Deaths From Environmental Hypoxia and Raised Carbon Dioxide

Christopher M. Milroy

ABSTRACT

This paper reviews deaths in which there is an environment that is low in oxygen and/or has elevated levels of carbon dioxide. These deaths present problems to autopsy pathologists, as the autopsy is typically negative and postmortem toxicology cannot be used to detect the effects of hypoxia and raised levels of carbon dioxide. Deaths from hypoxia and raised carbon dioxide may be encountered in work- and nonwork-related environments. Typically these are accidents, but suicides may be encountered and criminal charges may follow these events. Environments that have been associated with these events include mines, tunnels, sewers, and pits. Transportation incidents may also be associated with hypoxic events, particularly aircraft and submarines. When an atmosphere low in oxygen is entered, collapse can be rapid, or immediate if the environmental oxygen is below 6%. Environments rich in carbon dioxide can also cause death, even with a high oxygen concentration. Such environments may be encountered in industrial settings, but also occur in natural disasters such as the Lake Nyos disaster. The identification of these deaths typically requires a coordinated investigation with safety inspectors and other experts in industrial- and work-related deaths. *Acad Forensic Pathol.* 2018 8(1): 2-7

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INTRODUCTION

Deaths associated with a depleted atmosphere are not uncommon and are encountered in such scenarios as plastic bag asphyxia with accompanying inhalation of helium (1). However, a more difficult investigation can involve deaths associated with environmental hypoxia, and all forensic pathologists are likely to encounter such deaths in their careers. This may be in a work or nonwork-related incident (2). The environment may have a low oxygen content or the oxygen content may have been replaced by another irrespirable gas.

Gases can be divided into irritant gases, asphyxiant gases, and drug-like gases and vapors (3). Irritant gases are substances that as a rule are corrosive. They irritate mucosal surfaces and cause inflammation in the airways. They can be divided into primary irritants, which have little or no systemic toxic effects, and secondary irritants, which do. Asphyxiant gases interfere with the supply and utilization of oxygen by the body. Simple asphyxiant gases, such as helium and hydrogen, simply replace oxygen, whereas chemical asphyxiants, like hydrogen cyanide, prevent cellular respiration. Drug-like gases and vapors include anesthetic gases, hydrocarbons, and solvents that have pharmacological-like actions after absorption. Gases may also be flammable or nonflammable.

This paper concentrates on environmental deaths associated with low oxygen, raised carbon dioxide that may accompany lowering of oxygen level, as well as asphyxiants that displace oxygen, rather than chemical asphyxiants and drug-like gases and vapors.

DISCUSSION

The Normal Atmosphere

Air is normally composed of approximately 78% nitrogen, 21% oxygen, 1% argon, 0.035% carbon dioxide, and small amounts of other gases including hydrogen, methane, ozone, carbon monoxide, and water (4).

Barometric pressure falls with increased altitude in a logarithmic fashion, so the partial pressure of oxygen also decreases. At 5800 m, barometric pressure is around half that at sea level. At the summit of Mount Everest, barometric pressure is only 28% of barometric pressure at sea level. While the percentage of oxygen in the air does not change with altitude, the barometric pressure does, making the effective oxygen in the atmosphere decrease. At sea level, therefore, the effective percentage of oxygen is 21%; at 1500 m, 17.3%; at 3000 m, 14.4%; and at 5000 m, 11.2%. At the peak of Everest, the effective oxygen percentage is 6.9%. Permanent human habitation is seen below 5500 m and is unusual above 3000 m, though some populations do live above this altitude at effective oxygen concentrations below 14.5%. Visitors to these high altitudes are at risk of high altitude sickness (5).

Hypoxia

Hypoxia can be divided into four types (6). Hypoxic hypoxia is the result of a reduction in oxygen tension in arterial blood. This is the type seen with breathing in environments with low oxygen but can also result from hypoventilation, depression of central breathing mechanisms, and obstruction of the airway. Anemic hypoxia results from low or ineffective hemoglobin concentrations resulting from hemorrhage, abnormal hemoglobins (e.g., sickle cell disease, iron deficiency anemia, and methemoglobinemia), or otherwise. Ischemic hypoxia is the result of low blood flow, with local or systemic effects, preventing adequate delivery of oxygen to tissues (e.g., heart failure or local ischemia). Cytotoxic hypoxia occurs when normal cellular respiration is prevented, such as by cyanide poisoning.

Effects of Environments Depleted of Oxygen

The effects upon a person of an environment lower in oxygen than normally present in that environment depends on how low the oxygen tension is (7). In an environment where oxygen is between 18-21%, there are no discernible effects. Below 18%, there is an increasing inability to perform mental tasks. Some occupations involve working in lower oxygen concentrations to reduce fire risks. Typically, these con-

centrations are 13-15%, which at sea level are equivalent to altitudes of 2700 to 3850 m. People at these concentrations may have some cognitive impairment, taking slightly longer to perform tasks, but these concentrations do not seem to affect health on an acute or long-term basis, though they may develop mild acute mountain sickness (8). Between 8-11%, there is a risk of fainting in minutes, between 6-8% oxygen this occurs rapidly, and below 6% collapse will be immediate (7). The effects are summarized in **Table 1**.

Confined Spaces and Environments Low in Oxygen with Increased Carbon Dioxide

Confined Spaces and Mixed Gases

Confined spaces are well recognized to be associated with low environmental oxygen and/or the build-up of toxic gases. Such places include mines, sewers, pits, trenches, tanks, deep holes, industrial rooms, and vehicles including submarines and aircraft. People rapidly exposed to these environments may die unexpectedly and investigation requires an assessment of the environmental gases as well as the autopsy (3, 9-16).

Mines have been associated with a number of gases that are hazardous to health. One such example, known as black damp, was a mixture of nitrogen and carbon dioxide, the latter gas typically forming 12-15% of the environment produced by the consumption of oxygen by oxidative processes, such as combining with coal, iron, or timber (3). Fire damp, the explosive gas methane, is present in coal seams under pressure. Sudden death may occur in silos. Deaths due to this phenomenon have been recognized for over a century, and its now known the gas involved is nitrogen dioxide (17-19).

Environments High in Carbon Dioxide

Atmospheres that are high in carbon dioxide can cause sudden death. This may be seen in combination with low oxygen. Such scenarios include closed atmospheres where oxygen is used up and carbon dioxide builds up. This has been seen in cars with catalytic converters that remove carbon monoxide, wine vat rooms with dry ice, rooms with carbon dioxide fire extinguisher mechanisms, and in some natural disasters such as volcano lake eruptions, where large amounts of carbon dioxide can be released and have resulted in multiple fatalities (20-26). In the Lake Nyos incident in Cameroon in 1986, over 1700 people were killed and there were another 5000 survivors from what was believed to be the massive release of carbon dioxide from the lake (27). A similar incident took place in Lake Monoun, a nearby lake, in 1984, killing 37 people, and an incident in Indonesia in 1979 killed 137 (28). An industrial accident in an ice cream factory in Israel, when there was release of liquid carbon dioxide, resulted in the almost immediate incapacitation of 25 workers, though none died in this incident (29). Carbon dioxide concentrations above 10% have been considered lethal. In one experiment, dogs administered 80% oxygen and 20% carbon dioxide died, indicating that carbon dioxide is toxic (30).

The Autopsy

In deaths where there has been an environment depleted in oxygen and/or with a high carbon dioxide, the autopsy will typically be negative for the cause of death. The classic "signs" of asphyxia are so nonspecific as to be meaningless. There may be underlying, preexisting disease that may contribute to death, such as atheroscle-

Table 1: Effects of Oxygen Concentration

Concentration of Oxygen	Effect
18-21%	No discernible symptoms
11-18%	Reduction in physical and mental performance without appreciation
8-11%	Possible fainting in minutes with risk of death below 11%
6-8%	Fainting occurs after a short time
0-6%	Fainting occurs almost immediately

rotic and hypertensive heart disease, but determination of death will rely on the history and scene examination. Toxicological examination should be performed, although the primary issues of lack of oxygen and carbon dioxide build up cannot be measured. Argon and helium can be measured, but the methodology for their identification lie outside routine postmortem toxicology.

Case Study

A seaman on a rig support ship entered the anchor room of the ship to secure a rattling anchor. He immediately collapsed. A colleague saw him collapse, radioed the bridge, entered the room, and then he immediately collapsed as well. Another seaman tried to enter the room wearing a breathing apparatus, but he could not get in so he donned an Emergency Escape Breathing Device then entered the room. It appears this piece of equipment became detached or was removed and he also collapsed. None of the three seamen could be resuscitated. Autopsies were performed in all three cases and were essentially negative. Images of the scene are available in the UK Marine Accident Investigation Branch (7).

The ship had been at sea for 28 days and the ship's anchor room had not been entered. The three bodies were then recovered by crew using breathing apparatus.

At port, the Health and Safety Executive Inspectors took air measurements and found the following, summarized (7) in **Table 2**:

The reduced concentration of oxygen was consistent with that obtained by a direct reading instrument on-site.

The slightly increased levels of carbon dioxide was felt to be due to microbial action on organic materials in the chain locker. However, the concentrations were within acceptable limits.

The analysis of the samples also indicated very low concentrations of volatile organic compounds, which were within acceptable limits.

The report stated:

There were no significant amounts of toxic gases in the chain locker, and the internal steel surfaces (including the anchor chains) were heavily rusted.

The increased concentration of argon (compared to the air reference value of 0.97%) indicated depletion of oxygen, rather than another gas displacing or diluting air within the chain locker.

Iron and steel when exposed to moist air will react with oxygen in the air to form iron oxide, that is rusting. Rusting requires both oxygen and water and is accelerated in the presence of salt. The corrosion of the steel within the chain locker caused the oxygen to be consumed in the process of rust formation, and this resulted in an oxygen deficient atmosphere.

The atmospheric measurements reported were taken 3 days after the accident. In the interim, the space had been opened, and rescuers wearing Breathing Apparatus had been working in the space. As a consequence, the air quality measurements taken were not representative of the atmosphere in the chain locker at the time of the accident.

The chain locker was tightly sealed with, effectively, no natural ventilation being present prior

Table 2: Atmosphere Measurements From Samples Taken

Gas	Concentration
Oxygen	15-19%
Nitrogen	78-82%
Argon	1-1.1%
Carbon dioxide (CO ₂)	0.07-0.14 parts per million
Carbon monoxide (CO)	0-4 parts per million
Hydrogen sulfide (H ₂ S)	0 parts per million

to the entry by the three crewmen. It is difficult to estimate the concentration of oxygen at the time of the accident, but based on the speed of effect and available data from other incidents it is likely that oxygen concentrations in the chain locker at the time of the accident were below 10%.

In the opinion of the specialist Health and Safety inspector, the depleted oxygen concentration in the chain locker was the primary reason for the collapse and subsequent death of the three crewmen (7).

Further expert analysis concluded that corrosion within the sealed chain locker (since the locker had last been certified gas-free) could have led to a loss of oxygen resulting in an atmosphere that was unable to support human life; levels as low as 4.4 % (by volume) were estimated to have been possible.

The extracts are taken from an investigation by the UK Marine Accident Investigation Branch (7). The autopsies were conducted by the author.

The Captain of the ship was prosecuted under section 58 of the UK Merchant Shipping Act 1995, the section dealing with conduct endangering ships, structures, or persons. He was acquitted (31).

CONCLUSION

This paper has briefly described some scenarios in which people can die suddenly in environments with abnormal composition. These cases require detailed analysis of the scene and, particularly, an analysis of environmental gases when in industrial or workplace settings. There may be a prosecution related to health and safety/labor safety laws or even under the criminal law. While typically accidents, deaths from suicides may be encountered. The possibility of criminal charges may result from these deaths.

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