Hyperbaric Oxygen Therapy: A Working Definition

- Hyperbaric oxygen (HBO2) is a treatment, in which a patient breathes 100% oxygen intermittently while inside a treatment chamber at a pressure that is higher than sea-level pressure.
- Must be 1.4 ATA or higher to qualify as HBO.
- Topical high pressure oxygen therapy (bags/boxes) not supported by science or recognized by CMS.

Pressure Equivalents

- 1 ATA = 760 mmHg = 14.7 psi = 0 FSW
- 2 ATA = 1520 mmHg = 29.4 psi = 33 FSW
- 3 ATA = 2280 mmHg = 44.1 psi = 66 FSW

Pressure Equivalents

- ppO2 @ sea level = .21 x 760 = 160 mmHg
- ppO2 @ 2 ata = .21 x 1520 = 320 mmHg
- ppO2 @ 3 ata = .21 x 2280 = 480 mmHg
- ppO2 @ FiO2 of 1 @ 2 ata: 1 x 1520 = 1520 mm

Monoplace Chambers

Multiplace Chambers
The Gas Laws

- Boyle’s Law
- Charles’ Law
- Henry’s Law
- Dalton’s Law

- Developed at the end of the 18th century to explain relationships of pressure, volume, and temperature of gases in a system.

Boyle’s Law

- For a body of gas at constant temperature, the volume is inversely proportional to the pressure.

Charles’ Law

- For a body of gas at constant pressure, the volume is directly proportional to the temperature.

Dalton’s Law

- The sum of the partial pressures of gases in a system = the total pressure in the system.

\[ P_{\text{Total}} = P_1 + P_2 + P_3 \]

Physiology of HBOT

1) Mechanical effect
   - Reduction of bubble size
     - Boyle’s Law (the bubble law)

2) Effect of increased partial pressures of O₂
   - Oxygen behaves like a drug at pressures much higher than atmospheric pressures so, like other drugs, there are specific indications, side effects, and adverse effects.

Reduction of Bubble Size

<table>
<thead>
<tr>
<th>Pressure in Atmospheres</th>
<th>Relative Volume</th>
<th>Relative Surface Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>6</td>
<td>17%</td>
<td>30%</td>
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HBOT = hyperbaric oxygen therapy.
Effect of Increased PPO₂

Physiology of HBOT

- Large body of evidence supports intermittent hyperoxygenation of hypoperfused tissue beds
- Process only achievable by exposure to HBO₂
- Physiologically, produces directly proportional increase in plasma O₂ that is available for cellular metabolism
- Establishes adequate O₂ availability within vascularized tissue compartment surrounding wound
- Can we super-saturate hemoglobin?

Physiology (cont)

- Neutrophils, fibroblasts, macrophages, and osteoclasts all dependent on adequately oxygenated environment to carry out their functions
- Fibroblasts cannot synthesize collagen without O₂
- Proper oxygenation of vascularized tissue compartment crucial to initiation of wound repair process and becomes a rate-limiting factor for cellular functions associated with wound healing

Side Effects of HBOT

- Middle ear barotrauma
- Sinus squeeze
- Claustrophobia
- Progressive myopia
- Progression of cataracts
- CNS oxygen toxicity seizure
- Pulmonary oxygen toxicity
- Transient increase in BP and decrease in HR
- Pulmonary barotrauma

CNS = central nervous system.

Middle Ear Barotrauma

- Trauma to eardrum due to pressure changes
- Incidence approximately 2%-4%
- Eustachian tube dysfunction most common cause
- Rupture of TM or round window rare but possible
- Insertion of tympanostomy tubes is appropriate intervention if pain with pressurization or any evidence of trauma or hemorrhage to TM

TM = tympanic membrane.
Ocular Effects

- **Myopia**
  - Progressive development of myopia in 20%-40% of patients exposed to HBOT
  - Typically returns to baseline within 6 weeks but can in rare cases be permanent
  - Thought to be lenticular in etiology

- **Nuclear cataracts**
  - Growth of pre-existing cataracts seen with prolonged HBOT
  - Not reversible

CNS Oxygen Toxicity

- HBOT lowers CNS seizure threshold
- Prolonged exposure to O₂ under pressure can trigger epileptic-like seizure
- Spontaneous resolution with reduction of FiO₂ and pressure
- Preventable with mid-treatment air break
- Not a contraindication to future HBOT
- Risk factors: hypoglycemia, corticosteroids, narcotics

FiO₂ = inspired oxygen concentration.

Wound-Related Effects of HBO₂

- Improved leukocyte bacterial killing
- Antibiotic potentiation
- Suppression of synthesis of bacterial toxins
- Blunting of systemic inflammatory response
- Prevention of leukocyte activation and adhesion following ischemic reperfusion
- Stimulation of vascular endothelial growth factor and platelet-derived growth factor leading to angiogenesis
- Increase in wound fluid nitric oxide content


Net Effect of HBO₂

- Serial HBO₂ exposures lead to improved local host immune response, clearance of infection, enhanced tissue growth, and angiogenesis, leading to progressive improvement in local tissue oxygenation and healing of hypoxic wounds


Normal Wound Healing

- Progresses through orderly sequence of steps
  - Control of contamination and infection
  - Resolution of inflammation
  - Regeneration of connective tissue matrix
  - Angiogenesis
  - Resurfacing
- Several of these steps are critically dependent upon perfusion/oxygenation
  1. Fibroblast replication and collagen synthesis
  2. Angiogenesis
  3. Resistance to infection
  4. Intracellular leukocyte bacterial killing

Problem Wounds

- Failure to progress through orderly healing sequence, usually as a result of one or more of the following factors
  - Persistent infection
  - Malperfusion and hypoxia
  - Cellular failure
  - Edema
  - Unrelieved pressure or recurrent trauma
  - Improperly managed drainage/exudate
Measurement of Wound Hypoxia

- Transcutaneous oxygen tension (PtcO2) measurements provide direct, quantitative assessment of O2 availability to periwound skin
- Clark polarographic electrode generates a current that can be measured and converted to mmHg
- TcpO2 generally considered to be most useful in predicting failure of a wound to heal without intervention, failure to heal planned amputation, and failure to respond to HBO2

Approved Indications for HBOT

- Air or gas embolism
- Carbon monoxide poisoning
- Clostridial myonecrosis (gas gangrene)
- Crush injury, compartment syndrome, and other acute traumatic ischemia
- Decompression sickness
- Severe anemia
- Intracranial abscess
- Arterial insufficiencies
- Central retinal artery occlusion
- Enhancement of healing in selected problem wounds

HBOT Indications (cont)

- Necrotizing soft-tissue infections
- Chronic refractory osteomyelitis
- Delayed radiation injury (soft-tissue and bony necrosis)
- Compromised grafts and flaps
- Central retinal artery occlusion
- Acute thermal burn injury
- Severe anemia

Indications by Category

Absolute Contraindications

- Untreated pneumothorax
- Concomitant treatment with doxorubicin
- Concomitant or recent treatment with bleomycin

Relative Contraindications

- Acute viral upper respiratory infection
- Fever
- Seizure disorder
- Emphysema with CO2 retention
- History of spontaneous pneumothorax
- History of otosclerosis surgery
- Congenital spherocytosis
- History of optic neuritis

CO2 = carbon dioxide.


Common Off-label/Unapproved Uses of HBO₂

- Autism
- Cerebral palsy
- Lyme disease
- Multiple sclerosis
- Athletic injuries
- Rock stars

HBO₂ Treatment Protocols

- **Standard Wound Protocol**: 2.0 ATA: 90 minutes at treatment pressure plus time for descent and ascent; approximately 110 minutes total time

- **Radiation Injury Protocol**: 2.5 ATA: 90 minutes at treatment pressure plus time for descent, 10 minutes air break at 45 minutes and ascent; approximately 120 minutes total time

- **Carbon Monoxide Protocol**: 3 dive series beginning at 3.0 ATA (Weaver Protocol)

ATA = atmospheres absolute.

References


References (cont)

- Hyperbaric oxygen therapy for wound healing Part 1. Blue Cross Blue Shield Association TEC, Technology Assessment, August 1999 USA