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Hyperbaric Oxygen Therapy and Wound Healing

Karen E. Lucero Ortega
Gettysburg College

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Abstract

Hyperbaric Oxygen Therapy (HBOT) has been around since the 1860s and is now a well-established form of treatment. HBOT has been proven to be a safe therapeutic option and has been successful in treating non-healing wounds, traumatic wounds, and radiation-induced wounds. There has also been success in treating other conditions such as inflammatory bowel disease, carbon monoxide poisoning, and decompression sickness with HBOT. The way HBOT works is by exposing the body to 100% pure oxygen in a closed chamber, which exceeds normal atmospheric pressure by two to three times. With HBOT, large amounts of oxygen enters the body, which assists in controlling inflammation, improving the process of cleaning damaged cells leading to an improved immunity response. HBOT also relieves hypoxia, which increases the amount of oxygen dissolved in blood plasma to promote and accelerate the healing process.

Keywords

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Karen Lucero

Department of Health Sciences, Gettysburg College

HS 319: Environmental Physiology

Dr. Drury

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INTRODUCTION

Oxygen is a gas that the human body requires to function properly. In 1774, an English scientist, Priestley, first discovered oxygen and stated that the right amount of oxygen would benefit and assist with wound healing (Williams, 2003). Since Priestley's discovery of oxygen, the first hyperbaric chamber was built in France and later introduced in North America as hyperbaric oxygen therapy (HBOT) in the 1860s to treat nervous disorders, influenza, and other respiratory conditions (Bhutani & Vishwanath, 2012; Leifer, 2001). Due to early reports of oxygen toxicity, early HBO chambers used compressed air up until the late 1930s when pressurized oxygen was used to treat decompression sickness (Gill & Bell, 2004). Throughout the years, HBOT has become a well-established treatment for many conditions, especially wound healing (Bhutani & Vishwanath, 2012; Leifer, 2001; Sen & Sen, 2021).

HBOT involves exposing the body to 100% oxygen in a closed chamber, exceeding normal atmospheric pressure by two to three times (Bhutani & Vishwanath, 2012; Sen & Sen, 2021; Tibbles & Edelsberg, 1996). There are three kinds of chambers, multiplace, monoplace, and topical. Multiplace chambers accommodate between two to seven people and in this chamber, it is necessary to use masks to administer oxygen to the patient whereas monoplace chambers accommodate one person and don't require the patient to wear a mask because they are made of transparent acrylic (Bhutani & Vishwanath, 2012). Topical chambers are designed to fit only over the specific body part that needs treatment (Leifer, 2001). With more oxygen present in the chambers, there is higher inhalation of pure oxygen, which causes oxygen levels in the body to enhance due to the supersaturation of the patient's plasma and hemoglobin (Leifer, 2001).

Before looking into scheduling HBOT, medical professionals are expected to sit down and talk to explain to their patients what HBOT is, what to expect, and the potential risks and complications that the treatment may bring. Scheduling for HBOT varies and depends on the kind of wound treatment the patient is seeking. Most HBOT sessions tend to last between 60 and 90 minutes, with one or two daily sessions that the doctor prescribes for two to four weeks (Leifer, 2001). Each session in the hyperbaric chamber will last approximately two hours and take place in three different phases: compression, constant pressure, and decompression. During the compression and constant pressure phase, the atmospheric pressure inside the chamber is raised to an above-normal level. The compression phase can last from 10 to 30 minutes, whereas the constant pressure phase can last 60 to 90 minutes (Leifer, 2001). In the decompression phase, the atmospheric pressure inside the chamber is decreased back to normal levels and can take between 10 to 30 minutes (Leifer, 2001).

WOUND HEALING

HBOT has been successful in treating wounds and non-wounds. Wounds, where HBOT has been successfully used include non-healing wounds, traumatic wounds, and radiation-induced wounds. HBOT has also been used to treat other conditions such as inflammatory bowel disease, carbon monoxide poisoning, and decompression sickness (Alenazi et al., 2021; Leifer, 2001; Sen & Sen, 2021).

Non-healing wounds are wounds that have difficulty healing within a reasonable timeframe (Bhutani & Vishwanath, 2012). With non-healing wounds, healing starts with biochemical changes at the cellular level (Sen & Sen, 2021). Diabetic foot ulcers are very common and devastating complications in patients with diabetes (Niinikoski, 2003). Diabetic foot ulcers are treated with HBOT along with other wound management techniques such as wound debridement, dressings, strategies that relieve pressure, nutrition, and antibiotic management. Several studies focus on using HBOT to treat diabetic foot ulcers to avoid the devastating outcome of amputation. Since diabetes is the most common cause of lower extremity amputations, it makes up about 50-80% of all lower extremity amputations (Niinikoski, 2003). Treating diabetic wounds with HBOT has shown positive results to improve tissue hypoxia, enhancement in perfusion, and reduction in edema (Bhutani & Vishwanath, 2012; Lipsky & Berendt, 2010). For example, with decreased edema due to vasoconstriction, there is better diffusion of oxygen and nutrients through the tissue which can make the healing process a lot easier.

Traumatic wounds come from crush injuries and compartment syndrome, which can result in tears of major vessels and damage the microcirculation (Tibbles & Edelsberg, 1996). HBOT plays an essential role in treating traumatic wounds because it decreases neutrophil activation, which prevents margination, rolling, and accumulation of white blood cells, thereby reducing the production of free radicals by neutrophils and preventing reperfusion injury (Bhutani & Vishwanath, 2012). To treat traumatic wounds there needs to be interventions with debridement and repair of soft tissues before administering HBOT. HBOT should begin as soon as possible to avoid ischemic necrosis, major infections, reduce edema and prevent amputations (Bhutani & Vishwanath, 2012). It is highly encouraged that HBOT begins as soon as possible after the injury, approximately 4 to 6 hours from the injury.

Radiation injuries are caused by radiation exposure and are known to alter the normal physiology and anatomy of tissues (Tibbles & Edelsberg, 1996). Tissues that have been exposed to radiation are chronic and long-term, which can cause cellular proliferation, leading to decreased vascularity, local hypoxia, and eventually necrosis (Bhutani & Vishwanath, 2012; Tibbles & Edelsberg, 1996). HBOT has been noted to be very successful to treat radiation injuries due to hyperbaric oxygen present in the chamber. Normally, in the hyperbaric chamber, the oxygen would be increased to 100% at one atmosphere, but it would not be enough to help irradiated tissue. To treat irradiated tissue, higher arterial pressure would be required to promote angiogenesis and hyperoxygenation to the injured tissue, which provides more oxygen for irradiated tissues, but also encourages new blood vessel formation (Bhutani & Vishwanath, 2012; Goyal et al., 2022; Tibbles & Edelsberg, 1996).

NON-WOUND HEALING

Throughout the years, inflammatory bowel diseases (IBD), such as Crohn's disease and ulcerative colitis have become a global issue (Alenazi et al., 2021; Dulai et al., 2014). IBD is mainly characterized by chronic inflammation that is present in the gastrointestinal (GI) tract that can lead to symptoms such as abdominal pain, rectal bleeding, diarrhea, and fatigue (Alenazi et al., 2021). Generally, any form of treatment used for IBD is focused on reducing inflammation to accelerate the healing process. There have been significant improvements made in the past few decades that relate to IBD treatment and HBOT has been proven to be the most effective form of treatment for IBD. Since IBD is mainly driven by inflammation, HBOT provides high levels of oxygen that can assist in controlling inflammation, improving the process of cleaning damaged cells, which would improve immunity response, and relieving hypoxia, which dramatically increases the amount oxygen dissolved in blood plasma to promote wound healing (Alenazi et al., 2021; Dulai et al., 2014).

In the United States, carbon monoxide poisoning is the most common cause of death and occurs primarily through smoke inhalation. Common symptoms for less severely poisoned patients include headaches and nausea. Patients facing life-threatening carbon monoxide poisoning are mainly discovered through loss of consciousness, which consists of seizures and the possibility of entering a coma state, followed by neurologic deficits, and possible metabolic acidosis (Tibbles & Edelsberg, 1996). The standard treatment for carbon monoxide poisoning is oxygen. Several studies have found that applying HBOT to the course of treatment is the fastest method to reverse the hypoxia and some of the life-threatening effects of carbon monoxide poisoning (Gill & Bell, 2004). However, for carbon monoxide poisoning, HBOT is given in one single, longer session (Leifer, 2001). Patients who are severely poisoned would often be given HBOT treatment with hyperbaric oxygen between 2.5 to 3.0 atmospheres and patients who are less severely poisoned would be given HBOT with 100% hyperbaric oxygen for approximately 4 to 6 hours, or until symptoms go away (Tibbles & Edelsberg, 1996).

Decompression sickness (also called the bends) is common in the United States and mostly noted in scuba divers, but can occur in aviators and deep tunnel workers (Sen & Sen, 2021). Decompression sickness occurs when there is a change in atmospheric pressure due to the change in environment. For example, when scuba divers are breathing compressed air and return to the water surface too rapidly, the partial pressure of nitrogen dissolved in their tissues exceeds the ambient atmospheric pressure, which can form air bubbles in the blood and tissue (Sen & Sen, 2021; Tibbles & Edelsberg, 1996). There is a range of symptoms one can experience with decompression sickness, from skin rashes, and joint pain to paralysis and death. Since HBOT is accepted as the only treatment for decompression sickness it is important that when the first signs of decompression sickness first appear, treatment should not be delayed to reduce the size of bubbles and correct hypoxia (Gill & Bell, 2004; Sen & Sen, 2021; Tibbles & Edelsberg, 1996). It is highly recommended that patients who have decompression sickness receive HBOT at 2.5 to 3.0 atmospheres for 2 to 5 hours or until symptoms are relieved (Sen & Sen, 2021; Tibbles & Edelsberg, 1996).

BENEFITS OF HBOT

HBOT serves as a form of treatment and it is known to benefit the body in different ways. HBOT can increase tissue oxygen perfusion. Due to high oxygen intake during HBOT, blood oxygen levels increase, which can last for about four hours post-HBOT (Leifer, 2001). The way this works is with the help of Henry's law. Henry's law is a gas law that explains how the weight of a gas dissolved by a liquid is proportional to its partial pressure above the liquid. For example, the degree at which oxygen enters plasma is directly proportional to the partial pressure of the gas to which the liquid is exposed. With the help of HBOT, the solubility of oxygen in plasma is enhanced, which benefits hypoxic areas in the body (Leifer, 2001). HBOT can also enhance wound healing. During HBOT the partial pressure of arterial oxygen increases, which results in vasoconstriction. Vasoconstriction aids in treating wounds by reducing edema, reducing capillary pressure, and allowing oxygenated plasma into the tissues (Leifer, 2001). HBOT can also increase neo- and revascularization. With HBOT there are periods of hyperoxia that alternate with periods of normal oxygenation or hypoxia (Leifer, 2001). The alternation of periods forms a pattern where your body starts adjusting to certain changes, resulting in increased capillary formation and better circulation to tissues (Leifer, 2001).

COMPLICATIONS

HBOT has been proven to be a relatively safe therapeutic option for a variety of conditions. However, a person should only undergo HBOT for an approved purpose, that way they don't waste their time and money. If HBOT is used inappropriately it can lead to several adverse effects in patients. These side effects may not become evident until after an HBOT session, but they would most likely occur in the ear, nose and throat, eyes, lungs, cardiovascular system, and central nervous system (Leifer, 2001).

The most common complication with HBOT occurs in the middle ear, known as barotrauma of the ear. When one swallows, the pressure in the middle ear increases temporarily and allows the eustachian tubes to help equalize the pressure (Leifer, 2001). During HBOT, the pressure causes gas-filled spaces to contract, which requires equalization. Failure to equalize pressures can result in barotrauma. When barotrauma occurs in the middle ear it can cause a range of problems, from mild hyperemia of the tympanic membrane to the actual rupture of the tympanic membrane, eventually resulting in hearing loss (Sadri & Cooper, 2022; Sen & Sen, 2021). During HBOT paranasal sinuses expand, which means that air moves in and out of your sinuses, increasing the chances of air trapping occurring. Air trapping in the sinus can eventually lead to sinus barotrauma (Sadri & Cooper, 2022). A sinus barotrauma results in swelling and sinus pain. At higher than normal atmospheric pressure, the transmission of sound is altered. As atmospheric pressure increases the atmospheric density changes, which eventually affects the vibration of the vocal cords (Leifer, 2001). Overall, this results in slight temporary changes to one's voice causing their voice to sound either higher or lower.

Patients have stated that their vision either betters or worsens when they are in HBOT. During HBOT the shape of the lens flattens under atmospheric pressure, resulting in one temporary myopia (Leifer, 2001; Sadri & Cooper, 2022). Temporary myopia is the most common ocular complication from HBOT. However, temporary myopia is thought to be reversible after

HBOT. Vision will most likely improve at a rapid pace after 3 to 6 weeks and fully return to baseline in about 1 year (Sadri & Cooper, 2022).

When there is too much air trapped in the lungs it can become a problem. When air is trapped in the lungs, gas can expand and cause alveolar overdistension and rupture, also known as pulmonary barotrauma (Leifer, 2001). With HBOT, breathing 100% pure oxygen with increased atmospheric pressures is a part of the process. However, breathing in oxygen continuously can be toxic and cause damage to the alveolar lining (Leifer, 2001). Some early signs and symptoms of oxygen toxicity consist of chest discomfort, burning on inspiration, cough, and difficulty breathing (Leifer, 2001). Complications having to do with lungs can be serious if they are left untreated (Sadri & Cooper, 2022).

Too much oxygen in the body can bring complications to the central nervous system and the cardiovascular system. When there is too much oxygen being forced into the body by HBOT, it can cause central system oxygen toxicity (Hampson & Atik, 2003). Central nervous system oxygen toxicity is most likely to occur at hyperbaric pressures that reach 4 ATA, but can also appear at any point during the treatment (Leifer, 2001). Signs and symptoms of central nervous system oxygen toxicity are consistent with tremors, seizures, and loss of consciousness. However, seizures that occur due to central nervous system oxygen toxicity can stop on their own once the patient is breathing air (Sadri & Cooper, 2022). When it comes to the HBOT and the cardiovascular system, there can be detrimental effects on the cardiovascular system that can affect the patient. Cardiac output is strongly dependent on oxygen levels that are present in the tissues (Leifer, 2001). HBOT stimulates vagal activity and increases tissue oxygenation, which results in increased cardiac output and bradycardia due to increased oxygen and pressure (Goyal et al., 2022; Leifer, 2001). Signs and symptoms can consist of a slower pulse than baseline, which has to do with disturbances in electrical activity (Goyal et al., 2022; Leifer, 2001). Overall, patients that undergo HBOT continuously and experience cardiac symptoms should check in with their cardiologists to avoid any future complications (Sadri & Cooper, 2022).

HBOT COST & ACCESSIBILITY

HBOT has been recognized to be an advanced and effective treatment for several chronic medical conditions (Lipsky & Berendt, 2010; Sadri & Cooper, 2022). However, HBOT consists of relatively advanced and expensive technology. Before initiating HBOT, clinicians must ensure that their patients have availability and accessibility to HBOT since proximity can affect the cost of the treatment. The initial installment for hyperbaric chambers ranges in cost from $85,000 for a one-person unit to more than $500,000 for units of two or more people, plus the $200,000 needed for necessary facility modifications (Leifer, 2001).

A patient's treatment costs strongly depend on several important factors, such as the condition or reason for HBOT, the insurance plan, and the severity of symptoms (Katz, 2017). HBOT has been approved by the FDA as a standard treatment for many conditions and when a procedure is approved by the FDA, it is most likely that the patient's insurance will cover the cost (Katz, 2017). When it comes to insurance plans and location there are two kinds of HBOT programs, a hospital-based and an independent one. Hospital-based HBOT programs accept most insurance but are only able to treat patients with conditions that have FDA approval for HBOT to treat (Katz, 2017). In the United States, health insurance is usually purchased or provided by the government to certain groups. In terms of HBOT, the cost usually ranges from $50,000 through Medicare to about $200,000 in private pay (Lipsky & Berendt, 2010). However, it does depend on the kind of coverage one has. Hospital-based programs have much higher patient out-of-pocket costs with higher co-pays or co-insurance responsibilities (Katz, 2017). The average time for one HBOT session is 90 minutes, which means that one session would cost between $300 and $400 (Tibbles & Edelsberg, 1996). For example, if a patient needed 30 to 40 sessions for wound treatment, the price would range from $9,000 to $16,000 (Tibbles & Edelsberg, 1996). The severity of the patient's symptoms plays a role in determining the course and cost of HBOT. If a patient's symptoms are severe, healthcare providers will most likely recommend HBOT to patients and the more sessions a patient attends, the more the course of treatment will cost – both through insurance co-pays and co-insurance (Katz, 2017). Other than costs, accessibility to HBOT is also a concern. Since HBOT is only available in a minority of communities, accessibility is very limited, which contributes to the cost of HBOT, making them much more expensive (Lipsky & Berendt, 2010).

CONCLUSION

HBOT is the next step into the future of wound healing and non-wound healing. Studies have shown that HBOT promotes higher levels of oxygen intake that enhance other biochemical processes to assist in wound healing. Studies are still being developed to see if HBOT can be a standard form of treatment for healing other forms of injuries such as TBI, stroke, etc. More research is still needed to investigate the side effects of HBOT and if there are any prevention methods clinicians can tell their patients about.

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