Good Pressure

What You Need to Know bout Hyperbaric Chambers

Most sport divers have a limited knowledge of hyperbaric chambers, and yet these facilities are often an injured diver's best friend. In extreme cases, a timely treatment in a hyperbaric chamber can prevent a lifetime of paralysis; it can also mean the difference between life and death.

To allay the common fears and misconceptions about hyperbaric chambers, this article addresses divers' frequently asked questions.

By Hillary Viders

WHAT EXACTLY ARE HYPERBARIC CHAMBERS, AND FOR WHAT ARE THEY USED?

Hyperbaric chambers are vessels in which patients breathe 100 percent oxygen to treat various medical conditions at pressures greater than normal atmospheric (sea level) pressure. Hyperbaric chambers that are used to treat divers suffering from decompression illness are often called "recompression chambers." Unlike other fields of medicine, the clinical aspects of diving hyperbarics were developed by military personnel, whereas clinical hyperbaric oxygen therapy (HBOT) used for medical applications was developed primarily by civilian health officials.

The concept of hyperbaric therapy is certainly not new. Documentation shows that breathing pressurized air was used therapeutically as early as the 1660s. Although the use of hyperbaric oxygen has traditionally been more restricted in the United States, it has been used in other countries for more than 100 years.

First used to treat the bends in deep-sea divers who surfaced too rapidly, the technology was developed in the late 1800s. In the last 30 years, however, HBOT has become much more widely accepted, as scientific evidence has shown it to be a remarkable and versatile treatment. A committee of the Undersea and Hyperbaric Medical Society (UHMS), sets recommendations for which diseases hyperbaric oxygen therapy is appropriate. These conditions are: gas gangrene, carbon monoxide poisoning, smoke inhalation, cyanide and hydrogen sulfide poisoning, burns, selected soft-tissue infections, problem wounds, crush injuries, skin grafts, spinal injuries, amputations, osteomyelitis, radiation injury to tissues and blood loss anemia.

WHAT IS THE PRINCIPLE BEHIND HYPERBARIC OXYGEN THERAPY?

The effectiveness of HBOT is based on a common underlying principle: oxygen is delivered to tissues and cells by being temporarily incorporated in the hemoglobin within the body's red blood cells. Under normal conditions, when air is taken into the lungs and passes into the blood supply, hemoglobin is almost 100 percent saturated with oxygen.

However, injury or disease may disrupt that process, depriving tissues and cells of some or all of their required oxygen. Under these circumstances, normal atmospheric pressure is not strong enough to force the required amount of oxygen into the body. Although the hemoglobin does not absorb much more oxygen, HBOT saturates the blood plasma, which comprises the bulk of the blood, with oxygen, thereby increasing delivery to the tissues and cells. Compared to air, which has 21 percent oxygen at 1 ata, 100 percent oxygen at 3 ata causes a 10- to 15-fold increase in plasma oxygen concentration with a resultant increase in tissue oxygenation.

In addition to hyperoxygenating the blood, oxygen delivered at appropriate pressure greatly enhances the body's white blood cells' ability to kill bacteria and fight infection. It also reduces edema, or fluid accumulation, through vasoconstriction (narrowing of blood vessels), and helps the body lay down wound-repairing connective tissue. These results cannot be duplicated with topical oxygen, which is applied to a patient through vented plastic bags or cups. There is no evidence, however, thta topical oxygen therapy is of any medical benefit.

HOW DOES HYPERBARIC OXYGEN WORK TO HELP RESOLVE DIVING INJURIES?

Hyperbaric oxygen therapy has long been accepted as the definitive treatment for pressure-related diving injuries. These injuries are known collectively as decompression illness (DCI), a term that includes arterial gas embolism (AGE) and decompression sickness (DCS). These two diseases are described separately because their presumed causes are different.

Knowing the location of the nearest chamber does not mean that the facility is open, operational and able to administer the necessary treatment the diver requires. Call DAN first.

From a practical standpoint, however, distinguishing them from one another may be impossible, based on the diver's signs and symptoms. And besides, the initial treatment and stabilization of an injured diver should be based on his condition, not on which of the two diseases the diver is actually suffering from. If you suspect a diving injury, get yourself — or your diving companion — to an emergency facility and an oxygen source as soon as possible.

DCI is thought to occur with the formation of bubbles within tissue that block blood circulation and the transport of oxygen. Arterial gas embolism, on the other hand, is caused by bubbles that enter the arterial circulation through the tearing of lung tissue. The definitive treatment of decompression sickness and arterial gas embolism starts with recompression therapy, to reduce bubble size and promote bubble resolution.

Arterial Gas Embolism

Though it's not a common occurrence, a diver can encounter problems when ascending from a dive: the pressure the water exerts on the body decreases, resulting in expansion of the air in the diver's lungs. If the diver surfaces too quickly or if the diver fails to exhale — even from a relatively shallow depth — air trapped in the lungs expands and may rupture lung tissue. This releases gas bubbles into the circulatory system, which then transports these bubbles to the body tissues.

As these air bubbles circulate, they can cause dramatic results by interrupting blood flow to the brain, heart or other tissues. Although AGE is typically caused by a breath-holding ascent, it may also be the result of lung problems, such as bronchitis, asthma, smoking or anatomical abnormalities that can trap air in the lungs. ***Divers with arterial gas embolism must be stabilized immediately in an emergency medical facility and, if possible, recompressed as soon as possible.***

Decompression Sickness

During a dive, the body tissues absorb nitrogen from the breathing gas in proportion to the surrounding pressure. As long as the diver remains at pressure, the gas presents no problem. If the pressure is removed too quickly — e.g., when a diver surfaces too quickly — the nitrogen comes out of solution and forms bubbles in the tissues and bloodstream. This commonly occurs as a result of violating — or approachingtoo closely — the dive table limits, but it can also occur even when accepted guidelines have been followed. (It's always wise to stay away from the very edge of the table limits and use the tables or computer conservatively.)

DCI Risks

Also, there are various physiological risk factors for DCI, that vary among individuals. Age, physical fitness, fatigue, dehydration, body build and other anatomical differences are thought to play a role. In fact there is little data indicating just how much these factors increase the liklihood of decompression sickness.

When a bends "hit" occurs, inert gas bubbles form in body tissues. These bubbles can block local blood supply and also interact with the body in ways that are not entirely clear. Depending on the quantity and location of the bubbles, DCI symptoms may be pronounced, such as a sharp pain in a joint or a visible skin rash, but they can also be subtle. The appearance of symptoms may not come until some time after the diver returns to the surface, or they may develop if a diver flies in a commercial airplane too soon after diving. Severe cases of DCI may involve the brain, the spinal cord or the cardiopulmonary system.

Decompression illness creates two types of problems in the body: mechanical and chemical.

"Mechanical" refers to bubbles aggregating at a site in the body, which causes swelling, distortion and damage to cells and tissues. "Chemical" refers to how the body reacts to the presence of bubbles and to the blockage of oxygen to the cells.

Chemical changes may include blood clotting, formation of fat emboli, activation of platelets and leukocytes and lactic acid accumulation. These reactions further impair the circulatory system. If bubbles obstruct blood flow to the spinal cord and if the blood flow is not restored quickly, cells will die, resulting in permanent damage.

In response to decompression illness, one of the immediate goals of hyperbaric oxygen therapy is to reduce the size of the offending bubbles. The physical pressure exerted on the patient in the chamber reduces, in accordance with Boyle's Law, the size of the gas bubbles in tissues. At 5 ATAs for example, a bubble is reduced to 20 percent of its original volume and 60 percent of its original diameter.

Breathing 100 percent oxygen while under pressure in a hyperbaric chamber greatly increases the gradient for eliminating any gas bubbles in tissue, thereby accelerating their reabsorption. Breathing oxygen under pressure also delivers oxygen to hypoxic (oxygen-deprived) tissues, that can maintain cell function until normal blood flow is restored.

HOW MANY DIFFERENT TYPES OF CHAMBERS ARE THERE? and HOW ARE THEY DIFFERENT?

Hyperbaric chambers are usually classified into two main categories: monoplace and multiplace.

Monoplace Chambers

First introduced in the 1960s, monoplace chambers were designed to accommodate only one patient. Tubular in shape and usually constructed of clear acrylic material, these small chambers use a 100 percent oxygen environment and can be pressurized only to 3 atmospheres absolute (ATA).

The high concentration of oxygen in these one-person chambers precludes the use of any electronic equipment. However, specially adapted ventilators and monitoring systems in some monoplace chambers do allow treatment of critically ill patients.

Because treatment times and patient access in monoplace chambers are limited, they are used primarily for less severe cases of decompression illness and non-diving injuries. These chambers are popular in hospitals because they are relatively inexpensive, compact and require fewer personnel than large chambers. A major disadvantage of monoplace chambers is the patient is relatively isolated, which makes administering drugs and evaluating treatment progress difficult.

Multiplace Chambers

The preferred vessels everywhere for treating injured divers, multiplace chambers are made of steel and are usually either cylindrical or igloo-shaped.

They have room for between two and 18 patients (sizes vary) and incorporate a minimum pressure capability of 6 ATAs. Trained personnel — RNs, paramedics and/or DMTs — accompany the patient during treatment, where they can carefully monitor the patient's signs and symptoms and give drugs and fluids. Multiplace chambers use an air environment, and patients breathe oxygen or other therapy gases through a face mask, hood or endotracheal tube.

Medical staff may enter and exit the chamber during treatment via a system of "locks," or doorways, that can be independently pressurized to allow the transfer of attendants and medical equipment. Another major advantage of this chamber is its capacity for extended treatment times. Disadvantages include higher costs than monoplace chambers; they require more personnel; and the large size makes it impractical in a small setting.

Portable Chambers

A subset of the monoplace chambers, small portable chambers have recently been introduced into the diving community. These small, inflatable devices are designed for emergency treatments in remote areas and operate on air from a compressor or scuba tanks. They are lightweight and inexpensive, but are pressure rated to only 3 ATAs and, therefore, of limited use for diving injuries.

Several models of small portable monoplace chambers are available. Perry Baromedical Services manufactures one with wheels for easy maneuvering. Hyperlite and Chamberlite also make small portable chambers. Folded in a trunk-like carrying case, these chambers are easy to transport and can be inflated via a standard scuba tank.

Large transport chambers are made of steel and are much heavier than the inflatable chambers. They are used primarily to transport patients during military, commercial and scientific diving operations. Although their pressure rating of 6 ATAs enables them to treat most injuries, their designated use is as transport vessels; in addition, they must mate exactly with the multiplace chamber in a medical facility. The U.S. Navy transport chambers, which have the most advanced technology and design, are used currently used by the Navy's Mobile Diving and Salvage Units (MDSU) in remote locations. The cone-shaped transport chamber is a 6 ATA chamber and is usually part of a "flyaway system," one that can be loaded into a helicopter or aircraft and one in which the patient is transported under pressure.

The Alfred Hospital in Melbourne Australia has just introduced a new prototype chamber concept: an entire concrete hyperbaric facility room that can be used to treat a variety of diving and clinical injuries. The chamber resembles a regular hospital room with windows and bathrooms; it measures approximately. 2.8 m/ 8 f high, 13 m / 40f long, and 3.6 m / 12 f long. A "triple lock" facility, its different areas are pressurized at sea level, 3 ATAs or 6 ATAs. Although the cost is now $1.5 million, these chamber rooms may become very popular.

WHAT HAPPENS DURING A CHAMBER TREATMENT?

In the case of an arterial gas embolism and severe DCS, hyperbaric pressure is crucial for reducing the size of the offending bubbles. HBO treatments follow a specific protocol called a treatment table. There are many different treatment tables, each one specifying a particular pressure/time profile and when oxygen should be breathed.

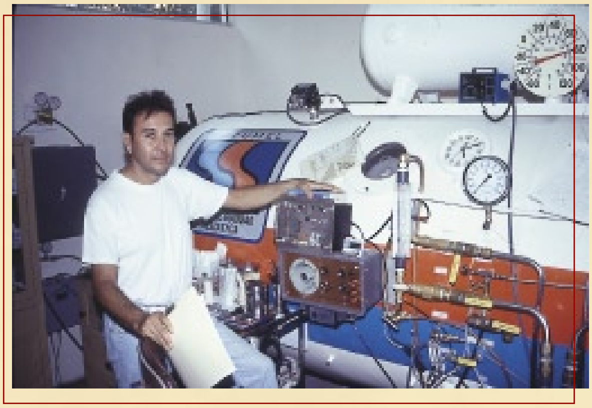
The most common treatment table for recreational diving accidents is the U.S. Navy Treatment Table 6.

Other treatment tables may be used for different types of diving accidents and severity of symptoms. They go to depths of 108 feet or deeper and may last for a few hours or days. In addition, there are specific treatment tables for treating non-diving conditions, such as carbon monoxide poisoning, severe infections, such as gangrene and tissue damage. The treating physician can tell the patient exactly what type of treatment table should be used and why.

To reduce the risk of fire in chambers from static electricity sparks, patients and attendants wear 100 percent cotton or fire-retardant clothing, including cotton covers for shoes, which may have picked up oil or grease from the street. All electrical equipment must be of low-voltage or completely sealed. Certain items that contain volatile flammable components cannot be taken into the chamber: lighters, matches, hearing aids, watches, makeup, lipstick or lip balm, hairspray, hair oil, synthetic fabrics, hard contact lenses, petroleum jelly, ointments or any items made of flammable material.

During the treatment, an inside attendant cares for patients, handles operations and communicates with the outside personnel (attendant / timekeeper, medical supervisor and physician) through a headphone or speaker / microphone unit. Visual observation is also possible from inside and outside the chamber through view ports, windows or closed-circuit television. Depending on the size and configuration of the chamber, a patient may sit in a chair or lie down on a berth. Patients are fitted with either an oronasal mask or a hood for breathing therapy gases, which may be oxygen, nitrox or heliox.

Patients in a hyperbaric chamber are asked to remain quiet and relaxed, with talking and moving about kept to a minimum. They may be allowed to read books and magazines, watch television, play cards, relax, even sleep



during treatment. Sitting or reclining is preferred to crossing one's legs, which could compromise circulation. When the chamber is pressurized, patients will be asked to clear their ears, just as if they were making a diving descent.

Rarely, patients who need HBO are unable to clear. In these cases, clearing may be possible if the pressurization is very slow — sometimes be as slow as 1-fsw/min. If a patient will need multiple treatments or is absolutely unable to clear, a procedure called a myringotomy may be performed. In this procedure, local anesthetic is placed in the ear canal to "numb" the eardrum, and then a special instrument is used to create a tiny hole in the eardrum. The hole vents the gas from the middle ear, allowing clearing even if the Eustachian tubes are completely blocked. The hole will heal by itself in a few days, with no residual damage or hearing impairment.

As the pressure increases with descent, patients are advised to expect to experience heat and stuffiness; later, upon ascent, the expansion of the gases causes the ambient air to cool considerably.

Because chambers are steel "bells," they tend to be very noisy. When the chamber is pressurized or waste gases are dumped, the noise is usually too loud to talk over. As the pressure in the chamber increases, so does the gas density, which distorts voices and makes them difficult to understand. Overall, chamber treatments are not painful or unpleasant, but some patients may feel claustrophobic. (In some cases, the attending physician may administer a relaxation medication).

HOW DO I KNOW IF I NEED A CHAMBER? and HOW CAN I FIND ONE?

AGE and DCS are serious medical emergencies that require early recompression treatment. Symptoms of decompression illness most often show up within 15 minutes to 24 hours after a diver surfaces. If you fly after diving, symptoms may appear later. If you have signs and symptoms of decompression illness, the sooner you are treated in a chamber, the greater your chances of recovery.

In the early management of a diving injury, however, all symptoms of DCI are considered together, and first responders should not waste time trying to make a definitive diagnosis. Any injured diver should be given emergency oxygen at the dive site while the dive emergency plan is activated. Even if initial symptoms are relatively mild, they can rapidly worsen and should not be ignored.

Documented cases show that some divers initially refused treatment, insisting that their weakness, fatigue or joint pain were caused merely by a poorly fitting wetsuit or an arduous dive; these same diver then became paralyzed within a few hours. Always report symptoms immediately, and have a trained professional monitor them and provide 100 percent oxygen.

Sometimes symptoms may improve when breathing 100 percent oxygen. Do not take this as a sign the problem is resolved; symptoms may recur at a later time. Always seek medical help, even if symptoms improve.

Assuming you need a chamber, how can you locate one? After a dive, if you are experiencing any of the signs and symptoms listed in the sidebar, or if you just don't "feel right," let a dive leader or supervisor know right away. Have someone contact DAN's Diving Emergency Hotline at (919) 684-4DAN collect or (919) 684-8111.

The medical experts at DAN will assist with diagnosis and initial treatment of the injury, supervise referral to an appropriate medical facility and locate the nearest available hyperbaric chamber. It is NOT advisable to take an injured diver directly to a chamber without first contacting DAN. Knowing the location of the nearest chamber does not mean that the facility is open, operational and able to administer the necessary treatment the diver requires.

Additionally, the diver may first need to be stabilized and evaluated for other injuries in an emergency room. And if emergency evacuation is needed, the Coast Guard, EMS or, in the case of DAN members, *TravelAssist*, must be activated. All divers should have a good dive accident management plan that includes equipment for contacting these groups.

Last, it should be noted that hyperbaric treatment is not indicated for every dive-related injury. The diving professional(s) on the scene, assisted by DAN's medical staff via phone or radio, should determine if a diver needs to be transported to a chamber. The bottom line is, "When in doubt, CALL DAN."

WILL MY MEDICAL INSURANCE COVER THE EXPENSE?

Unfortunately, hyperbaric treatments are expensive, especially those that require extended staff, time, equipment and gas supply. Depending where you are, one six-hour treatment for decompression illness in a multiplace chamber can cost several thousand dollars, not including air evacuation or hospital emergency room fees.

Some insurance companies cover hyperbaric treatments for medical conditions such as carbon monoxide poisoning and burns, but many do not cover chamber treatments or air evacuations for scuba diving injuries. To avoid the high cost of a diving injury, divers are strongly advised to sign up for diving insurance and medical evacuation coverage.

ABOUT THE AUTHOR

Hillary Viders, an EMT, has worked as a hyperbaric chamber technician, and has taught numerous Dive Accident Management programs to professional rescue teams, including the FBI Special Operations.

ARTERIAL GAS EMBOLISM

Symptoms

- Dizziness
- Visual blurring
- Chest pain
- Disorientation
- Personality change
- Paralysis or weakness

Signs

- Bloody froth from mouth or nose
- Paralysis or weakness
- Convulsions
- Unconsciousness
- Breathing may stop
- Death

Note: *Symptoms and signs usually appear during or immediately after surfacing and may resemble a stroke.*

DECOMPRESSION SICKNESS

Symptoms

- Unusual fatigue
- Skin itch
- Pain in arms, legs or torso
- Dizziness
- Numbness, tingling and paralysis
- Shortness of breath

Signs

- Skin may show a blotchy rash
- Paralysis, weakness
- Staggering
- Coughing spasms
- Collapse or unconsciousness

Note: *Symptoms and signs usually appear within 15 minutes to 12 hours after surfacing; but in severe cases, symptoms may appear before surfacing or immediately afterwards. Delayed occurrence of symptoms is rare, but it does occur, especially if air travel follows diving.*

– From DAN's "Dive and Travel Medical Guide"

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