Altitude And Oxygenation

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Citation

G Nehrenz. *Altitude And Oxygenation*. The Internet Journal of Aeromedical Transportation. 1999 Volume 1 Number 1.

Abstract

INTRODUCTION

In the aeromedical transport of the critically ill or injured patient, it is important to understand the effects of the changing environment on the patient, as well as on equipment function. The environment of the aircraft cabin predisposes the crew and patient to varying oxygen, pressure, heat, vibration and humidity levels which increases the effective workload on all members aboard.[1,2] Preparation for these changes in terms of patient readiness, and crew familiarity may reduce or at least minimize the effects of flight.

At altitude, it is vitally important to monitor oxygenation as cabin altitude changes. The goals of oxygen therapy are:

1. to increase the alveolar concentration of oxygen
2. to decrease the demand on the pulmonary system
3. to decrease myocardial work

The gas laws impact our understanding of the methods of gas exchange between the atmosphere and the human body, as well as the potential problems which may occur due to altitude change. Applying this understanding and knowledge to the field of airborne patient care enhances the outcome for the patient.

SELECTED GAS LAWS

BOYLES LAW

Boyle's law states that, "at a constant temperature, the volume of a given gas is inversely proportional to the pressure of which it is subjected too." To simplify this statement, Boyle's Law is the law of Constant Temperature / Gas Expansion.

As altitude increases, the gas inside a closed space is subject to expansion. This expansion may be as great as 20% at an altitude of 8,000 feet when temperature remains constant, such as in the human body. This is an important factor of consideration in dealing with bodily injuries or diseases such as pneumothorax or bowel obstruction. For instance, bowel gas in the area of the uterus may hasten the delivery process as the body attempts to relieve the surrounding pressure created by gas expansion.

Boyle's law also explains the mechanism by which air is exchanged between the atmosphere and the lungs. If the container a gas occupies is doubled, the pressure within the container will be halved. The lungs work under this principle. As the chest expands due to the movement of the thoracic cage and diaphragm, the container (chest) increases in size. This action decreases the pressure within the chest cavity to that of sub-atmospheric, causing ambient air to rush in until the pressure is equal to atmospheric.

Gas expansion can effect equipment designed to hold gas. For instance, anti-shock trousers or MAST suits contain gas and are used to apply pressure to the lower extremities [3]. As altitude increases, the gas inside the suit will expand causing the pressure exerted on the patient to rise. This increase must be monitored in order to assure patient safety.

DALTONS LAW

Dalton's law is the law of partial pressure. This law states that, "the total pressure of a gaseous mixture is equal to the sum of the partial pressures of its constituent gases." Expressed mathematically Dalton's law states that for a mixture containing "n" gases;

For example, the partial pressure of oxygen at sea level is,

As a further example of Dalton's law, the partial pressures of the more concentrated gases are listed in table 1.1.

Table 1.1: Partial pressures of gases in the atmosphere

To gain further understanding of Dalton's law a simple example is used. If a container has 4 molecules of nitrogen, each striking the sides of the container 1 time, we would have a pressure of 4. If we then added two molecules of oxygen, each striking the container 1 time, we could say that we have a pressure of 2. If combined the contents of the 2 containers will have a pressure of 6. Both gases are exerting their own partial pressures, but combined, they make up the total pressure of 6.

This same principle applies to atmospheric composition. As seen in Table 1.1, each gas exerts its own partial pressure, and when combined, they make up the total barometric or atmospheric pressure. It is important to consider oxygen in terms of partial pressure versus percentage.

HENRYS LAW

Henry's Law states that, "the weight of a gas dissolved in a liquid is directly proportional to the weight of the gas above the liquid." The amount of gas that will dissolve into a liquid is dependent upon the partial pressure of the gas as well as the solubility.

Henry's law brings with it the understanding of gas transfer between the alveoli and the blood. Gases move from an area of higher concentration, to that of a lower concentration.

Decompression sickness is a direct result of the principles described in Henry's law in that as the partial pressure of the gas surrounding the body decreases, less gas will be held in the various body fluids.

A bottle of carbonated soda is a good example of this principle. With the cap on the bottle, the gas above and within the liquid are in a state of equilibrium. Equilibrium means that as many molecules are entering the liquid as are exiting the liquid; a 1:1 relationship.

When the cap is removed, gas pressure above the liquid decreases allowing gas within the liquid to be released in an effort to equalize the pressure above the liquid, which causes the formation of bubbles. This action also occurs in the human body during rapid decompression, as seen in divers that return to the surface of the water at to rapid a rate (the bends).

GRAHAMS LAW

Graham's law states that, "the rate of diffusion of a gas through a liquid medium, is directly proportional to the solubility of the gas, and inversely proportional to the square root of its density or its gram molecular weight."

An example of this law is that carbon dioxide is nineteen times more diffusible than oxygen due to its solubility factor. Because carbon dioxide has a higher gram molecular weight (table 1.2), if solubility were removed as a factor, oxygen would be slightly more diffusible.

Table 1.2

ATMOSPHERIC COMPOSITION

Atmospheric composition remains constant throughout the atmosphere of concern in aviation medicine. Oxygen is 20.95% of the atmosphere and Nitrogen is the major constituent at 78% (Table 1.3) up to approximately 60 miles above the Earth's surface.[4]

The pressure exerted by each gas is the point of focus.

Table 1.3; Dry atmospheric composition

Knowledge of the available oxygen pressure available at altitude is important for the proper treatment of the critically ill or injured patient in flight. Computation of the oxygen partial pressure is easily accomplished as seen in table 1.4.

Table 1.4: PO2 equals 20.95% of atmospheric pressure

Changes in barometric pressure are charted as means and not absolutes. Table 1.5 is the national standard for barometric pressure at altitude.

Table 1.5: The earth's atmosphere

ICAO 1964 ADAPTED

AVIATION MEDICINE #1 pg. 10. [5]

Table 1.7: Barometric pressure conversion millimeters of mercury to inches of mercury

Standard Atmosphere, F.A.A. 1980

MANAGEMENT OF OXYGENATION

As altitude within the cabin of the aircraft increases, the oxygen tension of the patient gas will decrease. Table 1.8 is an example of this action.

Table 1.8

Because the patient in table 1.8 required 334.4 mmHg, an oxygenation deficit would occur at 10,000 feet.

OXYGEN ADJUSTMENT EQUATION

In order to adjust the oxygen percentage delivered (FIO2) to the patient to combat changes in cabin altitude, oxygen delivery must be considered in terms of mmHg delivered instead of percentage of inspired air. This is accomplished by using the equation in Table 1.9.

Table 1.9

For example, a patient is transported from sea level (760 mmHg) to an altitude of 3000 feet (681 mmHg). The patient is on a mechanical ventilator at 30% upon arrival at the referring facility. The following would be used to determine the amount of oxygen required at 3000 feet to deliver the same mmHg of oxygen at altitude.

$(.30 \times 760) / 681 = .33$ or 33%

HYPOXIA

Hypoxia is defined as an inadequate supply of oxygen for proper cell function. Hypoxemia is a deficiency of oxygen content in the blood. The four categories of hypoxia are as follows:

HYPOXIC HYPOXIA

This form of hypoxia is cause by reduced oxygen in the atmosphere or an inadequate gas exchange in the lungs.

ANEMIC HYPOXIA

This disorder is caused by a reduction in the oxygen-carrying capacity of the blood, such as with sickle cell anemia and carbon monoxide poisoning.

STAGNANT HYPOXIA

This form of hypoxia occurs when cardiac output does not meet the demands of the body. This results in shock, venous pooling and possible cardiac arrest.

HISTOTOXIC HYPOXIA

This is prevalent in patients with problems such as cyanide poisoning. The body is unable to utilize the available oxygen.

RESPIRATORY COMPROMISE DUE TO HYPOXIA

A balance tends to be struck at altitude. As altitude increases, the available oxygen decreases causing stimulation of the aortic and carotid bodies, causing an increase in pulmonary ventilation. At the same time, the increase in ventilation causes a decrease in arterial carbon dioxide, suppressing respiration.

All forms of hypoxia carry the same dangers at altitude. Hypoxic hypoxia can be corrected by reducing the cabin altitude to bring the patient within the limits of their cardiopulmonary system or by delivering supplemental oxygen. All other forms of hypoxia occur with or without increases in altitude and will be exacerbated by increases in altitude and the reduction of available oxygen. Providing supplemental oxygen will improve the PAO2 but the underlying cause must be assessed and corrected.

ALTITUDE RELATED PROBLEMS

PHARMACOLOGIC CLEARANCE

It has been found that the clearance of caffeine occurs more rapidly with hypobaric hypoxia. From this study, it was assumed that an alteration in clearance of other medications may occur and changes in the actions of other medications may be unpredictable.[6]

HYPOXIA, HORMONE AND ELECTROLYTE CHANGES

De Angelis, et al, (1996) studied the behavior of hormones in acute hypoxia. The results showed an early increase of plasma renin activity (PRA) paradoxically associated with a decrease of aldosterone plasma levels. The later returned to the baseline values at 180 minutes, whereas PRA remained increased throughout the exposure.

Both arginine-vasopressin (ADH) and the atrial natriuretic peptide (ANP) significantly increased, while a new putative hormone, the so-called digoxin-like substance (DLS) did not show significant changes. There conclusion was that the data demonstrated a specific sensitivity of the hormonal systems to hypoxia, which may be influences by the time of exposure.[7]

HIGH ALTITUDE PULMONARY EDEMA

High Altitude Pulmonary Edema (H.A.P.E.), is a form of acute mountain sickness seen in some individuals exposed to altitudes unfamiliar to the body, typically above 2700 m.[8] In many cases, this is brought about by exertion at this unfamiliar altitude. H.A.P.E. can occur in any age group, sex, or race. The clinical presentation may mimic pulmonary edema, pneumonia, or myocardial infarction. The specific symptoms may include:

- Tachycardia
- Headache
- Palpitations
- Weakness

- Sleep difficulties
- Drowsiness
- Dull back pain
- Anorexia
- Warm/flushed for 24 hours
- Nausea / vomiting (common in children)

These patients tend to improve as lower altitudes are reached and ambient oxygen increases.

SUMMARY

It is vitally important to understand the changing conditions for the patient. It is necessary to preflight the patient to assure that they are capable of safe flight and can adapt to the changing atmospheric conditions with or without assistance. In many cases it is much safer for the patient to remain in a medical facility, if possible, until somewhat stabilized instead of using the scoop-and-run technique. If possible, check the patients blood gases, tidal volume and their reserves prior to flight. Be aware of the cabin altitude and make oxygenation and medication adjustments to match the surroundings.

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