Hyperbaric Oxygen Therapy: HBO 101

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2014 ACOI Annual Convention
Baltimore, MD
Objectives

- Educate the physician on the physiology of hyperbaric oxygen therapy.
- Analyze indications for hyperbaric oxygenation therapy.
- Become familiar with contraindications for hyperbaric oxygen therapy.
HBO Therapy defined

- Medical treatment
- Enclosed chamber
- 100% oxygen
- Delivered at greater than one atmosphere pressure
History of HBO Therapy: Atmospheric Pressure

- Henshaw, 1662
- English physician and clergyman
- 1\textsuperscript{st} recorded use of altered atmospheric pressure for therapeutic purpose.
- Tx for pulmonary disease.
- Sealed room call “domicillium”
- Pressure raised or lowered by a pair of organ bellows and series of valves.
History of HBO Therapy: Oxygen

- Discovered by:
  - Carl Wilhelm Scheele, Swedish chemist in 1772, published 1777.
  - Priestly got the credit.
  - “Allegedly” French physician Caillens used “oxygen” therapy in 1783.
History of HBO Therapy: The French Connection

- **Emile Tabarie**, French physician, 1832, credited for renewed interest in HBO therapy.
- Optimized patient comfort and safety. Increasing air pressure gradually and slowly decreasing over a 2 hour period. Similar to today's dosing schedule.
- **Junod**, French physician, 1834, first purpose-built hyperbaric chamber.
  - Steam engine frame, compression to 4.0 atmospheres absolute.
  - Treated at a faster rate of compression and decompression causing increased complications.
History of HBO Therapy: Coming to America

- J. Leonard Corning, New York, neurologist, late 1880s.
- Brought “compressed air baths” to United States.
- First electrically powered.
- Treated paralytic decompression sickness as well as brain and spinal cord injuries and diseases.
History of HBO Therapy: Hollands contribution

- Dr Ite Boerema
- Professor of Surgery, University of Amsterdam in Holland.
- Began performing cardiac surgery within HBO operating rooms with impressive results.
Theory behind HBO therapy: Mechanical/Physiological

- Direct pressure
- Hyper-oxygenation
- Antimicrobial activity
- Vasoconstriction
Direct Pressure

- Reduction in bubble size.
- **Boyle’s Law**: "At a fixed temperature, the volume of a gas is inversely proportional to the pressure exerted by the gas."
- Treatment for decompression sickness and cerebral arterial gas embolism.
Hyperoxygenation - delivery of oxygen

- Increased partial pressure of oxygen (PaO2)
- Each hemoglobin molecule has four Fe²⁺heme sites for binding oxygen.
- Arterial Hgb is 97% saturated at atmospheric pressure.
- Only 3% of sites are not bound or bound with something else.
- Only allowing for a 3% increase in O2 delivery.
Hyperoxygenation - delivery of oxygen

- Increases in dissolved O2
- Any extra O2 is dissolved in plasma.
- FiO2 (fraction of inspired oxygen) at normal air pressure is 21%.
- 100% FiO2 at 3 atm increases up to 2000 mmHg from 760 mmHg at sea level.
- Results in O2 from 3 ml/L blood to 60 ml/L.
- 20 times the amount of oxygen circulating in plasma.
Hyperoxygenation - promotion of angiogenesis and neovascularization

- Indirect and delayed response after serial treatments.
- Budding vessels require structural support from basement membrane formed from collagen.
- HBO therapy increases oxygen to advancing capillary cells.
- Allows for growth into hypoxic areas.
- Results in new vascular supply to advance quickly and improve wound healing.
Collagen synthesis

- Collagen is synthesized and deposited by fibroblasts.
- Fibroblasts replicate within the range of 40-60 mmHg PO2.
- Less than this reduces collagen synthesis.
- Maximum rate of production seen at 250mmHg. The level at which 90% of fibroblasts function at full capacity at 2.0 ata.
Blood glucose levels affect on collagen synthesis and deposit

- Fibroblasts cannot synthesize or deposit collagen with a blood glucose level >200mg/dL.
- HBO patients with blood glucose levels less than 200mg/dL had an 89% healing rate.
- HBO patients with blood glucose levels above 200mg/dL had a 24% healing rate.
Oxygen diffusion distance

- By delivering 100% O2 at 3atm:
  - Venous diffusion is doubled
  - Arterial diffusion is quadrupled
Oxygen diffusion distance

- Normal breathing room air at 21% O2 = 36 microns
- HBO breathing 100% O2 at 2 ata = 280 microns
- Greater than 1500mmHg of arterial blood O2 can be seen while breathing 100% O2 at 2 ata.
  - Increases oxygen gradient closer to the wound.
  - Decreasing ischemia and hypoxia.
  - Increasing wound healing.
  - Enhances leukocyte microbiocidal function
**Antimicrobial activity**

- 2 major immune pathways are activated in wounds; phagocytosis and intracellular killing.
- Primary cell is the neutrophil, which depends on high partial pressure of oxygen.
- Neutrophil utilizes phagosomal oxidase as a major component of defense.
- Located in phagocytic membrane, uses oxygen to catalyze superoxide.
- Superoxide is bactericidal and initiates cascades that produce other oxidants important in killing bacteria (H2O2).
Antimicrobial activity

- Intraphagosomal oxidant production depends on conversion of oxygen to superoxide.
- This process is very sensitive to partial pressure.
- Reaction occurs at 40 to 80 mmHg.
- Wound hypoxia impairs infection clearance while increased PO2 seen in HBO therapy increase infection clearance.
- Antibiotics such as Aminoglycosides are transported into bacterial cells via oxygen-dependent transport mechanisms. Increasing oxygen will increase the antibiotics fighting ability.
Mechanical Effects of HBO: Vasoconstriction

- O2 induces vasoconstriction in some organ systems more than others.
- Vessels of the brain, retina and skeletal muscle are most affected by O2 vasoconstriction.
- Decreased in delivered oxygen secondary to O2 vasoconstriction in vascular beds has not been seen in theory or observation.
- It does however reduce edema. Inflow is reduced 20% while maintaining outflow. Reduction in edema of 20%.
Ischemia - Reperfusion Injury

Pathophysiology of injury:
1. Ischemic event.
2. Reduced delivery of metabolic substrates.
4. ATP needed for energy dependent cell functions.
5. Cell death from pure ischemia.
6. direct irreversible injury

Reperfusion:
1. Causes change in cell architecture.
2. Causes change in tissue architecture.
3. Results in edema.
4. Results in influx of leukocytes.
5. Indirect injury
Ischemia - Reperfusion Injury

Oxygen paradox: reperfusion of tissue with oxygenated blood greatly enhances tissue damage as apposed to non oxygenated blood.

Second oxygen paradox: extreme hyperoxygenated blood from HBO therapy to ischemic tissue prevents tissue damage
Ischemia - Reperfusion Injury

- HBO therapy reduces **indirect injury** by preventing down regulation of leukocyte receptor sites.
- Net effect of inhibiting leukocyte endothelial intravascular adhesion.
- Effective for about 8 hours post HBO treatment.
Treatment protocols:

- Oxygen inspired with increased pressure is a potent drug.
- Must be administered carefully to avoid toxic effects.
- Patient’s response and injury determine number of treatments.
- Visits may occur as many as 3 times a day.
- Time may last as long as 120 min.
Treatment protocols:

- Treatments may be as little as one for carbon monoxide poisoning to 20 or 30 for problem wound healing. Radiation tissue injury may see as many as 60 treatments for optimal benefit.
HBO therapy: Lasting effect

- HBO therapy exposes patient to about 2 hours of hyperoxia.
- Researchers suggest it takes 6 to 8 hours for PO2 levels to drop back to the tissues baseline PO2 level.
- Baseline levels of wound tissue may be 20 mmHg at start of treatment and require at least 40 mmHg for normal wound healing.
- Each treatment will raise resting wound tissues PO2, resulting in less suboptimal healing time between treatments.
Indications for treatment with HBO

- Delayed Radiation injuries
- Gas Embolism (venous and arterial)
- Decompression Sickness
- Carbon Monoxide poisoning
- Chronic Wounds
- Compromised Grafts and Flaps
- Clostridial Myositis
- Necrotizing Fasciitis
- Zygomycotic infections

- Chronic Osteomyelitis
- Crush injuries
- Central Retinal Artery Occlusion
- Acute Sensory-Neural Hearing Loss
- Idiopathic Sudden Sensorineural Hearing Loss
- Severe Anemia
- Intracranial Abscess
- Acute Thermal Burn injury
Delayed Radiation Injuries

- Currently over 10 million cancer survivors in the US.
- Estimated 60% had radiation as part of their treatment.
- Delayed injuries include soft tissue and bony necrosis as well as progressive obliterative endarteritis.
- Benefits include: hyperoxygenation, enhanced antimicrobial activity, and vasoconstriction.
Osteoradionecrosis of the Mandible

Before HBO therapy

After 30 HBO treatments
Gas Embolism (venous and arterial)

- Entry of gas into the vascular system usually iatrogenic.
- Estimated lethal volume of gas in an adult 200-300ml or 3-5 mg/kg.
- Results in cardiovascular, pulmonary and neurological sequelae.
- Benefits from HBO therapy include: **direct pressure**, **hyperoxygenation**, and **vasoconstriction**.
- Currently treatment of choice.

Effects of HBO on Outcome after AGE

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<tr>
<th></th>
<th>% patients</th>
<th>N = 411</th>
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<tr>
<td>HBO Full Recovery</td>
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<td>HBO Residual</td>
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<td>HBO Death</td>
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<td>No Recompression</td>
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Decompression Sickness (the bends)

- An acute condition occurring during or shortly after reduction in ambient pressure caused by a bubble.
- Bubble formation can occur in only 1.35 ata (11 feet of seawater).
- Paresthesia and pain most common initial symptom.
- Expansion of bubbles cause direct tissue damage as well as increasing pressures in varies organs.
- Benefits of HBO therapy: direct pressure, hyperoxygenation, and vasoconstriction.
Treatment for pain only or mild cutaneous symptoms use U.S. NAVY TREATMENT TABLE 5
TREATMENT FOR DS with neurological symptoms and for Arterial Gas Embolism
use U.S. NAVY TREATMENT TABLE 6
Carbon Monoxide Poisoning

- CO enters body via lungs and binds to Hgb causing hypoxic stress and distributes to tissues.
- Causes platelet-neutrophil aggregation/activation leading to tissue damage, heart and brain damage from hypoxic/ischemic stress, perivascular damage, and excitotoxicity.
Carbon Monoxide Poisoning

- Benefits from HBO therapy: hyperoxygenation and vasoconstriction.
Chronic Wounds

- Multidisciplinary approach is necessary.
- Place patient at the center of care reinforcing the patient’s rights and responsibilities leads to a better understanding and outcome.
- Benefits of HBO therapy: hyperoxygenation, vasoconstriction, and enhanced antimicrobial activity.
Compromised Grafts and Flaps

- Ischemia is the usual cause of failure.
- Neutrophil and macrophage both require O2 during inflammatory phase to fight off infection.
- Fibroblasts require O2 during the repair and remodeling stage for collagen synthesis.
- Benefits of HBO therapy: hyperoxygenation, vasoconstriction, and antimicrobial activity.
Failed skin graft treated with HBO therapy
Clostridial Myositis
(Gas Gangrene)

- Incubation period from time of injury to symptom onset is 1-4 days. Can be as short as 6 hours or as long as 3 weeks.
- Symptoms progress rapidly from pain, tense edema, pallor, skin color changes to possible hemorrhagic bullae may form in ½ of the cases.
- HBO is an adjunct to surgical debridement, not a replacement.
- Benefits from HBO therapy include: hyperoxygenation, enhanced antimicrobial activity, and vasoconstriction.
Clostridial Myositis
(Gas Gangrene)
Necrotizing Fasciitis (flesh eating bacteria)

- Acute and potentially fatal infection that attacks the superficial and deep facial layers.
- Can be mixed flora infections in about half of the cases.
- HBO again is used as an adjunct to surgery and antibiotics.
- HBO therapy separates potentially viable tissue from non viable before surgery.
- Benefits of HBO therapy include: hyperoxygenation, enhanced antimicrobial activity, and vasoconstriction.
Necrotizing Fasciitis (flesh eating bacteria)
Chronic Osteomyelitis

- Refractory osteomyelitis is a bone infection that fails to respond despite adequate surgical debridement and antibiotic treatment.
- HBO therapy again is used as an adjunct to surgery and antibiotics.
- Benefits from HBO therapy include: hyperoxygenation, enhanced antimicrobial activity, and vasoconstriction.
Chronic osteomyelitis (bone infection) with open wound for 2 years, treated with hyperbaric oxygen therapy.
Crush Injuries

- Crush injury is the diagnosis in about 1/5 of admissions in a Level 1 trauma center.
- HBO therapy has been used as a last resort for graft failure and uncontrolled infection.
- Used in conjunction with surgery.
- Benefits from HBO therapy include: hyperoxygenation and vasoconstriction.
Crush Injuries
Central Retinal Artery Occlusion

- Sudden and painless loss of vision.
- Emergent ophthalmic injury.
- Oxygen consumption of the retina is the highest of any organ (13ml/100g/min).
- Benefits of HBO therapy include: hyperoxygenation.
Central Retinal Artery Occlusion
Acute Sensory-Neural Hearing Loss
Idiopathic Sudden Sensorineural Hearing Loss
- Incidence reported to range from 5 to 20 per 100,000 persons per year.
- 12 retro and prospective case-controlled studies have shown HBO therapy and glucocorticosteroids better than steroid alone (1650 pts).
- Benefits of HBO therapy include: hyperoxygenation
Acute Sensory-Neural Hearing Loss
Idiopathic Sudden Sensorineural Hearing Loss
Severe Anemia

- Increases dissolved oxygen concentration carried in the plasma.
- Benefits of HBO therapy include: hyperoxygenation.
Severe Anemia

Wife with

Husband without
Intracranial Abscess

- Relieves hypoxia.
- Reduces peri-focal brain edema.
- Augments treatment of anaerobic flora.
- Benefits of HBO therapy include: hyperoxygenation, vasoconstriction, and enhanced antimicrobial activity.
Intracranial Abscess
Acute Thermal Burn Injury

- Total injury includes: circulatory damage, edema, fluid loss, and secondary infections.
- Treatment consists of: limiting tissue fluid loss and limit wound extension and conversion of viable tissue.
- Benefits of HBO therapy include: hyperoxygenation, vasoconstriction, and enhanced antimicrobial activity.
Acute Thermal Burn Injury
Contraindications to HBO therapy

- Inadequate hyperbaric facility.
  - Chamber improper for medical use.
  - Staff not adequately trained.
  - Lack of equipment, procedures, or an emergency plan.
Contraindications to HBO therapy

- **Absolute:**
  - Unvented pneumothorax
  - Acute severe bronchospasm
  - Concomitant tx with doxorubicin
  - Concomitant or recent use of bleomycin

*HOW ABOUT NO*
Contraindications to HBO therapy

- Relative:
  - Upper airway inf.
  - Allergic rhinitis
  - Chronic sinusitis/otitis
  - COPD/emphysema
  - h/o pneumothorax or thoracic surgery
  - h/o ENT surgery
Contraindications to HBO therapy

- Relative continued:
  - Epilepsy
  - Optic neuritis
  - Uncontrolled HTN (art)
  - Uncontrolled heart failure
  - Claustrophobia
  - Dangerous behavior
Reference:


- Special thanks to Healogics