Chlorine
September 2003

Introduction

Chlorine, an element number 17 on the periodical chart, is among the most widely distributed elements known. Although not commonly found in its free form, it is found in sodium chloride in seawater, as well as natural deposits of carnallite and sylvite which make up roughly 2% of the earth's surface materials. The elemental gas is produced by electrolysis of sodium chloride brine.

Chlorine's most important use is as bleach in the manufacture of paper and cloth. It is also used widely as a chemical reagent in the synthesis and manufacture of metallic chlorides, chlorinated solvents, pesticides, polymers, synthetic rubbers, and refrigerants. Sodium hypochlorite, which is a component of commercial bleaches, cleaning solutions, and disinfectants for drinking water, wastewater purification systems, and swimming pools, releases chlorine gas when it comes in contact with acids.

Chlorine: Overview

Chlorine in its free, elemental form is a non-combustible, yellow-green gas with a distinctive, pungent odor and strong oxidizing effects. Because it is highly reactive, it does not remain in its free form for very long, typically combining with other elements to forms salts. Its effects on the human body are related to its slight solubility in water, where it quickly forms hypochlorous acid – HClO – and hydrochloric acid – HCl. The hypochlorous acid molecule is very unstable and rapidly decomposes to form oxygen free radicals that greatly enhance chlorine's oxidizing and corrosive effects. It is this corrosive effect that causes injury when chlorine reacts with water within body fluids and the eyes, mucous membranes, and upper respiratory tract are the tissues most commonly involved.

Chlorine was among the first gases used in chemical warfare. Clouds of the gas could be seen drifting across the battlefields of World War I in attempts to drive enemy soldiers from the protection of their trenches and bunkers. Being heavier than air, it would settle into the trenches until weather conditions helped it dissipate or until it reacted with surrounding compounds and water.

Its use as a terrorist weapon is anticipated because of its easy availability. It is found in a wide variety of commercial and home products and the elemental gas is cheap and easy to produce.

Chlorine: Toxicity

As a gas, chlorine's main route of exposure is through inhalation, although solutions capable of releasing chlorine, such as sodium hypochlorite, can be highly corrosive to the skin and gastrointestinal tract. Upon contact with water in the body, chlorine quickly forms hydrochloric acid and the oxygen free radicals, as previously mentioned. The corrosive effects of these agents combine to cause tissue damage, damage that can be severe in response to high doses. In addition, hypochlorous acid itself can penetrate cells and react with cytoplasmic proteins to form N-chloro derivatives that can destroy cell structure.

An exposure to levels of 1 to 2 parts per million can generally be tolerated for a prolonged period, although OSHA has set a limit of 1 part per million for chronic exposure situations, that is, 8 hours a day for 5 days a week. At 3 to 6 parts per million, the eyes and nasopharynx will become irritated, while concentrations above 15 parts per million can produce significant injury. It has been calculated that the lowest lethal concentration for a 30-minute exposure is 430 parts per million, while an exposure to 1000 parts per million can be fatal within minutes.

It should also be mentioned that children may be more vulnerable to the effects of chlorine gas. Since chlorine settles to low-lying areas, a child's short stature places him at the point of greatest exposure. Also, inexperience limits his ability to recognize the danger and move from the area and very young children may not be able to move from the area on their own. From a physiologic perspective, children also have smaller airway diameters, a higher minute volume per kilogram of weight, and a greater lung surface area to body weight ratio – all of which increases the level of exposure and potential for injury.

Protective Equipment

There are a variety of rubber and plastic materials resistant to chlorine thus, very effective protective gear is available. Emergency personnel should wear protective clothing and masks that are appropriate to the type of exposure they expect to encounter. In areas of high chlorine gas concentrations, air-purifying or supplied-air breathing equipment should be used. It is also important that emergency vehicles carry chlorine-resistant plastic sheeting and bags to contain and isolate contaminated clothing and other materials. This prevents further spread and secondary exposure to the chemical.

Detection

Chlorine's distinctive odor and yellow-green color make it relatively easy to identify, especially for anyone who has encountered it before. In addition, there are a wide variety of commercially available monitors and gas sensors that can be used to detect chlorine's presence in an area before serious exposures can occur. Most of these sensors can detect the gas in concentrations between 0 and 20 parts per million and, obviously, the more sensitive the sensor the more useful it is in preventing injury.

Decontamination

The first rule of decontamination is to remove victims from the area of exposure and into fresh air. Following that, the victim's clothing should be removed to limit continued exposure to chlorine trapped within the fibers of the clothes. If the eyes have been exposed, they should be flushed immediately with copious amounts of lukewarm water for a minimum of 15 minutes or until the sense of irritation is gone. Likewise, exposed skin and hair should be flushed well with water for at least 5 minutes, followed by a thorough washing with soap and water and an additional rinse.

Signs and Symptoms

The diagnosis of chlorine exposure is a clinical one that is confirmed by detection of the chemical at the site of exposure. Depending upon the dose, symptoms may be immediate or delayed.

In general terms, the victim of a chlorine exposure will experience dizziness, agitation, anxiety, nausea and vomiting. If the eyes were exposed, even to low concentrations, there will be a burning discomfort, spasmodic blinking or involuntary closing of the eyelids, redness, signs of a chemical conjunctivitis, and tearing, often profuse. At high concentrations, the cornea may suffer burns. The corrosive effects of chlorine on the skin will produce burning pain, inflammation, sweating, and, at higher concentrations, burns. Healthcare providers should also be alert to frostbite injuries in victims exposed to liquefied chlorine.

Signs and Symptoms

As a gas, chlorine's major route of serious injury is by inhalation. Breathing very small amounts of chlorine for even short periods can have adverse effects on the respiratory system. At low concentrations, from 1 to 10 parts per million, there is irritation to the eyes, nasal mucosa, pharynx, and upper airways, resulting in burning pain in the eyes and nose, a sore throat, a stinging chest pain, and dry cough. At concentrations greater than 15 parts per million, there is rapid progression to pulmonary distress with airway constriction and pulmonary edema. At this level, the victim will experience tachypnea, dyspnea, a feeling of suffocation, and/or hemoptysis; and cyanosis, wheezing and rales will be evident on exam. Pulmonary injury may progress over several hours and ultimately result in lung collapse. Since there can be a delay in the presentation of symptoms, anyone complaining of shortness of breath, severe cough, or chest tightness following chlorine exposure should be hospitalized and, at a minimum, observed until he or she is symptom-free.

The cardiovascular system is secondarily affected by a chlorine exposure from the resulting hypoxia. Initially the patient will exhibit tachycardia and hypertension, but if the hypoxia is not corrected hypotension will follow and can progress into cardiovascular collapse.

Chlorine exposures can also produce a form of acid-base imbalance called hyperchloremic metabolic acidosis. This acidosis is a result of the addition of hydrochloric acid to the body and a sudden overload of chloride ions which offsets the low bicarbonate level expected in acidosis and produces a normal anion gap. This acidosis can be severe and produce all of the physiologic ramifications of such an acid-base imbalance.

Treatment

The treatment of chlorine exposure starts with decontamination and basic first aid, including advanced life support as indicated for those patients who are comatose, hypotensive, seizing, or displaying dysrhythmias. There is no specific antidote or treatment for chlorine toxicity and care is primarily supportive.

Following decontamination, the eyes should be thoroughly examined and visual acuities determined. Chemical conjunctivitis should be treated appropriately, and corneal burns require urgent ophthalmologic consultation.

If the skin shows evidence of serious chemical burns, these should be treated as you would treat a thermal burn. Full-thickness burns require the evaluation of a surgeon or tertiary burn center as indicated. For frostbite injuries, the involved area should be gradually rewarmed using a water bath at a temperature of 102 to 108 degrees Fahrenheit, or 40 to 42 degrees Celsius. This should continue until a pink to red flush returns to the skin, often within 20 to 30 minutes.

Treatment

The treatment of cardiopulmonary injury will be dependent upon the level of exposure and mild injuries may only require observation and supportive care. Victims of moderate pulmonary exposures will benefit from the administration of humidified 100% oxygen and typically may be released once their symptoms have resolved. With severe respiratory compromise, however, it is critical to secure the airway and maintain ventilation using endotracheal intubation under direct visualization or cricothyroidotomy. Because of possible damage to the nasopharynx and airways, blind nasotracheal intubation or the use of an esophageal obturator must be avoided. The damaged airways increase the victim's risk for pneumonia, and if there are mental status changes, the risk for aspiration pneumonia is great, further indicating the need for a secure airway. So, be aware of this risk and consider prophylactic antibiotic treatment in severe pulmonary injuries. The organisms most likely to produce problems are those typically found in nosocomial infections: enteric gram negative rods, streptococcus pneumoniae, Haemophillus influenza, and methicillin sensitive staphylococcus aureus, as well as anaerobes, Legionella, Acinetobacter, and pseudomonas aeruginosa. Methicillin resistant staph (MRSA) must also be considered if encountered in your hospital. Empiric treatment would follow the ATS 3 guidelines for severe pneumonia with risk factors. This includes ciprofloxacin or an aminoglycoside, plus either piperacillin, piperacillin/tazobactam, a third generation cephalosporin, aztreonam, or imipenem. Vancomycin should be considered if MRSA is suspected.

For patients in bronchospasm, the use of aerosolized bronchodilators is warranted and no additional adverse cardiac or bronchial sensitizing effects are known when using such medications in a chlorine exposure. Similarly, for stridor in children, racemic epinephrine at a dose of 0.25 to 0.75 milliliters of 2.5% solution in 2.5 milliliters of sterile water, should be considered, repeating this dose every 20 minutes as needed.

In victims, routine labs should include a CBC, basic metabolic panel, and pulse oximetry or arterial blood gases. A chest X-ray is also necessary. Should the labs reveal a hyperchloremic metabolic acidosis, as revealed by a normal anion gap in the face of metabolic acidosis, treatment with bicarbonate makes physiologic sense and should be instituted in the acidosis is severe enough.

Long Term Medical Sequelae

In most cases, pulmonary function normalizes within 2 weeks after an acute exposure and there is complete recovery. However, chemical-irritant type of asthma, called reactive airways dysfunction syndrome (RADS) may result and produce prolonged flu-like symptoms and pulmonary impairment. Chlorine has not been classified for carcinogenic effects but the association of cigarette smoking and chlorine fumes may increase the risk of cancer. There is no information on chlorine's potential to cause reproductive or developmental harm.

Environmental Sequelae

Even at low levels, chlorine is known to cause environmental harm because of its strong oxidizing effects. Most direct releases of chlorine into the environment are into the air and surface water. Once released, chlorine quickly reacts with inorganic material to form chloride salts and with organic material to form chlorinated organic chemicals. Although organisms living in the soil and water are at greatest risk, chlorine's high reactivity means that it is unlikely to move through the soil or enter the groundwater and environmental damage is somewhat limited to the immediate area of exposure.

Summary

In summary, terrorists can be expected to use chlorine because it is inexpensive and readily available commercially and by direct production. As a natural element it is highly oxidizing and reactive and upon contact with water in body tissues, it forms hypochlorous and hydrochloric acid which can directly produce serious tissue damage. In addition, hypochlorous acid decomposes into free oxygen radicals which enhance chlorine's oxidizing effects and cause additional damage. Although exposure to concentrations as low as 3 to 6 parts per million can cause irritation, its calculated minimum lethal dose over a 30 minute exposure is 430 parts per million. The signs and symptoms vary depending on the exposure level and can manifest as anything from mild eye irritation to full-blown pulmonary edema and cardiovascular collapse. In terms of therapy, decontamination and basic first aid are critically important and care is primarily supportive.