Full Recovery of Two Simultaneous Cases of Hydrogen Sulfide Toxicity

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Hydrogen sulfide (H_2S) is a toxic, malodorous gas released from a variety of natural sources, including natural gas, sulfur deposits, sulfur springs, and decaying organic substances. H_2S is responsible for many occupational toxic exposures, with 52 occupational deaths from H_2S exposure reported in the United States between 1993 and 1999.[1] Of these deaths, 21% involved a worker dying along with another coworker.[1] Of the 44 deaths caused by exposure to fumes, gases, and vapors in 2002, H_2S was the second leading cause after carbon monoxide.[2]

Persons at risk for occupational exposure to H_2S include those who work in petroleum refineries, sewage treatment plants, sewers, septic tanks, and hot water tanks. The petroleum industry statistically has the highest risk of H_2S exposure. Significant toxic exposures are usually the result of ill-equipped or poorly educated employees, with 48% of deaths (12 of 25 recorded cases) occurring in workers who were in their first year of employment.[1] We report the cases of 2 coworkers who were simultaneously exposed to high concentrations of H_2S gas. Both patients were treated with sodium nitrite and fully recovered.

CASE PRESENTATION

History of Exposure

On the day of admission, 2 recycling workers (patient 1 and patient 2) entered a catch basin of sludge in an underground enclosed sewer tank with a third coworker. About 5 minutes after entry, the men became dizzy and decided to leave the tank. While climbing out of the tank, patient 1 fainted and fell 5 ft onto patient 2, and both remained unconscious until they were rescued. The remaining coworker was able to climb out of the tank and call for help. Experts measured the air quality in the tank and found it contained 240 ppm of H_2S, 0 ppm of methane, and 18.5% oxygen. After a 15-minute extrication, the 2 patients were transferred to the local trauma center (estimated exposure time, 26 min).

Patient 1

Patient 1, a 28-year-old man, presented to the emergency department (ED) unconscious. He had a Glasgow Coma Scale score of 3, agonal respirations, and initial examination findings as follows: blood pressure, 136/75 mm Hg; heart rate, 112 bpm; respiratory rate, 14 breaths/min; temperature, 97.0°F; and arterial oxygen saturation (Sao_2), 82% on 100% nonrebreather. Physical examination demonstrated sluggish pupils and leftward deviation of the left eye. He was intubated, and his oxygen saturation rose to 91%. An initial chest radiograph demonstrated bilateral upper lobe opacities suggestive of aspiration pneumonitis or early pulmonary edema. Electrocardiogram demonstrated sinus tachycardia at 130 bpm with lateral ST depressions. Trauma work-up was negative. Sodium nitrite was administered 20 minutes after arrival, and within minutes the oxygen saturation dropped to 86% but eventually stabilized. Results of laboratory and radiographic testing are shown in **Table 1**. The patient was subsequently transferred to the intensive care unit.

The patient remained on ventilatory support until he was extubated on the morning of hospital day 3. A repeat chest radiograph demonstrated clear lung fields. The patient's mental status continued to improve and returned to baseline by the end of hospital day 3. The elevation in troponin I (peak troponin, 6.1 mg/mL) was thought to be caused by a demand

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Table 1. Initial Laboratory and Radiographic Results for the Case Patients

Laboratory Test	Patient 1	Patient 2	Normal Values
pH	7.28	6.88	7.35–7.45
P_{CO_2} (mm Hg)	42	38	35–45
P_{O_2} (mm Hg)	64	444	78–92
HCO_3 (mEq/L)	19	8	22–32
Oxygen saturation (%)	91	98	93–98
White blood cell count (per μL)	12.7×10^3	17.0×10^3	$4.4–11.0 \times 10^3$
Hemoglobin (g/dL)	17.3	16.2	11.4–15.4
Platelet count (per μL)	227×10^3	393×10^3	$150–400 \times 10^3$
Sodium (mEq/L)	138	141	135–145
Potassium (mEq/L)	2.6	2.9	3.6–5.1
Chloride (mEq/L)	102	103	98–110
Bicarbonate (mEq/L)	19	11	20–30
BUN:creatinine	13:1.3	15:1.6	
Glucose (mg/dL)	235	242	70–106
Carboxyhemoglobin (%)	0.0	0.0	0–7
Methemoglobin (g/dL)	0.7	1.1	0–1.8
Drug screen	Negative	Negative	
Cyanide level (3 h; μg/dL)	0	N/A	0–20
Peak CK (U/L)	2884	8637	20–210
Peak troponin (mg/mL)	6.1	0.64	< 0.15
CT of the head and neck	Negative	Negative	–
FAST	Negative	Negative	–

BUN = blood urea nitrogen; CK = creatine kinase; CT = computed tomography; FAST = focused abdominal sonography for trauma; N/A = not available.

ischemia, possibly from his elevated heart rate and the anoxic effects of the H_2S gas on the heart. The patient was discharged on hospital day 5 without residual complaints or neurologic deficits.

Patient 2

Patient 2, a 25-year-old man, was unconscious at the scene of exposure but became combative upon arrival in the ED. The patient had a Glasgow Coma Scale score of 10 with initial examination findings as follows: blood pressure, 134/75 mm Hg; heart rate, 143 bpm; temperature, 97.0°F; Sa_{O_2}, 89% on 100% nonrebreather. The patient was intubated because of respiratory distress and hypoxia. An initial chest radiograph was suggestive of early alveolar edema or aspiration pneumonitis. Electrocardiogram demonstrated sinus tachycardia with lateral ST depressions and peaked T waves anteriorly. Sodium nitrite was administered, and the oxygen saturation remained in the mid-90% range. Bicarbonate therapy was begun after laboratory testing showed a pH value of 6.88 (Table 1). On completion of the trauma work-up, patient 2 was transferred to the intensive care unit.

The patient's pH normalized, and the bicarbonate drip was discontinued near the end of hospital day 1. Repeat chest radiograph 6 hours later demonstrated clear lung fields. He continued to be agitated and was unable to follow commands until hospital day 3, when he was extubated. On hospital days 4 and 5, the patient complained of dizziness followed by headache, but all symptoms subsequently resolved. On hospital day 6, the patient was discharged with no residual complaints or neurologic deficits.

DISCUSSION

H_2S is a colorless gas with an odor similar to that of rotten eggs. H_2S is produced primarily through decomposition of organic material and is oxidized by photochemically generated free radicals. H_2S can be found in various natural sources, including sulfur springs, sulfur deposits, petroleum, volcanic gases, natural gas, and decaying organic material. The half-life of H_2S ranges from 12 to 37 hours, depending on the ambient temperature.

Exposure to H_2S most often occurs by inhalation but can occur with ingestion or skin contact. Exposure to H_2S is commonly measured in parts per million (ppm). One of the most dangerous features of H_2S poisoning is olfactory accommodation, also known as olfactory nerve paralysis. Workers who are exposed to more than 150 ppm H_2S can experience olfactory paralysis, potentially leading to prolonged exposure. Physiologic responses to acute exposure to H_2S correlate with ambient concentrations (**Table 2**).

Mechanism of Action and Metabolism of H_2S

H_2S inhibits mitochondrial cytochrome *c* oxidase, which paralyzes the electron transport system and prevents cellular utilization of oxygen (a mechanism similar to that of cyanide).[3] In addition, H_2S binds to hemoglobin in red blood cells, thereby interfering with oxygen transport. Together, these mechanisms lead to increased anaerobic metabolism, cytotoxic anoxia, and subsequent lactate accumulation.[4,5]

The metabolism of H_2S involves 3 pathways. The major metabolic pathway is via spontaneous oxidation of H_2S into nontoxic products, such as polysulfides, thiosulfate, and sulfate. This process consumes oxygen and occurs primarily in the liver, kidney, and lungs.

Second, H_2S can be sequentially methylated in the gastrointestinal tract to form nontoxic products. All nontoxic products resulting from spontaneous oxidation or methylation are excreted by the kidneys.[5] Finally, H_2S can react with metallic ions or disulfide-containing proteins to create toxic products.[3] Because H_2S is metabolized so quickly, it is difficult to obtain accurate readings of true exposure.[6]

Clinical Presentation

Signs and symptoms of H_2S toxicity vary according to concentration and duration of exposure (Table 2). Once H_2S enters the body, it becomes widely distributed, with the respiratory system and central nervous system being the primary targets.[3] Pulmonary manifestations range from local irritation and cough to apnea and pulmonary edema. Local irritation of the mucous membranes of the eyes and respiratory tract are early signs of H_2S exposure. In addition, many patients present with marked cyanosis. Pulmonary edema occurs in up to 20% of H_2S exposures, producing copious, frothy, bloody secretions.[3] Apnea is a particularly dangerous manifestation and can lead to seizures, cardiovascular collapse, and death.

Neurologic manifestations range from transient loss of consciousness to prolonged coma. Patients may have headache, lateralizing motor signs, seizures, somnolence, agitation, and vertigo. Sudden loss of consciousness upon exposure to toxic concentrations of H_2S is colloquially referred to as the "knockdown" phenomenon. This is often followed by an equally abrupt return to consciousness upon introduction to an open, fresh-air environment. A large case series of workers exposed to H_2S reported that 75% of patients experienced an initial loss of consciousness; however, only 13% were unconscious upon arrival at the hospital.[7] In some cases, H_2S toxicity can lead to permanent neurologic sequelae.[8]

Cardiovascular manifestations can include hypotension, tachycardia, bradycardia, ischemia, myocardial infarction, and cardiac arrest, usually from prolonged hypoxia.[3] Other manifestations include nausea, vomiting, keratoconjunctivitis, blurred vision, photophobia, blepharospasm, and lacrimation.

In lethal H_2S exposure, the cause of death is thought to be respiratory paralysis resulting from the toxic effects of sulfides on the respiratory centers of the brain. Experimental evidence has shown a selective uptake of sulfide into the brainstem during and after exposure.[9]

Management

Treatment of patients with H_2S toxicity, both prehospital and hospital, is multifaceted with an initial focus on the airway, oxygenation, and supportive care.[10]

Table 2. Olfactory and Physiologic Response to Hydrogen Sulfide Exposure

Concentration (ppm)	Effect
0.13–0.15	Lowest detectable odor
4.6	Easily detectable odor
10	Eye irritation
27	Strong unpleasant odor
50–100	Slight conjunctivitis, respiratory irritation after 1 h
100	Coughing, eye irritation, throat irritation, loss of sense of smell after 1 h, death after slow mental status decline over 48 h
150	Olfactory nerve paralysis (no odor)
200–300	Marker respiratory and conjunctival irritation after 1 h
500–700	Headache, pulmonary edema, death within 30 min
700	Rapid loss of consciousness
1000	Convulsions, coma, respiratory paralysis, death within minutes

Data from Hendrickson, RG, Chang A, Hamilton RJ. Co-worker fatalities from hydrogen sulfide. Am J Ind Med 2004;45:346–350; *and* Beauchamp RO Jr, Bus JS, Popp JA, et al. A critical review of the literature on hydrogen sulfide toxicity. Crit Rev Toxicol 1984;13:25–97.

Prehospital management. Early decontamination is an important aspect of patient care, as patients may continue to be exposed if H_2S remains on their clothing and skin. Decontamination of both the scene and the patient is also important in protecting prehospital and ED employees. As with all environmental injuries, prehospital personnel should focus on safety and utilize available personal protective devices, including self-contained breathing apparatus and clothing to avoid secondary contamination through the skin and mucous membranes. Conscious patients should first receive 100% oxygen and cervical spine precautions in the event of a related traumatic injury, and secondary decontaminants should be removed en route. For unconscious patients, early airway control with intubation is required.

Hospital management. Aggressive supportive therapy is warranted in H_2S exposures, and many of the prehospital management procedures apply in the ED as well.[11] Administration of 100% oxygen, prompt treatment of seizures with benzodiazepines or phenobarbital, and management of severe hypotension may be required. Patients may require intubation, ventilatory support, and

trauma evaluation. There are no reported cases of severe H_2S toxicity to hospital personnel, making full decontamination prior to primary survey most likely unnecessary. However, authors have noted headaches, light dizziness, and slight nausea after exposure to these patients.[11]

There is no proven treatment for H_2S exposure. Theoretical support based on pathophysiology and a few case reports suggests use of 2 agents from a cyanide antidote kit. A cyanide kit, available in most EDs, contains amyl nitrate, sodium nitrite, and sodium thiosulfate. Amyl nitrate is a pill that must be crushed and inhaled every 30 minutes; it produces sulfmethemoglobin and can be used even if intravenous access has not been obtained. Prompt administration of 3% sodium nitrite is supported by a few anecdotal reports.[12] Nitrites effectively induce methemoglobinemia and the resultant ferric heme has a greater affinity for H_2S than cytochrome-*c* oxidase, thereby freeing cytochrome-*c* oxidase and allowing aerobic metabolism to resume. The recommended dose of sodium nitrite is 0.12 to 0.33 mg/kg in children and 300 mg in adults.[13]

Sodium thiosulfate is used to treat cyanide toxicity, but not H_2S toxicity. In cyanide toxicity, both free serum cyanide and cyanomethemoglobin are detoxified by sulfur transferase. Sulfur transferase is an enzyme that converts cyanide to thiocyanate, which is renally eliminated. Sulfur transferase regenerates methemoglobin, which can subsequently detoxify additional cyanide. The rate of action of sulfur transferase is improved with the availability of a sulfur donor, and therefore sodium thiosulfate is used. However, because H_2S is not detoxified by sodium transferase, use of thiosulfate in H_2S toxicity is unnecessary.

Anecdotal evidence has also suggested that hyperbaric oxygenation (HBO) therapy may be beneficial, but its use is controversial.[14–16] In most cases, HBO is unnecessary because of the rapid clearance of H_2S, the rarity of severe intoxications, and the success of supportive therapy with intubation, oxygenation, and use of amyl nitrate and sodium nitrite. However, in cases in which initial therapy is unsuccessful, HBO should be considered.

CONCLUSION

We believe this is the first reported case of 2 simultaneously critically ill patients with H_2S exposures who were intubated and treated with sodium nitrite and who experienced full recovery without neurologic complications. A working knowledge of potential local environmental hazards and adequate prehospital notification play a large role in successful care of patients with environmental exposures. Further research is required to examine the role that the cyanide kit plays in successful management in these cases. **HP**

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