HBO-PAST, PRESENT, AND FUTURE

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Safety Director - Hyperbaric Medicine
Objectives

- Definition of hyperbaric medicine.
- History and evolution.
- Discuss how we got where we are today.
- Review of current acceptable practices.
- Where HBO may be going in the future.
Who Traveled the Farthest

ROLL CALL!
WHERE ARE YOU FROM??
Hyperbaric Defined

- **Hyper**- meaning over, above, or beyond.
- **Baric**- weight or pressure of the atmosphere.

Hyperbaric oxygenation is achieved when 100% oxygen is administered in a pressurized environment greater than one atmosphere.

This combination of pressure and oxygen allows for us to deliver very high doses of oxygen to our patients.
Origins of HBOT

- 1662- British physician Nathaniel Henshaw attached a set of organ bellows to his “domicilium” allowing air to be compressed or removed from it (the same year Boyle’s gas law was published). Claimed to treat lung infections.
- 1774- English scientist John Priestly discovers oxygen.
- 1834- First “metalized” chamber constructed in France, was made of copper, and could achieve a pressure of 2-4 atm. Treated pulmonary diseases.
- 1877- Widespread use of hyperbaric chambers, but only with AIR.
- 1878- Paul Bert determined the cause of DCI was the release of nitrogen bubbles into the blood and tissues during decompression. He also described the benefits of breathing oxygen during recompression. Published *Barometric Pressure* which described DCI, O2 toxicity, and bubble theory.
Diving Equipment

- 1690- Edmund Halley constructed an air resupply device. Thames River demonstration dove 5 people to 60 feet for 90 min. This gave rise to the dive bells used today.
- 1823- Dive suit was patented.
- 1825- First SCUBA device was created.
- 1830- Dive suit was operated to 100 ft.
1875, Milan, Italy. “Compressed Air Baths”
Mysterious Illness

- 1841- Fist caissons used for coal excavation. Workers complained of arm and knee pain which went away when they went back into the caisson.
- 1860-70- Brooklyn Bridge caisson. 110 cases, 2 fatal.
- 1870- Saint Louis Bridge, 119 cases, 14 fatal.
Inadvertant creation of a hyperbaric environment, reported at high as 55psi (3.75 ATM change).
Workers would become ill, crushing joint pain, numbness and tingling in their fingers.
Would feel better when the went to work!?!
The “Bends”

- The Grecian Bend, an 1820’s fashion statement where a stooped posture was considered fashionable.
- Term was coined after observing the position tunnel workers would assume while suffering from DCI.
On-Site Treatment

- 1890- Ernest William Moir constructed the first on site chamber to treat caissons disease during the construction of Hudson River Tunnel in New York City.
- Further refinements in caisson construction limited pressurization to specific areas.
Disciplinary Crossover

- 1906- John Scott Haldane was commissioned by the British Navy to study decompression illness.
- 1908- Haldane developed the first decompression tables.
- 1912- US Navy expanded on Haldane's work. This led to the publication of the first United States Navy Diving Manual.
### Table 9-7: No-Decompression Limits and Repetitive Group Designators for No-Decompression Air Dives

<table>
<thead>
<tr>
<th>Depth (fsw)</th>
<th>No-Stop Limit</th>
<th>Repetitive Group Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Unlimited</td>
<td>A 57  B 101  C 158  D 245  E 426  *</td>
</tr>
<tr>
<td>15</td>
<td>Unlimited</td>
<td>F 36  G 60  H 88  I 121  J 163  K 217  L 297  M 449  N  *</td>
</tr>
<tr>
<td>20</td>
<td>Unlimited</td>
<td>O 26  P 43  Q 61  R 82  S 106  T 133  U 165  V 205  W 256  X 330  Y 461  Z  *</td>
</tr>
<tr>
<td>25</td>
<td>595</td>
<td>A 20  B 33  C 47  D 62  E 78  F 97  G 117  H 140  I 166  J 198  K 236  L 285  M 354  N 469  O 595</td>
</tr>
<tr>
<td>35</td>
<td>232</td>
<td>A 14  B 23  C 32  D 42  E 52  F 63  G 74  H 87  I 100  J 115  K 131  L 148  M 168  N 190  O 215  P 232</td>
</tr>
<tr>
<td>40</td>
<td>163</td>
<td>A 12  B 20  C 27  D 36  E 44  F 53  G 63  H 73  I 84  J 95  K 108  L 121  M 135  N 151  O 163</td>
</tr>
<tr>
<td>45</td>
<td>125</td>
<td>A 11  B 17  C 24  D 31  E 39  F 46  G 55  H 63  I 72  J 82  K 92  L 102  M 114  N 125</td>
</tr>
<tr>
<td>50</td>
<td>92</td>
<td>A 9  B 15  C 21  D 28  E 34  F 41  G 48  H 56  I 63  J 71  K 80  L 89  M 92</td>
</tr>
<tr>
<td>55</td>
<td>74</td>
<td>A 8  B 14  C 19  D 25  E 31  F 37  G 43  H 50  I 56  J 63  K 71  L 74</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
<td>A 7  B 12  C 17  D 22  E 28  F 33  G 39  H 45  I 51  J 57  K 60</td>
</tr>
</tbody>
</table>
US Navy Dive Table 9.8

Table 9-8. Residual Nitrogen Time Table for Repetitive Air Dives.

Locate the diver’s repetitive group designation from his previous dive along the diagonal line above the table. Read horizontally to the interval in which the diver’s surface interval lies.

Next, read vertically downward to the new repetitive group designation. Continue downward in this same column to the row that represents the depth of the repetitive dive. The time given at the intersection is residual nitrogen time, in minutes, to be applied to the repetitive dive.

* Dives following surface intervals longer than this are not repetitive dives. Use actual bottom times in the Air Decompression Tables to compute decompression for such dives.

<table>
<thead>
<tr>
<th>Repetitive Group at Beginning of Surface Interval</th>
<th>Repetitive Group at the End of the Surface Interval</th>
<th>Dive Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>15</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td>20</td>
</tr>
<tr>
<td>D</td>
<td>D</td>
<td>25</td>
</tr>
<tr>
<td>E</td>
<td>E</td>
<td>30</td>
</tr>
<tr>
<td>F</td>
<td>F</td>
<td>35</td>
</tr>
<tr>
<td>G</td>
<td>G</td>
<td>40</td>
</tr>
<tr>
<td>H</td>
<td>H</td>
<td>45</td>
</tr>
<tr>
<td>I</td>
<td>I</td>
<td>50</td>
</tr>
</tbody>
</table>

Note: For depths and intervals not listed, use interpolation or consult the appropriate tables.
1955- First application of HBO to treat radiation induced injuries.

1955- Boerma proposed using HBO during cardiac surgery. In 1960 *Life Without Blood* was published detailing the use of plasma alone to transport oxygen. This was vital in proving the healing properties of HBOT.

1970- First HBO conditions list and recommended protocols was were created in Milwaukee WI.

1972- 125 approved conditions were listed as possible candidates for HBOT. By 1979, the last was down to 25 conditions. In 2014, there are now 14.

1974- (Sheffield) The well know 2.4 ATA treatment table was developed at Brooks AFB.
CMS Approved Conditions

**Acute Conditions**
- CO exposure
- Decompression Illness
- Gas Embolism
- Gas Gangrene
- Crush Injuries
- Necrotizing Fascitis
- Thermal Burns
- Idiopathic Sudden Sensorineural Hearing Loss

**Chronic Conditions**
- Arterial Insufficiencies
- Osteomyelitis (refractory)
- Compromised Skin Grafts and Flaps
- Intracranial Abscesses
- Delayed Radiation Injuries (soft tissue and bone)

*Severe Anemia*

*Subject to review based on pt condition/religious beliefs*
1928, The Cunningham Sanitarium was built in Ohio.  
5 stories tall, 64 feet in diameter, 900 tons, and cost one million dollars.  
Claimed to treat diabetes and cancer.  
Dr. Cunningham believed that exposing organisms to oxygen would stop them from multiplying.  
Operated for 5 years, and in 1934 was sold and renamed the Ohio Institute of Oxygen.  
A failing economy led to it’s demise and closure. In 1942, the chamber was scraped for $25,000. Its metal was recycled and used to build ships for WWII.
Compromised Blood Flow

- Blood vessel
- Red blood cells block off the blood flow
- Diffused oxygen
- Plasma (fluid) still flows through the damaged blood vessel
- Restriction (occlusion) due to injury, disease, blood clot, etc.
- Tissues break down due to lack of oxygen
Oxygen Absorption into the Plasma During HBO

- Increase in diffusion distance into the tissue
- Restriction (occlusion) of the blood vessel reduces blood and oxygen flow
- Red blood cells block off the blood flow
- Diffused oxygen
- Plasma can carry 100% oxygen under pressure
- 100% oxygen under pressure diffuses from the plasma up to three times further into the tissues
Henry’s Gas Law

The amount of a gas that can be dissolved into a liquid is directly proportional to its partial pressure.
Boyle’s Law

Pressure and volume have an inverse relationship when temperature is constant. If a volume of gas is decreased, the pressure increases.

\[
\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}
\]
Example
Barotrauma

- All air filled spaces in the body are subject to barotrauma, which may result in damage to the body's tissues.
  - Middle ear
  - Lungs
  - GI track
  - Sinus
- Proper training is important for patients and staff.
Gay-Lussac’s Law

- Temperature-Pressure relationship.
- Volume constant, the pressure is directly related to the absolute temperature.

\[ \frac{P_1}{T_1} = \frac{P_2}{T_2} \]

- $P_1$, $P_2$ are pressure of gas
- $T_1$, $T_2$ are Temperature of gas
Example

- As attendants, we experience this every time we dive.
- When we compress or “dive” the chamber, it gets warm inside.
- When we ascend the chamber back to 1ATA, it gets cooler.
- Bullet fired from a gun.
- Any rapid release of a pressurized gas (tire exploding, pressure rupture, etc).
Off the Cuff

Corporations have found a use for hyperbarics. They place potential CEO candidates inside, pressurize, and ask them to buckle a belt around their waist. Those that are successful are disqualified. Nobody wants a CEO that buckles under pressure!!
Types of HBO Chambers

- **Class A** - multiplace, can accommodate 2 or more patients.
- **Class B** - single or mono-place chambers
- **Class C** - experimental, laboratory, and veterinarian uses.
Class A Chambers
Delivery and Installation
First UHIC Chamber
Class B Chambers
Class C Chambers
HBO in the 21st Century

- HBO is expensive.
- HBO studies are becoming rare and heavily scrutinized. (DOD and mild TBI/PTSD)
- Insurance companies are reviewing HBO related cases.
- There has been an identified need for a repository of HBO related information and studies.
Two Schools of Thought

- UHMS-Undersea Hyperbaric Medical Society
  - CMS driven, scientifically proven treatment
  - National Accreditation
  - UHMS published protocols

- IHMA- International Hyperbaric Medical Society
  - Off label treatment
  - Cover veterinarian services
  - Focus on non-traditional delivery of HBOT
What NOW!!
New Applications for Hyperbaric Oxygen Therapy: Traumatic Brain Injury

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Conflicts of Interest

• No financial conflicts of interest to disclose
Objectives

• To discuss the use of hyperbaric oxygen therapy in novel applications

• To introduce a hyperbaric oxygen therapy clinical trial being conducted at the University of Iowa
PRIMARY AND SECONDARY BRAIN INJURY:
Goal is to STOP secondary injury!

ICP: Intra Cranial Pressure
CPP: Cerebral Perfusion Pressure
CPP = MAP - ICP

Primary Brain Injury → Tissue pressure ↑ → Secondary Brain Injury → Edema ↑ → Ischemia ↑

CBF ↓

Image courtesy New York Academy of Sciences
Cerebral Blood Flow

Image courtesy neuroanesthesia.info
Low Cerebral Metabolic Rate is Associated with Poor Outcome

Jaggi and Obrist, J Neurosurg 72:176-182, 1990
Brain tissue oxygenation monitoring
HBO and CMRO$_2$

**Graph**

- **CMRO$_2$ posttreatment/pretreatment mean**
  - HBO (n = 19)
  - 100% FiO$_2$ (n = 14)
  - Control (n = 19)

**Time**

- Pre-treatment
- Post-treatment

**References**

Rockswold, J Neurosurg 112:1080-1094, 2010
HBO and Lactate/Pyruvate Ratio

Pre-treatment Post-treatment

Time

L/P ratio posttreatment/pretreatment mean

HBO (n = 20) 100% FiO2 (n = 12) Control (n = 18)

Rockswold, J Neurosurg 112:1080-1094, 2010
HBO and Intracranial Pressure

![Graph showing the mean difference of ICP (mmHg) over time for HBO (n=26), NBH (n=21), and Control (n=21). Pre-treatment and Post-treatment are indicated.}

Rockswold, J Neurosurg 112:1080-1094, 2010
Potential Mechanisms for HBO in TBI

• Pre-clinical findings
  - Depressed mitochondrial function following injury is restored
  - ATP production is improved
  - Ischemia induced brain cell loss is attenuated
  - Neuronal apoptosis is reduced
  - Cognitive deficits are markedly attenuated
  - Intracranial hypertension is reduced
## Hyperbaric Oxygen Brain Injury Treatment Trial

<table>
<thead>
<tr>
<th>Arm</th>
<th>Dose (Oxygen Toxicity Units, $\nu_a \times 100$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (1.0 ATA)</td>
<td>0</td>
</tr>
<tr>
<td>1.5 ATA</td>
<td>260</td>
</tr>
<tr>
<td>2 ATA</td>
<td>416</td>
</tr>
<tr>
<td>NBH (100% FiO2 at 1.0 ATA)</td>
<td>540</td>
</tr>
<tr>
<td>2.5 ATA</td>
<td>592</td>
</tr>
<tr>
<td>1.5 ATA+NBH</td>
<td>620</td>
</tr>
<tr>
<td>2 ATA+NBH</td>
<td>776</td>
</tr>
<tr>
<td>2.5 ATA+NBH</td>
<td>952</td>
</tr>
</tbody>
</table>

Treatments given BID x 5 days
Hyperbaric Oxygen Brain Injury Treatment Trial

Inclusion Criteria

• Age 16-65 years, requiring mechanical ventilation
• Severe TBI, defined as a iGCS of 3 to 8 in the absence of paralytic medication
• For patients with a GCS of 7 or 8 or motor score = 5, Marshall CT score > 1
• For patients with an alcohol level > 200 mg/dl, Marshall CT score > 1
• For patients not requiring a craniotomy/craniectomy or any other major surgical procedure, the first HBO$_2$ treatment can be initiated within 8 hours of admission
• For patients requiring a craniotomy/craniectomy or major surgical procedure, the first HBO$_2$ treatment can be initiated within 14 hours of admission
Hyperbaric Oxygen Brain Injury Treatment Trial

• Primary Outcome
  – Neurologic outcome (GOS-E) at 6 months.

• Secondary Outcomes:
  – Intracranial pressure monitoring
  – Therapeutic intensity scores
  – Brain tissue oxygenation
  – Adverse events
Hyperbaric Oxygen Brain Injury Treatment Trial

**Oxygen Toxicity**

- No patient will undergo HBO\textsubscript{2} treatment with a P/F ratio < 200 or if a PEEP > 10 cm of H\textsubscript{2}O is required to achieve a P/T ratio > 200
- Specific attention to adverse events related to HBO\textsubscript{2} treatment, e.g., pulmonary dysfunction
- The incidence of pulmonary dysfunction will be compared across treatment groups vs controls
Hyperbaric Oxygen Brain Injury Treatment Trial

- Hennepin County Medical Center / University of Minnesota
- University of Maryland
- University of Nebraska
- Duke University Medical Center
- University of Iowa
- Ohio State University
- University of California - San Diego
- University of Alabama - Birmingham
- Detroit Receiving Hospital
- Hamilton General Hospital - Canada
- Honor Health / Osborn Medical Center - Scottsdale
- Advocate Lutheran General Hospital / University of Illinois
- Baylor University Medical Center
- Spectrum Health / Michigan State University
- Medical College of Wisconsin
- University of Kentucky
Conclusions

• Wear helmets and seat belts
• You can’t do anything about the bonk
• You can do a lot to limit secondary injury by thinking carefully about the pathology and neurophysiology
• Hyperbaric oxygen therapy may be one strategy to reduce secondary injury
• Clinical trial (HOBIT) is currently underway
New Applications for Hyperbaric Oxygen Therapy: Traumatic Brain Injury

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