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Utilization of Hyperbaric Oxygen Therapy and Induced Hypothermia After Hydrogen Sulfide Exposure

Mir J. Asif, DO and **Matthew C. Exline, MD**
The Ohio State University, Division of Allergy, Critical Care, Pulmonary, and Sleep Medicine, 201 Davis Heart and Lung Research Institute, 473 West 12th Ave, Columbus, OH 43210

Abstract

Hydrogen sulfide is a toxic gas produced as a byproduct of organic waste and many industrial processes. Hydrogen sulfide exposure symptoms may vary from mild (dizziness, headaches, nausea) to severe lactic acidosis via its inhibition of oxidative phosphorylation, leading to cardiac arrhythmias and death. Treatment is generally supportive. We report the case of a patient presenting with cardiac arrest secondary to hydrogen sulfide exposure treated with both hyperbaric oxygen therapy and therapeutic hypothermia with great improvement in neurologic function.

Keywords

Hydrogen Sulfide; Hyperbaric Oxygen; Therapeutic Hypothermia

Introduction

Hydrogen sulfide (H_2S) is a colorless, highly flammable, and toxic gas which is ubiquitous to the environment. Also known as dihydrogen sulfide, sulfur hydride, or hydro-sulfuric acid, the compound is usually recognized by its distinctive “rotten egg” smell. It is produced as a natural by-product of decaying organic matter by anaerobic bacteria and can also be found in geologic formations including volcanic vents and natural gas wells[1]. Exposure to H_2S predominantly occurs through an inhalation route which may lead to illness and symptoms ranging from nausea and vomiting to end organ ischemia including cardiac arrest.

In 2007, there were an estimated 1134 documented exposures with a resultant 13 fatalities in the United States[2]. The mainstay of treatment for H_2S exposure is supportive care with some institutions reporting utilization of hyperbaric oxygen (HBO_2) therapy with success[3]. We describe a case of a 24 year-old man presenting with cardiac arrest secondary to hydrogen sulfide exposure treated with both hyperbaric therapy as well as induced hypothermia which has not previously been reported.

Case

A 24 year-old male oil well worker without significant medical history presented to the ICU after being found down at approximately 9am after an explosion at his job site. Following the explosion, our patient went to render aid to a collapsed coworker that was closer to the blast. During his efforts, our patient was overcome by the fumes and also collapsed. Fellow

Correspondance should be directed to Matthew Exline. phone (614)247-7707, fax (614)293-4799, matthew.exline@osumc.edu.

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workers on the site were unable to rescue either man until EMS arrived on the scene approximately 20 minutes later to retrieve the victims. Upon retrieval by EMS, our patient was unresponsive and in cardiac arrest. Prompt CPR was initiated and cardioversion was needed for an undocumented “unstable rhythm”. With intubation and resuscitation, EMS crews were able to obtain a spontaneous rhythm and he was taken to the local emergency department for further medical care. Upon initial evaluation in the ED the patient was noted to be unresponsive on mechanical ventilation. He also had a strong odor of rotten eggs consistent with hydrogen sulfide exposure. The remainder of his initial examination was otherwise unremarkable except for his poor neurologic status. Initial lab work was notable for an ABG showing a pH of 7.25 pCO_2 of 40 mmHg, pO_2 of 332 mmHg, and bicarbonate of 14 mmol/L, demonstrating an acute uncompensated metabolic acidosis. His troponin was elevated at 0.27 ng/ml indicating demand ischemia and an ECG showed sinus tachycardia. The remainder of his basic metabolic panel and a complete blood count were within normal limits.

After initial stabilization and decontamination, he was transported to our medical center for further care arriving nine hours after his initial exposure. On arrival, he was hemodynamically stable off vasopressor support on ventilator settings of VC-CMV, rate 8, tidal volume 550 ml (6 ml/kg IBW), PEEP of 16 cm H_20, and 100% FiO_2. Based on his pO_2 his PEEP setting was weaned rapidly to 8 cm H_20 prior to hyperbaric therapy. Repeat labs showed improvement in the metabolic acidosis with an ABG showing pH of 7.43 and bicarbonate of 22 mmol/L. Lactate was 1.2 mmol/L and troponin had increased to 1.1 ng/ml. Thiosulfate levels were not checked and based on the delay in his arrival to our center, he was not considered a candidate for sodium or amyl nitrite therapy. His chest x-ray was remarkable for low lung volumes, but otherwise clear. A subsequent CT of the head without contrast was negative for an acute bleed and there was no evidence of increased intracranial pressure.

After further assessment, the decision was made to treat the patient with hyperbaric oxygen (HBO_2) to help assist with his inhalation injury. This was initiated within one hour of arrival at our facility, ten-hours after initial injury. The patient required initiation of a propofol drip and vecuronium to maintain ventilator synchrony while being placed in a monoplace hyperbaric chamber at 3 atmospheres of oxygen for one hour followed by 2.5 atmospheres of oxygen for an additional hour. Overall, the patient tolerated 2-hours of HBO_2 therapy well without any hemodynamic compromise. Due to his cardiac arrest, he was considered a good candidate for the induced hypothermia protocol and this was initiated on arrival to the ICU, approximately 14-hours after his initial injury with a goal temperature range of 32–34 deg C for 24-hours. Associated with his hyperbaric therapy, he did have sinus bradycardia with a heart rate between 40 and 60 beats per minute. He also experienced a brief episode of hypotension for which he was administered norepinephrine and a fluid bolus with improvement in blood pressure.

Following 24-hours of therapeutic hypothermia the patient was rewarmed per protocol. His neurological exam demonstrated improvement. He was able to follow commands and was successfully extubated on hospital day #3, 50-hours following initial injury. He was discharged on hospital day #5 in stable condition with a residual complaint of short term memory loss. However, shortly after discharge the patient began to experience dysarthria, tunnel vision, and right arm numbness. He was admitted to the physical medicine and rehabilitation service for further care. His visual and motor functions were found to be intact, but he did have some residual cognitive deficits including poor working memory and a mild expressive aphasia requiring outpatient therapy. During subsequent visits the patient complained of chronic headaches, but slow improvement in his cognitive function. He was subsequently lost to follow-up at our facility approximately 6-months after his discharge.

Discussion

This case represented an uncommon situation where hydrogen sulfide poisoning required the use of both hyperbaric oxygen therapy and induced hypothermia protocol for cardiac arrest. Our patient is one of few in the literature that we are aware of who has received this therapy and survived such an insult. Most applications utilizing both these interventions have been reported in the neurology literature in severe head injury cases[4].

For decades, hydrogen sulfide (H_2S) exposure has been a concern in occupational and environmental settings such as mining, sewage processing, liquid manure processing, crude petroleum drilling, leather tanning, rubber vulcanization, and asphalt roofing. Exposures often involves multiple victims as coworkers are exposed while attempting rescue of the initial victims, as in our patient's case, and often these are inexperienced workers in their first year of employment[5]. Inhalation is the predominate route of exposure although toxicity has also been seen with skin and eye contact[6]. Acute inhalation leads to rapid absorption through the alveolar-capillary membrane and clinically mimics carbon monoxide poisoning but with greater potency[7]. At the molecular level, H_2S competitively inhibits the cytochrome oxidase aa3 system, thereby disrupting oxidative phosphorylation and aerobic metabolism[8]. Patients will exhibit signs of ischemia with accumulation of lactic acid leading to metabolic acidosis. Organs most affected include the lung, brain, and heart. Acute exposures to high concentrations can lead to bronchiolitis and reactive airway disease, eventually progressing to pulmonary edema and acute respiratory distress syndrome (ARDS)[6]. Neurological symptoms may range from mild symptoms such as dizziness, headaches, and slight confusion to more serious insults such as seizures, cerebral edema, and anoxia[8]. Cardiac involvement most commonly seen includes arrhythmia and cardiac arrest from ischemia.

H_2S poisoning is suspected by history and clinical symptoms and confirmed by lab findings. Witnesses may give a history of gas exposure and patients will often have the distinctive smell of rotten eggs and classically their silver coins turn black from the creation of metallic sulfides on the surface of the coins[6]. Clinical signs of exposure include headaches, confusion, agitation, lethargy, and hypoxia. Initial labs usually indicate an acute uncompensated metabolic acidosis on chemistry panel and ABG. Further testing may indicate both an elevated lactate level and an abnormally high oxygen tension on venous blood gases due to the uncoupling of oxidative phosphorylation and decreased uptake of oxygen by the peripheral tissue. Thiosulfate levels, a metabolite from oxidation of H_2S can be checked in the urine in nonfatal cases and in serum for fatal cases[9].

Treatment efforts have been directed at supportive measures to maintain adequate oxygenation and perfusion of end organs. Along with oxygen, sodium and amyl nitrite have also been shown to help in treating H_2S poisoning. Nitrite administration results in formation of methemoglobin which has a higher affinity for H_2S than the cytochrome oxidase aa3 system. This creates competitive inhibition of the sulfide-cytochrome interaction and allows for continued aerobic metabolism. Subsequently, the hydrogen sulfide molecule becomes unbound and oxidized to less harmful metabolites[10]. Literature has shown that nitrite administration should ideally be within the first 5–10 minutes of exposure at a dose of 0.33 ml/kg of 3% sodium nitrite for maximum effectiveness.

Another treatment modality which has been suggested by a handful of case reports for hydrogen sulfide poisoning is hyperbaric oxygen therapy (HBO_2). Currently, the Undersea and Hyperbaric Medical Society (UHMS) recommends HBO_2 therapy for 14 conditions including carbon monoxide poisoning, gas gangrene, severe osteomyelitis, and most recently acute retinal arterial occlusion[11]. The Food and Drug Administration concurs with these

indications with the exception of retinal arterial occlusion which has not been approved by the FDA at this time.

HBO_2 therapy involves placing patients in either a closed monoplace (a single patient often in a recumbent position) or multiplace (multiple patients) chamber while administering 100% pure oxygen up to 3 atmospheres. The dive pressure, duration, and number of repeated dives vary depending on indication. In the case of hydrogen sulfide toxicity, there is no recommended specific treatment protocol, most case reports cite using a similar dive pressure and duration as is used to treat carbon monoxide poisoning[12].

This intervention increases oxygen availability to the peripheral tissue. In individuals with normal lung function,, the majority of oxygen in the blood is transported bound to hemoglobin, while dissolved oxygen only accounts for a fraction of the total oxygen carrying capacity at 0.3 mls per 100 ml of blood. However, administering 100% oxygen at 2.5 atmospheres increases dissolved oxygen content up to 5.5 ml per 100 ml of blood which can meet the resting oxygen requirements of peripheral tissue[13]. Hyperbaric therapy may be used even in patients with normal arterial oxygen tension but suspected peripheral ischemia, as its use helps reduce lactate accumulation and replenishes post-ischemic ATP production[14]. In patients with abnormal lung function as measured by the alveolar to arterial (a/A) oxygen ratio, their tissue oxygenation during HBO_2 therapy will improve, but often to a lesser extent than in those patients with normal lung function indicating that they may need either higher pressures or repeated treatments to achieve the benefits seen in patients with a normal pulmonary function[15].

In critically ill patients, the hemodynamic effects of HBO_2 therapy may be important. The primary hemodynamic effect of HBO_2 is usually sinus bradycardia resulting in a decreased cardiac output. This bradycardia may be either due to both increased parasympathetic tone due to increased oxygen pressure on the myocardium and decreased sympathetic cardiac stimulation[16]. It is thought this bradycardia is the main reason for overall decreased cardiac output although there may also be an increase in peripheral vascular resistance[16].

Therapeutic hypothermia has been well studied over the last two decades as a modality used to treat neurologic injury and ischemia usually in the context of cardiac arrest. Early studies demonstrated a clinical benefit in patients with severe brain injuries and further research confirmed that moderate systemic hypothermia improved neurologic outcomes in the brain[17, 18]. Two randomized control trials in Australia and Europe in 2002 showed patients who experienced out of hospital cardiac arrest had neurologic benefit when exposed to mild therapeutic hypothermia (32–34 degrees Celsius) for 24 hours post-arrest. Therapeutic hypothermia is thought to be protective due to a reduction in cerebral oxygen consumption and it is postulated a reduction in free-radical formation, intracellular acidosis, retardation of proteolytic enzymes, protection of the fluidity of lipoprotein membranes, and a reduction in excitatory neurotransmitters[19]. Patients initiated on a therapeutic hypothermia protocol must also be closely monitored for hemodynamic changes including bradycardia, hypotension, and decreased cardiac output[20]. Our patient met inclusion criteria for therapeutic hypothermia due to his witnessed out of hospital arrest, and was cooled according to AHA Guidelines[21].

There is no data on the use of therapeutic hypothermia in hydrogen sulfide toxicity or poisoning with other inhibitors of oxidative phosphorylation such as cyanide either as monotherapy or in conjunction with hyperbaric oxygen. However, there is biologic plausibility that it would be beneficial. Hyperbaric oxygen therapy increases tissue oxygen delivery and drives off H_2S while induced hypothermia decreases cellular oxygen requirements decreasing ATP-demand and slowing deenergization of the cell. Induced-

hypothermia also may reduce the production of toxic oxygen radicals during uncoupled respiration in the mitochondria which has been shown to be responsible for some of the toxicity of hydrogen sulfide[22].

It is important to note that any conclusions based on a single case report would be premature. Though our patient suffered a prolonged period being down in the field prior to restoration of spontaneous circulation, based on his age and previous level of health, he may have sustained the same level of neurologic recovery without either HBO_2 or hypothermic therapy. The use of HBO_2 and hypothermic therapy both may require additional sedation for patient comfort which may be deleterious in a patient with otherwise impaired cognition and lead to increased time on the ventilator. Care should be taken prior to initiating these therapies on patients that do not meet established criteria[11, 21].

Conclusion

There are few case reports of the combination of therapeutic hypothermia and hyperbaric oxygen therapy in general and no reports of the use of combined therapy for hydrogen sulfide toxicity specifically. We report a case of a young man exposed to toxic levels of hydrogen sulfide gas and subsequent cardiac arrest treated with both hyperbaric oxygen therapy and induced hypothermic protocol and discharged home with an improved neurologic outcome.

Acknowledgments

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