POLISH HYPERBARIC RESEARCH 4(77)2021
Journal of Polish Hyperbaric Medicine and Technology Society

POSSIBLE APPLICATIONS OF HYPERBARIC OXYGEN THERAPY- NARRATIVE REVIEW

Barbara Nieradko-Iwanicka[1)], Daria Przybylska[2)], Piotr Siermontowski[3)], Cezary J. Kowalski[5)], Marta Wójciak-Czuła[4)], Andrzej Borzęcki[1)]

[1)] Department of Hygiene and Epidemiology, Medical University of Lublin, Poland, ORCID 0000-0002-4839-6003, ORCID 0000-0001-5920-2262
[2)] Department of Dermatology, Venerology and Pediatric Dermatology, Independent Public Healthcare Unit No.1 in Lublin, Poland, ORCID 000-0001-9628-2919
[3)] Department ofUnderwater Works Technology, Naval Academy in Gdynia, Poland
[4)] Team Ophtalmology Department Mazowiecki Szpital Brudnowski in Wasaw, Poland
[5)] Department of Pharmacology, Toxicology and Environmental Protection, Faculty of Veterinary Medicine, University of Life Sciences, Lublin,Poland ORCID 0000-0003-1751-0042

ABSTRACT

Hyperbaric oxygen therapy is a method supporting the treatment of many diseases. Oxygen therapy treatments are conducted in hyperbaric chambers, in which patients breathe pure, 100% oxygen with higher than atmospheric pressure. This allows to increase the amount of oxygen supplied to all cells of the body many times over. The treatment with hyperbaric oxygen therapy enables the patient to recover faster and be fully active, and also reduces the costs of standard treatment.
The aim of the study was to summarize the possible applications of hyperbaric oxygen therapy. The available literature in the PUBMED database was reviewed in September 2022 with the use of the phrases 'hyperbaric oxygen therapy', 'therapeutic applications'. The indications for therapy in a hyperbaric chamber are all kinds of diseases, both acute and chronic. The method supports the nourishment and regeneration of cells and tissues of the organism, and also slows down the aging process. However, due to the possible side effects of such therapy, patients should be qualified for its use after a careful analysis of their clinical condition and coexisting diseases. To sum up: hyperbaric oxygen therapy is most often used in the treatment of skin diseases and injuries, burns, and peripheral vascular diseases.
Keywords: oxygen therapy, hyperbaric chamber, COVID-19.

ARTICLE INFO

PolHypRes 2021 Vol. 77 Issue 4 pp. 73– 84
ISSN: 1734-7009 **eISSN:** 2084-0535
DOI: 10.2478/phr-2021-0022
Pages: 12, figures: 0, tables: 0
page www of the periodical: www.phr.net.pl

Publisher
Polish Hyperbaric Medicine and Technology Society

Original article

Submission date: 13.06.2021 r.
Acceptance for print: 14.09.2021 r.

INTRODUCTION

Hyperbaric oxygen therapy (HBO) is a therapeutic procedure involving the use of pure oxygen at increased pressure for the patient to breathe. It takes place in specially designed hyperbaric chambers. The pressure exerted on the patient undergoing hyperbaric therapy is the sum of atmospheric pressure and the pressure in the chamber (atmosphere absolute - ATA). In currently available hyperbaric chambers, the pressure is usually around 2.5 ATA. [1].

The device, which became the prototype for modern hyperbaric chambers called "domicilium", was designed in 1662 by the British physician and physiologist Nathaniel Henshaw. This device made it possible to breathe air of increased or reduced pressure thanks to a special system of valves and bellows pumping air into a hermetically sealed steel room. Compressed air was used to treat respiratory diseases. Healthy people also used this chamber to prevent lung diseases, facilitate breathing, and improve digestion and general well-being. In Europe, hyperbaric chambers entered general use in the 19th century [2].

High pressure allows you to multiply the amount of oxygen supplied to the cells and tissues of the body. This allows oxygen to be delivered even to areas of the body that are poorly supplied with blood. Proper oxygenation improves all vital functions of the body. Under hyperbaric conditions, oxygen is supplied to the body's cells not only by hemoglobin oxygenation, but also dissolved in blood plasma. It was shown that one liter of blood serum contains 3 ml of physically dissolved oxygen. Breathing 100% oxygen in normobaric conditions, the saturation of the blood serum with oxygen increases to 20 ml / l. The use of 100% oxygen in hyperbaric oxygen conditions increases the concentration of dissolved oxygen in the serum to 50 ml / l [3].

A standard treatment of oxygen therapy conducted in a hyperbaric chamber consists of three 20-minute cycles of hyperbaric oxygen breathing, between which there are five-minute breaks in breathing air. The total time for breathing hyperbaric oxygen is 60 minutes per exposure. The procedure also includes two ten-minute periods of compression and decompression at the beginning and end of the procedure, respectively, during which patients breathe air [1].

TYPES OF HYPERBARIC CHAMBERS

Currently, several types of chambers are used to conduct HBO [1]:

- Single-seat chambers are intended for one person. They allow the treatment to be carried out, both in the supine and sitting position. The procedure takes place without the use of an oxygen mask. These chambers come in various shapes. These are cylindrical chambers in which the patient is lying down, and spherical chambers where the patient is treated in a sitting position.
  Multi-site chambers that enable the procedure to be performed for several patients at the same time. The procedure takes place in a sitting position. The inside of the chamber is filled with air under increased pressure. Patients inhale oxygen through the mask.
- Gamow bags. The treatment chamber consists of an inflatable, portable bag in which high pressure is maintained. It is mainly used at high altitude to treat high altitude cerebral edema and pulmonary edema.

MECHANISM OF ACTION OF HYPERBAR OXYGEN ON THE BODY

The consequence of exposure to oxygen at higher than atmospheric pressure is a series of physical, biochemical and physiological changes taking place in the human body. Parallel to the increase in pressure, the volume of gas bubbles in the blood decreases, the carboxyhemoglobin half-life decreases, vasoconstriction occurs and the swelling of damaged tissues is reduced [1,3].

The mechanism of the anti-inflammatory effect of HBO results from the inhibitory effect of such therapy on the synthesis of inflammatory mediators, such as: nitric oxide, prostaglandin E2, TNF-α, interleukin 1β, interleukin 12, interferon γ, as well as the reduction of mRNA expression and type 2 cyclooxygenase. influence on the synthesis of pro-inflammatory cytokines, the consequence of HBO treatment is an increase in the release of anti-inflammatory cytokines, mainly interleukin 10 [4,5].

It is worth noting that higher oxygen pressures stimulate angiogenesis. Activation of the processes of formation of capillary blood vessels enables the improvement of oxygenation and the supply of nutrients to a number of cells, tissues and internal organs of the body, as well as facilitates the removal of unnecessary cellular metabolites. HBO stimulates fibroblasts, which are responsible for the synthesis of, among others collagen and elastin ensure skin elasticity [6].

HBO also regulates the activity of osteoclasts, cells significantly involved in the metabolic processes of bone tissue [7].

The influence of HBO on the immune system of the organism has been proven. When applied at pressures of up to 2.5 ATA, oxygen inhibits lipid peroxidation and beneficially stimulates the immune system. Higher pressures may have the opposite effect. HBO stimulates the antimicrobial function of neutrophils by influencing their ability to phagocytose. This treatment disrupts the cellular metabolism of both Gram-positive and Gram-negative bacteria, thus reducing the production of bacterial toxins. The effect of oxygen on the bacteria, however, depends on the pressure used. The pressure ranging in the range of 0.6–1.3 ATA promotes the growth of bacteria, while above 1.3 ATA inhibits it, disrupting the metabolism of bacterial cells. Oxygen is significantly more effective against anaerobic bacteria. HBO also enhances the effects of antibiotics and sulfonamides. Therefore, HBO is a recognized factor supporting the treatment of severe bacterial and fungal infections, including septic conditions [1].

It has also been confirmed that HBO increases the number of stem cells circulating in the body, which move to damaged cells and tissues, contributing to their revitalization [8].

The multidirectional influence of HBO causes a continuous expansion of indications for its use.

The aim of the study was to summarize the possible applications of hyperbaric oxygen therapy.

INDICATORS FOR USE HBO

The indications for therapy in a hyperbaric chamber are both acute and chronic diseases. Among acute diseases that are an indication for HBO and at the same time covered by NHF reimbursement, the following should be mentioned: decompression sickness, carbon monoxide poisoning, gas embolism, e.g. during surgery or catheterization, musculoskeletal injuries, multi-organ injuries, acute soft tissue ischemia, necrotic infection of soft tissues, 2nd and 3rd degree burns, deafness, which is the result of an acoustic trauma or is idiopathic. Chronic diseases qualified for hyperbaric therapy are: diabetic foot, complications after amputations (necroses, inflammations), bone necrosis or the risk of tissue necrosis, radiation damage, otitis externa, tissue infections after injuries, bedsores, abscesses, difficult-to-heal wounds [1,9].

The effectiveness of treatments in hyperbaric chambers has also been confirmed in the treatment of chronic skin diseases, including severe atopic dermatitis, poorly responding to standard methods of therapy [10].

HBO is also used to treat anemia caused by blood loss. This method plays an important role in the treatment of cardiovascular diseases, arterial hypertension, atherosclerosis, and stroke [11]. HBO, through its strengthening effect on the immune system, is helpful in the treatment of severe infections, including septic conditions [3].

It has also been proven that this method slows down the aging process, supports the nourishment and regeneration of cells. Therefore, hyperbaric oxygen is widely used in aesthetic medicine and cosmetology [12].

Studies on the effectiveness of HBO in patients with Alzheimer's disease confirmed slower progression of the disease and even improved cognitive functions, which significantly improved the quality of life of patients and extended their period of independence. This is mainly due to the improvement of metabolism in the nervous tissue and the improvement of cerebral microcirculation [13].

HBO is also used in pediatrics. The positive effect of this method of therapy has been proven in autistic children and in children with cerebral palsy. Recent studies show that many children with autism suffer from hypoperfusion in the temporal and frontal lobes of the central nervous system. Improving blood flow, increasing the oxygenation of nerve cells has a positive effect on concentration, improves the speed of association and reaction, improves mood, reduces the severity of irritability and anxiety. HBO therapy also improves muscle tone, which has a positive effect on the body's motor skills [14,15].

CONTRADICTIONS TO USE HBO

An absolute contraindication to HBO is untreated pneumothorax. Before the planned start of treatment in the hyperbaric chamber of a patient with pneumothorax, it is necessary to decompress it by installing a drainage. There is a risk of developing pneumothorax during decompression, which is a state of immediate threat to life [3,16].

Another contraindication to HBO is treatment with cytostatics such as: Doxorubicin, Bleomycin, Cisplatin. Doxorubicin is an anthracycline antibiotic with anti-tumor activity. The drug builds into the DNA structure of cancer cells and causes its disruption and fragmentation. Doxorubicin in combination with hyperbaric therapy damages the heart muscle. Before starting HBO, the drug should be discontinued about 2-3 days before the planned start of the procedures [17]. Bleomycin is a polypeptide anti-cancer antibiotic that inhibits the synthesis of genetic material and the division and growth of cells, leading to the initiation of the processes of apoptosis and aging of cancer cells. This drug increases the toxic effects of oxygen on the lungs. There are reports of the development of interstitial pneumonia and the development of acute respiratory failure in Bleomycin-treated patients who received 32–45% oxygen during surgeries. HBO is absolutely contraindicated even if the patient has stopped taking this drug [18].

Cisplatin is an inorganic compound containing platinum. Platinum complexes react with DNA, creating cross-links both within the molecule and between DNA molecules. The formation of abnormal bonds disrupts the structure of DNA, contributes to the formation of breaks in the DNA strand, disrupts the synthesis of DNA and RNA, and prevents cell division. HBO in combination with the use of Cisplatin increases the cytotoxic effect of this drug. It interferes with collagen synthesis and the functioning of fibroblasts, which significantly impairs wound healing. The increased ototoxic effects of cisplatin have also been demonstrated in experimental animals treated in a hyperbaric chamber [19].

Absolute contraindications to HBO also include the use of drugs such as Disulfiram and Mafenid. Disulfiram is used to treat alcohol dependence. It is an aldehyde dehydrogenase inhibitor that blocks the production of superoxide dismutase, and consequently weakens the efficiency of the antioxidant systems of the organism. Mafenide is an antibacterial agent, an inhibitor of carbonic anhydrase. It belongs to the group of sulfonamides. This drug is used in the topical treatment of skin diseases, burns and burn wounds complicated by infections. It causes peripheral vasodilation, which, in combination with the central vasoconstriction resulting from HBO, impairs wound healing [1].

Relative contraindications to the use of HBO include emphysema. Carbon dioxide retention in patients with chronic obstructive pulmonary disease stimulates breathing. Patients are at risk of apnea while taking HBO. Treatment of these patients in a hyperbaric chamber should be preceded by intubation and mechanical ventilation. In patients with emphysema, the use of HBO is associated with the risk of rupture of the emphysema bladder during decompression. Relative contraindications to HBO also include patients with a pacemaker. The use of very high pressure can deform some parts of the starter. It has been proved, however, that standard oxygen pressures in hyperbaric chambers did not lead to disturbances in the functioning of these devices [3].

Acute pulmonary viral infections may worsen during HBO. This may result from overlapping with an already existing infection, irritation of the lungs with oxygen. For other infections, e.g. chronic sinusitis, it is proposed to interrupt or delay treatment in the chamber until improvement occurs, except in patients requiring urgent HBO. Increased body temperature is also a relative contraindication to HBO. Fever predisposes to seizures.

Before starting HBO, try to lower your high body temperature. For urgent indications, in addition to antipyretics, the patient should receive prophylactic anticonvulsants. Epilepsy, as well as the lowered seizure

threshold, are not an absolute contraindication to HBO.

However, patients should receive anticonvulsants in advance, ensuring their therapeutic level in blood serum before starting treatment [1,20].

Congenital spherocytosis is also mentioned among the relative contraindications to HBO. In the course of this disease, HBO may lead to increased haemolysis. Patients with spherocytosis who require treatment in a hyperbaric chamber should not be disqualified. However, the therapists must be prepared for the possibility of complications. A relative contraindication to HBO is also a history of optic neuritis. In these patients, treatment should be discontinued in the event of any symptoms suggesting a threat of changes in the organ of vision [3].

According to current reports, the coexistence of neoplastic disease is not a contraindication to HBO. In oncology, HBO is used to increase the tumor's sensitivity to radiation. Data on the effect of HBO on the stimulation of tumor growth and metastasis has not been confirmed. Many cancer patients undergoing radiotherapy require HBO due to tissue damage and necrosis [21].

OXYGEN TOXICITY AND COMPLICATIONS OF HYPERBARIC OXYGEN THERAPY

In the human body, molecular oxygen undergoes many changes, resulting in the formation of reactive oxygen species. According to some authors, a healthy person converts from 3 to 10% of molecular oxygen into its reactive forms [22,23]. Efficiently operating antioxidant mechanisms keep them at a constant, safe level. However, their high concentration leads to the development of a number of pathologies resulting from oxidative stress. Reactive oxygen species damage protein and nucleic acid molecules, cause lipid oxidation, damage cell membranes, and take part in the initiation of apoptosis. Their influence on the development of cardiovascular diseases and neurodegenerative diseases has been proven [3].

Long-term stay in an environment with increased oxygen content and under increased pressure leads to an increase in oxidative stress. In people exposed to a hyperbaric environment, the antioxidant defense is weaker compared to people who are constantly in normobaric conditions [23,24,25].

The cells and tissues of the body are protected against the harmful effects of reactive oxygen compounds by, among others, proteins such as: transferrin, ferritin, lactoferrin, and haemosiderin, which bind transition metals and inhibit the production of toxic oxygen compounds. Antioxidant compounds (vitamin E, ascorbic acid, beta-carotene), enzymes (superoxide dismutase, catalase, glutathione peroxidase) and regulatory factors such as nitric oxide, adenosine, and some cytokines also have a protective effect [22,26,27].

The body's response to oxidative stress is also the synthesis of hest shock proteins (HSPs), which play a key role in maintaining cellular homeostasis. These proteins are called "chaperones". They protect other proteins from aggregation and are involved in taking the correct structure. HBO has been proven to increase the expression of these proteins in the lung tissue and in the cells of the spinal cord [18,28].

In addition to the antioxidant mechanisms, a number of external factors affect the oxygen tolerance of the body. Factors such as carbon dioxide, thyroid hormones, insulin, adrenaline, noradrenaline, hyperthermia, vitamin E deficiency, and steroids reduce oxygen tolerance [22,24,27].

Factors increasing oxygen tolerance include: hypothermia, glutathione, magnesium, selenium, beta-blockers, and chlorpromazine [3,22,25].

Respiratory symptoms are the first to appear in oxygen poisoning. Early symptoms of oxygen poisoning are irritation of the larynx and trachea, nasal swelling, chest tightness and pain. These symptoms may appear Respiratory symptoms are the first to appear in oxygen poisoning. Early symptoms of oxygen poisoning are irritation of the larynx and trachea, nasal swelling, chest tightness and pain. These symptoms may appear after 24 hours of breathing with 100% oxygen under normobaric conditions or after 6 hours of breathing with 100% oxygen at a pressure of 2 ATA. Longer exposures damage the alveolar epithelium and the capillary endothelium, resulting in pulmonary edema and atelectasis followed by hypoxia. The deterioration of the patient's clinical condition is due to the reduction of the vital capacity of the lungs. The early symptoms of oxygen toxicity to the lungs are reversible. Intermittent oxygen administration is the cornerstone of pulmonary toxicity prophylaxis. Therefore, oxygen is administered in three 20-minute sessions separated by 5-minute breaks for breathing compressed air. To standardize the assessment of the exposure of the organism to oxygen, the unit pulmonary toxicity dose UPDT has been introduced. 1 UPDT = breathing 100% oxygen for 1 min at sea level. Tables developed for this purpose are used to quantify the amount of oxygen used. The daily dose should not exceed 1440 UPDT. Respiratory symptoms appear first when applying pressures up to 2.5 ATA, while cerebral symptoms appear when applying higher pressures [3].

The toxic effect of oxygen on the central nervous system can be revealed after a short time of breathing 100% oxygen under increased pressure. The neurotoxic effects of oxygen may be evidenced by symptoms such as nausea, dizziness, hiccups, trembling of the eyelid and facial muscles, visual and hearing disorders, hallucinations, difficulties in breathing, unjustified fatigue and anxiety. In severe poisoning, there is a loss of consciousness and tonic-clonic convulsions. The most characteristic symptoms are seizures of generalized seizures of the "grand mal" type [3,20].

Neurological complications in the course of HBO occur relatively rarely in patients while maintaining the recommended level of pressure and duration of the procedure. In the past, they have been reported with a frequency of 1 in 10,000 treatments. In recent years, however, their frequency has increased and is at the level of 1 in 2000–3000 procedures. Many authors believe that this is associated with an increase in the number of comorbidities in patients undergoing HBO procedures as a risk factor, as well as with changes in therapeutic protocols for hyperbaric oxygen therapy. The identified risk factors for the occurrence of neurological complications include the use of higher than recommended pressure, CO2 retention, radionecrosis of the brain tumor, hypoglycemia and hyperthyroidism [29].

HBO complications may result not only from the toxic effects of oxygen, but also may be a consequence of a barotrauma. Such an injury is the result of the influence of the application of increased pressure on the gas spaces in the human body, the volume of which cannot be changed quickly, and thus the pressure cannot be equalized. Barotrauma (barotrauma) may affect the

middle ear, paranasal sinuses and lungs. About 15-20% of patients undergoing HBO sometimes experience ear pain or a feeling of blockage in the Eustachian tube. Barotrauma to the paranasal sinuses, mainly the frontal sinuses, is usually associated with a coexisting acute infection of the upper respiratory tract. This is one of the relative contraindications to HBO. Pulmonary barotrauma is a very rare complication that may develop in the form of a pneumothorax or even rupture of lung tissue [30].

The eye complications of HBO include myopia and cataracts. Myopia is the most common temporary condition reported by approximately 20% of patients undergoing HBO. Vision returns to normal within approximately three months after completing HBO. The cause of the temporary deterioration in vision is not fully understood. It is believed that this may be due to changes in the curvature of the cornea due to pressure fluctuations during compression and decompression, or to metabolic changes in the cornea and changes in lens refraction. Cataract is a rare complication, which may occur mainly in elderly patients and in patients with diabetes [3].

There are reports indicating the possibility of hypoglycaemia in diabetic patients treated in a hyperbaric chamber.

However, in these patients severe hypoglycaemia is very rarely observed, more often in type 1 diabetes. Hypoglycaemia results from increased insulin release in diabetics and faster glucose metabolism in the brain [31]. However, most authors suggest that HBO does not cause a clinically significant decrease in glycaemia [32].

Claustrophobia can also be a problem that hinders running HBO. Studies have shown that it occurs in one in 50 patients undergoing HBO. This applies to patients treated in multi-person as well as single-person chambers. In the currently used hyperbaric chambers, it is possible to maintain contact with the patient, which makes it possible to control this problem. In cases where it is necessary to continue therapy, sedatives administered to patients before the procedure are effective in preventing such conditions [16].

USE OF HBO IN PATIENTS WITH COVID -19 DIAGNOSIS

Recently, the importance of oxygen therapy in a hyperbaric chamber has been emphasized in patients diagnosed with COVID-19, as well as in patients convalescing after SARS-CoV-2 infection. Most infected patients develop mild or asymptomatic disease. However, some of them show symptoms of severe respiratory failure requiring hospitalization in the intensive care unit. Supportive measures such as nasal cannula oxygen therapy, oxygen mask, non-invasive ventilation, mechanical ventilation, and even extreme measures such as extracorporeal membrane oxygenation (ECMO) do not improve oxygenation in some patients. In such patients, attempts are made to use HBO. This therapy is effective in increasing tissue oxygenation by increasing the amount of dissolved oxygen in the plasma. HBO also reduces inflammation, reducing the adverse effects of a cytokine storm in COVID-19 patients.

HBO effectively minimizes the side effects of hypoxia resulting from pneumonia in the course of COVID-19, increases the body's efficiency and accelerates regenerative processes. This therapy significantly improves the quality of life of patients and reduces the intensity of symptoms such as: tiring cough, lack of physical condition, chronic fatigue, trouble concentrating and depressed mood [33].

The authors of Gorenstein et al., On the basis of studies carried out in a group of 20 patients aged 30 to 79 years with respiratory failure in the course of COVID-19, emphasized the high effectiveness and safety of using hyperbaric oxygen and the positive effect of the treatments on the health of the subjects [34].

Similar results were presented by other authors who conducted studies among patients with positive results of SARS-CoV-2 infection. The study patients had low oxygen saturation despite the use of oxygen therapy with high oxygen flow. HBO was used to prevent the need for mechanical ventilation. These patients received from one to six treatments in dedicated single-site hyperbaric chambers [35,36].

To date, however, relatively few studies have been conducted on the use of HBO in the group of patients infected with SARS COV2. The number of references on this issue is also limited. Therefore, the final confirmation of the potential efficacy of HBO therapy in COVID-19 pneumonia requires evaluation in the future in randomized clinical trials.

CONCLUSION

Despite the complications and possible side effects, HBO is a valuable method of treating many diseases. Its effectiveness is confirmed by numerous studies. When used in conjunction with other methods, it shortens the total treatment time and lowers costs. However, this therapy should be used after proper selection of patients and planned according to their clinical condition and comorbidities, as, like any therapy, it is associated with the possibility of side effects.

REFERENCES

1. Paprocki J., Gackowska M., Pawłowska M., Woźniak A.. Aktualne zastosowanie hiperbarii tlenowej. Med Rodz. 2016, 19,4, 217-222.
2. Narożny W., Siebert J. Możliwości i ograniczenia stosowania tlenu hiperbarycznego w medycynie. Forum Medycyny Rodzinnej. 2007, 1, 4, 368–375.
3. Szymańska B., Kawecki M., Knefel G. Kliniczne aspekty hiperbarii tlenowej. Wiad. Lek. 2006, 59, 105-109.
4. Bigley N.J., Perymon H., Bowman G.C., Hull B., Stills H.F., Henderson R.A.. Inflammatory cytokines and cell adhesion molecules in a rat model of decompression sickness. J Interferon Cytokine Res. 2008, 28, 55–63.
5. Kudchodkar BJ, Jones H, Simecka J, Dory L. Hyperbaric oxygen treatment attenuates the pro-inflammatory and immune responses in apolipoprotein E knockout mice. Clin Immunol. 2008, 128,3,435-441.
6. Godman C.A., Chheda K.P., Hightower L.E., Perdrizet G.,Shin D.G., Giardina C. Hyperbaric oxygen induces a cytoprotective and angiogenic response in human microvascular endothelial cells. Cell Stress Chaperones. 2010,15,431–42.
7. Hadi H.A., Smerdon G.R, Fox S.W. Hyperbaric oxygen therapy suppresses osteoclast formation and bone resorption. J Orthop Res. 2013,31,11,1839-1844.
8. Geng C.K., Cao H.H., Ying X., Yu H.L. Effect of mesenchymal stem cells transplantation combining with hyperbaric oxygen therapy on rehabilitation of rat spinal cord injury. Asian Pacific Journal of Tropical Medicine.2015,8,6,468-473.
9. Klimek M., Szaraniec W.; Rojczyk E., Wilemska-Kucharzewska K., Kucharzewski M. Rola Tlenu W Procesie Gojenia Ran. Leczenie Ran . 2017, 14,3, 103-108.
10. Olszański R. , Konarski M. , Siermontowski P. Leczenie tlenoterapią hiperbaryczną (HBOT) jako opcja terapeutyczna dla chorych na atopowe zapalenie skóry (AZS) – doświadczenia własne i przegląd piśmiennictwa. Polish Hyperbaric Research. 2017, 60,27-30.
11. Cozene B., Sadanandan N., Gonzales-Portillo B., Saft M., Cho J., Park Y.J. Borlongan C.V. An Extra Breath of Fresh Air: Hyperbaric Oxygenation as a Stroke Therapeutic. Biomolecules 2020, 10, 1279-1305.
12. Tamaki A., Silverman D.A., Ozer E. The Role of Hyperbaric Oxygen in Head and Neck Reconstruction and Facial Cosmetic Surgery. Facial Plast Surg.2020, 36, 6, 753-759.
13. Harch P.G., Fogarty E.F. Hyperbaric oxygen therapy for Alzheimer's dementia with positron emission tomography imaging: a case report. Med Gas Res. 2018,8,181-184.
14. Granpeesheh D., Tarbox J. Dixon D.R., Wilke A.E., Allen M.S., Bradstreet J.J. Randomized trial of hyperbaric oxygen therapy for children with autism. Res Autism Spectr Disord 2010,4, 268-275.
15. Sakulchit T., Ladish C., Goldman R.D.. Hyperbaric oxygen therapy for children with autism spectrum disorder Canadian Family Physician. 2017, 63, 6, 446-448.
16. Clark J. Side effects. w Gesell L.B. Hyperbaric oxygen therapy indications. Durham, Undersea and Hyperbaric Medical Society Inc. 2008, 215–220.
17. Chatterjee K., Zhang J., Honbo N., Karlier J.S.: Doxorubicin cardiomyopathy. Cardiology 2010, 115, 155-162.
18. Tanaka K., Tanaka Y., Namba T., Azuma A., Mizushima T. Heat shock protein 70 protects against bleomycin-induced pulmonary fibrosis in mice. Biochem Pharmacol. 2010,80,920–923.
19. Cobanoglu H.B., Vuralkan E., Arslan A., Mirasoglu B., Toklu A.S. Is Hyperbaric Oxygen Therapy Effective in Cisplatin-Induced Ototoxicity in Rats. Clin Exp Otorhinolaryngol. 2019,12,1, 66–71.
20. Fischer I.,Barak B. Molecular and Therapeutic Aspects of Hyperbaric Oxygen Therapy in Neurological Conditions. Biomolecules 2020, 10, 1247-1264.
21. Moen I, Stuhr L. Hyperbaric oxygen therapy and cancer – a review. Targ Oncol, 2012, 7, 233–242.
22. Kozakiewicz M. , Olszański R. , Siermontowski P. , Dąbrowiecki Z. , Kędziora J. Procesy pro - i antyoksydacyjne w warunkach hiperbarii. Polish Hyperbaric Research. 2011,1,34, 21-26.
23. Kozakiewicz M., Kędziora J., Kędziora-Kornatowska K., Pawluk H., Olszański R., Dąbrowiecki Z., Kornatowski T. Wpływ hiperbarii na wybrane parametry stresu oksydacyjnego we krwi nurków. Polish Hyperbaric Research. 2005,3,12, 7-1.
24. Paprocki J., Pawłowska M., Sutkowy P., Piechocki J., Woźniak A. Równowaga oksydacyjno-antyoksydacyjna we krwi osób z nagłym niedosłuchem czuciowo-nerwowym po przeprowadzonym pierwszym zabiegu hiperbarii tlenowej – badanie wstępne. Polish Hyperbaric Research. 2017,4,61, 15-24.
25. Szyller J., Kozakiewicz M., Siermontowski P. Wpływ hiperoksji i hiperbarii na ekspresję białek szoku cieplnego i aktywność syntazy tlenku azotu – przegląd badań. Polish Hyperbaric Research. 2017, 1,58, 41-50.
26. Gałecka E.,Jacewicz R.,Mrowicka M.,Florkowski A., Gałecki P. Enzymy antyoksydacyjne – budowa, właściwości, funkcje. Pol Merk Lek. 2008, 25,147,266- 268.
27. Paprocki J., Pawłowska M., Piechocki J., Woźniak A. Wybrane wskaźniki stresu oksydacyjnego we krwi obwodowej osób z nagłym niedosłuchem czuciowo-nerwowym leczonych terapią kortykosteroidową skojarzoną z hiperbarią tlenową. Biuletyn Polskiego Towarzystwa Medycyny i Techniki Hiperbarycznej. 2017, 24, 80-82.
28. Ni X.X., Ni M., Fan D.F., Sun Q., Kang Z.M., Cai Z.Y., Liu Y., Liu K., Li R.P, Xu W.G. Heat-shock protein 70 is involved in hyperbaric oxygen preconditioning on decompression sickness in rats. Exp. Biol.Med. 2013, 238,1, 12-22.
29. Szymańska B, Kawecki M, Knefel G. Clinical aspects of hyperbaric oxygenation. Wiad Lek. 2006,59,1-2,105-109.
30. Siermontowski P, Spałek E. Uraz ciśnieniowy zatok obocznych nosa u nurków. Polish Hyperbaric Res. 2005, 1,10,31–36.
31. Stevens S.L., Narr A.J., Claus P.L., Millman M.P., Steinkraus L.W. Shields R.C., Buchta W.G., Haddon R., Wang Z., Murad M.H. The incidence of hypoglycemia during HBO2 therapy: A retrospective review. Undersea Hyperb. Med. 2015, 42, 3, 191-196.
32. Iii M.H., Wojcik S.M., Swaby J., Boes T. Blood glucose levels in diabetic patients undergoing hyperbaric oxygen therapy. Undersea Hyperb Med. 2019, 46,4, 437-445.
33. Senniappan K., Jeyabalan S., Rangappa P., Kanchi M. .Hyperbaric oxygen therapy: Can it be a novel supportive therapy in COVID-19? Indian J Anaesth.2020, 64,10, 835-841.
34. Gorenstein S.A., Castellano M.L., Slone E.S., Gillette B. , Liu H., Alsamarraie C., Jacobson A.M., Wall S.P., Adhikari S., Swartz J.L., McMullen J.J.S., Osorio M., Koziatek C.A., Lee D.C. Hyperbaric oxygen therapy for COVID-19 patients with respiratory distress: treated cases versus propensity-matched controls .Undersea Hyperb Med.Third-Quarter. 2020,47,3,405-413.
35. Thibodeaux K., Speyrer M., Raza A., Yaakov R., Serena T.E. Hyperbaric oxygen therapy in preventing mechanical ventilation in COVID-19 patients: a retrospective case series J Wound Care. 2020, 1, 29(Sup5a), 4-8.
36. Guo D., PanS., Wang M., Guo Y. Hyperbaric oxygen therapy may be effective to improve hypoxemia in patients with severe COVID-2019 pneumonia: two case reports Undersea Hyperb Med.2020,47,2,181-187.

Daria Przybylska
Katedra i Klinika Dermatologii, Wenerologii i Dermatologii Dziecięcej,
Uniwersytet Medyczny w Lublinie