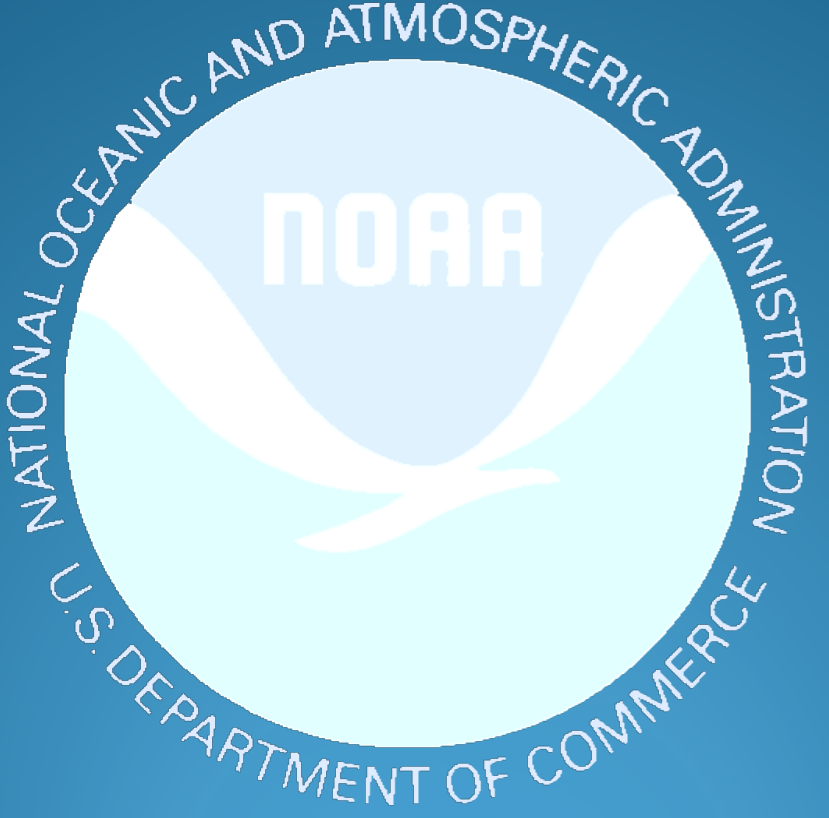
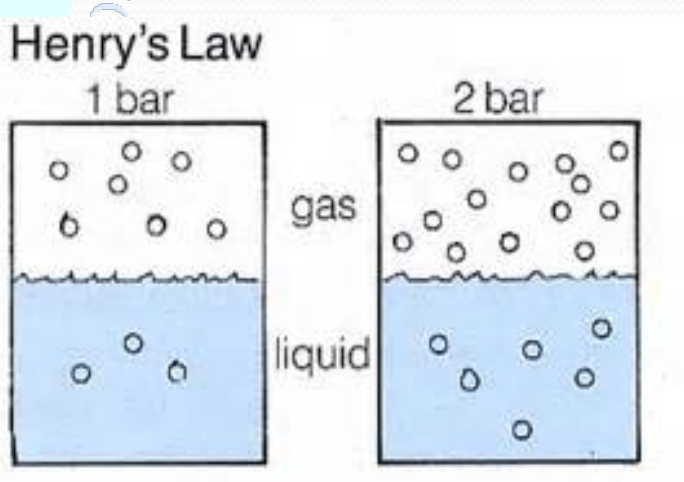
Physiology of Immersion



Henry's Law

- 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"



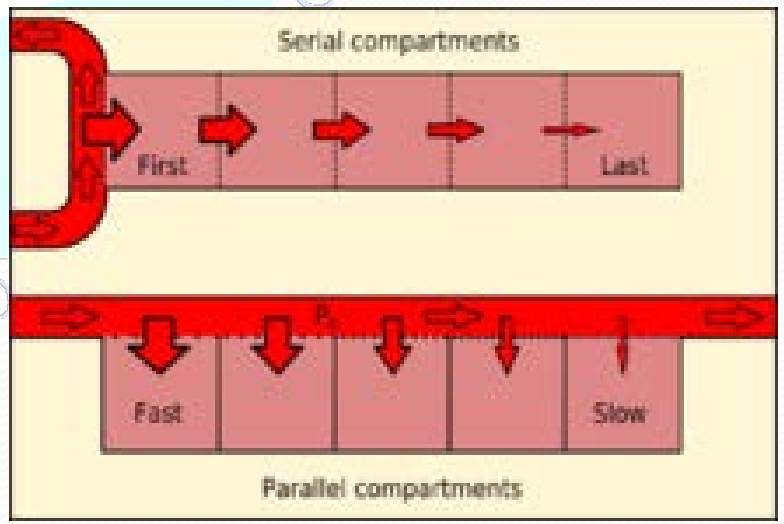
Gas absorption and Elimination

- 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 N_2 in the body

Compartments and Half-times

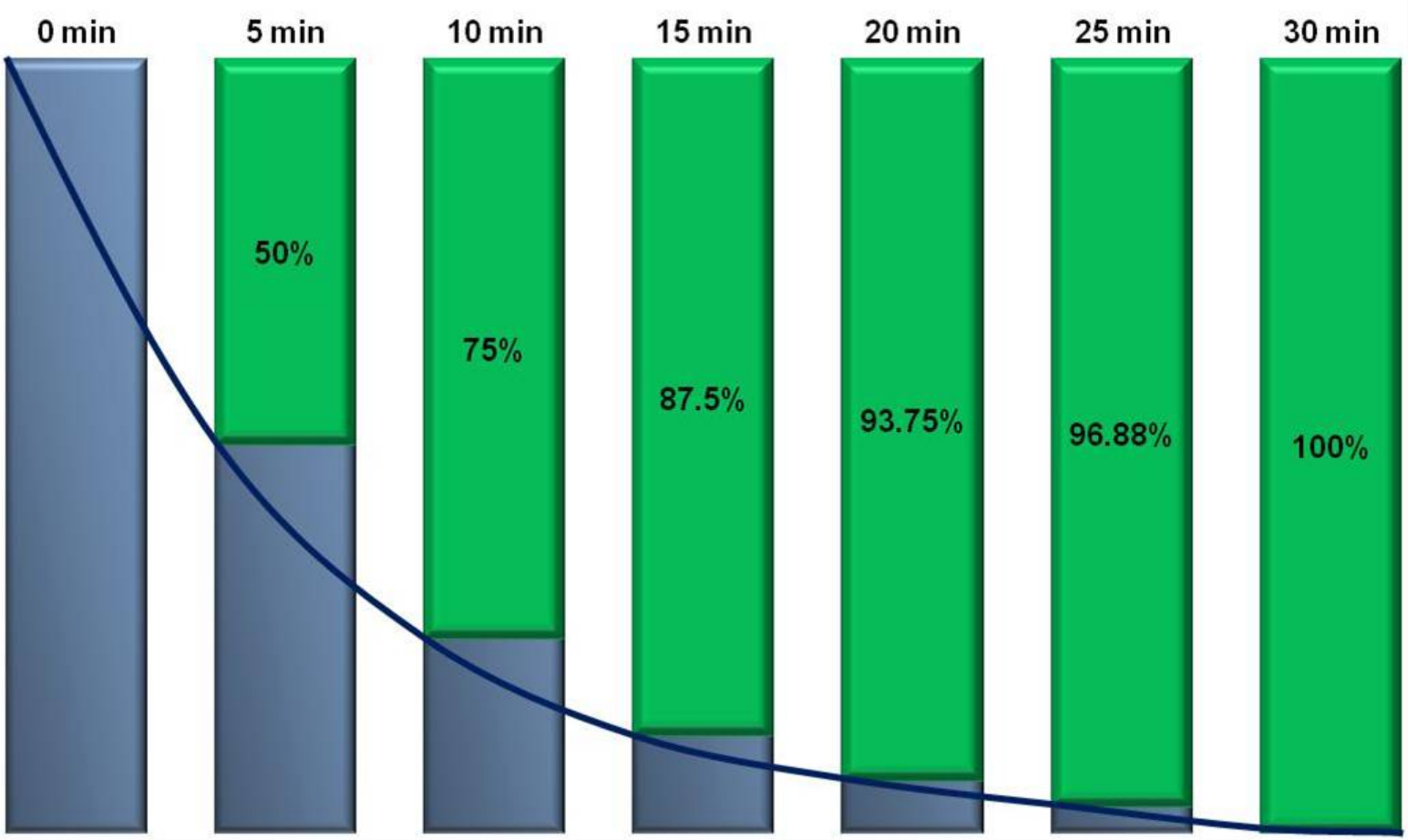
- Body tissues saturate at different rates:
  - Brain and spine saturate quickly
  - Muscles and organs saturate at a moderate rate
  - Bones saturate slowly
- Scientists use mathematical models with theoretical "compartments" to simulate various saturation rates.



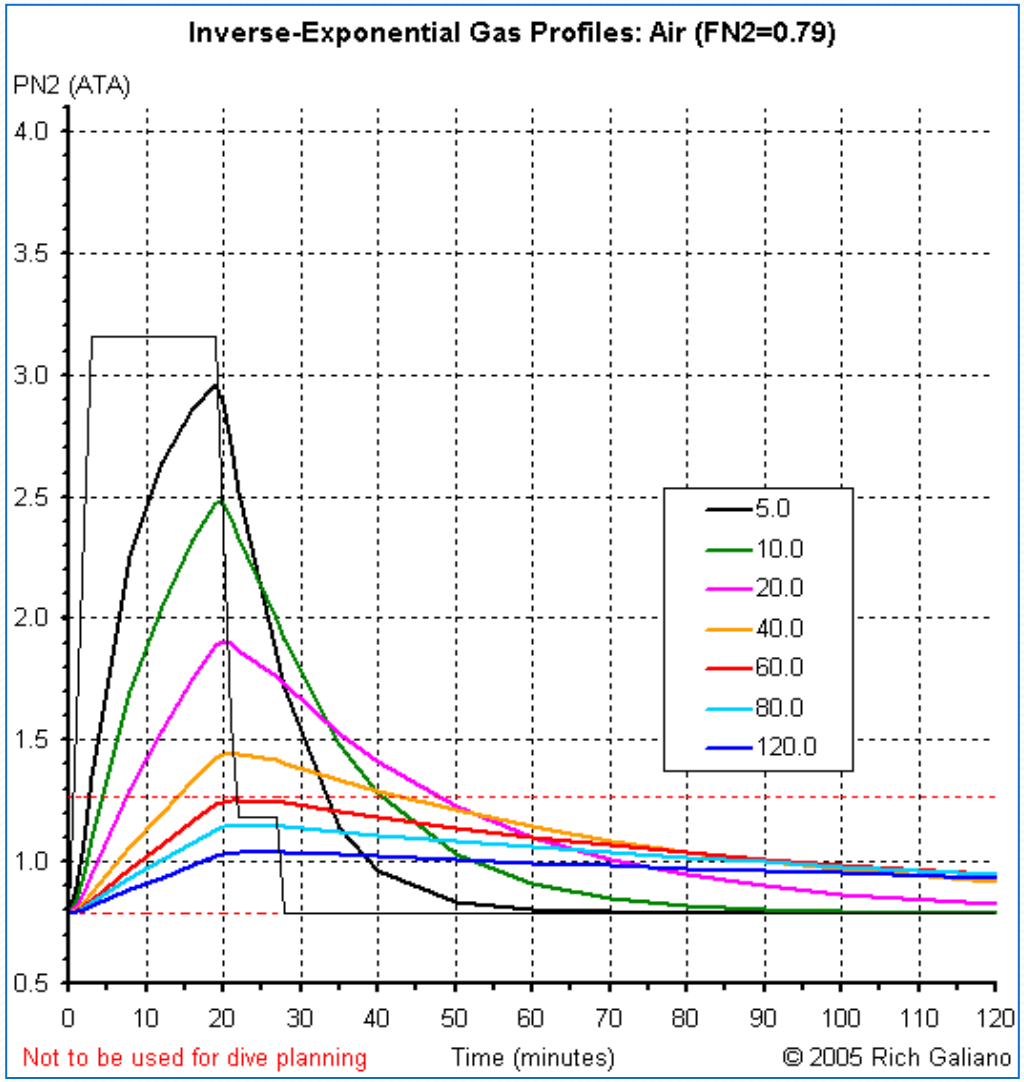
Compartments and Half-times

- 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



Compartments and Half-times



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

Pennefather, J. (2002) Cold and Hypothermia. In: Edmonds, Lowry, Pennefather, & Walker. *Diving and Subaquatic Medicine, 4th Ed.* Hodder Arnold. Ch 28.

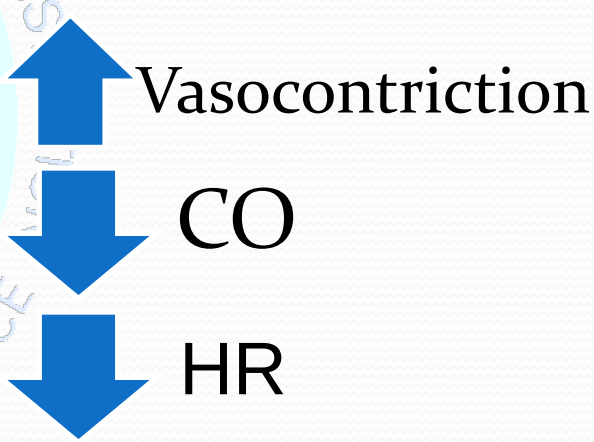
DIVING REFLEX

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

Kjeld T, Pott, FC & Secher NH. Facial immersion in cold water enhances cerebral blood velocity during breath-hold exercise in humans. *Jounal of Applied Physiology* 106: 1243-1248, 2009.

The Diving Response Includes:

- Peripheral vasoconstriction
- Reduced cardiac output
- Bradycardia



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Diving Response

Dry Breath Hold:

- ↓ Muscle Oxygenation
- ↑ Middle Cerebral Artery Mean Flow Velocity

Kjeld T, Pott, FC & Secher NH. Facial immersion in cold water enhances cerebral blood velocity during breath-hold exercise in humans. *Jounal of Applied Physiology* 106: 1243-1248, 2009.

Immersion

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

Lowry C: *Cardiac problems and sudden death.* In: Edmonds C, Lowry C, Pennefather J, Walker R, ed. *Diving and Subaquatic Medicine,* London: Arnold; 2002:402.

Immersion

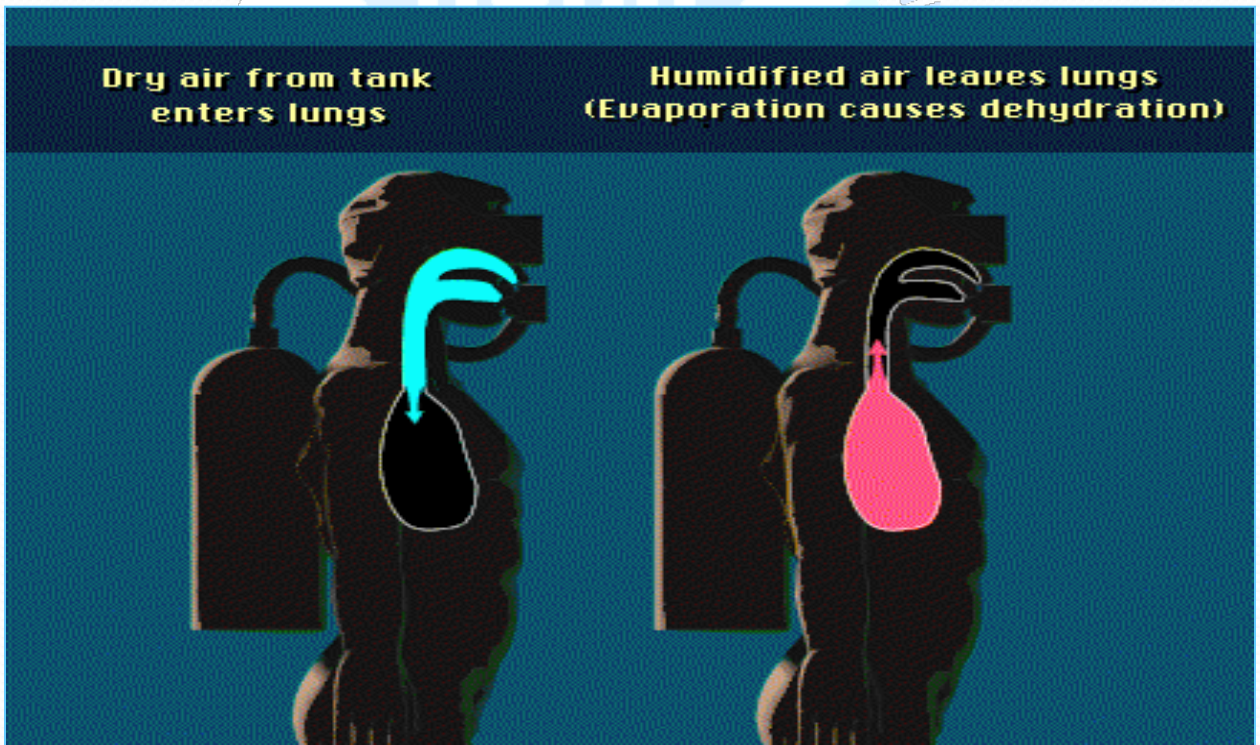
- Urine Production can reach 0.75 ml/min in the first hour of cold water immersion.
- Suppression of ADH
- Reduced renal tubular reabsorption
- Decreased sensitivity of the tubules to ADH.

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%



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CRAMPS

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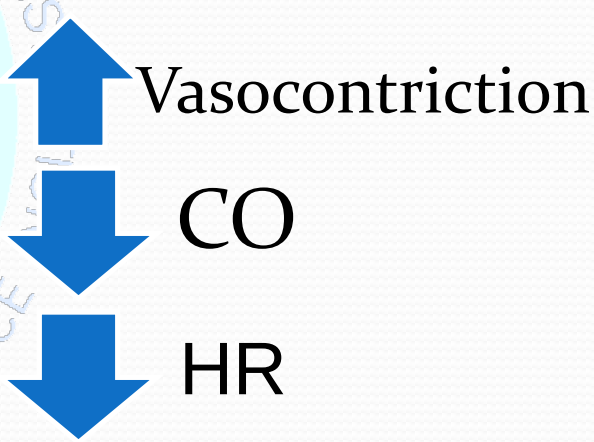

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CRAMPS

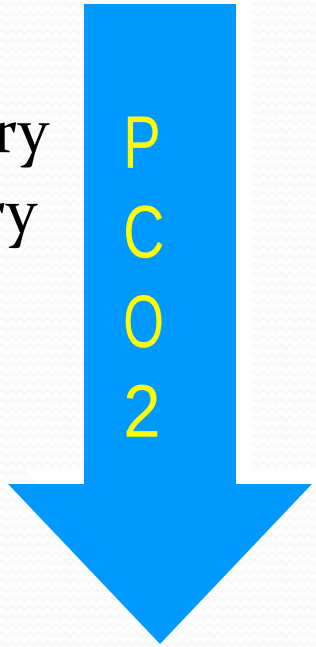
- ↑ Vasoconstriction
  - ↓ Muscle Oxygenation

+ anaerobic metabolism in working muscles?

Kjeld T, Pott, FC & Secher NH. Facial immersion in cold water enhances cerebral blood velocity during breath-hold exercise in humans. *Jounal of Applied Physiology* 106: 1243-1248, 2009.

Ventilation

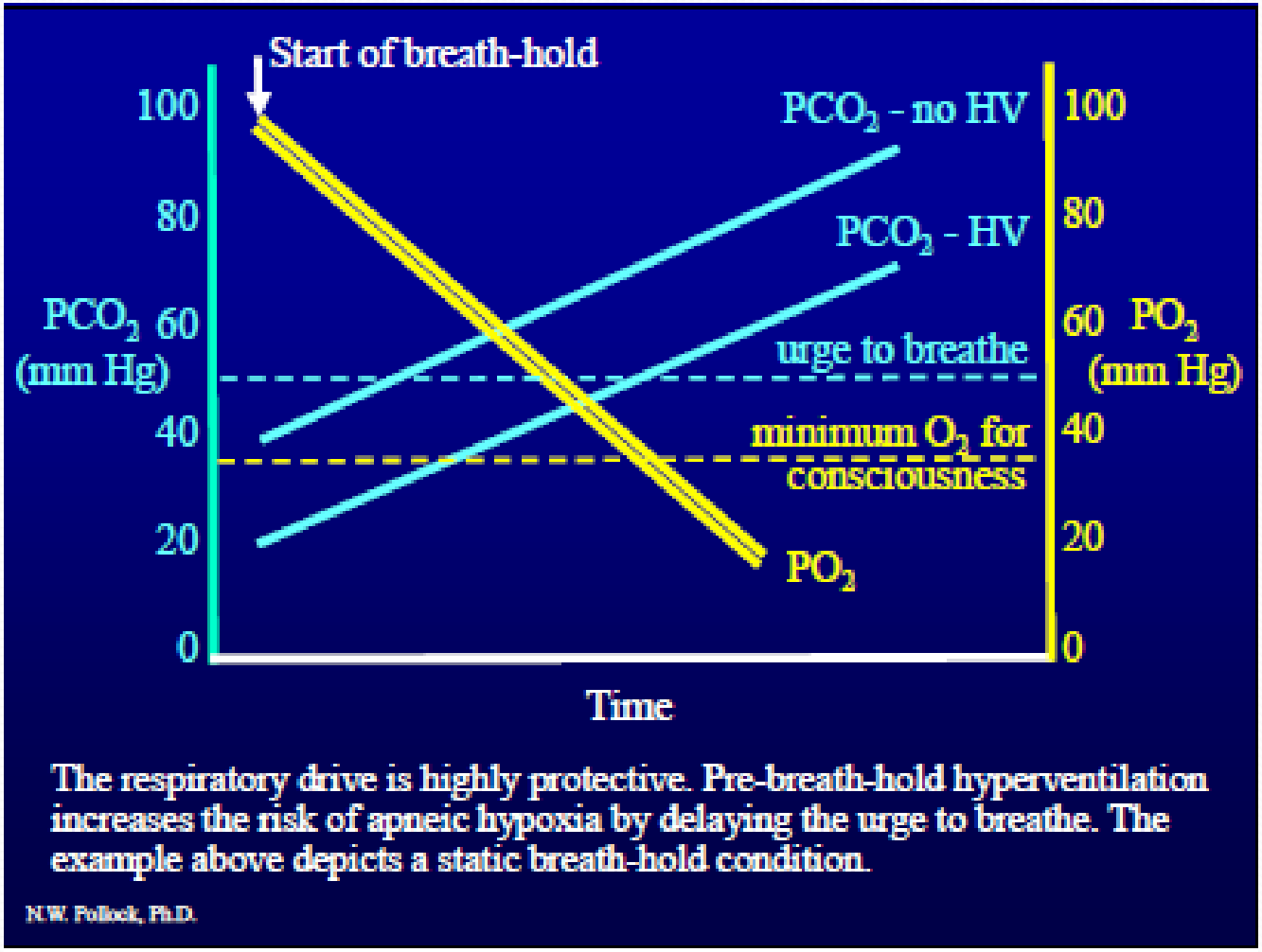
- Ventilatory drive triggered by
  - Increased $PaCO_2$ (hypercapnia) - Primary
  - Decreased PaO_2 (hypoxemia) - Secondary
- Effect
  - Decreases PCO_2 (Hypocapnia)
  - Barely increases PO_2
  - Increases time before PCO_2 demands breathing
  - Unconsciousness from low PO_2 can occur before PCO_2 reaches threshold

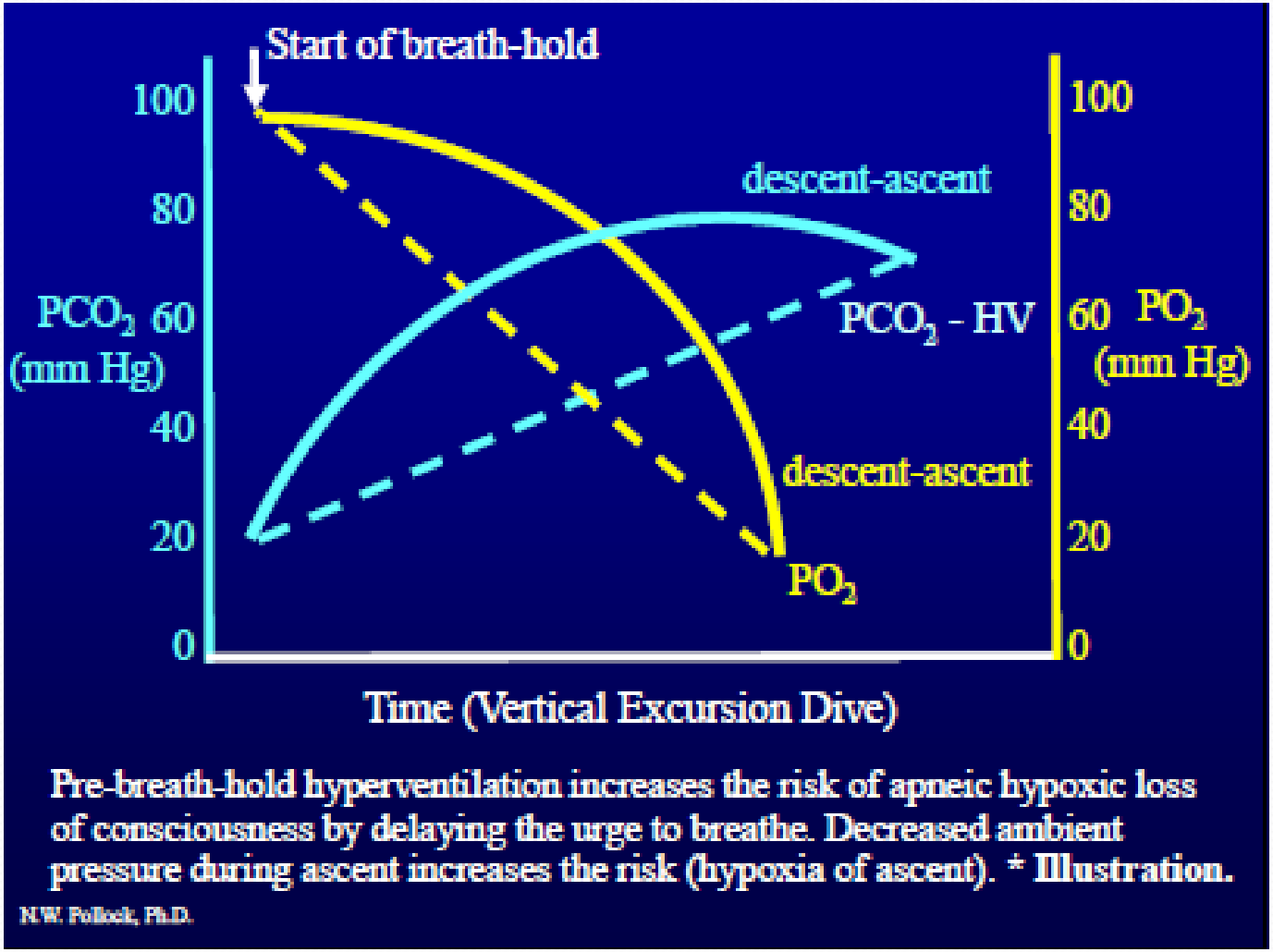


Hyperventilation is dangerous

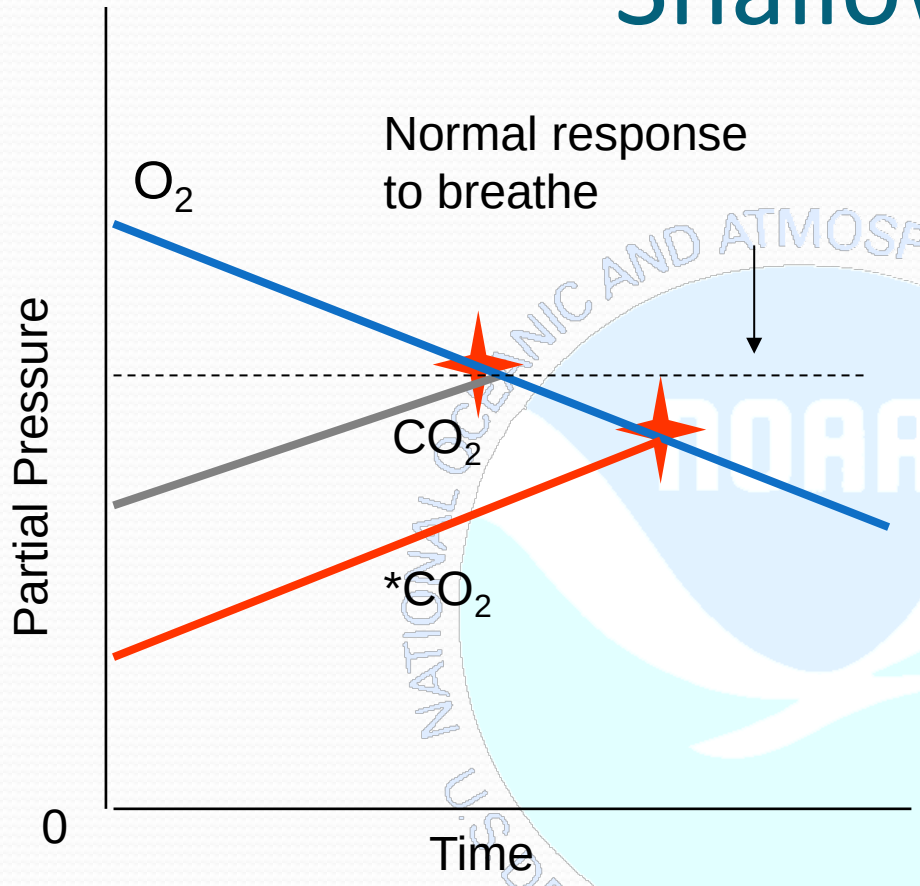
SHALLOW WATER BLACKOUT

- 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!


Start of breath-hold
100
80
60
40
20
0
PCO2 (mm Hg)
PCO2 - no HV
PCO2 - HV
urge to breathe
minimum O2 for consciousness
PO2
100
80
60
40
20
0
PO2 (mm Hg)
Time
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.
N.W. Pollock, Ph.D.


Start of breath-hold
100
80
60
40
20
0
PCO2 (mm Hg)
descent-ascent
PCO2 - HV
descent-ascent
PO2
100
80
60
40
20
0
PO2 (mm Hg)
Time (Vertical Excursion Dive)
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.
N.W. Pollock, Ph.D.

Shallow-Water Blackout

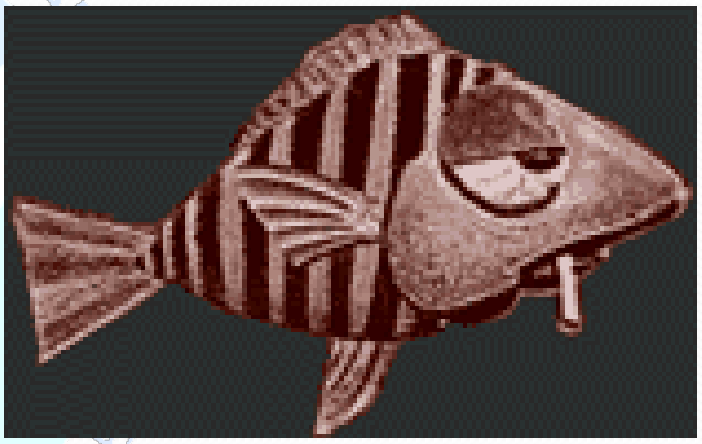


After hyperventilation = loss of consciousness

- 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”



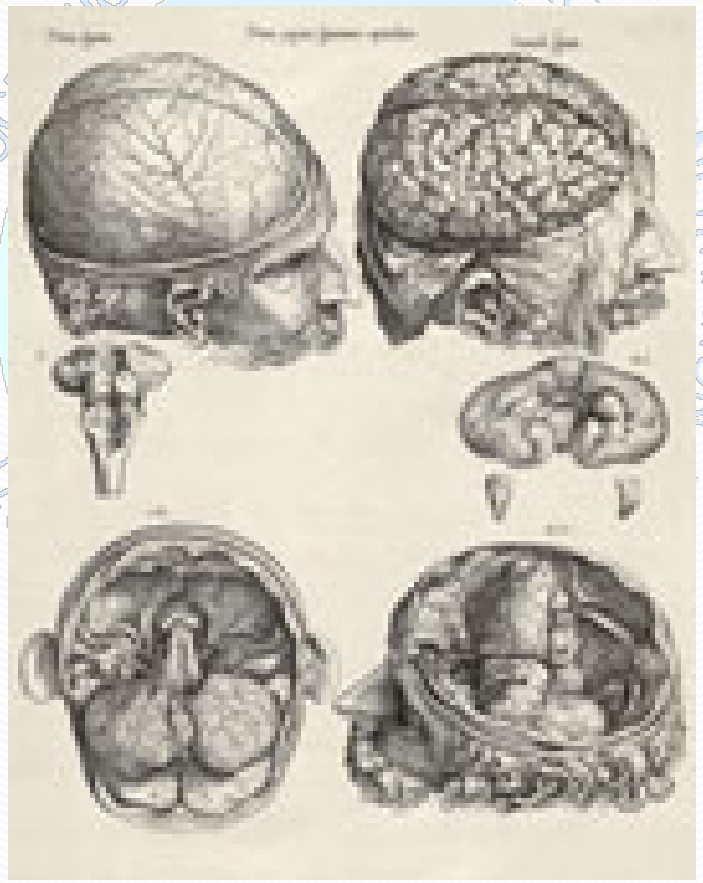
Effects of Smoking

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



MEMORY & COGNITIVE FUNCTION

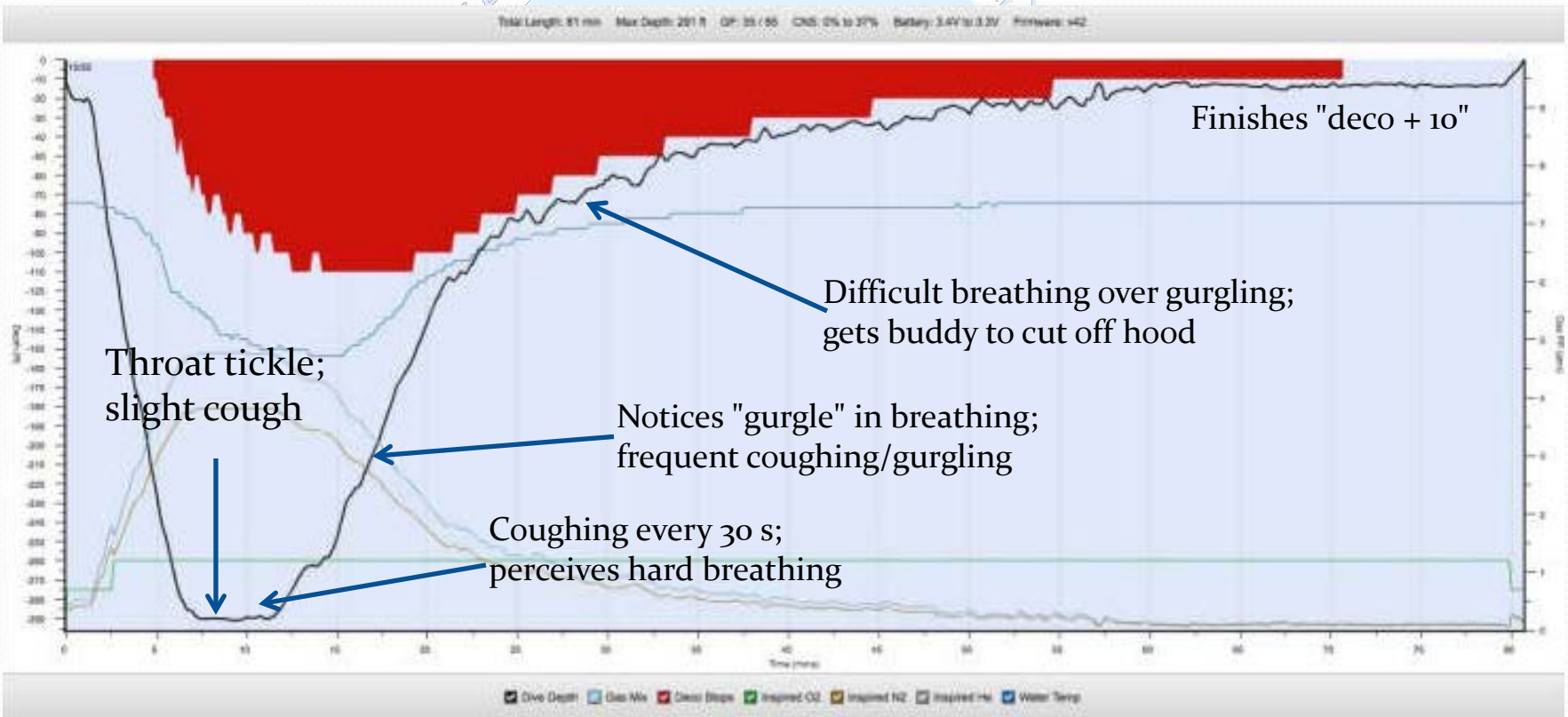
- Neurological effects
  - Some reports of concentration and memory decrements
  - Some have suggested that there is a mild cerebral injury not measurable by neurological exam or psychometric testing

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?