Dysbarism: Osmosis Caused by Dissolved Gas?

Abstract. *The pressure in an osmometer, filled with nitrous oxide–saturated water separated from water by a polyurethane polyether membrane 2.5 microns in thickness, rose slowly by 8 to 20 millimeters (of water) in 10 minutes before gradually returning to close to zero within 2 hours. The permeation coefficient of the membrane was approximately 1000 times greater for water than for gases. The osmotic pressure of water saturated with nitrous oxide at 1 atmosphere, derived from the freezing point of the gas solution, was 1.5 atmospheres. It is concluded that dissolved gases exert osmotic pressure. Partial-pressure gradients of dissolved gases in the tissues of animals and man should cause flows of water along osmotic gradients, which may partially account for some of the symptoms and signs of dysbarism.*

The signs and symptoms of decompression sickness are generally attributed to bubbles in body fluids supersaturated with gases (*1*). Maximum permissible rates of decompression are believed to be limited only by critical degrees of supersaturation with gases and of blood flow–dependent elimination of gas from the tissues. However, Heimbecker *et al.* (*2*) have reported, in hamsters and dogs after rapid decompression, capillary stasis and hemoconcentration, with a corresponding increase in extracellular volume, apparently not caused by bubbles. Obviously, dysbarism due to compression cannot be caused by bubbles, yet divers have reported bone and joint pains while under exposure to increasing ambient gas pressures; interestingly they attributed the pains to loss of lubricant, referring to this condition as "no joint juice" (*3*).

We now report experimental results clearly demonstrating that dissolved gas exerts osmotic pressure; we propose that osmosis caused by dissolved gas is a factor yet unrecognized in the pathogenesis of dysbarism.

The osmotic pressure of a solution can be determined indirectly by measurement of its freezing point: lowering of the freezing point by 1°C corresponds to an osmotic pressure of 12.06 atm. Theoretically the osmotic pressure of a gas in solution should equal the product of its partial pressure and its solubility coefficient.

We have determined the freezing point of distilled water that has been equilibrated with nitrous oxide at normal ambient pressure, and computed its osmotic pressure to be 1.5 atm. This value agrees well with the one to be expected from the solubility of nitrous oxide in water at 0°C (*4*).

The osmotic pressure of a substance in solution can be measured directly only if the solution is separated from the solvent by a membrane that is impermeable to the solute and permeable to the solvent. There appears to be no material that is impermeable to gases while being readily permeable to water, but a membrane through which water passes relatively freely and a gas in solution passes relatively slowly would suffice for demonstration of transient osmotic effects.

Osmosis in an osmometer with a "leaky" membrane causes a transient rise in pressure, followed by an eventual return to zero-pressure when the solute concentrations on both sides of the membrane become equal. The properties of a new polymer, polyurethane polyether (*5*), seemed to be suitable for our purpose, since its permeation coefficient for water is approximately 1000 times greater than for gases.

A membrane of polyurethane polyether, approximately 2.5 μ thick, was cast and applied to one end of a cylinder 2.5 cm tall by 2.5 cm in diameter; the other end was closed with a stopper through which protruded a capillary tube that served as a manometer. The membrane was supported by nylon mesh and metal gauze to prevent bulging. The cylinder was filled with distilled water equilibrated with nitrous oxide at normal atmospheric pressure, and the membrane end of the cylinder was then immersed in distilled water.

In a series of eight experiments the water level in the manometer rose slowly by 8 to 20 mm during the first 10 minutes, briefly remained stationary, and then fell gradually during the next 2 hours almost to its original level. The gas solution in the cylinder was stirred during the experiments.

The sum of the chemical potentials in any system must be zero, so that osmotic gradients must exist whenever there are partial-pressure gradients of dissolved gases. Osmosis caused by dissolved nitrous oxide in our osmometer, with its leaky membrane, simulates conditions in the tissues of gas-breathing divers in which transient gas-tension gradients follow sudden changes in ambient pressure.

When a diver is exposed to increased atmospheric pressures, the partial pressure of inert gas in his blood temporarily exceeds the partial pressure of inert gas in poorly perfused tissues. Dissolved-gas concentration gradients, producing osmotic gradients, may cause water to flow from poorly perfused tissues such as articular cartilage to well-perfused tissues such as synovial membrane. Joint pains may then result from dehydration of articular surfaces. When the diver has breathed compressed gas for some time and "slow compartments" have taken up significant amounts of inert gas, an osmotic flux of body water in the opposite direction may be expected upon his return to the surface. Such water shifts may cause hemoconcentration, capillary stasis, and impaired exchange of gases in the tissues.

Osmotic gradients caused by dissolved inert gas tend to be transient, but osmotic gradients caused by dissolved oxygen tend to persist as a result of the consumption of oxygen in the tissues. The magnitudes of osmotic water shifts and their sequelae during compression, decompression, and breathing of hyperbaric oxygen can be evaluated only in the intact organism. The observations reported by Heimbecker *et al.* (*2*) suggest that such osmotic shifts may be sizable.

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5. Mobay Chemical Co., Pittsburgh, Pa., which we thank for the material.

27 May 1968