Hyperbaric Oxygen Therapy

by John H. Dirckx, M.D.

Hyperbaric oxygen therapy (HBOT) is a form of treatment that lies outside the mainstream of American medical practice. All the same, some background information on the topic may be welcome to the medical transcriptionist.

HBOT is the administration of oxygen at higher than atmospheric concentration, in an environment of higher than atmospheric pressure, for medical reasons.

Oxygen is the third most abundant element in the universe, making up 1% of the mass of the sun, 20% of the air we breathe, 50% of the earth's crust, and 88% of water. The alchemists of old rightly judged that gold, silver, lead, mercury, and sulfur are elements, but they mistakenly placed air (a mixture of oxygen and nitrogen) and water (a compound of oxygen and hydrogen) in the same category. Late in the eighteenth century, the researches of Scheele, Lavoisier, Priestley, and others gradually brought to light the existence and nature of the gaseous elements oxygen, nitrogen, and hydrogen.

Early experiments with animals showed that atmospheric oxygen is essential to life. Advances in biochemistry during the past two centuries have clarified the role of oxygen in thousands of chemical reactions that take place in living things. Meanwhile, the inhalation of oxygen at higher than atmospheric concentration (but at normal atmospheric pressure) has become a standard procedure in the treatment of conditions ranging from acute myocardial infarction to chronic obstructive pulmonary disease.

The use of elevated atmospheric pressure as medical therapy began in the seventeenth century, long before the discovery of oxygen. The first hyperbaric chambers were purely experimental, and when they failed to cure anything, work in that line was abandoned.

Around the middle of the nineteenth century, compressed air began to be used to force water from coal mines, tunnels, diving bells, and caissons around the piers of bridges under construction. Underwater workers and deep sea divers suffered no ill effects except popping or aching ears while working at higher than atmospheric pressure. On returning to normal pressure, however, they often experienced excruciating joint pains and other ills, which sometimes proved fatal.

This disorder was variously called decompression sickness, caisson disease, and "the bends" (because pain caused victims to assume distorted postures). Eventually it was recognized as an illustration of Henry's Law, one of the basic principles of classical physics. Henry's Law states that the volume of a gas that can be dissolved in a liquid is directly proportional to the pressure of the gas within the system.

An unopened bottle of carbonated soft drink, beer, or champagne contains a fluid in which carbon dioxide gas is dissolved at higher than atmospheric pressure. When the bottle is opened, the drop in the pressure of the gas causes some of it to come out of solution in the form of bubbles.

When a human being spends several hours in an environment of elevated atmospheric pressure, the gases of which air is composed—oxygen and nitrogen—become dissolved in the blood at higher than normal concentrations. If decompression (the return to normal atmospheric pressure) takes place too quickly, bubbles of gas form in the circulation, the joints, and elsewhere. Oxygen bubbles quickly disperse because oxygen is biologically active. Bubbles of molecular nitrogen, which is inert, take much longer to resolve, and can cause permanent tissue damage and even fatal vascular occlusion.

Even before the cause of decompression sickness was clearly understood, an effective treatment had been discovered. Recompression, a return to higher than atmospheric pressure, shrinks or redissolves nitrogen bubbles. A more gradual drop to normal pressure then results in the formation of nitrogen bubbles small enough to be excreted by the lungs. Recompression, increasingly performed in chambers designed specifically for the purpose, relieved the bends and saved the lives of many divers and other underwater workers. Schedules for safe rates of decompression were gradually established.

Another risk of breathing compressed air, a particular danger for divers, is "the rapture of the deep." Deep sea divers can experience euphoria and hallucinations and display severe deterioration of judgment, sometimes with fatal consequences. In 1935 Dr. Albert Behnke, a Navy submarine medical officer, showed that these central nervous system effects are caused by the high concentration of nitrogen in the circulation that results when air is breathed at the pressure required to counteract the water pressure at a depth of 100 feet or more.

Two years later Dr. Edgar End, an intern at Milwaukee County Hospital, theorized that nitrogen narcosis could be

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prevented if divers breathed a mixture of oxygen and helium instead of air, with its 80% nitrogen content. Using himself as an experimental subject, and later in collaboration with Max Nohl, an engineer and professional diver, End developed gas formulas and decompression schedules that successfully prevented both nitrogen narcosis and the bends during and after deep dives in Lake Michigan. End joined the faculty of Marquette University School of Medicine (later reorganized as the Medical College of Wisconsin), where he lectured on underwater physiology until his death in 1981.

(If I may be permitted a personal note, I attended Dr. End's lectures in the early 1960s. He found a synopsis of the topic that I submitted in completion of an assignment so excellent that he requested, and of course received, my permission to duplicate it and use it as a handout at future lectures. A classmate broke my bubble by assuring me that Dr. End routinely acted out a similar travesty year after year. Probably that's why I couldn't find a copy of that synopsis when I undertook to write this article, and had to do the research all over again.)

Theoretically both nitrogen narcosis and the bends could be eliminated if pure oxygen were substituted for compressed air in underwater work and recreational diving. But the enormous cost of flooding an entire caisson or tunnel with pure oxygen and the risk of fire or explosion make this solution unworkable. In addition, marked elevation of the concentration of oxygen in the blood can cause seizures.

But the use of pure oxygen in recompression chambers to counteract decompression sickness is strongly supported by theoretical and practical considerations. While increased atmospheric pressure forces nitrogen bubbles back into solution, breathing 100% oxygen leads to a gradual washout of nitrogen from the circulation, so that with subsequent return to normal atmospheric pressure few or no nitrogen bubbles form.

The combination of elevated atmospheric pressure and the breathing of pure oxygen constitutes hyperbaric oxygen therapy. Although first used to treat decompression sickness, HBOT has found application in many other acute and chronic conditions. The basis of its effectiveness in most of those other conditions appears to be its ability to raise the concentration of oxygen in tissues.

HBOT achieves this result by two unrelated mechanisms. First, breathing pure oxygen under hyperbaric (higher than atmospheric) pressure virtually saturates hemoglobin, the constituent of red blood cells that transports oxygen in loose chemical combination from the lungs to the tissues. Breathing 100% oxygen at normal atmospheric pressure cannot achieve anything like this saturation.

Second, under increased atmospheric pressure, more oxygen gas is dissolved in the plasma (the fluid component of circulating blood). (Remember Henry's Law and all that carbon dioxide quietly lurking in the root beer until you pull the tab.) Although under normal conditions the transport of dissolved oxygen by the plasma is far less significant than its transport by hemoglobin, with HBOT the contribution of plasma transport to tissue oxygenation increases enormously. In fact, breathing pure oxygen at three times normal atmospheric pressure results in a 15-fold increase in the concentration of oxygen dissolved in plasma. That is a concentration sufficient to supply the needs of the body at rest even in the total absence of hemoglobin!

Increasing the oxygen supply to damaged or infected tissue promotes healing by stimulating angiogenesis (the formation of new capillaries) and enhancing the proliferation of fibroblasts (cells that produce collagen fibers for the repair of injury). These effects can be of critical importance in certain conditions, including wounds that refuse to heal because of severe mechanical damage, vascular compromise, or diabetes.

Delivery of oxygen to tissues at high concentrations can have beneficial effects beyond those noted. A rise in tissue oxygen causes vasoconstriction, which reduces edema in crushed or burned tissues and decreases intracranial pressure in acute head trauma and intracranial abscess. It also suppresses the growth of anaerobic bacteria (which prefer an environment low in oxygen) in gas gangrene and of some aerobic organisms involved in necrotizing soft tissue infections.

Although tissues, particularly those involved in superficial infections and nonhealing wounds, absorb some oxygen directly from a hyperbaric environment, the principal effect of HBOT is achieved through augmentation of oxygen delivery by the lungs. Local treatment of superficial lesions with oxygen applied through a topical unit under slightly elevated pressure is not HBOT and is only marginally effective.

The efficacy of HBOT in decompression sickness, air embolism, carbon monoxide poisoning, and other conditions mentioned above rests on firm theoretical grounds and is supported by the results of clinical trials. But the use of HBOT as treatment for autism, multiple sclerosis, cerebral palsy, inflammatory bowel disease, migraine headaches, Lyme disease, tinnitus, and numerous other disorders, although promoted by some who cite anecdotal reports of favorable outcomes, lacks justification by rigorously controlled studies.

The Undersea and Hyperbaric Medical Society (UHMS) was founded in 1967 to foster the exchange of data on the physiology and medicine of commercial and military diving. The organization publishes research findings and treatment protocols for various indications. Its Hyperbaric Oxygen Therapy Committee oversees the ethical practice of hyperbaric medicine, defining conditions for which hospital treatment with HBOT is reimbursed by third-party payers, including government agencies.

The earliest hyperbaric oxygen chambers were simply recompression chambers adapted for the administration of pure oxygen. These were built of the same materials and along the same lines as diving bells and had room for only a single occupant. In some of these, oxygen was administered by mask while the chamber pressure was raised with compressed air. In others, the entire chamber was flooded with pure oxygen at elevated pressure, although this was much more expensive and added to the risk of fire.

Although monoplace chambers were eventually equipped with windows, intercom systems, and even small air locks for the passage of food or medicine, they were extremely confining for the patient and allowed no opportunity for direct intervention by health care workers.

In hospital settings, multiplace chambers with room for several patients as well as for physicians or medical attendants soon made their appearance. Inside such a chamber both patients and medical staff breathe from flexible, transparent soft plastic helmets or tightly fitting aviators' masks, which supply pure oxygen. A multiplace chamber is equipped with means of removing exhaled carbon dioxide and water vapor from the atmosphere. In addition, exhaled oxygen must be continuously extracted from the atmosphere to reduce the risk of fire. The largest rectangular hyperbaric chamber in the U.S. is a 6000-square-foot facility built at the Mayo Clinic in 2007 with a seating capacity of 24.

One standard atmosphere (1.0 atm), the pressure exerted by the atmosphere at sea level, is defined as 760 torr (mm of mercury, mmHg), 29.92 inches of mercury (inHg), 14.696 psi (pounds per square inch), 1013.25 millibars, or 101.325 kPa (kilopascals). In HBOT parlance, a pressure of 1.0 atm is referred to as 1.0 ATA (for "atmosphere absolute").

A typical HBOT session (which may be called a "dive") consists of 90 to 120 minutes of pure oxygen breathing at 2.0 to 2.5 ATA. The duration, frequency, and total number of sessions of HBOT for various indications have not yet been standardized. For most conditions, treatments are administered once daily. For acute disorders such as decompression sickness and carbon monoxide poisoning, one or two sessions may suffice. For chronic disorders such as diabetic ulcers, therapy may be continued for 50 or more sessions. A session can cost up to $1000, depending on the facility.

Portable HBOT chambers made of nonrigid materials can achieve pressures of about 1.3 ATA. These less expensive units may be found in smaller healthcare facilities and are also used in homes. Although approved by the U.S. Food and Drug Administration (FDA) only for the treatment of altitude sickness, soft chambers are widely marketed and used for other purposes, including many for which evidence of efficacy is entirely lacking.

Hyperbaric oxygen therapy is not without its discomforts and dangers. The commonest adverse effect is pain in the ears due to stretching of the tympanic membranes by the pressure difference between the middle ear and the surrounding atmosphere. This is similar to what happens when you drive through the mountains or travel by air. Although many people are able to equalize pressures by wiggling their jaws or performing some variation of the Valsalva maneuver, some cannot. For these, surgical placement of ventilating tubes in the tympanic membranes may make the difference between a successful series of HBOT sessions and no treatment.

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Oxygen exhaled by patients receiving HBOT can create a fire hazard by raising the oxygen concentration in the environment. In order to reduce the risk of sparks, both patients and staff are required to wear exclusively cotton garments and not to take jewelry or other metallic objects into the chamber. Potentially flammable substances such as hairspray, perfume, aftershave, and oil-based cosmetics are also forbidden.

The maximum pressure for HBOT is 3.0 ATA, because oxygen toxicity, with pulmonary edema or seizures, can occur at pressures above that limit. Even below 3.0 ATA, a patient wearing a helmet or mask for HBOT may be instructed to remove it occasionally and breathe atmospheric air to permit the partial pressure of oxygen in the blood to drop. These intervals of breathing room air are called air breaks (not "air brakes"!). In a monoplace chamber that is filled with pure oxygen under pressure, the patient must breathe through a mask providing ordinary air in order to take an air break.

Hyperbaric therapy is contraindicated in untreated pneumothorax and (because of various biochemical interactions) in persons taking bleomycin, cisplatin, disulfiram, or doxorubicin and those who are being treated with topical mafenide for burn wounds. A history of thoracic surgery, severe emphysema, high fever, and upper respiratory infection are relative contraindications.

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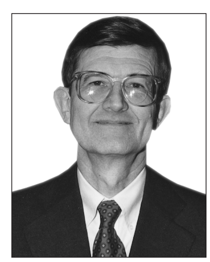

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