, but the airway should first be secured.

153.4. A 47-year-old woman is brought to the emergency department (ED) after being rescued from a house fire. She was found unconscious at the scene and intubated before arrival. Her vital signs are significant for hypotension and tachycardia. Physical examination is significant for soot in the oropharynx. No cutaneous burns are noted. You suspect that she is suffering from cyanide poisoning. What is the most appropriate immediate therapy?

A. Hyperbaric oxygen (HBO)
B. Intravenous (IV) hydroxocobalamin
C. IV methylene blue
D. IV sodium nitrite
E. Observation and supportive care

Answer: B. One of the two major treatments for cyanide poisoning is hydroxocobalamin (the other is the cyanide antidote kit). The nitrite compounds in the cyanide antidote kit convert hemoglobin to methemoglobin (MetHb), which in turn binds to cyanide. However, nitrites produce hypotension and the MetHb prevents proper oxygen deliver, which may compound the reduction in oxygen delivery associated with carbon monoxide (CO) poisoning. HBO has no role in acute cyanide poisoning. Methylene blue has been used for cyanide poisoning in the past but is not as useful as the cyanide kit. Its primary use is in treating methemoglobinemia. General supportive care is not appropriate because there is an antidote for this patient's poisoning.

153.5. A 22-year-old man is brought to the emergency department (ED) after being found unconscious in a car with an intentionally prominent suicide note visible in the window. By the time he arrives in the ED, he has regained consciousness and is complaining of headache and nausea. Paramedics report that the car engine was not running when the patient was discovered. His vital signs and physical examination are normal. Which of the following therapies should be instituted?

A. Hyperbaric oxygen (HBO)
B. Intravenous (IV) methylene blue
C. IV sodium nitrite
D. IV sodium thiosulfate
E. Observation and supportive care

Answer: E. This patient has been exposed to hydrogen sulfide (a common form of suicide in some parts of the world), which has similar effects on the mitochondria as cyanide. However, hydrogen sulfide is rapidly removed from the body; and as long as patients are recovering, removal from the source is usually all that is necessary. HBO and methylene blue have no role in hydrogen sulfide poisoning. Sodium nitrite can be used in patients who are not recovering once removed from the source or for severe exposures. Sodium thiosulfate is not necessary because hydrogen sulfide is detoxified by a different pathway than cyanide and does not need a sulfur donor.

153.6. A 51-year-old man is brought to the emergency department (ED) after being found unconscious and was intubated by emergency medical services (EMS) before arrival. His vital signs reveal hypotension but are otherwise normal. His physical examination is nonspecific. On 100% oxygen by endotracheal tube, his pulse oximetry reveals 100% saturation. Results of an arterial blood gas (ABG) are pH 7.05, partial pressure of carbon dioxide (Pco_2) 27 mm Hg, and partial pressure of oxygen (Po_2) 65 mm Hg. Which one of these findings is inconsistent with simple carbon monoxide (CO) poisoning?

A. Hypotension
B. Oxygen saturation 100%
C. Pco_2 27 mm Hg
D. pH 7.05
E. Po_2 65 mm Hg

Answer: E. Measurement of oxygen saturation and Po_2 values is complicated in CO poisoning. Carboxyhemoglobin (COHb) is essentially falsely read as oxyhemoglobin by pulse oximeters, so a high oxygen saturation is expected by pulse oximetry. Po_2 is a measurement of dissolved oxygen in the blood; this result is independent of CO exposure and is not useful in determining whether CO poisoning is present; thus it should be normal. Metabolic acidosis with an elevated lactate is common because CO impairs aerobic metabolism; respiratory compensation is appropriate.

153.7. What is the major benefit of hyperbaric oxygen (HBO) therapy for patients suffering from carbon monoxide (CO) poisoning?

A. Decreased rate of hospitalization
B. Improvement of 24-hour mortality
C. Improvement of 30-day mortality
D. Prevention of delayed cardiovascular complications
E. Prevention of delayed neuropsychiatric complications

Answer: E. There is controversy regarding the role of HBO therapy for patients with CO poisoning, but the best evidence suggests that it can significantly decrease the incidence of delayed neuropsychiatric complications. There is no change in rate of hospitalization, nor on overall mortality, either short term or long term. There are no delayed cardiovascular symptoms associated with CO poisoning.

153.8. Assuming that all patients have similar vital signs and complaints of headache and nausea, which of the following patients suffering from carbon monoxide (CO) poisoning should be considered highest priority for hyperbaric oxygen (HBO) therapy?

A. A 22-year-old otherwise healthy man with a carboxyhemoglobin (COHb) level of 30%
B. A 25-year-old otherwise healthy pregnant woman with a COHb level of 25%
C. A 30-year-old otherwise healthy man also suffering from cyanide poisoning with a COHb level of 15%
D. A 35-year-old otherwise healthy woman with second-degree burns to 20% of her body and with a COHb level of 20%
E. A 67-year-old asymptomatic woman with coronary artery disease and with a COHb level of 25%

Answer: B. Pregnant patients should be considered for HBO therapy. CO binds more strongly to fetal hemoglobin than to adult hemoglobin and can cause severe hypoxia to the fetus. There is controversy about an absolute level of COHb that requires HBO therapy. HBO does not benefit cyanide victims, nor is it indicated in uncomplicated burn patients or those with stable comorbidities.