Apollo Medicine 2012 December
Volume 9, Number 4; pp. 318–322

Review Article

Use of hyperbaric oxygen therapy in management of orthopedic disorders

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ABSTRACT

The management of musculoskeletal disorders is an increasing challenge to clinicians. Successful treatment relies on a wide range of multidisciplinary interventions. Adjunctive hyperbaric oxygen (HBO) therapy has been used as an orthopedic treatment for several decades. Positive outcomes have been reported by many authors for orthopedic infections, wound healing, delayed union and non-union of fractures, acute traumatic ischemia of the extremities, compromised grafts, and burn injuries. HBO therapy significantly reduces the length of the patient's hospital stay, amputation rate, and wound care expenses.

Keywords: *Hyperbaric, Sports injury, Osteomyelitis, Healing, Fracture*

INTRODUCTION

Hyperbaric oxygen therapy is defined as "A mode of medical treatment in which the patient is entirely enclosed in a pressure chamber and breathes 100% oxygen at a pressure greater than 1 atmosphere absolute (ATA)".[1]

HBO therapy was designed for and initially used to treat patients involved in diving accidents or with decompression sickness. However, its indications have increased over the past few decades. Currently, there are 14 indications for HBO therapy approved by the Undersea and Hyperbaric Medical Society (UHMS) in the United States (Table 1). Many musculoskeletal disorders, such as refractory osteomyelitis, diabetic foot ulcers, non-union of fractures, severe soft tissue infections, and compromised grafts, are difficult to manage and require multidisciplinary treatment.[2] To improve the management of such cases with advanced antibiotics, debridement, modern orthopedic devices and aggressive wound care has been used. The outcome, however, has not been optimal. HBOT in adjunct with the above treatment modalities has shown to be of great benefit in the management of these hard-to-treat problems. It reduces the morbidity and mortality of these orthopedic diseases, as well as the cost of the care.[1,2]

PHYSIOLOGICAL BASIS OF HYPERBARIC OXYGEN THERAPY

Under normal conditions, we breathe air at sea level pressure and hemoglobin (Hb) is 95% saturated. At this time 100 ml blood carries 19 ml O_2 combined with Hb and 0.32 ml dissolved in plasma (Fig. 1). At this same pressure if 100% O_2 is inspired, O_2 combined with Hb increases to a maximum of 20 ml and that dissolved in plasma to 2.09 ml.[1–3]

According to Henry's Law, concentration of a gas dissolved in fluid is directly proportional to the pressure

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Received: 26.7.2012; Accepted: 6.8.2012; Available online 23.8.2012

http://dx.doi.org/10.1016/j.apme.2012.08.005

Table 1 UHMS approved indications for hyperbaric oxygen therapy.

1. Air or gas embolism
2. Carbon monoxide/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
10. Refractory osteomyelitis
11. Soft tissue/bone radiation necrosis
12. Compromised skin grafts and flaps
13. Thermal burns
14. Sensorineural hearing loss (approved in October 2011)

exerted on the gas. In other words, HBO therapy results in ''hyperoxic plasma,'' as HBOT cannot significantly increase amount of oxygen bound to Hb molecules but can increase amount of oxygen dissolved in plasma. The higher pressure during the HBO treatment pushes more oxygen into solution and amount of O_2 dissolved in plasma increases to 4.4 ml/dl at a pressure of 2 ATA and to 6.8 ml/dl at 3 ATA (Table 2).[3,4]

This additional oxygen in solution is almost sufficient to meet tissue needs of oxygen without contribution from oxygen bound to hemoglobin. This increased dissolved oxygen in plasma is responsible for most of the beneficial effects of hyperbaric oxygen.

Like any other treatment method, HBO therapy can also cause severe side effects and has associated risks. To understand more about this therapeutic modality, we reviewed forty-three papers published in the past four decades to

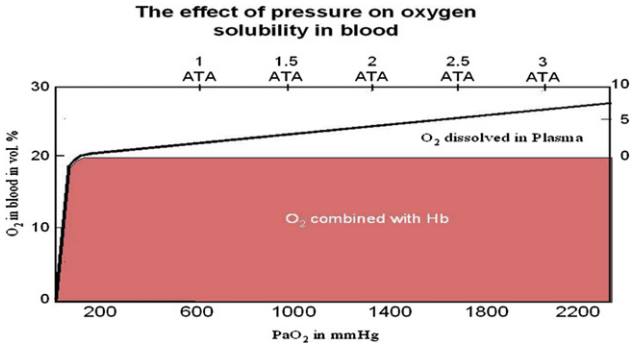

Fig. 1 HBO increases the amount of oxygen in solution and is responsible for its effects.

Table 2 Effect of pressure on arterial O_2.

O_2% level	ATA	Arterial O_2 tension (mmHg)	100% oxygen
21	1	100	0.32
100	1	660	2.09
100	2	1400	4.44
100	3	2200	6.80

clarify the mechanism, indications and contraindications, effectiveness, side effects, risks, and cost impact of HBO therapy.

ROLE OF HBO IN VARIOUS ORTHOPEDIC DISORDERS

1) HBO for osteomyelitis

HBO has been used for refractory osteomyelitis as an adjunctive therapy by many authors. Standard treatment for osteomyelitis includes radical local debridement, local antibiotic beads, systemic antibiotics and bone grafting to fill in bony defects. The term refractory osteomyelitis is applied to bone infections that fail to respond despite adequate surgical and antibiotic therapy.[5,6] Systemic host and local immunocompromised factors are frequently associated with refractory osteomyelitis. Failure of treatment or recurrence of osteomyelitis often leads to amputation. HBO can be used as an adjunctive treatment in chronic refractory osteomyelitis along with antibiotics, surgical debridement, and nutritional support. HBO enhances oxygen-dependent leukocyte killing through the production of hydrogen peroxide and superoxide by providing increased oxygen tension in the hypoxic tissue. Since the bactericidal activity of leukocytes in vitro is directly related to local oxygen tension, transient reversal of hypoxia might increase clearance of bacteria.[5–7] Secondly, optimal tissue oxygen tension enhances osteogenesis and neovascularization to fill the dead space with new bone and soft tissues. HBO has also been shown to enhance osteoclastic activity to remove bony debris. Finally, HBO also potentiates the antimicrobial effects of aminoglycosides, and possibly sulpha drugs and vancomycin, in the killing of susceptible bacteria.[8] Patients with osteomyelitis are usually treated at 2.0–2.5 ATA for 90–120 min per day and typically receive 20–40 treatments.[4]

2) HBO for compartment syndrome

In compartment syndrome, pressures in skeletal muscle compartments are sufficiently raised to reduce or halt

vascular in flow and for this reason, prompt surgical decompression is the first accepted treatment to restore tissue perfusion. Fasciotomy may be performed entirely on clinical grounds, or in response to a compartmental interstitial pressures greater than 30 mmHg absolute, or within 30 mmHg of the diastolic pressure.[9,10] Yet, following inadvertent calf compression and intra-operative hypotension, intra-compartmental calf pressures in excess of 35 mmHg bilaterally are reported to have been controlled by prompt HBO treatment without the need for fasciotomy. Where compartment syndrome is a risk, the early addition of HBO into the standard care of repeated examination and pressure readings may prevent progression

3) HBO for Crush injury

Crush injuries present frequently in emergency departments and these traumatic injuries cause widespread capillary damage, inflammation and tissue hypoxia. Hypoxia results in a negative cascade fostering further neurovascular injury leading to compounding disability. Crush injury is recognized immediately and treated aggressively with treatment of fracture, antibiotics and surgical debridement if required. HBO is administered at 2−3 ATA and is ideal adjuvant to basic management. Hyperbaric oxygenation impacts tissue hypoxia by providing enhanced oxygen delivery to peripheral tissues affected by vascular disruption, cytogenic and vasogenic edema and cellular hypoxia caused by extremity trauma.[11,12]

The Gustilo classification is used for evaluating the use of HBO in crush injuries and those in Class 3 A, B and C (compromised host, flaps or grafts required to obtain soft tissue coverage and major (macrovascular) vessel injury) are recommended HBO treatment for better results at lower costs. After appropriate resuscitation, macrovascular repair, and fracture fixation/stabilization, adjunctive HBO can reduce the penumbra of cells at risk for delayed necrosis and secondary ischemia.

4) HBO for gas gangrene

Gas gangrene or clostridial myonecrosis, is commonly encountered in those extremity-wounds that involve devitalized or necrotic soft tissues. Infection with *Clostridium perfringens* in devitalized tissue is the most common cause. Clostridial microorganisms are anaerobes that produce local and systemic toxins. Wide surgical debridement and appropriate antibiotic therapy remain the standard treatment modality. HBO therapy also has an anti-edema effect, causes activation of fibroblasts and macrophages, and stimulates angiogenesis.[13−17] In animal models, the addition of HBO therapy to standard management has been shown to have a synergistic effect in reducing morbidity and mortality. Although no prospective human studies are available, retrospective data indicate that concomitant hyperbaric oxygen therapy has resulted in a two-fold reduction in mortality

5) HBO for fracture healing

The healing of bony fractures is a complex and multifaceted process. However, extensive trauma, bone loss, unstable fixation, premature mobilization, extensive osteonecrosis and aging are factors that may delay or even stop the healing. Broken bones are very common and sometimes may take a long time to heal or in some cases may fail to heal.[18−21] Other factors which hinder fracture healing are poor blood supply and infection. The use of HBOT has been suggested as a way to enhance healing and treat non-union by targeting the zones of ischemia, facilitating new capillary network support and increases blood supply, reducing painful swelling and inflammation.

6) HBO for diabetic foot

With the increasing prevalence of diabetes in the community, morbidity and mortality as a result of diabetic feet has been increasing. Foot complications are one of the most serious and yet preventable complications of diabetes mellitus having an economic impact to the individual and adding the burden to the already inadequate healthcare resources.

Hyperbaric oxygen therapy can play a significant role when combined with conventional therapy in carefully selected wounds. Many disease states, such as diabetes, atherosclerotic cardiovascular disease, irradiation, and local trauma, lead to chronic hypoxic wounds. In these patients, most small wounds or minor trauma ultimately heal albeit delayed. It is the larger wounds in the compromised patient where the demand for oxygen exceeds the supply that the non-healing chronic wound develops. It is in these patients that adjunctive HBOT is beneficial.[22,23] Patients with Class 3, 4, or 5 Wagner lesions are considered for HBOT depending on the assessment of blood flow

7) HBO for sports injury

HBOT is used in a sports medicine setting to reduce hypoxia and edema and appears to be particularly effective for treating crush injuries and acute traumatic peripheral ischemias. HBOT is considered as an adjunctive therapy as soon as possible after injury diagnosis. Treatment pressures for acute traumatic peripheral ischemia range from 2.0 to 2.5 atmospheres absolute (ATA), with a minimum of 90 min for each treatment.

By coupling the advances in sports medicine, physical therapy and hyperbaric medicine, the time to recovery is accelerated. From muscle contusions and ankle sprains to delayed-onset muscle soreness; HBOT has been used to facilitate soft-tissue healing. To minimize

the time between injury and HBOT treatment, some professional sports teams have on-site centers. As many professional sport teams have discovered, HBOT is a real tool to enhance their performance and reduce downtime from injuries.[24,25]

SIDE EFFECTS

Most side effects of HBOT are mild, and rare; however, more severe side effects should be considered.[1−4] There are two categories of side effects:

1) Caused by atmospheric pressure changes:
   a) Middle ear barotraumas:
      When used in standard protocols HBO is safe. Commonest side effect may be slight pain in the ears due to a blocked Eustachian tube.
   b) Sinus barotrauma:
      This might occur due to inability to equalize pressure in sinus cavities because of allergies or sinusitis can lead to sinus barotraumas.
   c) Pulmonary barotraumas:
      The most serious side effect, which is very rare, is pneumothorax and tension pneumothorax. Boyle's law state that as pressure increases, volume decreases.
   d) Confinement anxiety:
      Claustrophobia can be minimized through adequate orientation to the process. In addition, attendance and reassurance by the nurse during the treatment will help to minimize anxiety.

2) Caused by the rise in oxygen partial pressure:
   a) Brain oxygen toxicity:
      The clinical manifestations are convulsions resembling grand mal seizures, which resolve completely without any neurological deficits after removal of the oxygen mask.
      It is pressure dependent and the threshold for immediate toxicity is reached by breathing 100% oxygen at 3.0 ATA. At lower partial pressures, the threshold is time dependent. To avoid oxygen toxicity, planned intervals are utilized during the hyperbaric treatment for air breathing.
   b) Oxygen lung toxicity:
      It is due to the cumulative damage from oxygen free radicals to lung parenchyma and airways. It is time dependent and may occur only in prolonged hyperbaric treatments.
   c) Transient myopia:
      It may occur following 40 repetitive HBOT sessions, but is reversed a few weeks after the cessation of treatment.
   d) Hypoglycemia:
      Persons with insulin dependency are at higher risk for episodes of hypoglycemia during periods of increased barometric pressure and 100% oxygen breathing. This complication is preventable and can easily be managed by appropriate pretreatment monitoring of blood sugars levels.

CONTRAINDICATIONS

The only absolute contraindication to HBOT is an untreated tension pneumothorax with few relative contraindications in which caution must be observed but which are not necessarily a contraindication to HBOT.[1,3]

- History of spontaneous pneumothorax
- Severe sinus infection
- Upper respiratory infection
- Asymptomatic pulmonary lesions on chest X-ray
- Uncontrollable high fever (greater than 39°C)
- History of chest or ear surgery
- Any anemia or blood disorder
- Any convulsive disorder
- History of optic neuritis or sudden blindness
- Middle ear infection
- Diabetes mellitus
- Pregnancy
- Nicotine use/addiction

COST BENEFIT ANALYSIS

Hyperbaric oxygen should be used in conjunction with the multidisciplinary treatment protocol and should be considered as an adjunct to other therapeutic procedures and hence improving the cost effectiveness for treatment of difficult orthopedic disorders.

CONCLUSION

Adequate tissue oxygen tension is an essential factor in wound healing. Chronic wounds are ischemic frequently and adequate oxygen levels can be reached only through adjunctive HBOT. This results in more normal fibroblast proliferation, angiogenesis, collagen deposition, epithelialization, and enhancement of bacterial killing. HBOT shortens healing time, and helps in preserving limbs thereby reducing overall costs. As part of a multidisciplinary program of wound care HBOT is cost effective and durable.

CONFLICTS OF INTEREST

All authors have none to declare.

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