Carbon Monoxide Poisoning
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This educational module has been reviewed by the International Association of Firefighters (IAFF).

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Carbon monoxide is the most frequent cause of poisonings in industrialized countries.

Chemistry of Carbon Monoxide

- **Gas:** Colorless, Odorless, Tasteless, Nonirritating
- Results from the incomplete combustion of carbon-containing fuels.
- Abbreviated “CO”
Chemistry of Carbon Monoxide

- Molecule consists of one carbon atom joined to one oxygen atom by a triple bond.
- Extremely stable molecule.

Sources of Carbon Monoxide

- Endogenous
- Exogenous
- Methylene chloride
Sources of Carbon Monoxide

**Endogenous:**
- Normal heme catabolism (breakdown):
  - Only biochemical reaction in the body known to produce CO.
- Levels increased in:
  - Hemolytic anemia.
  - Sepsis

**Exogenous:**
- House fires.
- Gas-powered electrical generators.
- Automobile exhaust.
- Propane-powered vehicles.
- Heaters.
- Camp stoves.
- Boat exhaust.
- Cigarette smoke.

**Methylene chloride:**
- Paint and adhesive remover.
- Converted to CO in the liver after inhalation.
Incidence

- CO is leading cause of poisoning deaths.
- CO may be responsible for half of all poisonings worldwide.
- ~5,000–6,000 people die annually in the United States as a result of CO poisoning.
- ~40,000–50,000 emergency department visits annually result from CO poisoning.

Incidence

- Accidental CO poisoning deaths declining:
  - Improved motor vehicle emission policies.
  - Use of catalytic converters.
Incidence

Most accidental deaths are due to:
- House fires.
- Automobile exhaust.
- Indoor-heating systems.
- Stoves and other appliances.
- Gas-powered electrical generators
- Charcoal grills.
- Camp stoves.
- Water heaters.
- Boat exhausts.

Incidence

Increased accidental CO deaths:
- Patient > 65 years of age.
- Male
- Ethanol intoxication.

Accidental deaths peak in winter:
- Use of heating systems.
- Closed windows.

Incidence

Significant increase in CO poisoning seen following disasters.
Primarily related to loss of utilities and reliance on gasoline-powered generators and use of fuel-powered heaters.
Incidence

- Fetal hemoglobin has a much greater affinity for CO than adult hemoglobin.
- Pregnant mothers may exhibit mild to moderate symptoms, yet the fetus may have devastating outcomes.

EXPOSURE

Environmental CO Exposure

- Environmental exposure typically <0.001% (10 ppm).
- Higher in urban areas
- Sources:
  - Volcanic gasses
  - Bush fires
  - Human pollution
CO Exposure

<table>
<thead>
<tr>
<th>Source</th>
<th>Exposure (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh Air</td>
<td>0.06-0.5</td>
</tr>
<tr>
<td>Urban Air</td>
<td>1-30</td>
</tr>
<tr>
<td>Smoke-filled Room</td>
<td>2-16</td>
</tr>
<tr>
<td>Cooking on Gas Stove</td>
<td>100</td>
</tr>
<tr>
<td>Actively Smoking a Cigarette</td>
<td>400-500</td>
</tr>
<tr>
<td>Automobile Exhaust</td>
<td>100,000</td>
</tr>
</tbody>
</table>

CO absorption by the body is dependent upon:
- Minute ventilation ($V_{min}$).
- Duration of exposure.
- Concentration of CO in the environment.
- Concentration of O₂ in the environment.

Exposure Limits

- **OSHA:**
  - 50 ppm (as an 8-hour time-weighted average).
- **NIOSH:**
  - 35 ppm (as an 8-hour time-weighted average).
Firefighter Risks

- CO is a significant and deadly occupational risk factor for firefighters.
- Sources:
  - Structure fires.
  - Apparatus fumes.
  - Portable equipment fumes.
  - Underground utility fires.
  - Closed-space rescue situations.
- CO is slightly lighter than dry air (Vapor Density = 0.97).

SCBA extremely important in CO prevention.

- CO often encountered during overhaul operations.

CO POISONING PATHOPHYSIOLOGY
Pathophysiology of CO poisoning first described by French physician Claude Bernard in 1857.

CO poisoning actually very complex. CO binds to hemoglobin with an affinity ~ 250 times that of oxygen. The combination of CO and hemoglobin is called carboxyhemoglobin (COHb).

CO displaces O₂ from the hemoglobin binding sites. CO prevents O₂ from binding. COHb does not carry O₂. COHb causes premature release of remaining O₂ into the tissues.
Pathophysiology

- COHb ultimately removed from the circulation and destroyed.
- Half-life:
  - Room air: 240-360 minutes
  - O₂ (100%): 80 minutes
  - Hyperbaric O₂: 22 minutes

Pathophysiology

- CO also binds to other iron-containing proteins:
  - Myoglobin
  - Cytochrome
  - Neuroglobin
- Binding to myoglobin reduces O₂ available in the heart:
  - Ischemia
  - Dysrhythmias
  - Cardiac dysfunction
Normal COHb Levels

<table>
<thead>
<tr>
<th>Source</th>
<th>COHb (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endogenous</td>
<td>0.4-0.7</td>
</tr>
<tr>
<td>Tobacco Smokers:</td>
<td></td>
</tr>
<tr>
<td>1 pack/day</td>
<td>5-6</td>
</tr>
<tr>
<td>2-3 packs/day</td>
<td>7-9</td>
</tr>
<tr>
<td>cigars</td>
<td>Up to 20</td>
</tr>
<tr>
<td>Urban Commuter</td>
<td>5</td>
</tr>
<tr>
<td>Methylene chloride (100 ppm for 8 hours)</td>
<td>3-5</td>
</tr>
</tbody>
</table>

Pathophysiology

Nitric oxide (NO):
- Highly-reactive gas that participates in numerous biochemical reactions.
- Oxygen free-radical levels increased with CO exposure.

Pathophysiology

Nitric Oxide (NO):
- Causes cerebral vasodilation:
  - Syncope
  - Headache
- May lead to oxidative damage to the brain:
  - Probable cause of syndrome of delayed neurologic sequelae (DNS).
  - Associated with reperfusion injury.
Pathophysiology

**Impact of CO on major body systems:**

**Neurologic:**
- CNS depression resulting in impairment:
  - Headache
  - Dizziness
  - Confusion
  - Seizures
  - Coma
- Long-term effects:
  - Cognitive and psychiatric problems

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Pathophysiology

46-year-old woman with chronic exposure to CO from old car.
COHb = 46%

**Autopsy:**
- Cherry-red tissues
- Cerebral edema
- Immediate cause of death: ventricular fibrillation due to CO poisoning.

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Pathophysiology

**Impact of CO on major body systems:**

**Cardiac:**
- Decreased myocardial function:
  - Hypotension with tachycardia.
  - Chest pain.
  - Dysrhythmias.
  - Myocardial ischemia.
  - Most CO deaths are from ventricular fibrillation.
- Long-term effects:
  - Increased risk of premature cardiac death.
Pathophysiology

Impact of CO on major body systems:

- **Metabolic:**
  - Respiratory alkalosis (from hyperventilation).
  - Metabolic acidosis with severe exposures.

- **Respiratory:**
  - Pulmonary edema (10-30%)
  - Direct effect on alveolar membrane.
  - Left-ventricular failure.
  - Aspiration.
  - Neurogenic pulmonary edema.

Pathophysiology

Impact of CO on major body systems:

- Multiple Organ Dysfunction Syndrome (MODS):
  - Occurs at high-levels of exposure.
  - Associated with a high mortality rate.

Pathophysiology Summary

- **Limits O\textsubscript{2} transport:**
  - CO more readily binds to Hb forming COHb.

- **Inhibits O\textsubscript{2} transfer:**
  - CO changes structure of Hb causing premature release of O\textsubscript{2} into the tissues.

- **Tissue inflammation:**
  - Poor perfusion initiates an inflammatory response.
Pathophysiology Summary

**Poor cardiac function:**
- \( \downarrow \) O\(_2\) delivery can cause dysrhythmias and myocardial dysfunction.
- Long-term cardiac damage reported after single CO exposure.

**Increased activation of nitric oxide (NO):**
- Peripheral vasodilation.
- Inflammatory response.

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Pathophysiology Summary

**Vasodilation:**
- Results from NO increase.
- Cerebral vasodilation and systemic hypotension causes reduced cerebral blood flow.
- NO is largely converted to methemoglobin.

**Free radical formation:**
- NO accelerates free radical formation.
- Endothelial and oxidative brain damage.

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Patient Groups at Risk

- Children.
- Elderly.
- Persons with heart disease.
- Pregnant women.
- Patients with increased oxygen demand.
- Patients with decreased oxygen-carrying capacity (e.g., anemias, blood cancers).
- Patients with chronic respiratory insufficiency.
CO POISONING
SIGN & SYMPTOMS

CO Poisoning

- Signs and symptoms usually vague and non-specific.
- You must ALWAYS maintain a high index of suspicion for CO poisoning!

CO Poisoning

- Signs and symptoms closely resemble those of other diseases.
- Often misdiagnosed as:
  - Viral illness (e.g., the “flu”)
  - Acute coronary syndrome
  - Migraine
- Estimated that misdiagnosis may occur in up to 30-50% of CO-exposed patients presenting to the ED.
Signs and Symptoms

Carbon Monoxide
The Great Imitator†

† - So is:
• Syphilis
• Lyme disease
• Fibromyalgia
• Lupus erythematosis
• Multiple sclerosis

CO Poisoning

Classifications:

Acute
Results from short exposure to a high level of CO.

Chronic:
Results from long exposure to a low level of CO.

Signs and Symptoms (Acute)

Malaise
Flu-like symptoms
Fatigue
Dyspnea on exertion
Chest pain
Palpitations
Lethargy
Confusion
Depression
Impulsiveness
Distractibility
Hallucination
Confabulation
Agitation
Nausea
Vomiting
Diarrhea
Abdominal pain
Signs and Symptoms (Acute)

- Headache
- Drowsiness
- Dizziness
- Weakness
- Confusion
- Visual disturbances
- Syncope
- Seizures
- Fecal incontinence
- Urinary incontinence
- Memory disturbances
- Gait disturbances
- Bizarre neurologic symptoms
- Coma
- Death

Firefighter Headaches

While CO should always be considered a possible cause of headaches in working firefighters, there are more common causes:

- Tight helmet ratchet.
- Too heavy a helmet (especially leather).
- Dehydration.

Signs and Symptoms (Chronic)

Signs and symptoms the same as with acute CO poisoning except that onset and severity may be extremely varied.
**Signs and Symptoms**

COHb levels do not always correlate with symptoms nor predict sequelae.

<table>
<thead>
<tr>
<th>CO ppm</th>
<th>Duration</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>8 hours</td>
<td>OSHA minimum</td>
</tr>
<tr>
<td>200</td>
<td>2-3 hours</td>
<td>Mild headache, fatigue, nausea, dizziness</td>
</tr>
<tr>
<td>400</td>
<td>1-2 hours</td>
<td>Serious headache—other symptoms intensify. Life-threatening &gt; 3 hours</td>
</tr>
<tr>
<td>800</td>
<td>45 minutes</td>
<td>Dizziness, nausea and convulsions. Unconscious within 2 hours. Death within 2-3 hours.</td>
</tr>
<tr>
<td>1,600</td>
<td>20 minutes</td>
<td>Headache, dizziness and nausea. Death within 1 hour.</td>
</tr>
<tr>
<td>3,200</td>
<td>5-10 minutes</td>
<td>Headache, dizziness and nausea. Death within 1 hour.</td>
</tr>
<tr>
<td>6,400</td>
<td>1-2 minutes</td>
<td>Headache, dizziness and nausea. Death within 25-30 minutes.</td>
</tr>
<tr>
<td>12,800</td>
<td>1-3 minutes</td>
<td>Death</td>
</tr>
</tbody>
</table>

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**Cherry red skin color is not always present and, when present, is often a late finding.**

**CO may be the cause of the phenomena associated with haunted houses:**

- Strange visions.
- Strange sounds.
- Feelings of dread.
- Hallucinations.
- Inexplicable deaths.
Long-Term Complications

Delayed Neurologic Syndrome (DNS):
- Recovery seemingly apparent.
- Behavioral and neurological deterioration 2-40 days later.
- True prevalence uncertain (estimate range from 1-47% after CO poisoning).
- Patients more symptomatic initially appear more apt to develop DNS.
- More common when there is a loss of consciousness in the acute poisoning.

Delayed Neurologic Syndrome

Signs and Symptoms:
- Memory loss
- Confusion
- Ataxia
- Seizures
- Urinary incontinence
- Fecal incontinence
- Emotional lability
- Disorientation
- Hallucinations
- Parkinsonism
- Mutism
- Cortical blindness
- Psychosis
- Gait disturbances
- Other motor disturbances
- Mutism
- Cortical blindness
- Psychosis
- Gait disturbances
- Other motor disturbances

Cardiac Complications:
- 230 sequential patients with moderate to severe CO poisoning treated with HBO.

<table>
<thead>
<tr>
<th>CO Myocardial Injury</th>
<th>Patients</th>
<th>Died (%)</th>
<th>5-year Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myocardial injury from CO</td>
<td>85</td>
<td>37.6</td>
<td>71.6</td>
</tr>
<tr>
<td>No Myocardial injury from CO</td>
<td>145</td>
<td>15.2</td>
<td>88.3</td>
</tr>
</tbody>
</table>

Long-Term Complications

- Depression and anxiety can exist up to 12 months following CO exposure.
- Higher at 6 weeks in patients who attempted suicide by CO.
- No differences in rates between accidental and suicide-attempt at 12 months.

CO DETECTION

Carbon Monoxide Detection

- CO detectors have been widely-available for over a decade.
- Still vastly underutilized.
- Underwriters Laboratories (UL) revised guidelines for CO detectors in 1998.
- Units manufactured before 1998 should be replaced.
Carbon Monoxide Detection

- Biological detection of CO limited:
  - Exhaled CO measurement.
  - Hospital-based carboxyhemoglobin levels (arterial or venous).

Technology now available to detect biological COHb levels in the prehospital and ED setting.
Referred to as pulse CO-oximetry

Hand-held devices now available to assess atmospheric levels of CO.
Multi-gas detectors common in the fire service:
- Combustible gases
- CO
- O₂
- H₂S
Carbon Monoxide Detection

- New generation pulse oximeter/pulse CO-oximeter can detect 4 different hemoglobin forms.
  - Deoxyhemoglobin (Hb)
  - Oxyhemoglobin (O2Hb)
  - Carboxyhemoglobin (COHb)
  - Methemoglobin (MetHb)

- Provides:
  - SpO2
  - SpCO
  - SpMet
  - Pulse rate

Pulse CO-Oximetry

- Uses finger probe similar to that used in pulse oximetry.
- Uses 8 different wavelengths of light (instead of 2 for pulse oximetry).
- Readings very closely correlate with COHb levels measured in-hospital.

Pulse CO-Oximetry

![Graph showing absorption at different wavelengths for Deoxyhemoglobin, Carboxyhemoglobin, Methemoglobin, and Oxyhemoglobin. Absorption peaks at 660 nm and 940 nm.]
Pulse CO-Oximetry

- CO evaluation should be routine at all levels of EMS and the fire service.
- All field personnel should be educated in use of the pulse oximeter and pulse CO-oximeter.

Missed CO poisoning is a significant area of legal liability for EMS and fire personnel.

CO POISONING TREATMENT

Diagnostic Criteria

- **Biologic:**
  - COHb > 5% in nonsmokers.
  - COHb > 10% in smokers.
- **Environmental:**
  - No confirmatory test.
Diagnostic Criteria

**Suspected:**
- Potentially-exposed person, but no credible threat exists.

**Probable:**
- Clinically-compatible case where credible threat exists.

**Confirmed:**
- Clinically-compatible case where biological tests have confirmed exposure.

Treatment

- Treatment is based on the severity of symptoms.
- Treatment generally indicated with COHb > 10-12%.
- Be prepared to treat complications (i.e., seizures, dysrhythmias, cardiac ischemia).

Administer high-concentration oxygen.
- Maximizes hemoglobin oxygen saturation.
- Can displace some CO from hemoglobin.
- Associated with improvements in neurological and cardiac complications.

The importance of early administration of high-concentration oxygen CANNOT be overemphasized!
Prehospital CPAP can maximally saturate hemoglobin and increase oxygen solubility. Strongly suggested for moderate to severe poisonings.

Efficacy of hyperbaric oxygen therapy (HBO) is a matter of conjecture although still commonly practiced. Generally reserved for severe poisonings. May aid in alleviating tissue hypoxia. Significantly decreases half-life of COHb.
Indications for HBO Therapy

**Strongly consider for:**
- Altered mental status.
- Coma.
- Focal neurological deficits.
- Seizures.
- Pregnancy with COHb>15%.
- History of LOC.

**Possibly consider for:**
- Cardiovascular compromise (e.g., ischemia, dysrhythmias).
- Metabolic acidosis.
- Extremes of age.

Treatment

- Continue to monitor SpO₂ and SpCO levels throughout treatment.
- Obtain 12-lead ECG (if ALS) and monitor ECG.
- Document findings and plot trends.
Treatment

First-generation pulse oximeters may give falsely elevated SpO\textsubscript{2} levels in cases of carbon monoxide poisoning.

Cannot distinguish between O\textsubscript{2}Hb and COHb.

CO Poisoning

Remember, CO poisoning is the great imitator.

Missed CO exposure often leads to death and disability.

CO is a particular risk for firefighters.

A simple COHb reading can save a life and possibly prevent long-term complications.

METHYLENE CHLORIDE
**Methylene Chloride Exposure**

- Methylene chloride slowly metabolized to CO.
- Victims do not pose contamination risks to rescuers.
- Victims with contaminated clothing or skin can secondarily contaminate response personnel by direct contact or through off-gassing vapor.
- Methylene chloride vapor may also off-gas from the toxic vomitus of victims who have ingested methylene chloride.

**Methylene Chloride Exposure**

- **Methylene chloride can cause:**
  - Acute CNS depression.
  - Respiratory depression.
  - Cardiac dysrhythmias.
  - Respiratory tract irritation (at high levels).
  - Non-cardiogenic pulmonary edema (at high levels).

**Methylene Chloride Exposure**

- **Treatment:**
  - No antidote for methylene chloride.
  - Support respiratory and cardiovascular functions.
  - Administer O₂ (O₂ is an antagonist of metabolically-produced carbon monoxide).
DOUBLE TROUBLE: CO and CYANIDE

Carbon Monoxide and Cyanide

- Cyanide more often encountered in fires than once thought.
- The effects of CO and cyanide are cumulative.
- Symptoms of cyanide toxicity often attributed to CO because of lack of a high index of suspicion.

Chemistry of Cyanide

- **Gas:**
  - Colorless.
  - Faint bitter almond smell.
  - Nearly 40% of the population cannot smell cyanide.
  - Sodium cyanide (NaCN) and potassium cyanide (KCN) are both white powders.
Chemistry of Cyanide

- Molecule consists of one carbon atom joined to one nitrogen atom by a triple bond.
- Cyanide anion is extremely toxic.

\[
\text{C} \equiv \text{N}^- \]

Cyanide

- Hydrogen cyanide is a product of combustion.

High in:
- Plastics.
- Wool
- Silk.
- Synthetic rubber.
- Polyurethane.
- Asphalt.

Cyanide

- Toxicity varies with chemical form.
- Hydrogen cyanide (HCN) gas at concentrations of 130 ppm can be fatal within an hour.
- OSHA permissible exposure levels are 10 ppm as an 8-hour time-weighted average.
Pathophysiology

Cyanide can be inhaled or ingested. Ingestion is more common with suicide or murders.

Cyanide is an irreversible enzyme inhibitor: Cytochrome c oxidase (aa₃). Part of the 4th complex of the electron transport chain. Found in the shelves (cristae) of the mitochondria in the cells.

Cyanide deactivates this enzyme.
Pathophysiology

- Cyanide stops the electron transport chain and stops energy production (ATP) in the cell.
- Tissues that primarily depend on aerobic respiration are particularly affected:
  - Heart
  - Central nervous system

Cyanide and CO both primarily affect the heart and CNS thus multiplying the ill-effects!

Cyanide Treatment

- Antidotes available:
  - Cyanide Antidote Kit:
    - Amyl nitrite.
    - Sodium nitrite.
    - Sodium thiosulfate.
    - Hydroxocobalamin.

Cyanide Poisoning

- Amyl nitrite is administered via inhalation or ventilation.
- Sodium nitrite is administered intravenously.
- Sodium thiosulfate is administered intravenously.
Cyanide Treatment

- The nitrites promote the formation of methemoglobin.
- Cyanide has a greater affinity for methemoglobin (MetHb) than the cytochrome oxidase enzyme.
- The binding of cyanide to MetHb frees cytochrome oxidase so that energy production is resumed.

Cyanide Treatment

- Sodium thiosulfate binds to cyanide and forms thiocyanate.
- Thiocyanate is much less toxic than cyanide anion and excreted through the kidneys.

Cyanide Treatment

- Hydroxocobalamin
  - Precursor to cyanocobalamin (Vitamin B₁₂).
  - Hydroxocobalamin combines with cyanide to form cyanocobalamin which is excreted through the kidneys.
  - FDA approval in US obtained in December 2006.
  - Marketed as Cyanokit™.
Cyanide Treatment

Problems (related to nitrites):
- MethHb does not transport O₂.
- The conversion of HB to MetHb changes the state of the heme molecule where O₂ binds.
- MetHb has heme in the ferric (Fe³⁺) state and not the ferrous state (Fe²⁺).
- O₂ can only bind to heme when in the Fe²⁺ state.

Concomitant CO and cyanide poisoning can significantly decrease the O₂-carrying capacity of the blood.

Combination of COHb and MetHB can significantly reduce the O₂-carrying capacity of the blood.

O₂-carrying capacity nearly halved!
Cyanide Treatment

Children are particularly at risk for hypotension and adverse effects from methemoglobinemia.

CO and Cyanide Poisoning

- Parts of cyanide antidote kit (amyl nitrite, sodium nitrite) induce methemoglobinemia.
- Cyanide antidotes and CO poisoning can lead to elevated COHb and MetHb significantly reducing O2 capacity of blood.
- Sodium nitrite should be avoided for combination cyanide/CO poisonings when SpCO >10%.
- Hydroxocobalamin converts cyanide to cyanocobalamin (Vitamin B12) which is renally-cleared.

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