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Review Article

Hyperbaric Oxygen Therapy: A Novel Treatment Modality in Problem Wounds

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Abstract **In the present article we review the types and uses of, and indications for hyperbaric oxygen therapy (HBO, HBO_2). We also discuss the physiological and therapeutic rationale of HBO, with special reference to problem wounds. We present HBO within its proper therapeutic context and briefly mention the current trends and challenges associated with its use.**

Keywords: **Hyperbaric oxygen therapy, Problem wound, Wound healing**

Introduction

Hyperbaric oxygen (HBO, HBO_2) is used for various conditions and illnesses. Traditionally, HBO was used to treat diving complications. Today it serves as a primary or adjunctive therapy for a various range of medical conditions. The therapeutic efficacy of HBO can be mainly explained by the simple physical relationships determining gas concentration, volume, and pressure. The purpose of HBO is to increase the amount of oxygen in the blood. Hyperbaric oxygen acts as a drug, eliciting varying levels of response at different treatment depths, durations, and dosages and has proven effective as adjunctive therapy for specifically indicated conditions. It is a new modality of treatment that is used for hypoxic wounds. The primary usage of HBO in the United States currently is for wound care.

What is hyperbaric oxygen therapy?

Hyperbaric oxygen therapy is defined as a systemic treatment in which the entire patient is placed inside a pressurized chamber and breathes 100% oxygen under a pressure greater than one atmospheric pressure (1 ATA). Current informa-tion indicates that pressurization should be to 1.4 ATA or higher[1]. The pressure increases the level of oxygen dissolved in the blood plasma affecting the immune system, wound healing, and vascular tone[2].

Depending on the response of the individual patient and the severity of the illness, treatment regimen varies from 90 to 120 minutes once or twice daily. Overall treatment time may range from less than one week to several months' duration, the average being two to four weeks[3]. HBO treatment for more than two months is usually not necessary. Treatment with HBO

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requires patients to enter a hyperbaric pressure chamber. In this chamber 100% oxygen can be compressed to a pressure that is greater than 1 ATA. Two chamber types allow this to happen; the monoplace chamber and the multi-place chamber[4,5].

2.1 Monoplace hyperbaric chambers (Figures 1a-c)

Modern monoplace chambers were first commercially introduced in the 1960's. A monoplace hyperbaric chamber is typically pressurized with 100% oxygen so that the patient receives treatment by breathing the chamber atmosphere directly. This system accommodates one patient at a time, and no medical staff can enter. A monoplace hyperbaric chamber can be pressurized to 3 ATA. There is an intercom system allowing two-way communication between inside and outside the chamber. Patients can

Figure 1a A patient is placed on a gurney and moved into a monoplace hyperbaric oxygen chamber.

Figure 1b Patients can rest, listen to the radio or watch TV during treatment.

Figure 1c The intercom system allows the patients and HBO staff to communicate constantly.

Figure 2a Multiplace chamber at the Wound Care and Hyperbaric Medicine Center, Nix Hospital, San Antonio, Texas, is capable of treating seven patients at one time.

Figure 2b HBO staff can accompany patients in a multiplace chamber. Patients breathe 100% oxygen via oxygen hoods.

watch TV or listen to music during the treatment.

2.2 Multiplace hyperbaric chambers (Figures 2a-b)

A multiplace hyperbaric chamber is a large pressure chamber. It can hold two or more people, depending on configuration and size. Medical personnel can accompany patients. This chamber is pressurized with compressed air while the patients breathe 100% oxygen via masks, head hoods, or endotracheal tubes.

A comparison of the advantages and disadvantages between monoplace and multiplace chambers is given in Table 1.

HBO can be used to treat a wide variety of conditions. Utilizing knowledge gained from clinical experience and basic science research, the Undersea and Hyperbaric Medical Society (UHMS) Committee on Hyperbaric Oxygen has approved the use of HBO as adjunctive or primary treatment for the diseases and conditions listed below[1].

1. Air or gas embolism
2. Carbon monoxide poisoning, or carbon monoxide poisoning complicated by cyanide poisoning
3. Clostridial myositis and myonecrosis (gas gangrene)
4. Crush injury, compartment syndrome, and other acute traumatic ischemias
5. Decompression sickness
6. Enhancement of healing in selected problem wounds
7. Exceptional blood loss (anemia)
8. Intracranial abscess
9. Necrotizing soft tissue infections (necrotizing fasciitis)
10. Refractory osteomyelitis
11. Delayed radiation injury (soft tissue and bony necrosis)
12. Compromised skin grafts & flaps
13. Thermal burns

Table 1 A comparison between monoplace and multiplace chambers.

Monoplace Chamber	**Multiplace Chamber**
Advantages	**Advantages**
1. Less expensive to purchase and operate	1. Greater working pressure (6 ATA)
2. Requires little space and relatively minor facility renovations	2. Constant patient attendance
3. Modest program capitalization	3. Ability to use a variety of electrically generated signals
4. Treatment protocol specific to patient and/or condition	4. Attendants able to enter and exit during therapy
5. Modest staffing requirements	5. Ability to manage complications such as pneumothorax without releasing pressure
6. Patient does not wear mask/hood/head tent for O2 delivery	6. Ability to conduct intensive care activities during treatment
7. Chamber pressurized with 100 % oxygen	
8. Patient comfort and avoidance of potential mask leaks	
9. Relatively mobile chamber for possible relocation	**Disadvantages**
10. No risk of decompression sickness in patient or attendants	1. Higher capitalization requirements
11. Add-on capability for ease of program expansion	2. Major space requirements; basement and/or ground floor level limitations
12. Ability to use diagnostic or therapeutic equipment (transcutaneous O2 monitor, NIBP, Ventilator, IV pump, EKG)	3. Higher operating costs
	4. Larger and experienced staffing requirements
	5. Risk of decompression sickness in internal personnel
Disadvantages	6. All patients on same protocol
1. Patient isolated during treatment	7. Uncertain O2 delivery tension at Pt. with face mask
2. Inability to suction patient	8. Severe maxillofacial and/or head and neck involvement possibly making effective delivery of oxygen difficult
3. Limited pressure capability at 3 ATA	9. Facility fire-associated decompression requirements
4. Pure oxygen environment; associated fire hazard	10. Significant equipment maintenance and system upkeep requirements
5. Increased risk of complications from pneumothorax and/or tension pneumothorax and arterial air embolism developing during decompression	

Clinical benefits of hyperbaric oxygen therapy

HBO was traditionally used to treat diving complications, but is currently indicated for treating conditions associated with the specialties of orthopedics, surgery, plastic surgery, maxillofacial and oral surgery, infectious disease, radiation oncology and emergency medicine. HBO can also be used successfully to treat diabetic wounds.

The therapeutic effects of HBO on complicated wounds include[6-11].

1. Increasing oxygenation (hyperoxygenation)
2. Killing or stopping bacteria (hyperoxia-enhanced antimicrobial activity)
3. Promotes new blood vessels (neovascularization)
4. Reduces swelling and inflammation by vasoconstriction
5. Improves the rate of wound healing

By providing pure oxygen in a pressurized chamber, HBO delivers 10 to 15 times more oxygen than if delivered at normal atmospheric levels. Oxygen diffusion influences healing in necrotizing infections and hypoxic wounds. Oxygen is essential to full leukocyte functioning, and leukocyte oxidative burst requires a PO2 greater than 30. HBO has been demonstrated to have an antimicrobial effect and to increase oxygenation of hypoxic wound tissues[6-8]. HBO enhances neutrophil killing ability, stimulates angiogenesis, and enhances fibroblast activity and collagen synthesis[7,9,10]. The therapeutic rationale for HBO is summarized in Table 2.

Table 2 Therapeutic rationale for hyperbaric oxygen therapy

Indications	Mechanisms of Efficacy
Acute thermal burns	Reduced edema Infection control Increased epithelization and graft take
Clostridial myositis and myonecrosis	Suppression of toxin production Enhanced neutrophil function Antibiotic potentiation
Other necrotizing soft tissue infections	Enhanced neutrophil function Antibiotic potentiation
Compromised skin grafts	Increased neovascularization Reduced edema
Compromised flaps	Amelioration of ischemia-reperfusion injury Reduced edema
Crush injury, compartment syndrome, and other acute ischemias	Amelioration of ischemia-reperfusion injury Reduced edema
Osteoradionecrosis	Increased neovascularization
Soft tissue radionecrosis	Increased neovascularization
Refractory osteomyelitis	Enhanced neutrophil function Antibiotic potentiation Increased osteogenesis
Problem wounds	Increased neovascularization Increased collagen deposition Increased epithelization Reduced edema Reduced inflammation Enhanced neutrophil function
Diabetic Foot Ulcers (Wagner Grade 3+)	Increased granulation Enhanced neutrophil function Reduced edema

Hyperbaric oxygen therapy in problem wounds

Problem wounds are defined as those that fail to show improvement within four weeks or complete healing in eight weeks despite standard medical and surgical intervention. These may include diabetic foot ulcers, compromised amputation sites, vascular insufficiency ulcers, and non-healing traumatic wounds. All of these wounds have underlying tissue hypoxia[11].

Wound healing is arrested by decreased fibroblast proliferation, collagen production, and capillary angiogenesis in an hypoxic environment. Hypoxia also allows growth of anaerobic organisms, further complicating wound healing. Investigations of problem wounds in animal models suggested that elevation of wound oxygen tension to normal enhanced wound healing. Sheffield and associates[12,13] confirmed hypoxia in chronic, indolent, human wounds and demonstrated elevation of wound oxygen tension with HBO.

Transcutanous oximetry has become increasingly popular as a method of patient selection for HBO. HBO provides a significant increase in tissue oxygen tension. It influences to enhance fibroblastic proliferation, increase collagen synthesis, promotes neo-vascularization, and bacterial clearance in wounds. HBO may be useful when underlying osteomyelitis is present or to improve the soft tissue envelope for reconstruction.

There has also been increasing interest in the use of HBO as an adjunctive treatment for problem wounds in selected cases. Evidence for the effectiveness of HBO is especially strong in diabetic foot ulcers classified as Wagner Grade 3 or higher, for which hyperbaric oxygen is widely considered standard therapy. Amputation in these patients is considered a final line of treatment.

An amputation is associated with a higher risk of contralateral limb loss and seems to increase long-term mortality rates. In addition, amputation decreases quality of life and comes with several significant emotional and financial consequences. HBO is a highly effective modality that helps the body's natural ability to heal wounds and prevent possible limb loss. Several research studies report a significant decrease in amputation rates in patients with diabetic foot ulcers and necrotizing fasciitis when using adjunctive HBO[14,15].

HBO is thus a non-invasive course of treatment effective in improving the healing of problem wounds and decreases the risk of lower extremity amputations. However, HBO should not be a replacement for other standard therapeutic measures. The standard of care for treating problem wounds, including holistic assessment, the maintenance of optimal blood glucose levels, use of debridement, administration of antibiotics to control infection, and adequate nutrition, are still of utmost importance.

Side effects and complications

Hyperbaric oxygen therapy is generally safe and well tolerated. Most side effects are mild and reversible, although severe consequences can occur in rare cases[16-20].

Complications of increased atmospheric pressure include:

1. Barotrauma of the ear
2. Pulmonary barotrauma, including pneumothorax, mediastinal emphysema, pulmonary tissue damage, and air embolism
3. Sinus barotrauma

Complications associated with oxygen toxicity include:

1. Central nervous system effects (Paul Bert effect)
2. Pulmonary effects (Lorraine Smith effect)
3. Ocular effects
4. Cardiovascular complications

The most common side effects are middle ear barotrauma and claustrophobia, which occur in 2% of treatments. Other mild side effects include sinus squeeze, serous otitis, reversible progressive myopia, and in about 1 per 10,000 treatments, pulmonary and neurologic manifestations of oxygen poisoning[21].

Conclusion

Hyperbaric oxygen is a drug with well defined physiological and pharmacological effects that is used for helping all the functions of the body that require oxygen. The duration and number of treatments depend on the disease condition and its severity. It has been shown to be an effective method for treating problem wounds in carefully selected cases. Careful monitoring during the treatment sessions and follow-up by highly trained physicians and nurses are recommended. HBO is used extensively in the management of a variety of disorders refractory to standard medical and surgical care. It is not designed to replace other proven methods of treatment but to supplement other forms of treatment such as surgery, antibiotics administration, and standard wound care. Future research in HBO is still needed and is ongoing.

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