

INHALATION INJURY AND TOXIC INDUSTRIAL CHEMICAL EXPOSURE

Original Release/Approval	23 Feb 2007	Note: This CPG requires an annual review.		
Reviewed:	May 2012	Approved:	7 Jun 2012	
Supersedes:	Inhalation Injury and Toxic Industrial Chemical Exposure, 7 Nov 2008			
<input type="checkbox"/> Minor Changes (or)	<input checked="" type="checkbox"/> Changes are substantial and require a thorough reading of this CPG (or)			
<input type="checkbox"/> Significant Changes	CPG essentially re-written; PI monitoring plan added			

- 1. Goal.** There are multiple toxic industrial chemicals (TICs) that act on the respiratory tract. This CPG reviews the most common TICs related in pulmonary injury. More information is available from the CDC, <http://www.bt.cdc.gov/agent/agentlistchem-category.asp>, and the Textbook of Military Medicine, http://www.bordeninstitute.army.mil/published_volumes/biological_warfare/biological.html
- 2. General smoke inhalation injury.** Smoke inhalation injury occurs from several agents. Thermal injury and chemical injury are the primary initial toxicities. Chemical injury occurs from several materials of combustion and pyrolysis.¹ Highly water soluble irritants such as acrolein, sulfur dioxide, hydrogen chloride and ammonia, and intermediate water soluble irritants such as chlorine and isocyanates are produced. Poor water soluble irritants are oxides of nitrogen and phosgene. Simple asphyxiants which displace oxygen include carbon dioxide and methane, and chemical asphyxiants which inhibit mitochondrial activity and reduce hemoglobin carrying capacity include carbon monoxide, cyanide, and hydrogen sulfide. Treatment is generally supportive. Some require antidotes. Most critically ill patients require unique ventilation techniques used for acute lung injury (ALI) and acute respiratory distress syndrome (ARDS).
- 3. Toxic industrial chemical (TIC) inhalational injury.** In general, the treatment of ALI and ARDS secondary to TICs is similar to that for smoke inhalation injury. The care is supportive with a focus on (1) airway management, (2) lung-protective ventilation strategies, (3) aggressive pulmonary toilet, and (4) avoidance of volume overload or rapid fluid infusion that might worsen pulmonary edema secondary to capillary leak. Patients requiring mechanical ventilation (MV) secondary to TIC inhalation, in particular chlorine, are at a higher risk of developing ventilator-associated pneumonia and should be monitored closely. The treatments in this CPG are primarily based on animal experiments. Evidence for clinical use in humans is limited.
 - a. Chlorine (CL₂).** Chlorine is used commonly in industry. It is commonly found in industrial and transportation accidents and may be used in military weapons such as IEDs. The IED is placed next to a tank or truck containing a large volume of compressed chlorine gas. Chlorine dissolves in water to form hydrochloric and hypochlorous acids. Chlorine has intermediate water solubility. Just after exposure the patient develops mucosal irritation (tearing, skin burning, drooling), but after large or sustained exposure the patient may develop cough, shortness of breath, and chest pain due to alveolar injury. If the patient develops pulmonary toxicity, it may worsen over days. Treatment is primarily skin decontamination, supplemental oxygen, beta agonists and ALI/ARDS ventilatory techniques.² Inhaled corticosteroids (e.g. fluticasone) improved secondary

Guideline Only/Not a Substitute for Clinical Judgment

June 2012

Joint Theater Trauma System Clinical Practice Guideline

outcomes in severely toxic animal models.³ Clinical data on the efficacy of corticosteroids after human exposure to lung-damaging agents are inconclusive as the number of well-structured controlled studies is small and the indications for administration of corticosteroids are unclear.⁴ Prone positioning mechanical ventilation maybe effective.⁵ Nebulized bicarbonate has not reliably improved outcomes.^{2,6,7} ([Appendix A.](#))

- b. **Phosgene (Carbonyl chloride, COCl₂).** Phosgene has a sweet, pleasant smell of mown hay. It is poorly water soluble, not noxious and does not prompt escape from the location by the victim. It was used in WWI as a chemical weapon. It is produced from the combustion of chlorinated hydrocarbons (welding, fires) and from synthesis of solvents (degreasers, cleaners). The primary symptom is delayed ALI, which can be delayed by nearly a day and severe. The mechanism of toxicity is release of hydrochloric acid and reactive oxygen species and free radicals in the lung epithelial layers. Decontamination is typically not needed once the patient leaves the exposure. Treat with observation, supplemental oxygen and ALI/ARDS ventilation techniques.
- c. **Hydrogen sulfide (H₂S).** Hydrogen sulfide smells like rotten eggs and is a chemical irritant. Exposures occur in waste management, petroleum, natural gas industries, and asphalt and rubber factories. The gas acts like cyanide and inhibits cytochrome oxidase, preventing mitochondrial oxygen use and cellular respiration. At lower doses, H₂S causes skin and mucous membrane irritation. At high concentrations, it produces a “knockdown” effect, a sudden loss consciousness. At these concentrations it can produce seizure, myocardial ischemia, keratoconjunctivitis, and upper airway and pulmonary injury. Treat with skin irrigation, supplemental oxygen, removal from exposure, intravenous sodium nitrite (300 mg), and supportive care.² Sodium nitrite can produce hypotension and methemoglobinemia (commonly 8-12%). Infuse it over 5-7 minutes.
- d. **Ammonia (NH₃).** Ammonia is a common industrial and household chemical used as a fertilizer, refrigerant, cleaning agent. NH₃ has a pungent odor. It is also used in plastic and explosive synthesis. NH₃ is transported in vehicles under pressure in liquid form at sub-zero temperatures. It reacts with water upon release, to form ammonium hydroxide (NH₄OH), a strong base, which produces mucosal irritation (tearing, skin irritation, eye pain and burns), severe upper airway irritation, and alkali skin burns. High concentrations or prolonged exposure duration (patient unconscious in a closed room) can produce tracheobronchial and pulmonary inflammation. It can produce ALI within 2-5 minutes of exposure. Treat with skin and eye irrigation, alkali burn skin care, supplemental oxygen, ALI/ARDS ventilatory techniques, and supportive care.²

4. Other common chemical toxins related to inhalational exposures

- a. **Cyanide (CN).** Cyanide is released in structural and vehicle fires and in occupational settings of chemical or synthetic material combustion. It is used in manufacturing of pesticides and synthetic materials, metal extraction, and in chemical laboratories. Cyanide inhibits mitochondrial cytochrome oxidase inhibiting cellular respiration and aerobic metabolism. Early or mild effects are mostly neurologic (dizziness, headache, nausea, and anxiety). Late or severe effects are coma, seizure, respiratory depression, hypotension, and tachycardia. Acute lung injury and pulmonary edema can occur in severe cases. Coma precedes apnea, and then hypotension develops. Hypotension or

Guideline Only/Not a Substitute for Clinical Judgment

June 2012

Joint Theater Trauma System Clinical Practice Guideline

cardiac arrest develops in 50% of cyanide exposures from fires.⁸ The triad of severe toxicity is hypotension, altered mental status, and lactic acidosis (commonly > 8 mmol/L).⁹ Treat with oxygen, mechanical ventilation, and antidotal therapy. The traditional antidote is the Cyanide Antidote Kit (sodium thiosulfate 12.5 gram IV and sodium nitrite 300 mg IV). A repeat of each drug may be given if no response. Sodium nitrite can cause hypotension and methemoglobinemia (8-12%) Infuse it over 5-7 minutes. Hydroxocobalamin was FDA approved in 2006 and has less serious effects. Infuse 5 grams IV over 7 minutes. It may be infused over 2-5 minutes in cardiac arrest or severe hypotension, and may be repeated if no clinical improvement.¹⁰

- b. **Fire suppressants.** Chemical fire suppressants are released in military vehicle fires. The most common is HFC227 (HFC-227EA, heptafluoropropane). It replaced bromotrifluoromethane (one of many “Halon”) in military vehicles. These “virgin Halons” were banned by the EPA in 1994.¹⁰ HFC227 is inert, a simple asphyxiant, and no cases of combustion related toxicity have been published or reported to the EPA or OSHA.^{12,13} HFC227 could convert to hydrogen fluoride in small amounts during a fire; however, treatment would be supportive, similar to other chemical exposures of inhalation injury.² Inhalational injuries sustained in an MRAP vehicle may involve exposure to hydrogen fluoride (HF) gas, which is a byproduct of combustion with standard fire suppression system devices. Exposure to HF may result in rapidly progressive or fatal respiratory failure despite minimal external evidence of trauma or inhalation injury. In service members involved in an MRAP fire who have shortness of breath, cough, or hypoxia, there must be a high level of suspicion for HF inhalation. Treatment is supportive. If hypocalcemia is present, administer calcium gluconate (1.5 ml of 10% Ca Gluconate in 4.5 ml water) nebulized q4hr until normalization of serum calcium levels. In the absence of significant burns, consider steroids if symptoms do not improve. Bronchopneumonia can develop within the first week. Long term, PFTs should be done with/without methocholine challenge to determine reactivity of the airways, for which steroids (systemic and inhaled) can be beneficial.

5. Performance Improvement (PI) Monitoring.

- a. Intent (Expected Outcomes).
 - 1) All patients who suffer severe toxic or chemical inhalation injuries will receive appropriate supportive care including intubation and mechanical ventilation when indicated
- b. Performance/Adherence Measures.
 - 1) All patients with severe toxic or chemical inhalation injuries received appropriate supportive care, including intubation and mechanical ventilation
- c. Data Source.
 - 1) Patient Record
 - 2) Joint Theater Trauma Registry (JTTR)
- d. System Reporting & Frequency.

Guideline Only/Not a Substitute for Clinical Judgment

June 2012

Joint Theater Trauma System Clinical Practice Guideline

The above constitutes the minimum criteria for PI monitoring of this CPG. System reporting will be performed annually; additional PI monitoring and system reporting may be performed as needed.

The system review and data analysis will be performed by the Joint Theater Trauma System (JTTS) Director, JTTS Program Manager, and the Joint Trauma System (JTS) Performance Improvement Branch.

- 6. Responsibilities.** It is the trauma team leader's responsibility to ensure familiarity, appropriate compliance and PI monitoring at the local level with this CPG.

7. References.

- ¹ Holstege CP, Kirk MA. Smoke inhalation. In: Goldfrank LR, ed. Goldfrank's toxicologic emergencies. 7th ed New York: McGraw-Hill, Medical Pub. Division; 2002:1469-1477.
- ² Nelson LS. Simple asphyxiants and pulmonary irritants. In: Goldfrank LR, ed. Goldfrank's toxicologic emergencies. 7th ed ed. New York: McGraw-Hill, Medical Pub. Division; 2002:1453-1468.
- ³ Wang J, Zhang L, Walther SM. Administration of aerosolized terbutaline and budesonide reduces chlorine gas-induced acute lung injury. *J Trauma*. Apr 2004;56(4):850-862.
- ⁴ DeLange DW, Meulenbelt J. Do Corticosteroids have a role in preventing or reducing acute toxic lung injury caused by inhalation of chemical agents? *Clinical Toxicology*. Vol 49, no 2. February 2011. pp 61-71
- ⁵ Wang J, Abu-Zidan FM, Walther SM. Effects of prone and supine posture on cardiopulmonary function after experimental chlorine gas lung injury. *Acta Anaesthesiol Scand*. Oct 2002;46(9):1094-1102.
- ⁶ Vinsel PJ. Treatment of acute chlorine gas inhalation with nebulized sodium bicarbonate. *J Emerg Med*. 1990 May-Jun 1990;8(3):327-329.
- ⁷ Pascuzzi TA, Storrow AB. Mass casualties from acute inhalation of chloramine gas. *Mil Med*. 1998 Feb 1998;163(2):102-104.
- ⁸ Borron SW, Baud FJ, Barriot P, Imbert M, Bismuth C. Prospective study of hydroxocobalamin for acute cyanide poisoning in smoke inhalation. *Ann Emerg Med*. 2007;49(6):794-801, 801.e791-792.
- ⁹ Baud FJ, Borron SW, Megarbane B, et al. Value of lactic acidosis in the assessment of the severity of acute cyanide poisoning. *Crit Care Med*. 2002;30(9):2044-2050.
- ¹⁰ Bebart VS, Tanen DA, Lairt J, Dixon PS, Valtier S, Bush A. Hydroxocobalamin and sodium thiosulfate versus sodium nitrite and sodium thiosulfate in the treatment of acute cyanide toxicity in a swine (*Sus scrofa*) model. *Ann Emerg Med*. Apr;55(4):345-351.
- ¹¹ McDougal JN, Dodd DE. Air Force approach to risk assessment for Halon replacements. *Toxicology Letter*. 1993;68(1-2):31-35.
- ¹² Emmen HH, Hoogendijk EM, Klopping-Ketelaars WA, et al. Human safety and pharmacokinetics of the CFC alternative propellants HFC 134a (1,1,1,2-tetrafluoroethane) and HFC227 (1,1,1,2,3,3,3-heptafluoropropane) following whole-body exposure. *Regul Toxicol Pharmacol*. 2000;31(1):22-35.

Guideline Only/Not a Substitute for Clinical Judgment

June 2012

Joint Theater Trauma System Clinical Practice Guideline

- ¹³ Robin ML. Review of thermal decomposition product formation from halocarbon fire suppression agents: suppression of class A fires. West Lafayette, IN1999.

Approved by CENTCOM JTTS Director,
JTS Director and CENTCOM SG

Opinions, interpretations, conclusions, and recommendations are those of the authors
and are not necessarily endorsed by the Services or DoD.

Guideline Only/Not a Substitute for Clinical Judgment

June 2012

APPENDIX A CHLORINE INHALATION

1. **Chlorine.** Stratify chlorine toxic patients into no symptoms, mild, moderate and severe. Treatment and observation periods can be tailored based on the severity of symptoms.
 - a. **No symptoms.** If no symptoms, then may be discharged if initial assessment (respiratory examination, vital signs, and pulse oximetry) is normal.
 - b. **Mild** (minimal symptoms, coughing, normal pulse oximetry, and no increased respiratory effort). Obtain chest radiograph, administer inhaled beta agonists, and observe for up to 6 hours. Most patients can be discharged.
 - c. **Moderate** (hypoxia, increased respiratory effort, normal chest radiograph) - Obtain chest radiograph, administer beta agonists, and admit for at least 12 hours. Consider inhaled steroids (fluticasone 200 mcg or similar agent) twice a day, early endotracheal intubation for increased respiratory effort, and inhaled ipratropium.
 - d. **Severe** (hypoxia, respiratory distress, often require intubation). Perform early endotracheal intubation with 8.0 tube to allow for bronchoscopy, obtain chest radiograph, administer beta agonists, and admit to ICU. Administer humidified oxygen and inhaled steroids (fluticasone 200 mcg or similar agent) twice a day. Consider inhaled ipratropium if not improving. If unable to administer inhaled steroids or if patient has significant bronchoconstriction consider intravenous steroids.
 - 1) ALI/ARDS. Perform similar ventilation strategies for ALI and ARDS, including increased PEEP and low tidal volumes. Evaluate daily for barotrauma. The patient may require high doses of sedatives to maintain synchrony with the ventilator.
2. **Important caveats.** A patient who is close to a large, dense chlorine exposure (IED detonated chlorine tank) or suffers a sustained exposure (unconscious in a chlorine filled room) may develop upper airway edema. In these cases, perform early intubation. Examine all exposed patients for eye, mucosal, and skin contamination which is manifested by corneal burns/abrasions, mucosal swelling, and skin erythema, blister, or burns. Decontaminate all symptomatic skin surfaces. Remove all exposed clothing. The trauma evaluation and treatment takes priority over the chlorine toxicity. Nebulized bicarbonate has not been reliably effective. It is made by mixing 1 ml of 8.5% sodium bicarbonate in 3 ml saline to create a 2% solution.
3. **Post discharge followup.** If available, obtain pulmonary function tests with lung volume assessment and DLCO. If the PFT is abnormal, obtain high resolution pulmonary CT scan to assess for pulmonary fibrosis.

- 4. Background and clinical effects.** Chlorine is a gas with intermediate water solubility. It will induce mild irritant symptoms (tearing, pungent smell, upper airway irritation), but will also induce delayed pulmonary edema following a dense or sustained exposure. Chlorine dissolution into lung water generates hydrochloric acid and hypochlorous acid. The hypochlorous acid decomposes to HCl and nascent oxygen (O⁻). The nascent O⁻ produces additional lung damage by free-radical formation. Chlorine was used in World War I as a chemical warfare agent.
- a. Early effects. Irritation of the eyes, nasal mucosa, upper airway, coughing, shortness of breath, and chest pain or burning
 - b. Late effects. Pulmonary congestion and edema and then ALI/ARDS.

APPENDIX B

ADDITIONAL INFORMATION REGARDING OFF-LABEL USES IN CPGs

1. **Purpose.** The purpose of this Appendix is to ensure an understanding of DoD policy and practice regarding inclusion in CPGs of “off-label” uses of U.S. Food and Drug Administration (FDA)–approved products. This applies to off-label uses with patients who are armed forces members.
2. **Background.** Unapproved (i.e., “off-label”) uses of FDA-approved products are extremely common in American medicine and are usually not subject to any special regulations. However, under Federal law, in some circumstances, unapproved uses of approved drugs are subject to FDA regulations governing “investigational new drugs.” These circumstances include such uses as part of clinical trials, and in the military context, command required, unapproved uses. Some command requested unapproved uses may also be subject to special regulations.
3. **Additional Information Regarding Off-Label Uses in CPGs.** The inclusion in CPGs of off-label uses is not a clinical trial, nor is it a command request or requirement. Further, it does not imply that the Military Health System requires that use by DoD health care practitioners or considers it to be the “standard of care.” Rather, the inclusion in CPGs of off-label uses is to inform the clinical judgment of the responsible health care practitioner by providing information regarding potential risks and benefits of treatment alternatives. The decision is for the clinical judgment of the responsible health care practitioner within the practitioner-patient relationship.
4. **Additional Procedures.**
 - a. **Balanced Discussion.** Consistent with this purpose, CPG discussions of off-label uses specifically state that they are uses not approved by the FDA. Further, such discussions are balanced in the presentation of appropriate clinical study data, including any such data that suggest caution in the use of the product and specifically including any FDA-issued warnings.
 - b. **Quality Assurance Monitoring.** With respect to such off-label uses, DoD procedure is to maintain a regular system of quality assurance monitoring of outcomes and known potential adverse events. For this reason, the importance of accurate clinical records is underscored.
 - c. **Information to Patients.** Good clinical practice includes the provision of appropriate information to patients. Each CPG discussing an unusual off-label use will address the issue of information to patients. When practicable, consideration will be given to including in an appendix an appropriate information sheet for distribution to patients, whether before or after use of the product. Information to patients should address in plain language: a) that the use is not approved by the FDA; b) the reasons why a DoD health care practitioner would decide to use the product for this purpose; and c) the potential risks associated with such use.