Physiology of Immersion
Definition:
− “The amount of any gas that will dissolve in a liquid at a given temperature is a function of the partial pressure of the gas that is in contact with the liquid and the solubility coefficient of the gas in the particular liquid”
Gas absorption and Elimination

- On-gassing is the absorption of gas into tissues over time when pressure increases
- Off-gassing is the elimination of gas from tissues over time when pressure decreases
- Tissues on-gas until they become “saturated”

Diving before total elimination means starting a dive with elevated N2 in the body
Compartments and Half-times

- Body tissues saturate at different rates:
  - Brain and spine saturate quickly
  - Muscles and organs saturate at a moderate rate
  - Bones saturate slowly

- Scientists use mathematical models with theoretical “compartments” to simulate various saturation rates.
Compartments and Half-times

- The time that it takes for a compartment to reach 50% saturation is called a “half time”
- After six half times, a compartment theoretically reaches 100% saturation
Compartments and Half-times

- 0 min: 50%
- 5 min: 75%
- 10 min: 87.5%
- 15 min: 93.75%
- 20 min: 96.88%
- 25 min: 100%
Compartments and Half-times

Inverse-Exponential Gas Profiles: Air (FN2=0.79)

PN2 (ATA)

Time (minutes)

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Not to be used for dive planning
Saturation Diving

- “Saturation” is when tissues hold all of the gas that they can hold at a given pressure.
- Once saturated, divers can remain at “storage” pressure until their work is done and then surface one time at the end of the job.
- Saturation diving poses special problems.
DIVING REFLEX

- Immersion in cold water may cause:
  - Tachycardia
  - Hypertension
  - Hyperventilation

Diving response initiated during apnea and augmented with facial immersion in cold water.

The Diving Response Includes:

- Peripheral vasoconstriction
- Reduced cardiac output
- Bradycardia

Diving Response

Dry Breath Hold:

- Muscle Oxygenation
- Middle Cerebral Artery Mean Flow Velocity

Immersion

- ↑ intrathoracic blood volume up to 700 mL.
- ↑ RAP by up to 18 mmHg.
- Transient ↑ in SV and CO by up to 100%.

Immersion

- Urine Production can reach 0.75 ml/min in the first hour of cold water immersion.
- Suppression of ADH
- Reduced renal tubular reabsorption
- Decreased sensitivity of the tubules to ADH.
Dehydration

- Breathing Low Humidity Air
  - Respiration: Loss of fluids from inhalation and exhalation of extremely dry breathing gases

Normal humidity level in the atmosphere is ≈ 30-70%
Humidity level in a pressurized scuba cylinder is ≈ 0.1%
Diving Response

Dry Breath Hold:

- Muscle Oxygenation
- Middle Cerebral Artery Mean Flow Velocity

CRAMPS
The Diving Response Includes:

- Peripheral vasoconstriction
- Reduced cardiac output
- Bradycardia

Muscle Oxygenation

Ventilation

- Ventilatory drive triggered by
  - Increased PaCO₂ (hypercapnia) - Primary
  - Decreased PaO₂ (hypoxemia) - Secondary

- Effect
  - Decreases PCO₂ (Hypocapnia)
  - Barely increases PO₂
  - Increases time before PCO₂ demands breathing
  - Unconsciousness from low PO₂ can occur before PCO₂ reaches threshold

Hyperventilation is dangerous
SHALLOW WATER BLACKOUT

- Hypoxia of Ascent (HOA)
- Cause: Excessive hyper-ventilation
- Signs and symptoms:
  - Beginning of breath-hold lightheadedness, faintness, blurred vision
  - At blackout--Unconsciousness, but no symptoms!
The respiratory drive is highly protective. Pre-breath-hold hyperventilation increases the risk of apneic hypoxia by delaying the urge to breathe. The example above depicts a static breath-hold condition.
Pre-breath-hold hyperventilation increases the risk of apneic hypoxic loss of consciousness by delaying the urge to breathe. Decreased ambient pressure during ascent increases the risk (hypoxia of ascent). * Illustration.
Shallow-Water Blackout

- Treatment: Rescue, life-support
- Prevention: Avoid excessive hyperventilation
EFFECTS OF SMOKING

• Short-term effects:
  - CO poisoning
  - Neurologic changes
  - Sensory loss
  - Heart rhythm and rate changes
  - Increased blood pressure
  - Increased DCS risk from blood “clumping”
Effects of Smoking

Smoking increases many of the risks of scuba diving

- Long-term effects:
  - Lung cancer
  - Obstructive lung disease
  - Heart problems

Prevention:
- Short term: Abstain at least several hours before diving
- Long term: Stop smoking
MEMORY & COGNITIVE FUNCTION
Neurological effects
- Some reports of concentration and memory decrements
- Some have suggested that there is a mild cerebral injury not measurable by neurological exam or psychometric testing
MEMORY & COGNITIVE FUNCTION

- Pathology - Bennett and Elliot, p 680-699
  - Some focal gray matter degeneration
  - Hyalinization of cerebral vessel walls
  - Evidence of neuronal tract degeneration

- Psychological effects
Case Report

- 49 y/o female tech diver
  - Day 4: 291 fsw; total run time 81 min; 10/50
  - Water temp 86F surface, 52F at depth
Case report

- Climbed ladder wearing gear to exit water
  - Good strength and balance
- Chief Complaints
  - Frequent modest cough, dyspnea, gurgling

Differential Diagnosis

- Decompression sickness?
  - Symptoms developed on the bottom
- Saltwater aspiration?
- Underlying cardiac disease?
Case report

- **Surface First Aid**
  - O₂ by demand mask; cough improved over 15 min
  - Met ambulance at dock after 20 min on boat
- **EMS/Evac**
  - Symptoms trigger protocol for helo to regional chamber
  - Patient refused; transport by ground to local hospital
- **Hospital treatment**
  - O₂, albuterol, solu-medrol, lasix
Case report:

Immersion Pulmonary Edema (IPE)

Day 1; 1630

Day 2; 0900
Immersion Pulmonary Edema (IPE)

- Fluid shift from capillaries into interstitial tissue of lungs
- Onset
  - Typically within 30-40 min of exposure
- Symptoms
  - Cough
  - Dyspnea
  - Possibly blood-tinged sputum
  - No chest pain
Immersion Pulmonary Edema (IPE)

- **Treatment**
  - Remove from water, normobaric O2, bed rest
  - Diuretics, inhaled beta-2 agonist
  - Consider CPAP

- **Return to diving?**
  - Probable following a single incident and after cardiac workup.
  - Doubtful after repeat insult
IPE Contributing Factors

- Central blood volume increase
  - Immersion = blood shift to thorax
  - Hyperhydration
  - Cold stress
- Work of breathing increase
  - Negative pressure breathing – immersion; influenced by body position and equipment (OC, CCR, snorkel)
  - Gas density
  - Exertion
- Pulmonary artery pressure elevation
  - Capillary stress failure and increased permeability
Questions?