



HBO 101



Texas Osteopathic Medical Association

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Hyperbaric Oxygen Therapy (HBOT)

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Hyperbaric Oxygen Therapy (HBOT)

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- Texas Health Harris Methodist Hospital
 - Hurst-Euless-Bedford (H.E.B.)
- Healogics Specialty Physicians

Hyperbaric Oxygen Therapy (HBOT)



**Texas health Harris Methodist
(HEB) Bedford Texas**



Objectives

- Become familiar with the fundamental aspects of wound healing and its interrelationship with oxygen
- Become familiar with the process of evaluating patients for and instituting hyperbaric oxygen therapy
- Recognize the physiologic and pharmacologic benefits of hyperbaric oxygen therapy

**Hyperbaric Oxygen Therapy
(HBOT)**

- **Back to the basics**

The Nine Essentials of Wound Healing

1. Adequate Perfusion
2. Non-Viable Tissue
3. Inflammation or Infection
4. Edema
5. Wound Microenvironment
6. Tissue Growth Optimized
7. Off-Loading
8. Pain Control
9. Host Factors

The Nine Essentials of Wound Healing

- 1. Adequate Perfusion**
2. Non-Viable Tissue
3. Inflammation or Infection
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7. Off-Loading
8. Pain Control
9. Host Factors

The Nine Essentials of Wound Healing

Pulse exam, vascular history
ABI 0.9-1.2
TBI greater than 0.65

The Nine Essentials of Wound Healing

If you can't get water to the garden.....the garden won't grow!!!!

The Nine Essentials of Wound Healing

1. Adequate Perfusion
2. **Non-Viable Tissue**
3. Inflammation or Infection
4. Edema
5. Wound Microenvironment
6. Tissue Growth Optimized
7. Off-Loading
8. Pain Control
9. Host Factors

The Nine Essentials of Wound Healing

After adequate perfusion
debridement in the form of

- Sharp surgical
- Selective
- Autolytic
- Enzymatic
- Biologic

The Nine Essentials of Wound Healing

**Wounds Won't
Heal in a
SEWER!!**

The Nine Essentials of Wound Healing

1. Adequate Perfusion
2. Non-Viable Tissue
- 3. Inflammation or Infection**
4. Edema
5. Wound Microenvironment
6. Tissue Growth Optimized
7. Off-Loading
8. Pain Control
9. Host Factors

The Nine Essentials of Wound Healing

**Wounds With
BUGS Don't
Heal!!**

The Nine Essentials of Wound Healing

1. Adequate Perfusion
2. Non-Viable Tissue
3. Inflammation or Infection
4. **Edema**
5. Wound Microenvironment
6. Tissue Growth Optimized
7. Off-Loading
8. Pain Control
9. Host Factors

The Nine Essentials of Wound Healing

**Wounds Don't Heal
in a Swamp!!**

The Nine Essentials of Wound Healing

1. Adequate Perfusion
2. Non-Viable Tissue
3. Inflammation or Infection
4. Edema
5. **Wound Microenvironment**
6. Tissue Growth Optimized
7. Off-Loading
8. Pain Control
9. Host Factors

The Nine Essentials of Wound Healing

**Wounds Don't Heal
Unless
The Environment
Supports
Healing**

The Nine Essentials of Wound Healing

1. Adequate Perfusion
2. Non-Viable Tissue
3. Inflammation or Infection
4. Edema
5. Wound Microenvironment
6. Tissue Growth Optimized
7. Off-Loading
8. Pain Control
9. Host Factors

The Nine Essentials of Wound Healing

**Tissue Growth is
OUR Business**

The Nine Essentials of Wound Healing

1. Adequate Perfusion
2. Non-Viable Tissue
3. Inflammation or Infection
4. Edema
5. Wound Microenvironment
6. Tissue Growth Optimized
7. Off-Loading
8. Pain Control
9. Host Factors

The Nine Essentials of Wound Healing

**Wounds Don't
Heal Under
Pressure!!**

The Nine Essentials of Wound Healing

1. Adequate Perfusion
2. Non-Viable Tissue
3. Inflammation or Infection
4. Edema
5. Wound Microenvironment
6. Tissue Growth Optimized
7. Off-Loading
8. Pain Control
9. Host Factors

The Nine Essentials of Wound Healing

**Controlled Pain =
Better Compliance**

The Nine Essentials of Wound Healing

1. Adequate Perfusion
2. Non-Viable Tissue
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5. Wound Microenvironment
6. Tissue Growth Optimized
7. Off-Loading
8. Pain Control
9. **Host Factors**

The Nine Essentials of Wound Healing

**Wounds Don't
Heal Without
Building Blocks!!**

Enhancement of Healing in Selected Problem Wounds

Normal wound healing Stages

- Hemostasis
- Inflammatory
- Proliferative
- Remodeling

Enhancement of Healing in Selected Problem Wounds

Normal wound healing Stages

- 1. Hemostasis**
 - stop bleeding
 - Platelet activation to form clots
 - Platelet degranulation to release cytokines and growth factors
- 2. Inflammatory**
 - The cleanup crew
 - Leukocytes with oxygen-dependent killing mechanisms
 - Macrophages with phagocytosis

Enhancement of Healing in Selected Problem Wounds

Normal wound healing Stages

- 3. Proliferative**
 - granulation tissue formation
 - Angiogenesis
 - epithelialization
 - fibroblast
- 4. Remodeling**
 - immature collagen is replaced by mature collagen

Stages of wound healing affected by O2 concentration

- Fibroblast proliferation
- Collagen synthesis
- Angiogenesis
- Antimicrobial activity
 - Intracellular leukocyte killing
 - Neutralization of endotoxins

Benefits of Hyperbaric Oxygen

Physiologic Effects:

- Improved leukocyte function and bacterial killing
- Antibiotic potentiation
- Enhanced collagen synthesis and cross-linking

Pharmacological Effects:

- Direct antimicrobial effects, toxin synthesis suppression
- Blunting of systemic inflammatory responses
- Prevention of leukocyte activation and adhesion
- PDGF-BB receptor stimulation (multiple effects)
- VEGF release and angiogenesis
- Detoxification (CO, CN, H₂S)

Hyperbaric Oxygen Therapy

- Hyperbaric Oxygen Therapy
 - Is the systemic intermittent administration of 100% oxygen delivered under pressure
 - Usually 2.0 to 2.5 ATA

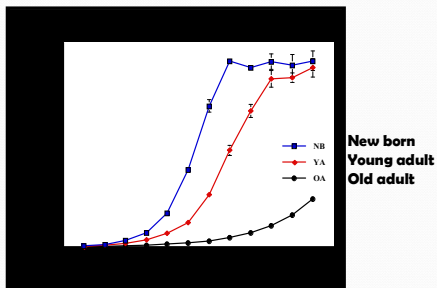
Hyperbaric Oxygen Therapy

- One ATA
 - 14.7 psi
 - 33fsw
- Mechanical effect
 - Boyle's Law
- Physiologic effect
 - Henry' Law
 - The partial pressure and concentration of a gas dissolved in liquid is determined by the partial pressure of the gas on the surface of the liquid.

Hyperbaric Oxygen Therapy

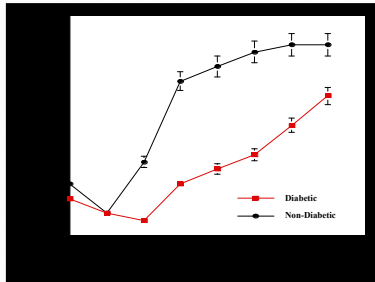
- HBOT
 - Increases O₂ tension 10 to 13 times higher than O₂ breathed at ambient pressure
 - Increases the capacity of blood to carry and deliver oxygen to compromised tissues
 - At these O₂ tensions oxygen now acts as a drug with several effects.

Age Associated Differences in Cellular Proliferation (*in vitro*)...



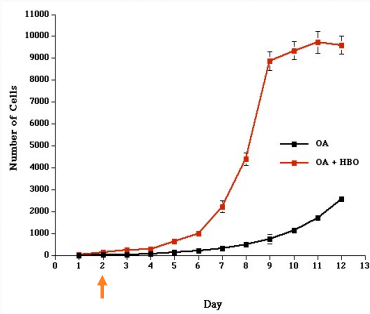
(Buras and Buras, Harvard Medical School, MGH, Boston)

Decreased Cellular Proliferation with Diabetes...



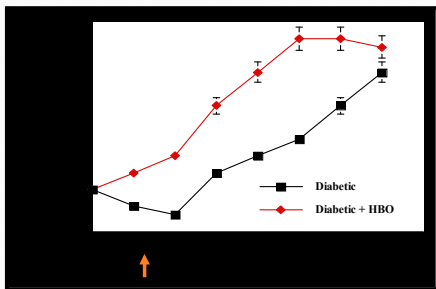
(Buras and Buras, Harvard Medical School, MGH, Boston)

HBO Dramatically Increases Old Adult Fibroblast Proliferation...



(Buras and Buras, Harvard Medical School, MGH, Boston)

HBO Dramatically Increases Diabetic Fibroblast Proliferation...



(Buras and Buras, Harvard Medical School, MGH, Boston)

Hyperbaric Oxygen Therapy

- Indication
 - Acute
 - Chronic

Emergency/Acute Indications

- Cerebral Arterial Air or Gas Embolism
- Carbon Monoxide Poisoning
- Cyanide Poisoning
- Hydrogen Sulfide Poisoning
- Clostridial Myositis & Myonecrosis
- Acute Traumatic Ischemia
 - Crush Injury
 - Compartment Syndrome
 - Replantation Limb/Digits Etc.



Emergency/Acute Indications

- Decompression Sickness
- Exceptional Blood Loss (Anemia)
- Intracranial Abscess
- Necrotizing Soft Tissue Infections
- Thermal Burns (Not CMS Approved)
- Combined Synergistic Necrotizing STI
- Compromised Skin Grafts/Flaps



Acute Traumatic Ischemia

Benefits of HBOT

- Hyperoxygenation
- Increases in capillary reabsorption decreasing edema
- Reduces reperfusion injury
 - generates scavengers to destroy oxygen radicals

Acute Traumatic Ischemia

- 4 year old slipped and fell into a riding lawn mower, sustaining a mid-calf amputation of his leg. Leg was successfully replanted.
- Ischemic time: 10 hours
- Tx' d aggressively with HBO



Acute Traumatic Ischemia



- Appearance of muscle three days after replantation shows 100% viability as HBO counteracted reperfusion injury.

Acute Traumatic Ischemia



- Three Months after Injury
- HBO @ 2.4 ATA x 90 minutes q8h x 6
- Then q12h x 4

Acute Traumatic Ischemia

- The result was excellent function of the leg. The patient regenerated his nerves and ended up with a sensate foot. He was able to walk and run with the aid of a brace.



Crush Injury

- Crush Injury with avulsion of palmar skin
- Appearance at time of presentation 1 hour after injury



Crush Injury

- Elevation of avulsed palmar skin of crushed right hand



Crush Injury

- Immediate post-op view
- Note vertical blue line through mid-palm
 - Area not expected to survive



Crush Injury

- 11 weeks post injury
- HBO @ 2 ATA x 90 minutes q8h x 3 then q24h x 17



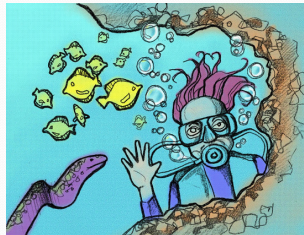
Crush Injury



- 11 weeks post injury
- Full range of motion

Non-approved Emergent Indications

- Retinal Artery Insufficiency
- Actinomycosis



Chronic/Elective Indications

- Problem Wounds
 - **Diabetic Foot Ulcers (Chronic; Wagner III)**
 - Arteriolar Insufficiency
 - Etc.
- Chronic Refractory Osteomyelitis
- Delayed Radiation Injury
 - Soft Tissue
 - Bony
- Meleney Ulcer (Invasive Group A Strep)



Ulcers

- Grade 0: Intact skin
- Grade I: Superficial without penetration to deeper layers
- Grade II: Deeper reaching tendon, bone, or joint capsule
- Grade III: Deeper with abscess, osteomyelitis, or tendonitis extending to these structures
- Grade IV: Gangrene of some portion of the toe, toes, and/or forefoot
- Grade V: Gangrene involving the whole foot or enough of the foot that no local procedures are possible

Grade I or II w/Infection = Grade III

Wagner FW. Foot & Ankle. 1981. 64-122

DFU

10/16/09



Wound photograph showing a deep ulcer on the lateral aspect of the right foot. A ruler is placed below the ulcer for scale. The ulcer is approximately 2 cm in length and 1 cm in width. The wound bed contains exposed red tissue and some yellowish debris.

DFU

11/20/09



Wound photograph showing a deep ulcer on the lateral aspect of the right foot. A ruler is placed below the ulcer for scale. The ulcer is approximately 2 cm in length and 1 cm in width. The wound bed contains exposed red tissue and some yellowish debris.

BODY PART: Anterior foot R2
 WOUND: # 2 DATE: 20 Nov 09
 CM 1 2 3 4

DFU

12/30/09



Problem Wounds

- Achilles tendon rupture repair
 - 4 months post-op
 - Suture line breakdown 2 weeks post-op
 - Multiple failed attempts at secondary closure



Problem Wounds



- TCOMs in the periwound area demonstrated soft tissue hypoxia immediately adjacent to wound edges

Problem Wounds

- 5 weeks post-HBO
- HBO @ 2 ATA x 90 minutes q24h x 20
- Routine wound care
- Oral antibiotics



Problem Wounds

- Posterior view
- Excellent range of motion
- Ambulating without difficulty



Problem Wounds



- Non-healing transmetatarsal amputation
 - Suture line breakdown
 - 3 mos s/p Fem/Tib bypass
- Considering BKA

Problem Wounds

- 10 weeks post-HBO
 - Complete healing
 - No surgical debridement
 - No revision
 - No BKA
- HBO @ 2 ATA x 90 minutes q24h x 20



Soft Tissue Radionecrosis

- Malignant Fibro-Histiocytoma
 - Wide excision
 - Radiation therapy
- 2 months post-op
 - Dehiscence
 - Radionecrosis
 - Purulent drainage



Soft Tissue Radionecrosis

- Close-up view
 - 9 x 6.5 cm
 - Stage III/IV Ulceration



Soft Tissue Radionecrosis



- 1 week post-HBO
 - 2 ATA
 - 90 minutes each
 - Q24h
 - 20 treatments
 - 5 days/week
- Routine wound care
- Oral antibiotics

Soft Tissue Radionecrosis

- 10 days post-STSG
- Ambulating without difficulty
- No further procedures required



Compromised Flap

- ORIF open fracture right Tibia
 - Wound break down
 - Exposed plate
 - Flap rotated
 - Skin graft to donor site
- Distal ischemia
- Impending necrosis



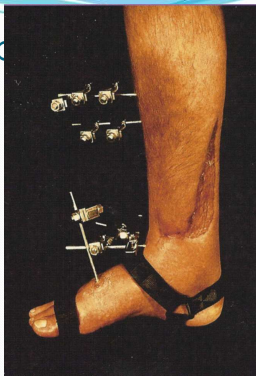
Compromised Flap

- Post-HBO x 10 Treatments



Compromised Flap

- Complete Healing
 - HBO @ 2.4 ATA x 90 minutes q12h x 6
 - Then 2 ATA x 90 minutes q24h x 14
- No further procedures necessary



Absolute Contraindications

- Untreated Pneumothorax
- Pregnancy (Almost)



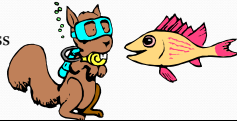
Relative Contraindications

- Upper Respiratory Infections
- Chronic Sinusitis
- Emphysema w/CO₂ Retention
- High Fevers
- History of Seizure Disorder
- Pregnancy



Relative Contraindications (Continued)

- History of Surgery for Otosclerosis
 - PE tubes
- Viral Infections
 - Get worse
- Congenital Spherocytosis
 - Hemolysis in presence of increased paO₂
- History of Optic Neuritis
 - May be associated with blindness



Complications & Side Effects

- Barotrauma of the Ear
 - Occurs frequently particularly on descent at shallower depths
 - PE tubes
- CNS Oxygen Toxicity
 - Occurs rarely 1,3/10,000 treatments occurs more frequently at depths of 2.4 ATA in greater.



Complications & Side Effects

■ CNS oxygen toxicity

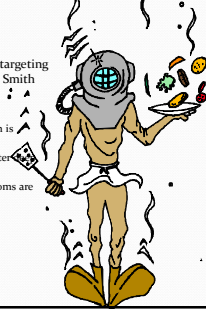
- C ON convulsion
- V vision, narrowing of visual fields
- E ear, tinnitus
- N nausea
- T twitching, facial
- I irritability
- D dizziness



Complications & Side Effects

■ Pulmonary Oxygen Toxicity

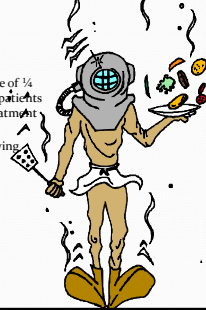
- Poisonous effects of extended to moderate PO_2 targeting the pulmonary system. Also called the Lorrain Smith effect
- Symptoms
 - substernal irritation intensifying until each breath is painful
 - Coughing increases until cannot be suppressed after inspiration
 - Shortness of breath can occur before other symptoms are observed



Complications & Side Effects

■ Visual Refractive Changes

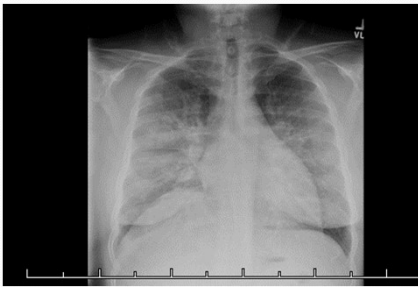
- hyperbaric oxygen may induce myopia at the rate of $\frac{1}{4}$ dpt change in eyeglass prescription per week in patients receiving prolonged daily hyperbaric oxygen treatment at 2-2.4 ATA for 90-120 minutes
- Myopia reverses slowly over several weeks following cessation of treatment.



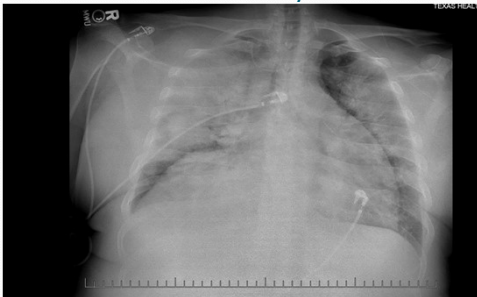
Complications & Side Effects

- Pulmonary toxicity case report
- 44-year-old male with no previous cardiac or pulmonary history developed acute pulmonary failure following his fourth HBO treatment was hospitalized for approximately 3 weeks 10 days of which was on a ventilator prior to recovery.

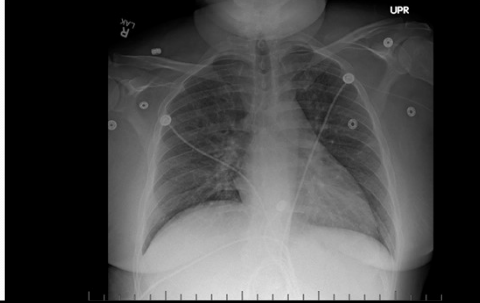
complications and side effects pulmonary toxicity



complications and side effects pulmonary toxicity

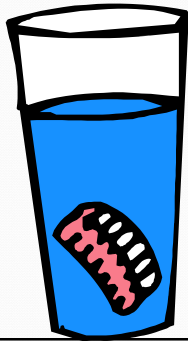


complications and side effects pulmonary toxicity



Complications & Side Effects (Continued)

- Numb Fingers
- Dental Problems
 - Occult abscess
- Claustrophobia



Hyperbaric Oxygen Therapy

- The big picture
 - Good wound care
- Assessment and treatment of vascular disease
 - Off loading
- Advance tissue therapy

