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

Chris and Chrissy Rouse

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

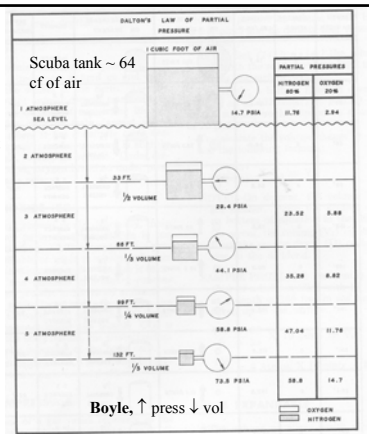
Medical Debriefing

- 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

1 ATM=33 ft (10 m)



Scuba tank ~ 64 cf of air

Boyle, ↑ press ↓ vol

Henry, gas dissovled = gas Pp & tissue solubility

Dalton, total press. = sum of the partial pressures

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

Nitrogen narcosis

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 Potencies of Inert Gases

INERT GAS	MOLECULAR WEIGHT	OIL/WATER SOLUBILITY	NARCOTIC POTENCY
Hydrogen	2	2.1	.56
Helium	4	1.7	.24
Neon	20	2.1	0.28
Nitrogen	28	5.2	1.0
Argon	40	5.3	2.3
Krypton	84	9.6	7
Xenon	131	20	25

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

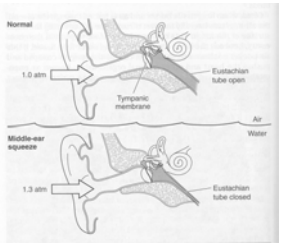
- Prevents HPNS
- reduces gas density
  - work of breathing increases with depth as gas density increases
  - helium and hydrogen are much less dense than air
  - mixed with O2 will support ventilation with light work at depths as deep as 1500m
- controls oxygen level (↓O2 as ↑depth)

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 41s
  - hyperven. + O_2, 20.1 min
- risks
  - blackout
  - barotrauma

Hyperbaric injuries

- Lung squeeze (30m or more)
  - TLC < RV
    - fluid is drawn into alveoli
    - alveoli rupture
    - pneumothorax
- Middle ear squeeze
  - affects 40% of divers



Hyperbaric injuries, cont.

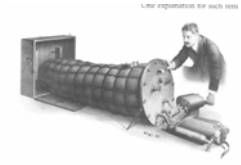
- Sinus squeeze (infection and allergies)
- face-mask squeeze (ruptured eye vessels)
- GI barotrauma (chew gum, carbonated fluids, beans)
- Alternobaric vertigo (unequal middle ear pressure)
- Air embolism(failure to breathe out during ascent)
  - has occurred in depths as little as 6 ft

Decompression Sickness

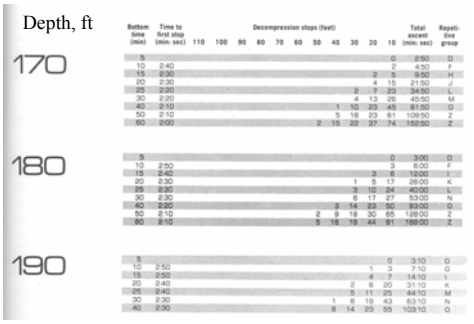
- Caissons used in 1840 to build bridges
  - bends, chokes, staggers (vestibular system)
- Nitrogen forms bubbles during ascent
- occurs after dives > 30m
- symptoms usually appear within 3 hrs of completing the dive
  - joint pain
  - neurological hits, paralysis, confusion
  - skin mottling

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 amts and stop

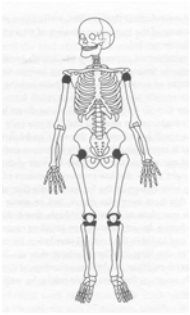


Decompression Tables



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

Jacques Cousteau and Emile Gagnan developed the demand value in 1943

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

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

CO_2 symptoms

Table 4.3
Signs and Symptoms of Acute Exposure to Elevated Carbon Dioxide Levels in Normal Men

CO_2 percent of inhaled gas*	Effects of exposure
0-4	No CNS derangement
4-6	Breathlessness, anxiety
6-10	Impaired mental capabilities
10-15	Severely impaired mental function
15-20	Loss of consciousness
>20	Muscular twitching, convulsions

* At sea level. At great depths, the effects of these CO_2 levels will be magnified.
Adapted from Clark and Thom 1997.

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

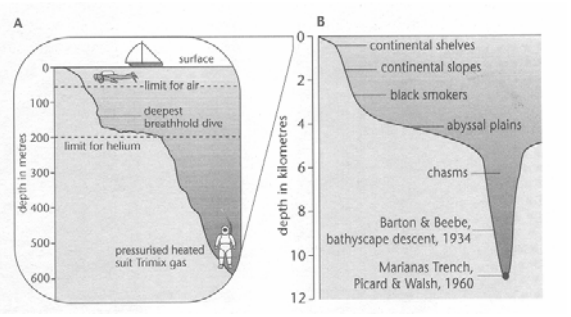
- Females?
  - Greater body fat (↑ nitrogen dissolved in fat)?
  - increased symptoms during menstruation
  - don't dive when pregnant!
- Age effect
  - > in middle-aged than younger men
- Foramen Ovale
  - inadequate closure of hole between right and left atria in 25% of people
  - bubbles may occur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

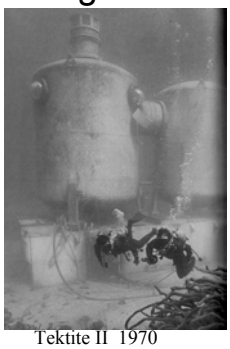
Limits

- 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**



Tektite II 1970

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