Hyperbaric Heart-Lung Bypass

Dennis Mills
Minneapolis, Minnesota

Attempts have been made repeatedly during the past 100 years to apply hyperbaric phenomena to medicine, necessary facts and principles were established at this time or previously, however knowledge of technical application was insufficient and the idea was forgotten. In the light of newly discovered facts in medicine, technology and engineering, a critical and exhaustive investigation is now being carried out, having for its aim the revision of accepted conclusions, and hopefully will enable all to benefit from the concept of hyperbaric medicine.

Brief Historical Survey

In 1659, Robert Boyle first devised and used his evacuation pump studying the reaction of animals to reduced atmospheric pressure. He was the first to show that a "vital material" in the air (oxygen) was necessary for maintenance of life.

The first practical application for the use of hyperpressure was made by a Frenchman, named Triger, in 1841 when he developed the first caisson for use in underwater construction work. Surgery was first performed under mild degrees of hyperpressure by Pravas in 1843.

In 1879, Fontaine postulated the value of performing surgery in a special operating room under increased atmospheric pressure and large enough for a complete staff.

The present period of increased interest in hyperbaric phenomena was ushered in by Boerema and his colleagues in Amsterdam with their publications in 1956, 1959, and 1961. Illingworth, Smith, and Lawson, writing from experience in the treatment chamber at the Western Infirmary in Glasgow, have added great impetus to the field. Drs'. Bernhard and Tank have completed a study at Children's Hospital Medical Center in Boston on the effect of oxygen inhalation at 3.0 to 3.6 atmosphers absolute upon infants with cyanotic congenital heart disease and it is apparent from their results that the patient did benefit from the application of hyperbaric oxygen to surgery.

Basic Physical Gas Laws Underlying Hyperbaric Physiology

The classic laws of gases are important in any consideration of ambient pressures. Henry's law (1803) states that the quantity of a gas dissolved into a liquid increased directly as the pressure exerted on the liquid by a given gas. Dalton's law (1807) states that in a mixture of gases, the quantity of a specific gas dissolved by a liquid depends upon the partial pressure of that gas in equilibrium with the liquid. The law of Boyle states that when temperature is constant, the gas volume is inversely proportional to pressure exerted on the gas. It is important to remember in considering the effects of pressures on the body that gases are compressible, whereas liquids are virtually incompressible. The final basic gas law, Charles' law states that the volume of a gas is directly proportional to its absolute temperature.

Continous arterialization of blood by a stream of oxygen bubbles was devised in 1882 by Dr. Schroder. Today adequate oxygenation of blood being returned to a patient after passing through the extracorporeal unit is still one of the technicians major concerns. Exposing a blood film to an oxygen atmosphere to achieve oxyhemoglobin involves four steps.

1. Diffusion through the layer of plasma surrounding the red cells.
2. Diffusion across the red cell membrane.
3. Diffusion within the red cell.
4. The chemical combination of oxygen with hemoglobin.

One of the principles that determines the amount of oxygen to reach step four and combine with hemoglobin is the partial pressure of oxygen which the red cell is exposed to. The schematic diagram in Fig. 1 illustrates the relationship

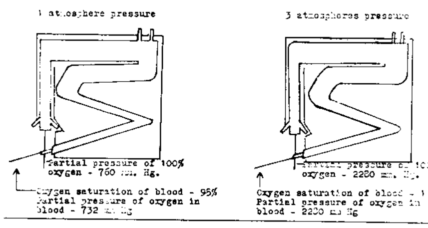

Figure 1

of the partial pressure of oxygen in a disposable bubble oxygenator in normal atmospheric conditions and under three atmospheres absolute*. Under normal atmospheric condition the red cell membrane of a patient on heart-lung bypass is exposed to 100% oxygen having an oxygen tension (PO2) of 760 mm. Hg. The hemoglobin, normally 97% saturated, becomes fully saturated, in addition more oxygen becomes physically dissolved in the other fluids of the blood. The total oxygen content of arterial blood is elevated from about 20 volumes per cent (ml of oxygen per 100 ml. of blood) to roughly 22 volumes per cent. A normal person is placed in a pressure chamber and his blood is exposed to 100% oxygen under increased ambient pressure, the oxygen tension and content of arterial blood rises. If the rise of oxygen pressure passing the blood is fully reflected, the PO2 will increase 760 mm. Hg. with each atmosphere (14.7 pounds per square inch) of increase in ambient pressure. The corresponding increase in arterial oxygen content will be roughly two volumes per cent per atomsphere. Since the hemoglobin is already fully saturated, all of this increase will be in the form of physically dissolved oxygen to a degree enabling hemoglobin to be literally removed from the circulating system and life maintained. An ambient pressure of three atmospheres absolute could thus yield an arterial

Ambient pressure* synonymous with atmosphere pressure. The result of the weight of the atmosphere producing a force on the surface of the earth.

Partial pressure* the number of molecules of a gas present in a specified volume at a given temperature.

Atmospheres absolute* includes normal atmospheric pressure (14.7 pounds per square inch) plus each additional atmoshere of pressure from an artificial force.

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PO2 of 2280 mm. Hg. and an increase of about six volumes per cent in arterial oxygen content above the normal level. It is axiomatic, however, that tissues must be perfused in order to participate in the desired "saturation" process. Thus many problems must be considered. Specific pathophysiologic mechanisms which will influence the effectiveness of hyperbaric oxygenation of tissues are: (1) abnormalities in the ventilation-perfusion ratio; (2) anemias and red cell membrane diffusion defects; (3) the status of the circulation in terms of peripheral blood pressure, degree of peripheral vasospasm, and rate of flow; (4) contact of specific tissues with the circulation blood or fluids in the vascular system.

Bubbling 100% oxygen through hypothermic blood at three atmosphere absolute for fifteen minutes (3 liters of oxygen per liter of perfusion rate) produces venous and arterial blood lines of equal bright red color. The assumption would be that the tissues are drawing oxygen from the supply being carried by the fluid make up of blood, leaving the hemoglobin 100% saturated or very close to that figure. The problem of adequate tissue oxygenation is eliminated, if physiologic arterial and venous pressures are maintained.

Bubbling oxygen through blood to achieve oxyhemgolbin produces hemolysis due to the trauma of the free air passing over the red cell. As the rate of oxygen flow is increased, more turbulence is produced, raising hemolysis proportionally. Inversely lowering the flow of oxygen, would lower the rate of hemolysis. As previously stated, the patient on heart lung bypass under increased ambient pressure, receives oxygen in excess of the body needs. Therefore, the oxygen flow rate could be lowered significantly, without sacrificing tissue oxygenation, subsequently lowering the rate of hemolysis.

There is little question that the patients state of oxygenation and red cell trauma can be improved with the aid of increased atmospheric pressure.

Due to the high concentration of oxygen in the atmosphere surronding the operating team, adequate fire precautions must be taken. By purging electrical bypass equipment with an inert gas, oxygen is eliminated from the immediate area, eliminating the possibility of fire. I must add that many other fire precautions are taken by the operating team however they are of no concern to the subject of this dissertation.

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