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Comprehensive evaluation of hyperbaric oxygen therapy: Mechanisms, applications, and clinical implications

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ABSTRACT

The aim of this work was to conduct a literature review encompassing the fundamental aspects of hyperbaric oxygen therapy (HBOT), including its basic principles, chamber types, and physiological mechanisms. This review outlines the different types of hyperbaric chambers, such as monoplace and multiplace chambers, detailing their design, operational requirements, and specific therapeutic uses. It explores the physiological mechanisms induced by HBOT, including its effects on partial pressure of gases, volumetric changes, and solubility, as well as biochemical and cellular impacts. The review also addresses the therapeutic indications of HBOT, such as its application in treating decompression sickness, gas embolism, and chronic wounds, alongside its limitations and contraindications. It evaluates the advantages and disadvantages of HBOT, highlighting the potential for complications

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such as barotrauma and oxygen toxicity. Emphasis is placed on the need for careful patient selection and adherence to treatment protocols to optimize outcomes and mitigate risks.

Keywords: Tissue Hypoxia, Hyperbaric Oxygen Therapy, Indications, Physiological Mechanisms, Chamber Types, Complications.

INTRODUCTION

Hyperbaric Oxygen Therapy (HBOT) is a therapeutic method where the patient breathes 100% oxygen inside a hyperbaric chamber, under a pressure greater than standard atmospheric pressure (typically between two to three times the atmospheric pressure at sea level). This procedure exploits the capacity of hyperbaric oxygen to promote tissue healing and recovery from various medical conditions.

From an etymological perspective, the term "hyperbaric" derives from the Greek roots "hyper-" (ὑπέρ), meaning "excess" or "above," and "baros" (βάρος), which translates to "pressure." Thus, hyperbaric refers to a state of increased pressure.

HBOT involves the inhalation of pure oxygen in a high-pressure environment, often complemented by assisted ventilation depending on the patient's clinical condition. This hyperbaric environment significantly increases the amount of oxygen dissolved in the blood plasma, facilitating the oxygenation of compromised tissues and promoting cellular repair processes and angiogenesis. The clinical application of HBOT ranges from the treatment of chronic wounds and antibiotic-resistant infections to carbon monoxide poisoning and gas embolism.

TYPES OF HYPERBARIC CHAMBERS

MONOPLACE CHAMBER

According to the Brazilian Society of Hyperbaric Medicine (SBMH), the installation of monoplace chambers must comply with the guidelines set forth by the Brazilian Association of Technical Standards (ABNT), specifically NBR 12188 [3,4]. In instances where compression is to be performed with air, it is necessary to install specific valves, duly identified by the manufacturer, and ensure that the air used possesses medicinal characteristics. This type of chamber is designed for single-person use within a hospital setting, providing comfort and privacy, while enhancing safety through the availability of intensive care facilities, such as infusion pumps and mechanical ventilation, during the treatment process.

A monoplace hyperbaric chamber can be described as a hermetically sealed compartment into which pure oxygen is pumped using precisely calibrated hospital-grade compressors. The chamber is cylindrical, constructed from steel, with an acrylic upper section to facilitate external observation. The doors must be perfectly sealed to withstand pressurisation at three absolute levels: normobaric (one atmosphere), superbariac (two atmospheres), and hyperbaric (above two atmospheres). This pressurisation is achieved with 100% oxygen, and during each 60-minute session, approximately 30 cubic meters of oxygen are consumed, although this value can vary depending on the selected and adjusted pressurisation level. To mitigate the sensation of claustrophobia in patients, these chambers are equipped with a communication system.

Caixeta (2003) highlights several advantages of monoplace chambers. One key benefit is that only the patient is subjected to compression through the inhalation of pure oxygen, allowing for immediate decompression if necessary. Additionally, the operation of these chambers requires only one person, with the assistance of a physician and a trained nurse. Monoplace chambers are also cost-effective and occupy less space in hospital resuscitation centres. Their ergonomic and practical design allows for easy transportation in ambulances to the site of emergency. However, there are notable disadvantages, including the isolation of the patient and the increased risk of fire and explosion due to the use of pure oxygen, which is a critical element for combustion. This necessitates strict adherence to stringent safety protocols[5].

MULTIPATIENT HYPERBARIC CHAMBERS

Multipatient hyperbaric chambers, as the nomenclature implies, are engineered to accommodate multiple patients concurrently. These chambers are pressurised using compressed air, with oxygen administered via masks or hoods, also allowing the presence of additional personnel alongside the patients. Among the notable advantages is the facilitation of direct medical supervision, which proves indispensable in severe hyperbaric incidents. In surgical scenarios, the utilisation of this type of chamber is paramount. Furthermore, conditions such as Decompression Sickness (DCS) and Arterial Gas Embolism (AGE) are more effectively managed within multipatient chambers, given their capability to sustain the requisite pressures for treating such medical emergencies. Nevertheless, the deployment of stationary multipatient chambers is accompanied by several disadvantages. These units are inherently complex, and their installation necessitates resolving substantial technical challenges. The operation of these chambers demands highly skilled personnel, potentially introducing organisational complications within the hospital infrastructure. Cases necessitating extensive oxygen contact with bodily tissues cannot be adequately addressed within these chambers, as employing oxygen throughout the entire chamber would not only be prohibitively costly but also significantly elevate the risk of fire and explosion. Moreover, these chambers typically occupy considerable physical space. The medical and nursing staff (internal guides) are subjected to the hyperbaric environment, requiring the selection of individuals with specific qualifications, supported by mandatory pre-employment (selection) and periodic (monitoring) medical examinations.

PHYSIOLOGICAL MECHANISMS INDUCED BY HYPERBARIC OXYGENATION

Under normal conditions, humans are subjected to an atmospheric pressure equivalent to one atmosphere (1 atm). However, for every 10 metres of depth underwater, the pressure exerted on the body increases by one atmosphere. Hyperbaric treatments utilise pressures ranging from 2.5 to 3.0

ATA (ATA: atmospheric pressure plus hydrostatic pressure). At these pressures, the human body experiences physical effects governed by the principles of diving physics.

EFFECTS ON THE PARTIAL PRESSURE OF GASES

According to Dalton's Law, the total pressure of a gas mixture is the sum of the partial pressures of its individual gases. Thus, as the pressure within the hyperbaric chamber increases, the partial pressures of the gases within the chamber correspondingly rise. The elevation of the partial pressure of oxygen (PPO2) leads to a significant increase in its solubility in the plasma.

VOLUMETRIC EFFECTS

Boyle-Mariotte's Law states that pressure and volume are inversely proportional, provided the temperature remains constant. This implies that all bodily air-filled cavities, especially pneumatic structures, will undergo corresponding volume changes under varying pressures (e.g., the digestive tract, middle ear, and paranasal sinuses) [11,12].

EFFECTS ON SOLUBILITY

According to Henry's Law, when pure oxygen is inhaled in a hyperbaric environment, there is a substantial increase in the arterial partial pressure of oxygen, which can exceed 2000 mmHg at an ambient pressure of 3 ATA. The oxygen is then dissolved in the plasma, increasing its transport capacity by over 22 times. Calculating the oxygen content in the plasma reveals that at sea level, the amount of dissolved oxygen is approximately 0 ml/dl, whereas at 3 ATA, it increases to around 6 ml/dl. This concentration is sufficient to meet cellular oxygen demands at rest, without requiring any contribution from oxygen bound to haemoglobin.

BIOCHEMICAL AND CELLULAR EFFECTS

DIRECT EFFECTS

The increase in the partial pressure of oxygen (PPO2), as described by Dalton’s Law, and the substantial enhancement of plasma oxygen transport and availability according to Henry’s Law, suggests that inhaled oxygen during hyperbaric therapy can effectively address pathologies related to tissue hypoxia. For instance, hyperbaric oxygen (HBO) can penetrate ischaemic tissues through capillary action and facilitate oxygen transfer via simple diffusion gradients [8,9].

INDIRECT EFFECTS

Infected tissues often exhibit reduced neutrophil polymorphonuclear (PMN) activity, particularly in the presence of concurrent conditions such as cardiac diseases (11,12). By reversing

tissue and cellular hypoxia through hyperbaric oxygen therapy, there is a restoration of first-line immune defence mechanisms, including an enhancement in the phagocytic capacity against certain bacteria. Additionally, as some bacteria, such as anaerobes like *Clostridium perfringens*, thrive exclusively in the absence of oxygen, hyperbaric oxygen therapy is expected to exert a bactericidal effect on these species and a bacteriostatic effect on others, such as certain strains of *Escherichia* and *Pseudomonas*.

Hyperbaric oxygen therapy (HBOT) is also capable of suppressing the production of clostridial alpha-toxin [6,7], contributing to the reversal of hypoxia in injured tissues and stimulating collagen matrix formation, which is crucial for angiogenesis and wound healing. Notably, the alternation between hyperoxia and normoxia constitutes a potent stimulus for neovascularisation in healing areas [8,9,10], thereby enhancing microvascular perfusion. This effect is likely associated with the increased synthesis of nitric oxide (NO) induced by hyperbaric oxygen. In tissues subjected to acute ischaemia, HBOT has demonstrated significant benefits. Animal studies using reperfusion injury and skin graft models have recorded that HBOT inhibits neutrophil adhesion and post-ischaemic vasoconstriction [11,12]

In acute carbon monoxide (CO) poisoning, carboxyhaemoglobin (HbCO) is formed, which is approximately 240 times more stable than oxyhaemoglobin. The half-life of HbCO in ambient air is 520 minutes. Breathing 100% oxygen at atmospheric pressure reduces this to 80 minutes, whereas hyperbaric oxygen at 3 ATA decreases it to 23 minutes. Both animal studies and clinical trials have observed that early administration of HBOT results in a reduction of neurological damage and sequelae associated with carbon monoxide exposure.

THERAPEUTIC INDICATIONS

The Brazilian Federal Council of Medicine, through Resolution CFM No. 1.457/95, has sanctioned the use of Hyperbaric Oxygen Therapy (HBOT) for a variety of clinical indications, establishing stringent criteria and guidelines for its application by qualified medical practitioners or under their direct supervision. It is essential to emphasise that HBOT does not encompass the use of pure oxygen in normobaric settings or topical applications through pressurised tents.

The current therapeutic indications for HBOT include:

1. Decompression Sickness (DCS): Commonly encountered by divers, DCS results from the formation of nitrogen bubbles in the tissues due to rapid ascent. HBOT facilitates the reabsorption of these bubbles and alleviates symptoms associated with DCS.
2. Gas Embolism: This condition involves the presence of gas bubbles in the vascular system, which can lead to severe complications. HBOT helps in reducing the volume of gas bubbles and mitigating their effects.

3. Traumatic Air Embolism: Arising from injuries that introduce air into the vascular system, this condition can be life-threatening. HBOT is employed to reduce the size of the air bubbles and enhance their elimination from the body.
4. Carbon Monoxide Poisoning: Carbon monoxide (CO) binds to haemoglobin with a much higher affinity than oxygen, forming carboxyhaemoglobin. HBOT accelerates the elimination of CO from the body and reduces the risk of neurological sequelae.
5. Cyanide Poisoning: Cyanide interferes with cellular respiration. HBOT aids in the treatment of cyanide poisoning by enhancing the delivery of oxygen to tissues and supporting detoxification processes.
6. Gas Gangrene: This severe, often life-threatening infection caused by anaerobic bacteria is treated with HBOT to inhibit bacterial growth and enhance tissue oxygenation.
7. Fournier's Gangrene: A rapidly progressing form of necrotising fasciitis affecting the perineum and genital region, where HBOT is used to improve oxygen delivery to the infected tissues and support healing.
8. Necrotising Soft Tissue Infections: Conditions such as cellulitis, fasciitis, and myositis, which are characterised by rapid tissue destruction, benefit from HBOT due to its effects on bacterial inhibition and tissue regeneration.
9. Acute Traumatic Ischaemias: HBOT is employed in cases of crush injuries, compartment syndrome, and reimplantation of amputated limbs to reduce tissue damage and promote healing through enhanced oxygen supply.
10. Acute Vasculitis: Inflammatory conditions of the blood vessels, including those caused by allergic reactions, drug responses, or biological toxins (such as venom from arachnids, snakes, or insects), can be treated with HBOT to alleviate inflammation and support tissue repair.
11. Thermal and Electrical Burns: HBOT is utilised to improve wound healing, reduce oedema, and increase the oxygenation of burn injuries, facilitating recovery and reducing the risk of complications.
12. Refractory Wounds: Chronic ulcers, pre-diabetic lesions, pressure sores, and wounds with dehiscence of sutures can be managed with HBOT to enhance healing and overcome resistance to conventional treatments.
13. Radiation Injuries: Injuries resulting from radiation therapy, including radiodermatitis, osteoradionecrosis, and mucosal actinic lesions, are treated with HBOT to stimulate tissue repair and reduce radiation-induced damage.
14. Compromised or At-Risk Flaps or Grafts: HBOT is beneficial in salvaging compromised surgical flaps and grafts by improving oxygenation and reducing the risk of graft failure.

15. Osteomyelitis: Chronic bone infections that do not respond well to antibiotics can be treated with HBOT to enhance the delivery of oxygen to the infected bone and improve the effectiveness of antimicrobial therapies.
16. Acute Anaemia: In cases where blood transfusion is not possible, HBOT can provide an alternative method to increase the oxygen-carrying capacity of the blood and support cellular respiration.

These indications reflect the versatility and effectiveness of hyperbaric oxygen therapy in managing a range of conditions through improved tissue oxygenation and enhanced healing processes.

INDICATIONS ACCORDING TO THE PROTOCOL OF THE BRAZILIAN SOCIETY OF HYPERBARIC MEDICINE

The Protocol of the Brazilian Society of Hyperbaric Medicine stipulates several indications for Hyperbaric Oxygen Therapy (HBOT), which include:

- Recovery of Compromised Tissues: HBOT is indicated for the regeneration and repair of tissues suffering from inadequate oxygenation.
- Clinical Conditions Where HBOT is the Sole Treatment Option: In instances where hyperbaric oxygen therapy is the only viable treatment modality.
- Severe and/or Complex Injuries: For managing injuries that are classified as severe or complex in nature.
- Failure to Respond to Conventional Treatments: When patients do not exhibit adequate response to standard therapeutic interventions.
- Injuries Requiring Surgical Debridement: For cases where surgical removal of necrotic tissue is necessary.
- Rapid Deterioration with Risk of Mortality: In situations where there is a swift decline in the patient's condition, posing a significant risk of death.
- Injuries in Sensitive Areas: Such as the face, hands, feet, perineum, genitalia, and breasts.
- Refractory Injuries and Frequent Recurrences: For injuries that are resistant to conventional treatment and those that exhibit frequent recurrences.

Treatment protocols for HBOT vary significantly based on the specific pathology being addressed. These variations are influenced by whether the condition is acute or chronic, due to the differing cellular responses in various types of inflammation, including subclinical forms. Generally, treatments are administered in sessions lasting between 90 and 120 minutes, with pressures ranging from 2 to 3 ATA, depending on the medical discretion and the particular pathology involved. In specialised cases, such as diving accidents or gas poisoning, higher pressures and extended treatment

durations may be necessary. Sessions may be conducted from one to three times per day, and depending on the phase of treatment, may involve alternating-day sessions. Typically, the number of sessions ranges from 10 to 30 for acute conditions and from 30 to 60 for chronic conditions[1,2,3].

ADVERSE EFFECTS AND COMPLICATIONS

HBOT can be associated with various adverse effects, which are related to pressure variations and/or oxygen toxicity. These effects depend on the dosage of hyperbaric oxygen administered and the duration of exposure. Potential adverse effects include:

- Pulmonary Toxicity: Manifesting as pulmonary oedema, dry cough, retrosternal pain, and haemoptysis.
- Neurological Toxicity: Characterised by paresthesias, pareses, and seizures.
- Barotrauma: Affecting the ears and sinuses, causing discomfort and potential injury.
- Visual Disturbances: Transitory changes in vision may occur.

The majority of side effects and complications associated with HBOT are attributable to Boyle's Law, which is evident during both compression (the increase in pressure within the hyperbaric chamber) and decompression phases.

BAROTRAUMA

Barotrauma refers to injuries resulting from the inability to equalise pressure in closed cavities. During decompression, expanding air can exert excessive force on the walls of these cavities, leading to pain, bleeding, or perforation. The most commonly affected cavity is the middle ear (OM), where barotrauma can cause varying degrees of damage to the tympanic membrane (TM), potentially culminating in its rupture. This injury occurs when the pressure within the OM cannot be equalised with the external environment through the Eustachian tube. Similar mechanisms can lead to barotrauma in the paranasal sinuses or other air-filled spaces, such as closed cavities in teeth, behind diving masks, and less frequently, in the inner ear, potentially causing acute vertiginous syndrome [14, 15, 16].

GAS EMBOLISM

Gas embolism is an uncommon occurrence in hyperbaric clinics but is notably more frequent among divers due to rapid pressure changes [17, 18]. This condition arises at the end of a hyperbaric treatment during decompression if the patient fails to exhale air from their lungs. According to Boyle's Law, the reduction in pressure within the chamber leads to the expansion of gases; if the air is not exhaled, it may result in pulmonary rupture and subsequent entry of air into the arterial

circulation. This complication is particularly likely in patients with pre-existing pulmonary conditions that trap air in the alveoli due to obstructed bronchioles [19].

DECOMPRESSION SICKNESS (DCS)

Decompression sickness (DCS) is caused by the formation of nitrogen bubbles during the decompression phase following hyperbaric exposure. These bubbles can form in the blood, obstructing microcirculation, and in various tissues such as the skin, nervous system, and joints. Factors such as non-compliance with decompression tables, fatigue, stress, and dehydration can exacerbate the likelihood of developing DCS [20]. Patients undergoing hyperbaric oxygen therapy are not at risk for DCS since they are eliminating nitrogen throughout the treatment. However, in a multi-patient chamber, if air is inadvertently administered via a mask instead of oxygen, DCS becomes a theoretical risk. With a clinical protocol involving two hours of oxygen breathing at 2 ATA, DCS would not be expected to cause significant problems, even if an error occurred during treatment; however, at 2.4 ATA, it could pose a problem. It is crucial to implement fail-safe mechanisms to ensure the correct administration of oxygen to patients[20].

The primary concern lies with the internal guide supervising the patients, who breathes compressed air and is therefore subject to DCS if decompression procedures are neglected (conditions requiring extended treatment or significant depths necessitate decompression stops) or if their metabolic demands are increased. Consequently, internal guides should be trained to recognise the principal symptoms of DCS and seek immediate assistance if symptoms arise to prevent worsening of the condition, which could lead to lasting sequelae [21]. DCS is classified into two clinical presentations: Type 1 and Type 2. Type 1 DCS is characterised by cutaneous and joint symptoms such as rash, pruritus, arthralgia, and fatigue. Type 2 DCS, which can evolve from Type 1 if untreated, presents with neurological symptoms such as paralysis (monoparesis or plegia due to spinal cord injury, hemiplegia) or coma resulting from cerebral injury [21].

OXYGEN TOXICITY

NEUROLOGICAL TOXICITY

Neurological toxicity, also known as the Paul Bert effect, manifests acutely with symptoms including facial pallor, diaphragmatic spasms, diaphoresis, bradycardia, distress, reduced visual field, tinnitus, auditory hallucinations, vertigo, seizures, nausea, emesis, syncope, and facial muscle contractions such as lip, malar, nasal, and eyelid twitching [22]. Seizures are rare and typically occur only at pressures close to or exceeding 3 ATA, or in individuals with predisposing conditions such as hyperthyroidism, fever, or a history of seizures.

PULMONARY TOXICITY

Pulmonary toxicity, or the Lorraine Smith effect, presents more insidiously and is generally minimal in conventional hyperbaric oxygen therapy (HBOT) sessions, where oxygen exposure and treatment pressures are limited. However, individual susceptibility to pulmonary toxicity varies. Special caution is warranted in cases where patients are ventilated with high concentrations of oxygen between HBOT sessions, or if HBOT is particularly intensive (more than one treatment per day over extended periods) or prolonged (one treatment per day over extended periods)[23].

CONTRAINDICATIONS

Contraindications for HBOT are relatively few, but certain pre-existing conditions or concurrent therapies may be considered absolute or relative contraindications[23].

ABSOLUTE CONTRAINDICATIONS

Untreated pneumothorax is the only absolute contraindication universally agreed upon by experts[7]. Additionally, conditions such as haemodynamic instability and the use of specific drugs are noted contraindications:

- Doxorubicin (Adriamycin): Experimental studies have demonstrated that this chemotherapeutic agent can lead to a 87% mortality rate when combined with HBOT. It is advisable to wait at least one week after the last dose of this medication before resuming HBOT.
- Disulfiram (Antabuse): According to Heikkika and Caixeta (2003), disulfiram inhibits the production of superoxide dismutase, a primary defence against oxygen toxicity. Consequently, it is contraindicated in patients requiring multiple HBOT sessions.
- Cisplatin: Used in the treatment of various cancers, cisplatin interferes with DNA synthesis, delaying fibroblast production and collagen synthesis. Evidence suggests that HBOT may enhance the cytotoxic effects of this drug on tissues, thereby impairing wound healing.
- Mafenide Acetate (Sulfamylon): This agent is highly effective against bacterial infections in burn patients, surpassing silver nitrate therapy. Mafenide inhibits carbonic anhydrase, leading to hypercapnia and peripheral vasodilation. If a burn patient requires HBOT, mafenide ointment should be thoroughly removed and replaced with silver sulfadiazine (Silvadene, Demazine, and others) [24].
- Untreated Pneumothorax: Patients with untreated pneumothorax are contraindicated for hyperbaric environments due to the risk of exacerbating the condition by increasing intrathoracic pressure.

- Asthma: Patients with asthma should not be placed in a hyperbaric environment due to the potential exacerbation of their condition.
- Use of Electrical Equipment: certain electrical chips used in orthopaedic surgeries, particularly in spinal procedures, necessitate consultation with the engineer responsible for the device. Generally, such devices are not treated in hyperbaric chambers due to the risks associated with static electricity.

RELATIVE CONTRAINDICATIONS

- Upper Respiratory Tract Infections and Chronic Sinusitis: These conditions may impede the effective equalisation of pressure in the middle ear and paranasal sinuses, necessitating a prudent interruption of hyperbaric oxygen therapy (HBOT) for a duration of 3 to 4 days whilst the underlying infections are managed therapeutically[25].
- Convulsive Disorders: Patients with a history of epileptic or convulsive disorders are at an elevated risk of oxygen toxicity, specifically the Paul Bert effect. In instances where HBOT is deemed indispensable, it is advisable to employ prophylactic anticonvulsant therapy, such as benzodiazepines, to mitigate the potential risks associated with oxygen exposure[26].

Other pertinent relative contraindications include:

- Emphysema with CO2 Retention: Individuals with emphysema and concurrent carbon dioxide retention should be meticulously monitored, as hyperbaric conditions could exacerbate respiratory complications.
- History of Spontaneous Pneumothorax: A history of spontaneous pneumothorax represents a significant risk factor, warranting careful assessment prior to the administration of HBOT due to the potential for pressure-related complications.
- History of Thoracic Surgery: Patients with a history of thoracic surgical interventions may experience altered physiological responses to hyperbaric conditions, necessitating a thorough evaluation before initiating HBOT.
- History of Otosclerosis Surgery: Previous surgical intervention for otosclerosis may predispose patients to difficulties with pressure equalisation, necessitating cautious consideration when planning HBOT.
- Viral Infections: The presence of active viral infections can complicate the application of HBOT, necessitating appropriate management and resolution of the infection prior to treatment.

- High Fever: Elevated body temperature may interfere with the safety and efficacy of HBOT, requiring careful monitoring and management to ensure optimal therapeutic outcomes.
- Congenital Spherocytosis: This haemolytic condition, which affects red blood cell morphology, requires vigilant monitoring due to potential complications associated with hyperbaric exposure.
- Claustrophobia: Patients with claustrophobia may experience significant psychological distress within the confined environment of the hyperbaric chamber, potentially impacting their ability to undergo HBOT.
- History of Optic Neuritis: Individuals with a history of optic neuritis should be closely monitored, as hyperbaric oxygen exposure may influence visual and neurological outcomes.
- Diabetes Mellitus: Patients with diabetes should undergo rigorous blood glucose monitoring using haemoglucotests, and adhere to a prescribed insulin regimen to manage glucose levels effectively during HBOT[26].
- In general, HBOT is not indicated by overall medicine, and this is due to a number of factors, especially in underdeveloped countries, being the lack of financial resources the main one. Nevertheless, in spite of that, HBOT offers substantial clinical advantages across a spectrum of medical conditions, primarily due to its ability to enhance oxygen delivery and ameliorate hypoxic damage at the cellular level. By significantly increasing the partial pressure of oxygen (PPO2) within the hyperbaric chamber, HBOT promotes augmented oxygen solubility in plasma, as described by Henry's Law. This enhanced oxygenation is crucial for managing hypoxic conditions, facilitating cellular repair and functional recovery in compromised tissues. For example, in the management of gas gangrene and necrotising fasciitis, the elevated PPO2 reduces microbial virulence and accelerates wound healing through improved collagen matrix formation and angiogenesis.
- Additionally, HBOT plays a critical role in infection control. It enhances the bactericidal activity of neutrophils and contributes to infection resolution by creating an oxygen-rich environment that inhibits the growth of anaerobic bacteria such as *Clostridium perfringens*. Furthermore, HBOT suppresses the production of alpha-toxin by clostridial species and exhibits bacteriostatic effects against various pathogens, which is particularly beneficial in treating complex infections that may be inadequately managed by conventional therapies.

- The therapy is also effective in managing acute ischemia and radiation-induced injuries. HBOT mitigates the effects of acute ischemia, reduces reperfusion injury, and improves outcomes in cases of thermal and electrical burns by preventing neutrophil adhesion and post-ischaemic vasoconstriction, thereby enhancing microvascular perfusion and tissue viability. In radiation-induced injuries, HBOT alleviates radiation dermatitis and osteoradionecrosis by improving oxygenation and promoting tissue repair.
- However, HBOT is not without its drawbacks, which primarily arise from the physiological effects of high-pressure environments and potential adverse reactions. Barotrauma, a common complication, occurs when pressure in closed cavities such as the middle ear and paranasal sinuses cannot be equalised during pressure changes in the hyperbaric chamber. This condition can lead to pain, haemorrhage, and even perforation of the tympanic membrane. Similar effects may occur in other air-filled spaces, including dental cavities and, less commonly, the inner ear, potentially causing acute vertiginous symptoms.
- Oxygen toxicity represents another significant risk associated with HBOT. Neurological toxicity, known as the Paul Bert effect, can result in seizures and a range of acute symptoms, such as facial pallor, auditory hallucinations, and convulsions, particularly at pressures exceeding 3 ATA or in individuals with predisposing conditions like hyperthyroidism or a history of seizures. Pulmonary toxicity, or the Lorraine Smith effect, presents as dry cough, chest pain, and pulmonary oedema, especially with prolonged or intensive exposure to hyperbaric oxygen.

Several conditions pose absolute contraindications to HBOT, including untreated pneumothorax and interactions with specific drugs. For instance, pneumothorax must be addressed prior to initiating therapy to avoid exacerbating the condition. Certain medications, such as adriamycin and disulfiram, are known to interact adversely with HBOT, necessitating careful patient evaluation and management. Additionally, relative contraindications, including upper respiratory tract infections and chronic sinusitis, require temporary suspension of therapy while addressing the underlying issues to prevent complications. Patients with convulsive disorders, emphysema, or a history of pneumothorax require additional precautions and potentially adjunctive treatments to mitigate risks associated with HBOT.

The efficacy of HBOT is highly contingent upon adherence to specific treatment protocols, which can vary significantly based on the clinical condition being treated. These protocols encompass session duration, pressure settings, and frequency of treatment, all of which must be tailored to optimise therapeutic outcomes and minimise risks. Complications such as barotrauma and

oxygen toxicity necessitate diligent monitoring and management, underscoring the need for rigorous protocols and experienced clinical supervision to ensure patient safety and therapy efficacy.

In conclusion, while HBOT presents considerable benefits for a range of medical conditions, its application is constrained by specific clinical scenarios and contraindications. The therapy's limitations highlight the importance of careful patient selection and adherence to established treatment protocols to achieve optimal results and mitigate potential risks.

FINAL CONSIDERATIONS

- Hyperbaric Oxygen Therapy offers significant therapeutic advantages by enhancing oxygen delivery to hypoxic tissues, promoting wound healing, and improving outcomes in various conditions such as infections, ischemia, and radiation injuries. Despite its benefits, HBOT is not without risks, including barotrauma and oxygen toxicity, which necessitate careful patient selection and adherence to treatment protocols. Absolute and relative contraindications, such as untreated pneumothorax and interactions with certain medications, must be meticulously managed to prevent complications. Overall, while HBOT is a potent therapeutic modality, its successful application requires a thorough understanding of its benefits, limitations, and the need for precise clinical oversight

REFERENCES

1. Ars, B., Dirckx, J., Ars-Piret, N., & Buytaert, J. (2012). Insights in the physiology of the human mastoid: Message to the surgeon. *International Advances in Otolaryngology, 8*(2), 296-310.

2. Doyle, W. J. (2007). The mastoid as a functional rate limiter of middle ear pressure change. *International Journal of Pediatric Otorhinolaryngology, 71*, 393-402.

3. Alper, C. M., Kitsko, D. J., Swarts, J. D., & Doyle, W. J. (2011). Role of the mastoid in middle ear pressure regulation. *Laryngoscope, 121*(2), 404-408.

4. Gaiede, M., Swarts, J. D., Alper, C. M., Doyle, W. J., & Seres, I. (2010). Middle ear pressure regulation: Complementary active actions of the mastoid and the Eustachian tube. *Otolaryngology--Head and Neck Surgery, 31*(4), 603-611.

5. Magnuson, B. (2003). Functions of the mastoid cell system: Auto-regulation of temperature and gas pressure. *Journal of Laryngology & Otology, 117*, 99-103.

6. Alicandri-Ciufelli, M., Marchioni, D., Presutti, L., Villari, D., & Feletti, A. (2012). Mastoid: A vestigial function in humans? *Medical Hypotheses, 78*, 364-366.

7. Todd, N. W., Pitts, D. B., & Ryu, J. H. (1987). Mastoid size determined with lateral radiographs and computerized tomography. *Acta Otolaryngologica, 103*, 226-231.

8. Park, M. S., Yoo, S. H., & Lee, D. H. (2000). Measurement of surface area in the human mastoid air cell system. *Journal of Laryngology & Otology, 114*, 93-96.

9. Csákányi, Z., Katona, G., Nemeth, A., & Sziklai, I. (2011). Volume and surface of the mastoid cell system in otitis media with effusion in children: A case-control study by three-dimensional reconstruction of computed tomographic images. *Otolaryngology--Head and Neck Surgery, 32*(1), 64-70.

10. Swarts, J. D., & Doyle, W. J. (2011). Relationship between surface area and volume of the mastoid air cell system in adult humans. *Journal of Laryngology & Otology, 125*(6), 580-584.

11. Sade, J., & Fuchs, C. (1996). Secretory otitis media in adults: I. The role of mastoid pneumatization as a risk factor. *Annals of Otology, Rhinology & Laryngology, 105*(8), 643-647.

12. Tos, M., & Stangerup, S. E. (1984). Mastoid pneumatization in secretory otitis. *Acta Otolaryngologica, 98*, 110-118.

13. Swarts, J. D., Alper, C. M., Seres, I., & Doyle, W. J. (2012). Mastoid geometry in a cross-section of humans from infancy through early adulthood with a confirmed history of otitis media. *International Journal of Pediatric Otorhinolaryngology, 76*(1), 137-141.

14. Cinamon, U., & Sadé, J. (2003). Mastoid and tympanic membrane as pressure buffers: A quantitative study in a middle ear cleft model. *Otolaryngology--Head and Neck Surgery, 24*(6), 839-842.

15. Doyle, W. J. (2000). Experimental results do not support a gas reserve function for the mastoid. *International Journal of Pediatric Otorhinolaryngology, 52*(3), 229-238.

16. Swarts, J. D., Alper, C. M., Kitsko, D. J., & Doyle, W. J. (2010). Surface area-volume relationships for the mastoid air cell system and tympanum in adult humans: Implications for mastoid function. *Acta Otolaryngologica, 130*(11), 1230-1236.

17. Koc, A., Eryilmaz, A., Hanci, D., Koksal, S., & Gungor, A. (2003). Evaluation of the mastoid air cell system by high resolution computed tomography: Three-dimensional multiplanar volume rendering technique. *Journal of Laryngology & Otology, 117*, 595-598.

18. Cinamon, U. (2009). The growth rate and size of the mastoid air cell system and mastoid bone: A review and reference. *European Archives of Oto-Rhino-Laryngology, 266*, 781-786.

19. Lee, D. H., Jun, B. C., Kim, D. G., & Yeo, S. W. (2005). Volume variation of mastoid pneumatization in different age groups: A study by three-dimensional reconstruction based on computed tomography images. *Surgical and Radiologic Anatomy, 27*(1), 37-42.

20. Colhoun, E. N., Wild, D. C., & Atkinson, M. E. (1988). A comparison between area and volume measurements of the mastoid air spaces in normal temporal bones. *Clinical Otolaryngology, 13*, 59-63.

21. Albernaz, P. M. (1933). Contribuição ao estudo radiográfico da mastoide. Valor da posição occipital posterior (Worms-Bretton-Altschul). *Revista Brasileira de Otorrinolaringologia, 1*(3), maio-junho.

22. Bento, R. F., Miniti, A., & Marone, S. (1992). Estudo da relação do tamanho da mastoide e resultados de miringoplastia. *Revista Brasileira de Otorrinolaringologia, 58*(1), 21-26.

23. Siegel, M. I., & Doyle, W. J. (1975). The differential effects of prenatal and postnatal audiogenic stress on fluctuating dental asymmetry. *Journal of Experimental Zoology, 191*(2), 211-214.

24. Diamant, M. (1940). Otitis and pneumatization of the mastoid bone. *Acta Otolaryngologica* (Suppl.), 41, 1-149.

25. Wittmaack, K. (1918). Über die normale und pathologische Pneumatization des Schläfenbeins einschließlich ihrer Beziehungen zu den Mittelohrerkrankungen. *Fischer*.

26. Hill, C. A. (2011). Ontogenetic change in temporal bone pneumatization in humans. *Anatomical Record, 294*(7), 1103-1115.