Hyperbaric Physiology

The Rouse Story

• Oct 12, 1992, off the New Jersey coast
• father/son team of experienced divers
• explore submarine wreck in 230 ft (70 m)
• breathing compressed air
• trapped in wreck & escaped with no time for decompression

Arrival at recompression facility

• Both divers directly ascend to dive boat
• Helicopter arrives at boat in 1 hr 27 min
• Bronx Municipal Hospital recompression facility
  – Chris (39 yrs) pronounced dead
  – Chrissy (22 yrs)
    • coherent and talking
    • paralysis from chest down
    • no pain
    • blood sample contained foam

Recompression efforts

• Recompression starts about 3 hrs after ascent
  – put on pure O2 and compressed to 60 ft
    • extreme pain as circulation returned
  – compressed to 165 ft, then over 5.5 hrs gradually ascended back to 30 ft., lost consciousness
  – back to 60 ft. Heart failure and death
• autopsy revealed that the heart contained only foam

Medical Debriefing

• Doctors conclusions regarding their treatment
  – nothing short of recompression to extreme depths - 300 to 400 ft
  – saturation treatment lasting several days
  – complete blood transfusion
  – deep helium recompression

Gas Laws

• Boyle’s Law
  – $P_1V_1 = P_2V_2$
• Dalton’s Law
  – total pressure is the sum of the partial pressures
• Henry’s Law
  – the amt of gas dissolved in liquid at any temp is proportional to it’s partial pressure and solubility
Gas problems during diving

- Rapture of the deep (Nitrogen narcosis)
- Oxygen toxicity
- Hypoxia
- Contaminated gases
- Hypercapnia

Martini’s Law

- Every fifty feet of depth is approximately equal to drinking one martini on an empty stomach (increased N2 in tissues)
- euphoria at > 30m
- at pressures > 100m, unconsciousness
- determines a physical limit for breathing air at depth
- no apparent adaptation in humans

Narcotic gases

- All Noble gases cause narcosis
  - outer shell filled with electrons
- chemically inert but narcotic properties depend on their solubility in body fat
- mechanism for narcosis is unknown (cell membrane)

| Table 13.1: Relative Narcotic Potency of inert Gases |
|-----------------|-----------------|-----------------|-----------------|
| Molecule        | Molecular Weight| Solubility      | Narcotic Index  |
| Hydrogen        | 3               | 2.1             | 0.60            |
| Helium          | 4               | 1.7             | 1.38            |
| Nitrogen        | 28              | 2.1             | 1.08            |
| Oxygen          | 32              | 2.2             | 1.40            |
| Argon           | 40              | 2.1             | 2.5             |
| Krypton         | 84              | 5.6             | 3.6             |
| Xeon            | 152             | 2.0             | 25.7            |

Oxygen Toxicity

- Occurs from breathing 100% O2 too long
  - in 1 ATM, > 12hrs
- Occurs from pressuring a gas mixture
  - in 7 ATM, > 5 min
- Symptoms
  - coughing, mild irritation under sternum, burning in trachea or bronchi
  - convulsions

High Pressure Nervous Syndrome (HPNS)

- Increasing pressure reverses the effects of narcosis
  - hyper-excitability effect
  - mechanism is also unknown
    - fluidity of membranes, NT release, post-synaptic effects?
- Forms a barrier to very deep diving
  - HPNS at pressures > 200m
**Symptoms of HPNS**
- Rapid tremor, poor coordination, involuntary jerking movements, microsleep
- No evidence of adaptation in humans
- Addition of narcotic gases decreases the effect and increases max depth
  - Trimix (helium, nitrogen, oxygen)
  - Heliox (helium and oxygen)
  - Nitrox (air enriched with oxygen)
- HPNS limits the max depth humans can dive

**Mixed gases**
- Prevents HPNS
- Reduces gas density
  - Work of breathing increases with depth as gas density increases
  - Helium and hydrogen are much less dense than air
  - Mixed with O2 will support ventilation with light work at depths as deep as 1500m
- Controls oxygen level (↓O2 as ↑depth)

**Breathe hold diving**
- Oldest form of diving
  - 4500 BC artifacts
  - Ama divers
- Time limitations
  - Usually about 60 s
  - Hyperventilation, 4.5 min
  - World record, 7 min 41 s
  - Hyperven. + O2, 20.1 min
- Risks
  - Blackout
  - Barotrauma

**Hyperbaric injuries**
- Lung squeeze (30 m or more)
  - TLC < RV
  - Fluid is drawn into alveoli
  - Alveoli rupture
  - Pneumothorax
- Middle ear squeeze
  - Affects 40% of divers

**Hyperbaric injuries, cont.**
- Sinus squeeze (infection and allergies)
- Face-mask squeeze (ruptured eye vessels)
- GI barotrauma (chew gum, carbonated fluids, beans)
- Alternobaric vertigo (unequal middle ear pressure)
- Air embolism (failure to breathe out during ascent)
  - Has occurred in depths as little as 6 ft

**Decompression Sickness**
- Caissons used in 1840 to build bridges
  - Bends, chokes, staggers (vestibular system)
- Nitrogen forms bubbles during ascent
- Occurs after dives > 30 m
- Symptoms usually appear within 3 hrs of completing the dive
  - Joint pain
  - Neurological hits, paralysis, confusion
  - Skin mottling
DCS Tables history

• Paul Bert--first described DCS
• JS Haldane--developed first DCS tables
  – descend rapidly, spend limited time on the bottom, ascend slowly to the surface in stages
  – ascend 1/2 way rapidly
  – ascend set amounts and stop

Decompression Tables

Dysbaric Osteonecrosis

• Divers with a history of DCS
• 20% in divers who work below 200m
• bubbles reduce capillary flow to bone and cause bone cells to die
• damage mainly in the end of long bones

Open Circuit Scuba Gear

• Air is fed with a demand regulator at ambient pressure
• air is exhaled to the water forming bubbles

Closed Circuit Scuba Gear

• Air is fed to the diver with a demand regulator at ambient pressure
• 100% O2 is recycled through a CO2 scrubber
• depth is limited
  – to < 8m for pure O2
  – to < 25m with 60% O2, 40% air
• must purge nitrogen periodically
• No bubbles

Jacques Cousteau and Emile Gagnan developed the demand value in 1943
Carbon Dioxide Toxicity
- Occurs with closed systems
  - diving for > 4-6 hrs
  - headache is usually the critical first warning
- Occurs at depth due to pressure
  - First described by JBS Haldane
  - Br sub Thetis sunk in 1939, 99 men died only 4 escaped
  - small escape chamber where men exhaled and CO2 increased to 6%
  - when escape pressure was pressurized to 10 ATM, CO2 effect became fatal

CO₂ symptoms

Cardiac arrhythmias
- Common during diving even in young divers
  - 22 x more arrhythmias when submerged
- Why?
  - blood pressure increase with breathe hold
  - pressure from wet suit on the carotid sinus
  - fatigue, dehydration, cold
  - increased central blood volume

Drowning
- A Perfect Storm pgs 179-186
- A graphic description of what it feels like to drown
  - based on report by James Lowson 1892
  - shipwreck survivor
- stages of drowning
  - struggling to hold breath
  - must breathe, water triggers laryngeal spasm
  - pain recedes, euphoric feeling, final thoughts
  - unconsciousness

Susceptible Populations for DCS
- Females?
  - Greater body fat (∆ nitrogen dissolved in fat)?
  - increased symptoms during menstruation
  - don’t dive when pregnant!
- Age effect
  - > in middle-aged than younger men
- Foramen Ovale
  - inadequate closure of hole between right and left atria in 25% of people
  - bubbles may occur in the cerebral circulation

Other precautions
- Avoid dehydration
- no strenuous exercise 6 hrs after diving
- do not fly for at least 12-24 hrs after diving
- increase decompression time when diving at altitude
Limits

- 30m, nitrogen narcosis (limit for air)
- 30 - 200m, oxygen toxicity and increased work of breathing (breathe mixed gases)
- > 200m HPNS, breathe trimix gas
- 450m, limit for open sea diving
- 600m, limit with pressure chamber

Saturation Diving

- Live and work at depths up to about 300m to avoid lengthy decompression
  - breathe heliox
  - following 100m, 4 d decompression
  - following 300m, 10 d decompression
- helium speech unscrambler
- 30°C living quarters

The abyss

- Abyssal plains
- need pressure-resistant vessels
  - 1620, first submarine (Cornelius Drebbel)
  - 1934, bathysphere, William Beebe and Otis Barton
  - 1940, bathyscaphe, Auguste Piccard
  - 1960, Trieste lands in Mariana Trench

1985 Alvin discovers the Titanic