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Applications of Hyperbaric Oxygen Therapy in Plastic Surgery

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Abstract

This study reviews the use of Hyperbaric Oxygen (HBO_2) therapy in plastic surgery patients. HBO_2 increase tissue oxygenation with increased oxygen pressure, secondary to the increased oxygen levels, neovascularization, vasoconstriction, activation of fibroblast activity, stimulation of collagen production, anti-inflammatory effects, immune stimulation are seen in the tissue. It might be helpful with; radiation induced necrosis, necrotizing fasciitis, crush injury, compartment syndrome, burns, compromised flap and graft surgery, prevention of scar formation, facelift surgery, ischemic non healing chronic wounds, minimally invasive procedures, replantation and revascularization in plastic surgery. Crush injury and compartment syndrome appear to benefit through preservation of ATP in cell membranes and reduces the leak into the interstitial space in the damaged tissues which limits edema. Radiation induced necrosis may cause decreased success rate of performed free flaps, difficulty in graft security, decreased viability of flaps, and the risk of repeated surgery. It also increases tissue oxygen tension in necrotizing fasciitis wounds whether caused by either a single organism or more frequently by a variety of microbes — both aerobic and anaerobic, thereby salvaging critically ischemic areas. In burn patients reducing edema, decreasing fluid requirements thus allows shorter hospital stays and decreased number of surgeries. In compromised graft and flap HBO_2 increase vessel diameter and revascularization, shortens recovery time with decreased tissue edema by vasoconstriction and pressure. HBO_2 appear to benefit as an adjunctive therapy where vicious cycle of hypoxia, inflammation and edema is seen in perioperative plastic surgery procedures.

Keywords: Hyperbaric oxygen; Plastic surgery; Radiation induced necrosis; Necrotising infections; Graft-flap surgery; Burns; Chronic wounds.

Introduction

Oxygen was first discovered by Joseph Priestley in the late 17th century. Due to increasing physiological studies, a cardiovascular surgeon found that oxygen can be used in hyperbaric treatments in 1956 [1]. Afterwards, although forgotten for a while, its use increased with studies showing its effectiveness. At the end of the 1970s, the basic terms and principles of HBO_2 therapy were published by The Undersea and Hyperbaric Medical Society and these guidelines have been revised periodically. In principal, hyperbaric oxygen is a treatment in which a patient breathes 100% oxygen intermittently or continuously while inside a treatment chamber at a pressure higher than at sea level pressure [2]. For this purpose, closed circuit systems were designed. In single or multi-person chambers oxygen is delivered to the patient through a mask, tube or a hood. The basis of the healing effect of HBO_2 therapy today is that tissue oxygenation is increased with increased oxygen pressure. Secondary to the increased oxygen levels, neovascularization, vasoconstriction, activation of fibroblast activity, stimulation of collagen production, anti-inflammatory effects, immune stimulation are seen in the tissue. At 1 ATA pressure, 97%-99% of oxygen is carried with hemoglobin in the bloodstream. The remaining oxygen is carried in the plasma as a dissolved gas. It is aimed to prevent hypoxia in the tissue by increasing the amount of oxygen dissolved in the blood with HBO_2 therapy. Vasoconstriction is observed in thin-walled vessels with the increased arterial and tissue oxygen pressure (such as choke vessels in hypoxia). Thus, the reduction of tissue edema is known to decrease tissue pressure in cases such as post-traumatic edema and compartment syndrome. With the increase of oxygen levels in the tissue, the synthesis of growth factors, which are crucial for the inflammatory and remodeling phase in wound healing also increase. Neoangiogenesis is accelerated by the secretion of these growth factors, and increased microvascular networks and oxygen levels create a synergistic effect on tissue [1,2]. The clinicians benefit from this healing effect in chronic wounds which are difficult and troublesome in plastic surgery practice. Also, the function of tissue cleansing improves with the secreted growth factors, increased oxygen levels and neoangiogenesis [3]. It also plays an important role in preventing the toxic effect of the organisms in macrophage activation, defects in leukocyte function and especially in anaerobic infections [3].The approved indications by the Undersea and Hyperbaric Medical Society for hyperbaric oxygen therapy listed below.

- Decompression sickness

- Acute arterial gas emboli
- Necrotizing fasciitis
- Gas gangrene
- Refractory osteomyelitis
- Acute blood loss anemia
- Failed skin grafts
- Chronic radiation injury
- Carbon monoxide poisoning
- Acute thermal injury
- Compartment syndromes
- Compression injury
- Cranial abscess
- Arterial insufficiency
- Acute sensory hearing loss

The side effects may include barotrauma, decompression sickness, oxygen toxicity, vomiting, cataracts, refractive error, fatigue, hypoglycemia, thrombocytopenia, headache, increased hair growth and respiratory distress. Most side effects are temporary and can be reversed by a symptomatic treatment or discontinuation of the treatment. The only absolute contraindication is untreated pneumothorax [3].

HBO_2 in Plastic Surgery Practice

Radiation induced necrosis

Radiotherapy (RT) for most tumors is successfully performed by oncologists. However, the possible side effects after the application cannot be ignored. The acute effects of RT are mostly temporary. However, late effects appear to be difficult to overcome. For example, fibrosis, skin atrophy, ulceration, skin necrosis, fistula, great vessel rupture, impaired wound healing are often the results of hypoxia and arteriosclerosis caused by RT [4]. Therefore, in the area where radiation is applied, clinicians may suffer from decreased success rate of performed free flaps, difficulty in graft security, decreased viability of local or regional flaps, and the risk of repeated surgery. In a study, HBO_2 administration was shown to increase the oxygen tension in such tissue by 80% with increased neovascularization [1]. In another study, mandibular osteonecrosis was found to reduce from 92% to 10% in a case with head and neck tumor where RT was applied using HBO_2 [5]. Perioperative HBO_2 is recommended to reduce the complications of RT. Williams et al. conducted a study with 14 patients with pelvic soft tissue radiation induced necrosis. All patients had gynecologic malignancy and underwent 15 sessions of hyperbaric oxygen therapy. All patients improved to complete resolution of necrosis with hyperbaric oxygen. Only one treatment failure happened [6]. In a review with 14 trials 752 participants HBO_2 found effective for non-neurological radiation tissue injury [7]. A single study by Tobey et al was a positive randomized controlled trial [8]. It was a small study with only 12 patients enrolled; however, it was double blinded and reported to be a positive trial by the authors. Details of randomization and outcome determinants were not clearly stated. Patients received either 100% oxygen at 1.2 ATA or 2.0 ATA. The paper states that those treated at 2.0 ATA experienced significant improvement compared to the control group.

Necrotizing fasciitis

Necrotizing fasciitis is a progressive, life-threatening, bacterial infection of the skin, the subcutaneous tissue and the underlying fascia. The patients usually have comorbidities initiating the disease. Slow or insufficient host immune response to the infection causes the rapid progression of the disease. Anaerobic bacteria tend to target and destroy the hypoxic regions. HBO_2 increases tissue oxygen tension in necrotizing fasciitis wounds whether caused by either a single organism or more frequently by a variety of microbes both aerobic and anaerobic, thereby salvaging critically ischemic areas [5]. This can be explained by increased leukocyte response to the infection and macrophage activation, prevention of proliferation of anaerobic bacteria, and increase of oxidation-reduction potential. HBO_2 assists wound healing as it can disable the toxins of certain bacteria [2]. Early diagnosis, timely and extensive debridement and appropriate antibiotic treatment are important in the treatment of this life-threatening soft tissue necrosis. In clostridial necrotizing fasciitis, the treatment plan may be at 3 ATA for 90 minutes three times in the first 24 hours and twice a day for the next 2 to 5 days. In non-clostridial necrotizing fasciitis cases, an initiation treatment with HBO_2 at 2-2.5 ATA for 90 minutes twice a day is recommended. Upon clinical response, it can be reduced to once a day and 30 sessions in total [9,10].

Crush injury and compartment syndrome

Acute ischemia can result in extensive tissue necrosis or even amputation of the affected limb. Even if the limb can be protected, problems such as non-union, infection, and non-healing wounds can be seen in the patient follow-up. In crush injuries, vasoconstriction leads to an overall decrease in tissue edema and increased tissue oxygenation. Another hypothesis that explains its edema-reducing effect was developed by Nylander [11]. According to hypothesis, HBO_2 enables cell reserves of Adenosine Triphosphate (ATP) to be maintained and reduces the leak into the interstitial space in the damaged tissues. In addition, the ischemic environment after trauma poses a risk for the development of anaerobic infection. In addition, ischemia after trauma poses a risk for anaerobic infections. The energy required for basic cellular activities during ischemia is supplied with a small and inadequate amount of energy released by glycolysis [11]. Thus, cell deaths after traumatic injuries are caused by mechanical factors as well as others. HBO_2 promotes aerobic metabolism by high supply of oxygen, and resistance to anaerobic bacteria [2]. As mentioned above, HBO_2 can reduce ischemia injury; however, reperfusion injury which is the harmful effect in which re-oxygenation induced tissue injury may occur. Free oxygen radicals and lipid peroxidation play a major role in reperfusion injuries. There are studies showing that HBO_2 therapy protects the tissue from lipid peroxidation by expanding roles of superoxide dismutases in cell regulation [12]. HBO_2 should be started as soon as possible in crush injuries and compartment syndromes (in 6 hours after trauma). The recommended treatment profile consists of hyperbaric oxygen at 2-2.5 ATA for 90 minutes, 3 times a day for the first 48 hours, followed by once a day for the next 2 to 5 days [9,10,13].

Burns

The skin is the human body's largest organ and carefully regulates the loss of fluid from the body. Fluid loss is a major factor associated with burn mortality. Therefore, some guidelines for fluid resuscitation in burn patients have been established and an effective dressing is recommended to avoid the tissue destruction. In the first 24 hours, the rapid extension of injury at the cellular level indicates that early intervention is likely necessary to limit burn injury progression. Cianci showed a reduction in the need for surgery from 8% to 3.7%, in a series of patients with 40%-80% burns (same age and same depth of burn) when compared to non-HBO_2 treated controls [14]. HBO_2 also reduces capillary occlusion pressure by minimizing platelet aggregation. Thus, capillary occlusion in the zone of coagulation occurring within the first two days of the injury is prevented. In summary, HBO_2 has potentially beneficial effects on the microcirculatory environment. It decreases tissue edema and supplies the needed oxygen. It also contributes to the production of collagen, which is the most prevalent component of the extracellular matrix, by increasing hydroxyproline levels in the wound tissue.

Flap and graft surgery

Surgical applications of skin flap and graft surgeries which are the fundamental techniques of plastic surgery, have recently required new studies on flap viability. HBO_2 therapy has been shown to be extremely useful in flap salvage, and help maximize the viability of the compromised tissue after the surgery. However, in the guideline of the Ministry of Health for the clinical practice, there are no indications associated with its preoperative planning in order to increase in flap viability. It has been used to improve ischemic wounds before skin grafting and to support the ischemic flaps as well as in the case of graft loss recurrence [15]. HBO_2 is urgently recommended for ischemic tissues [16]. In flap and graft surgery, HBO_2 shows its positive effects with the increase in vessel diameter and revascularization, shorter recovery time, decreased tissue edema by vasoconstriction and pressure on the flap [17,18]. However, the factors causing circulatory disorders (the anastomotic patency of free flaps, venous insufficiency, pedicle compression due to tight dressing, etc.) should be investigated before HBO_2 [19]. The recommended treatment profile consists of hyperbaric oxygen at 2-2.5 ATA for 120 minutes, twice a day for 20 days [9,10,20]. The sessions can be reduced to once a day based on clinical response.

Prevention of scar formation

In plastic surgery, keloid and hypertrophic scars are relatively common problems which may be troublesome in case of recurrence. Unlike a hypertrophic scar, keloid scars, which are more likely to occur in darker skinned individuals, extend well beyond the original boundaries of the wound, and often occurs on the chest, shoulders, upper back, back of the neck, and more frequently on the earlobes. The higher recurrence potential of a keloid scar compared to a hypertrophic scar keeps the clinicians in search of new treatments. The current treatment includes approaches such as steroid injections, excision, imiquimod, bleomycin, 5-fluorouracil laser removal, radiotherapy and silicone gel sheeting or a combination of these. The mechanisms of keloid formation include genetic and immunological contributions as well as other unclear factors. In some animal studies, factors such as hypoxic wound sites and other inflammatory factors during the healing process were found to be responsible for keloid formation [21]. All of these studies were based on the principles of the hyperoxic environment in hyperbaric oxygen therapy, balancing the inflammatory response, and inducing collagen production. However, in our current HBO_2 guideline, there is no indication for scar prophylaxis or prevention of recurrence.

Facelift surgery

During one's lifetime, healthy skin will have a tired, wrinkled and aged appearance due to several factors such as gravity, sun and ultraviolet exposure and aging. An increased life expectancy and welfare raises the interest in facelift surgeries. Facelift surgery in older patients is a procedure that can be complicated even in the most experienced hands. With an incision behind or in front of the ear or in the temporal area, the face can be stretched in composite facelift procedures. In fact, it is an indication mentioned earlier the in flap and graft surgery section, but face-lifting is another heading here since it is a specific aesthetic procedure. The use of HBO_2 in facelift procedures is based on increased oxygen transport, neovascularization and protection against ischemia reperfusion injury. In a prospective study on the effects of perioperative hyperbaric oxygen on bruising in facelifts, HBO_2 was shown to have a protective effect on ischemia and offer patients a quicker recovery in facelift surgery [22].

Chronic wounds

Patients with chronic wounds have a poor health-related quality of life in general and wound related costs including productivity loss in the workforce and medical interventions are substantial. Unlike normal wounds that often heal naturally, chronic wounds often remain in the inflammatory stage for more than 3 weeks, and fail to heal. HBO_2 is frequently used in the treatment of diabetic and ischemic foot ulcers, non-healing amputation stumps, chronic traumatic wounds, venous insufficiency ulcers. An important prognostic determinant of wound repair is the presence of hypoxia [23]. The partial pressure of oxygen in the chronic wound tissue may drop to 20 mmHg. In addition, a reduction in leukocyte functions and decreased phagocytic activity increase susceptibility to infections [18,23]. An infection added to the clinical status will cause a complication and a difficult recovery process. Before the use of HBO_2 in diabetic foot ulcers, a clinical assessment of vessel patency should be carried out because a low ankle-brachial pressure index can indicate that the patient will not benefit from HBO_2 [23]. In this patient group, bypass surgery or angioplasty options should be evaluated before treatment. Various studies have shown that HBO_2 therapy may reduce the risk of major amputation and also reduce the wound size and contribute to wound healing in chronic wounds [2,24]. Another study showed that HBO_2 alone was insufficient for the treatment

of diabetic foot ulcers; however, a combination of HBO_2 and Vacuum-Assisted Wound Closure (VAC) after wound debridement may increase the success of treatment. In addition, the use of HBO_2 therapy is limited in vascular ulcers and pressure ulcers, which are classified as chronic wounds. The recommended treatment profile based on clinical response consists of hyperbaric oxygen at 2-2.5 ATA for 90-120 minutes, once a day for 30 days [25,26].

Minimally invasive procedures

Recently, another aesthetic procedure that has been increasingly used is hyaluronic acid application. Hyaluronic acid-based dermal fillers have been proven to be safe and effective with careful application in a sterile environment. As it is a minimally invasive procedure, problems such as erythema, ecchymosis and itching after the application are often temporary. However, diffusion into the vascular lumen can cause problems such as skin necrosis, vision loss and stroke that may be both damaging for the patient and difficult for the clinician to manage. As for the complications of dermal fillers, better results can be obtained from HBO_2 when combined with vasodilators such as beraprost, alprostadil and nitroglycerin as well as aspirin and steroid [27]. In plastic surgery, another commonly used aesthetic process is chemical peel. Chemical peels are commonly classified based on their depth of skin penetration as superficial, medium, and deep peels. As deep penetration into the reticular dermis is most likely in medium and deep peels; possible outcomes may include pigmentation problems, abnormal wound healing, prolonged edema (up to 12 months), milia, photosensitivity and exfoliation. These complications can be reduced with the contribution of HBO_2 to new collagen production, facilitation of epithelialization and edema reduction [28].

Replantation and revascularization

Hand injuries occur as a result of a crush, avulsion, friction, burn, blunt trauma or their coexistence. It should be remembered that bones, tendons, muscles, nerves, vessels or skin may be affected. During the rehabilitation period, full functional recovery may not always be achieved. Functional upper limb reconstruction and rehabilitation becomes crucial at this stage because, prosthesis do not as closely approximate the function of the lost limb. Therefore, in order to increase the functionality of this important limb, different treatments to help acute wound healing are used. One of the most effective treatments is HBO_2, which should be started as soon as possible. Although there is no clear protocol, some studies recommend that a treatment profile based on a clinical response should consist of hyperbaric oxygen at 2-2.5 ATA for 90 minutes, twice a day. HBO_2 was shown to decrease finger amputation rates and effective in preserving partially viable tissue and restoring hand function in patients with mutilated hand injuries [29].

Conclusion

HBO_2 has been a proven treatment method used for many years now. The application in plastic surgery started in 1985. In the field of plastic surgery, HBO_2 is regarded as a successful adjunctive therapy for increasing tissue oxygenation and improving the hypoxic microenvironment. So it is important to be wise about when to apply HBO_2 is crucial for a plastic surgeon.

Conflict of Interest

Authors have no conflicts of interest to declare.

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