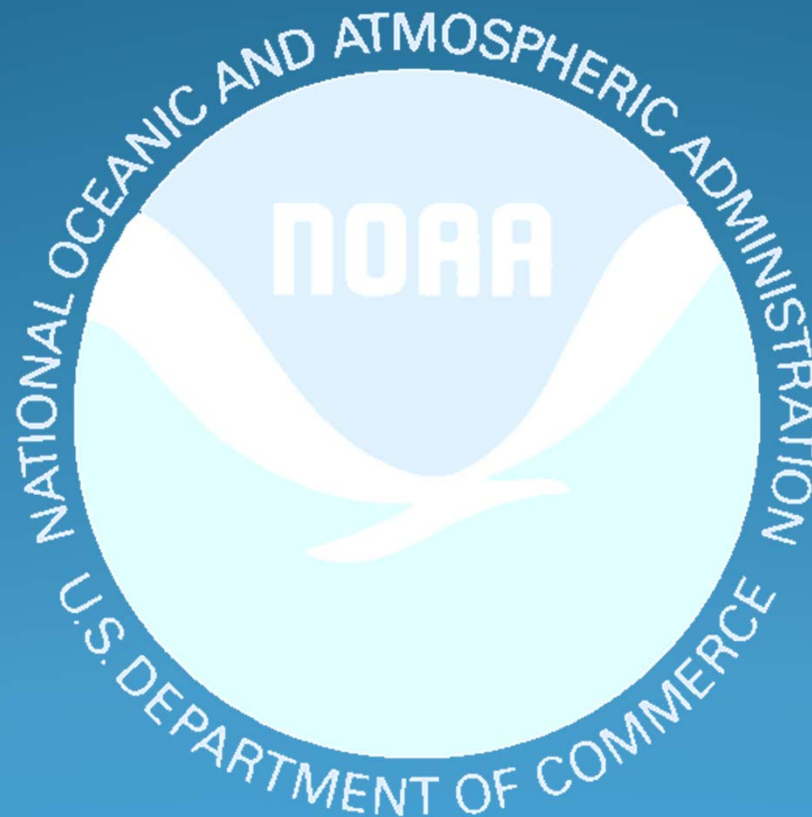
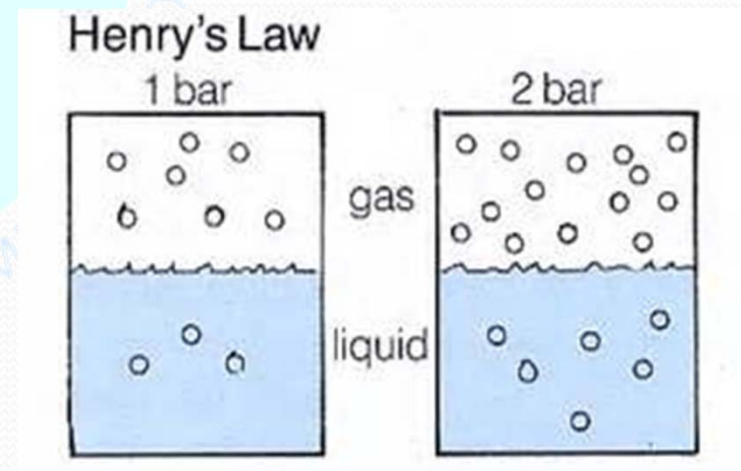


# Physiology of Immersion



# 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

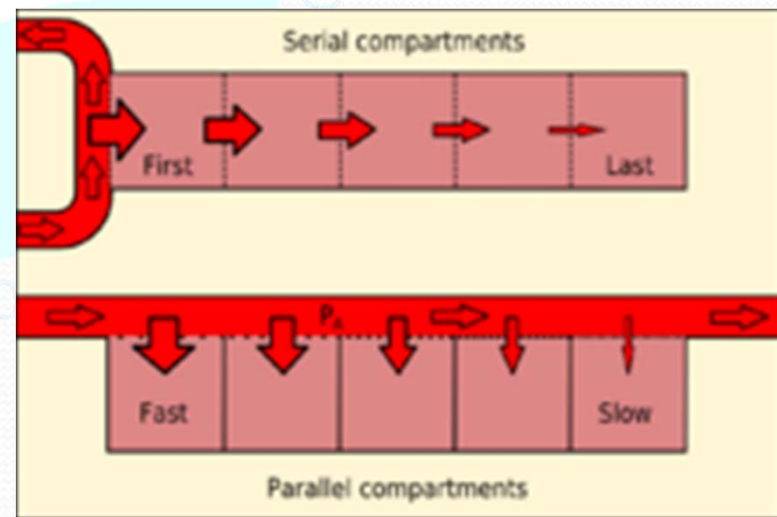
- On-gassing is the absorption of gas into tissues over time when pressure increases
- Off-gassing is the elimination of gas from tissues over time when pressure decreases
- Tissues on-gas until they become “saturated”

Diving before total elimination means starting a dive with elevated N<sub>2</sub> in the body



# Compartments and Half-times

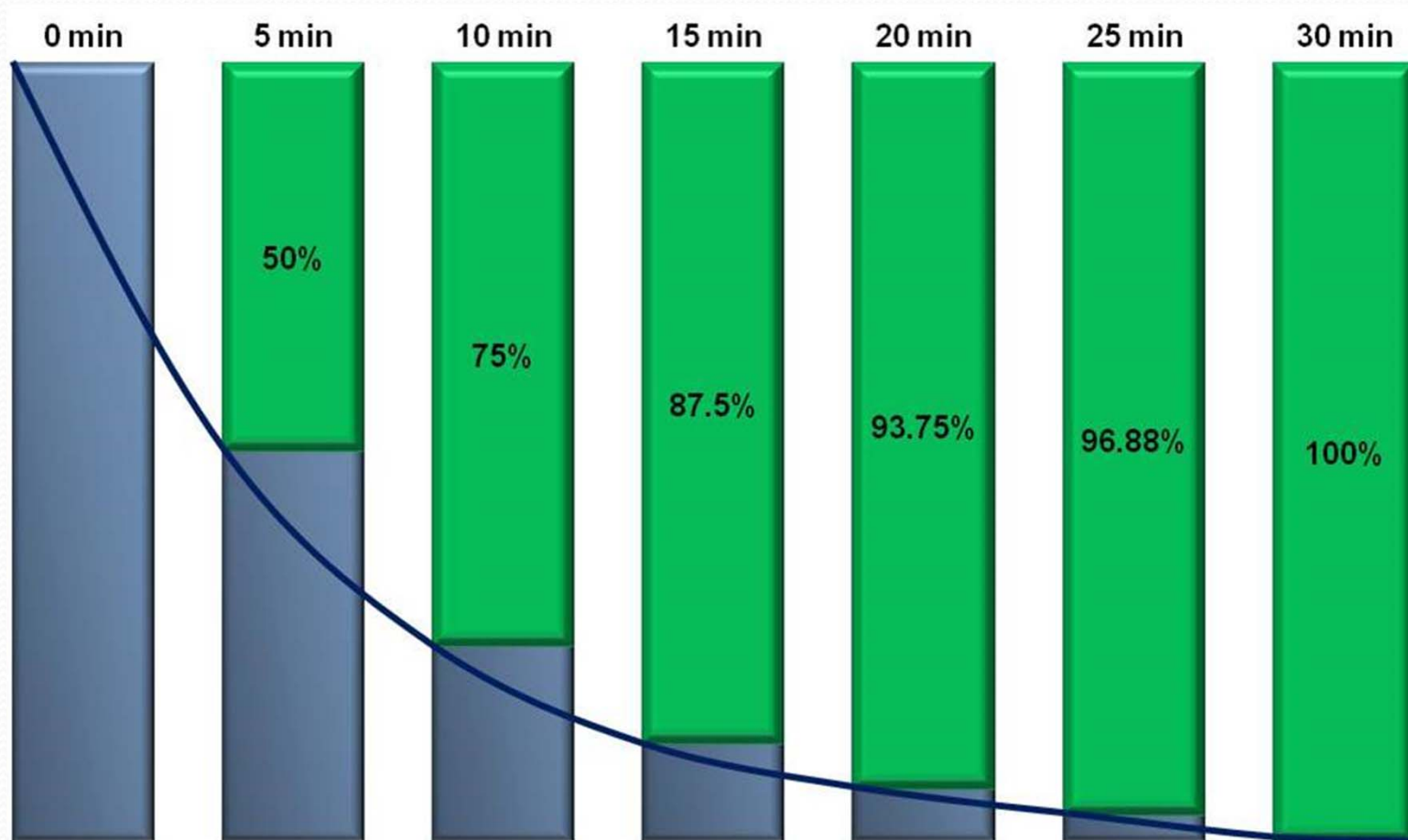
- Body tissues saturate at different rates:
  - Brain and spine saturate quickly
  - Muscles and organs saturate at a moderate rate
  - Bones saturate slowly
- Scientists use mathematical models with theoretical “compartments” to simulate various saturation rates.



# Compartments and Half-times

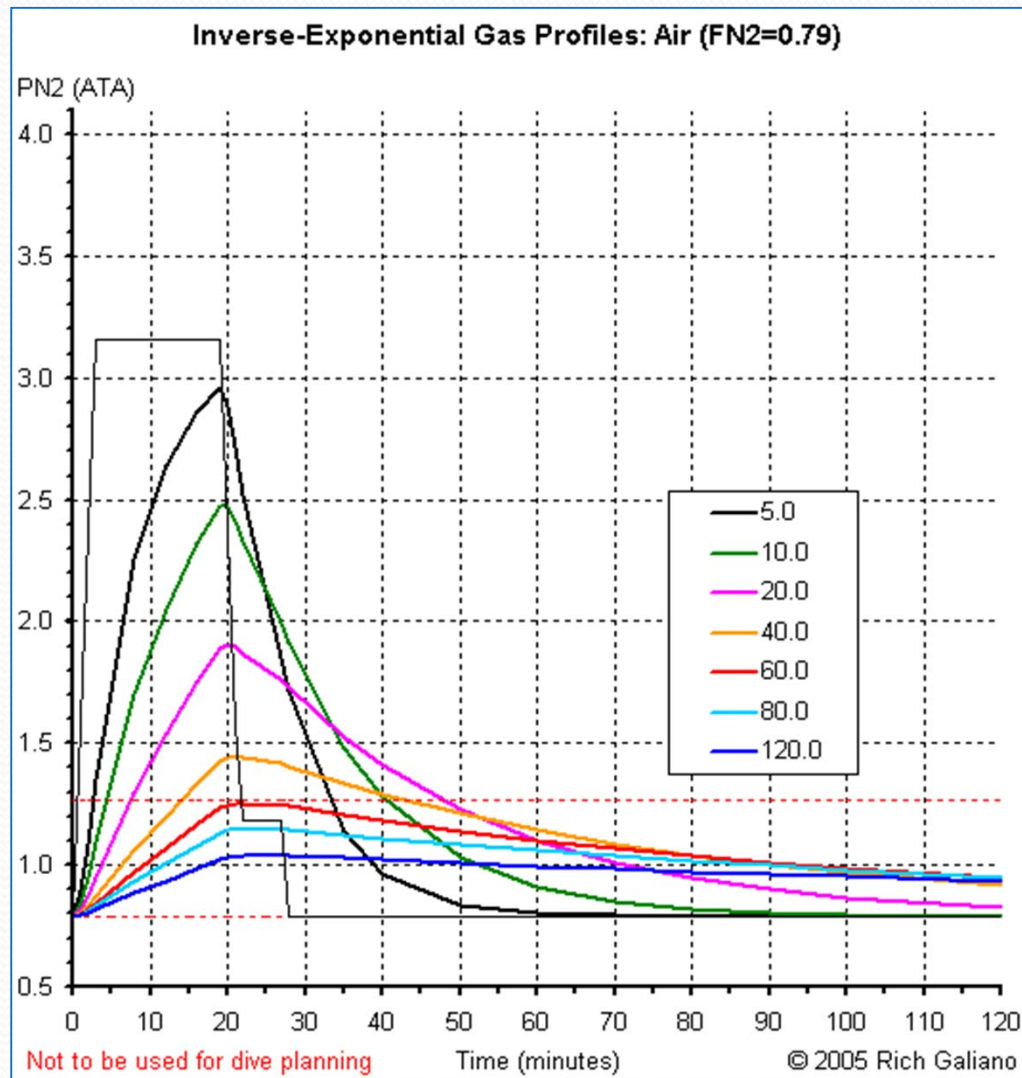
- The time that it takes for a compartment to reach 50% saturation is called a “half time”
- After six half times, a compartment theoretically reaches 100% saturation

# 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

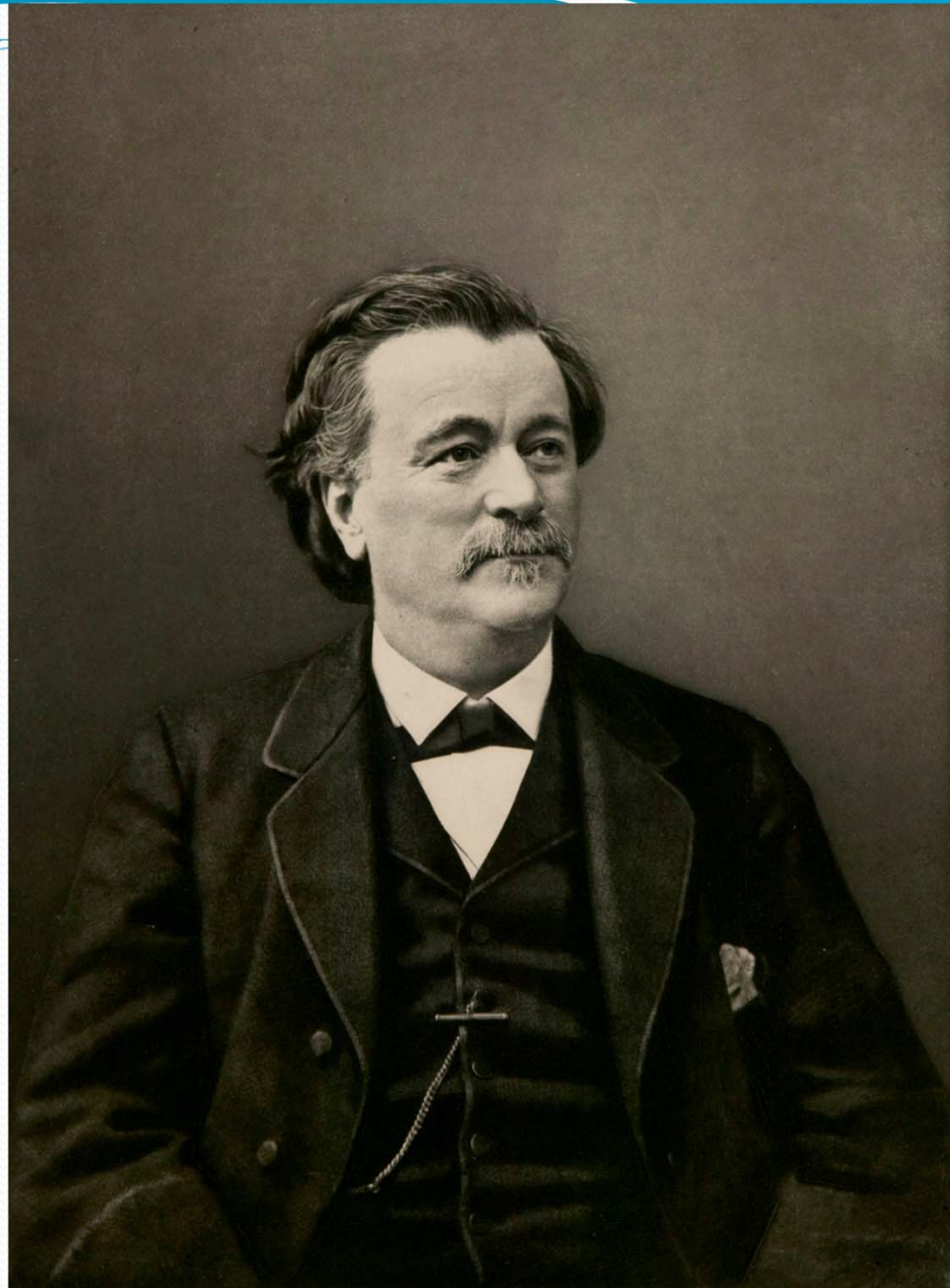
Pennefather, J. (2002) Cold and Hypothermia. In: Edmonds, Lowry, Pennefather, & Walker. *Diving and Subaquatic Medicine*, 4<sup>th</sup> Ed. Hodder Arnold. Ch 28.

# 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. *Journal of Applied Physiology* 106: 1243-1248, 2009.

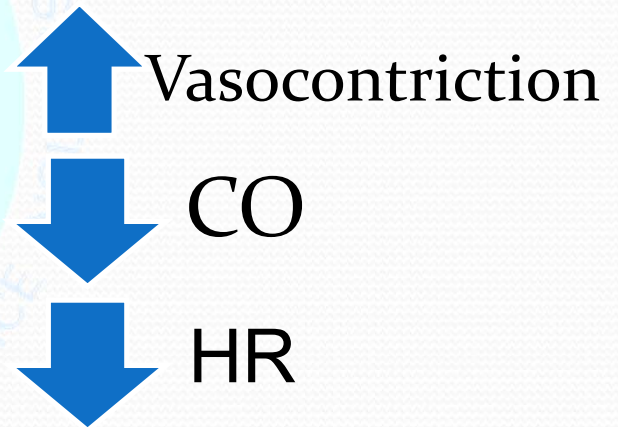






# The Diving Response Includes:

- Peripheral vasoconstriction
- Reduced cardiac output
- Bradycardia



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

# 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. *Journal 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

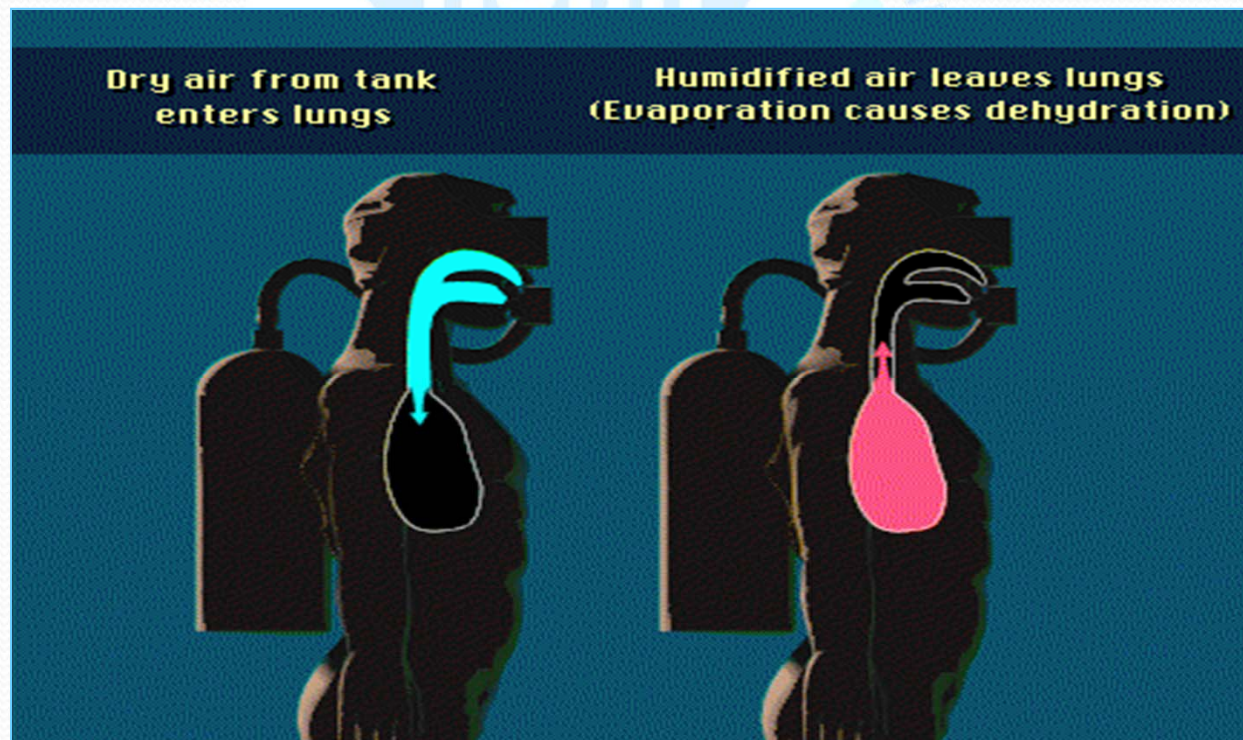
- Urine Production can reach 0.75 ml/min in the first hour of cold water immersion.
- Suppression of ADH
- Reduced renal tubular reabsorption
- Decreased sensitivity of the tubules to ADH.

# 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  $\approx 30\text{-}70\%$

Humidity level in a pressurized scuba cylinder is  $\approx 0.1\%$





# 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. *Journal of Applied Physiology* 106: 1243-1248, 2009.



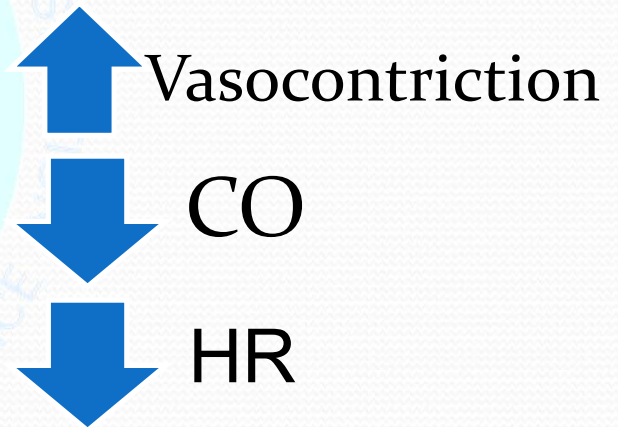
# CRAMPS



IC ADMINISTRATION  
US DEPARTMENT OF COMMERCE

# The Diving Response Includes:

- Peripheral vasoconstriction
- Reduced cardiac output
- Bradycardia



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



# CRAMPS



Vasoconstriction



Muscle Oxygenation

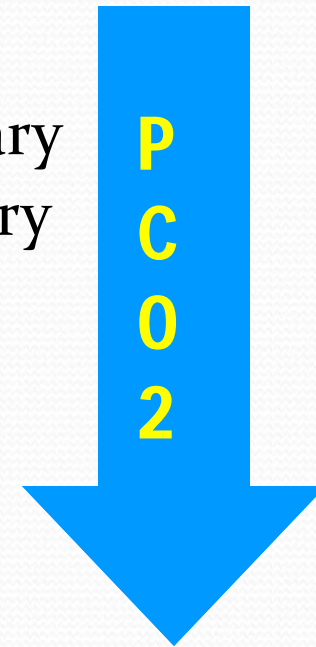
+ anaerobic metabolism in  
working muscles?

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



# Ventilation

- Ventilatory drive triggered by
  - Increased  $\text{PaCO}_2$  (hypercapnia) - Primary
  - Decreased  $\text{PaO}_2$  (hypoxemia) - Secondary
- Effect
  - Decreases  $\text{PCO}_2$  (Hypocapnia)
  - Barely increases  $\text{PO}_2$
  - Increases time before  $\text{PCO}_2$  demands breathing
  - Unconsciousness from low  $\text{PO}_2$  can occur before  $\text{PCO}_2$  reaches threshold

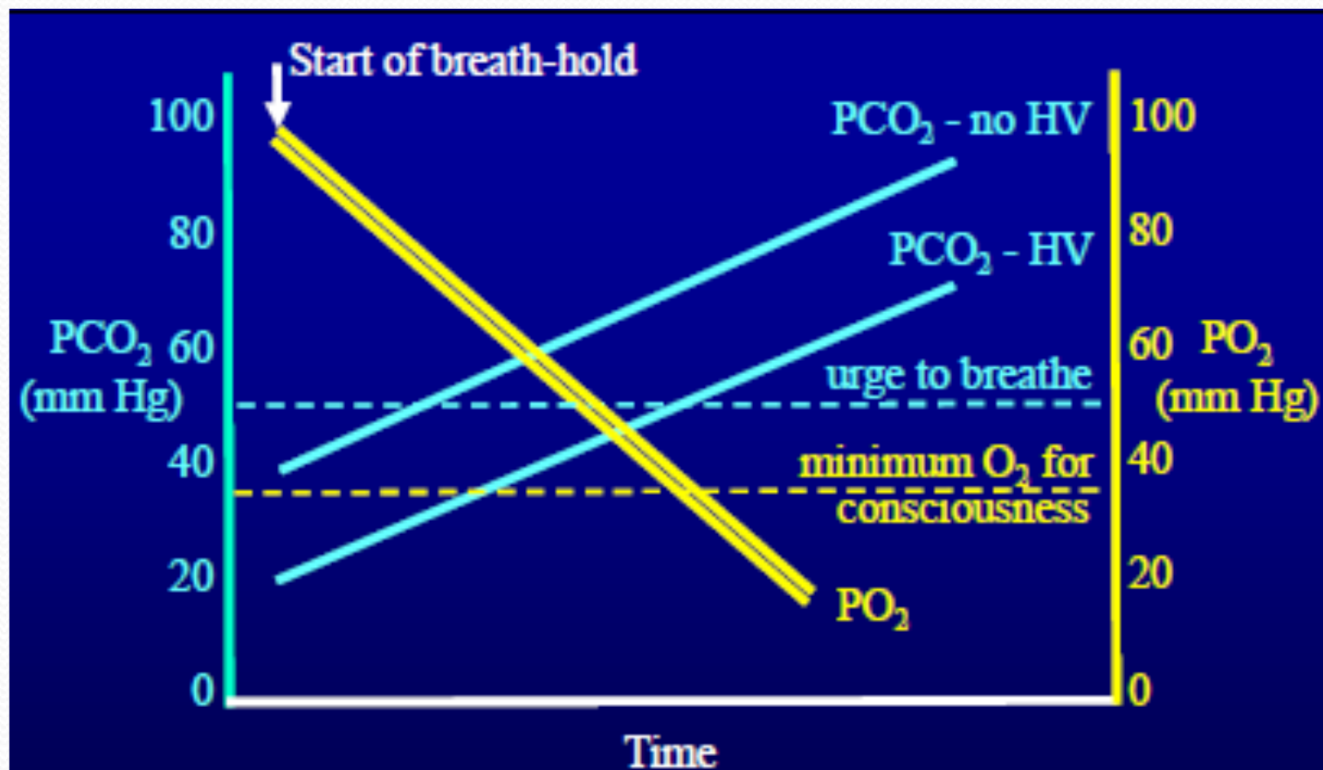


Hyperventilation is dangerous

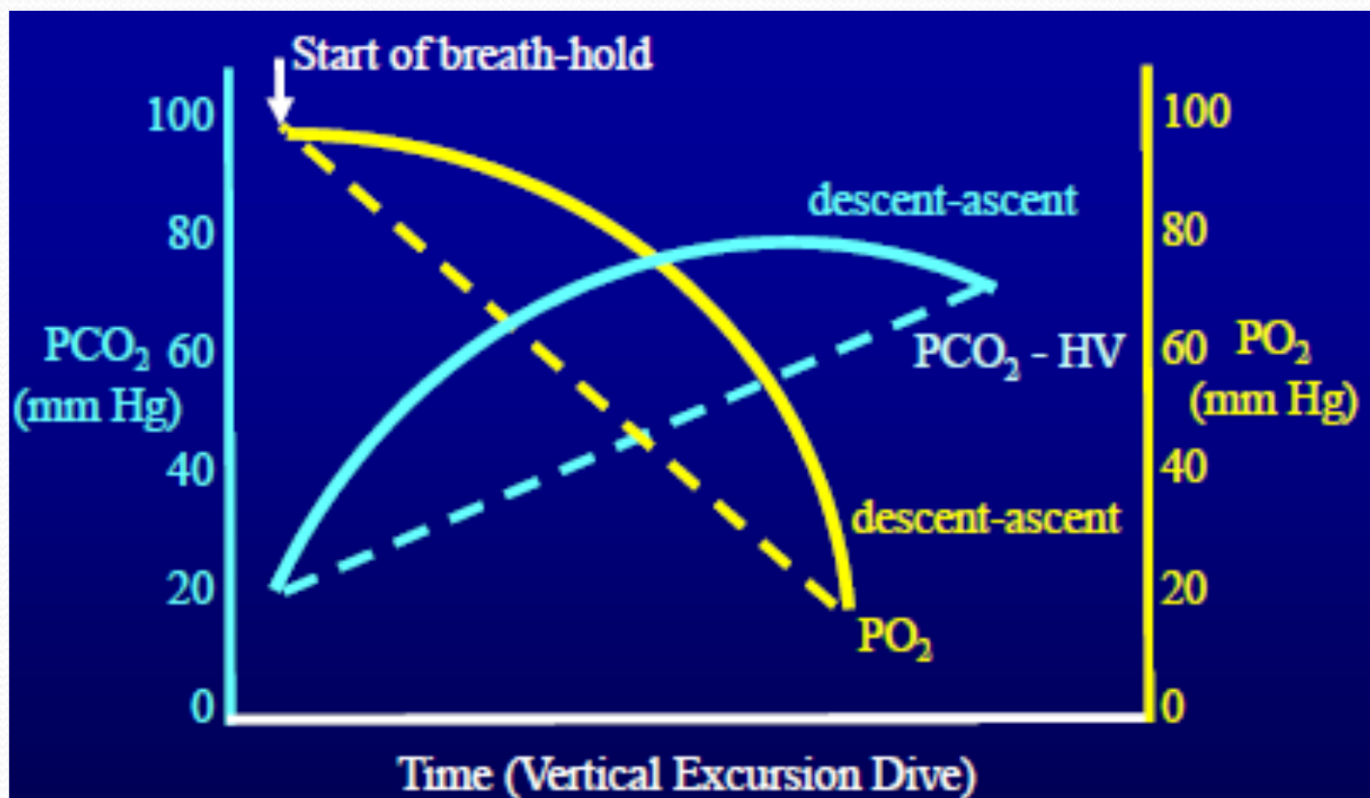
# SHALLOW WATER BLACKOUT

- 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!





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.

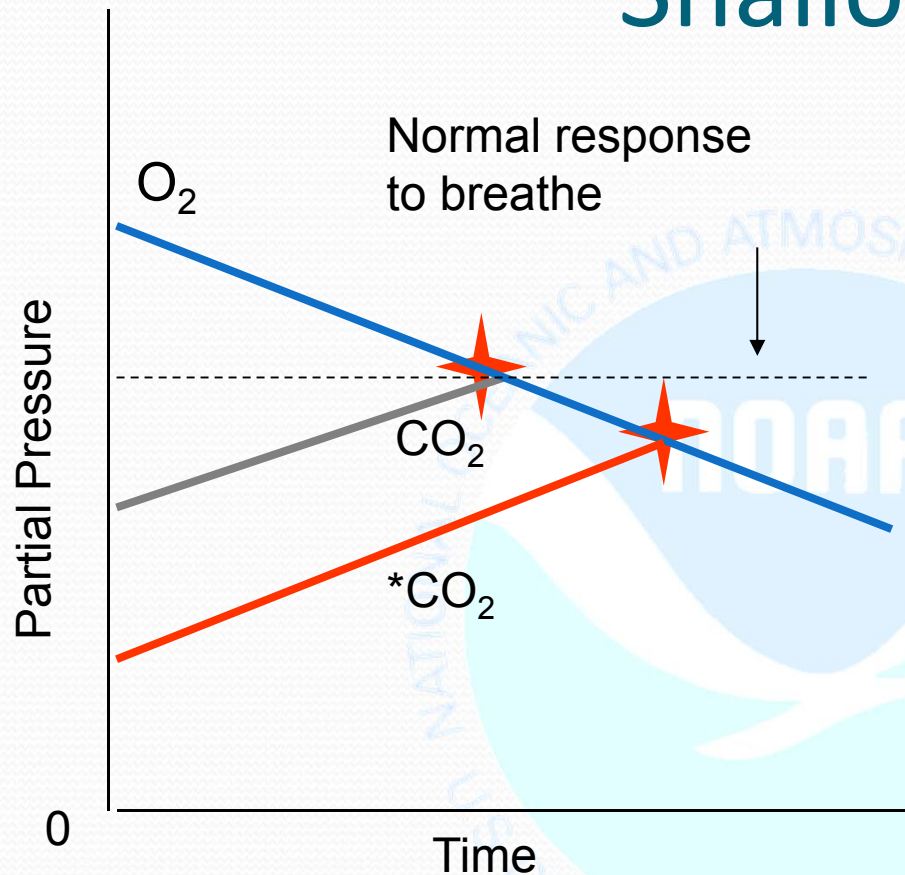


Pre-breath-hold hyperventilation increases the risk of apneic hypoxic loss of consciousness by delaying the urge to breathe. Decreased ambient pressure during ascent increases the risk (hypoxia of ascent). \* Illustration.

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

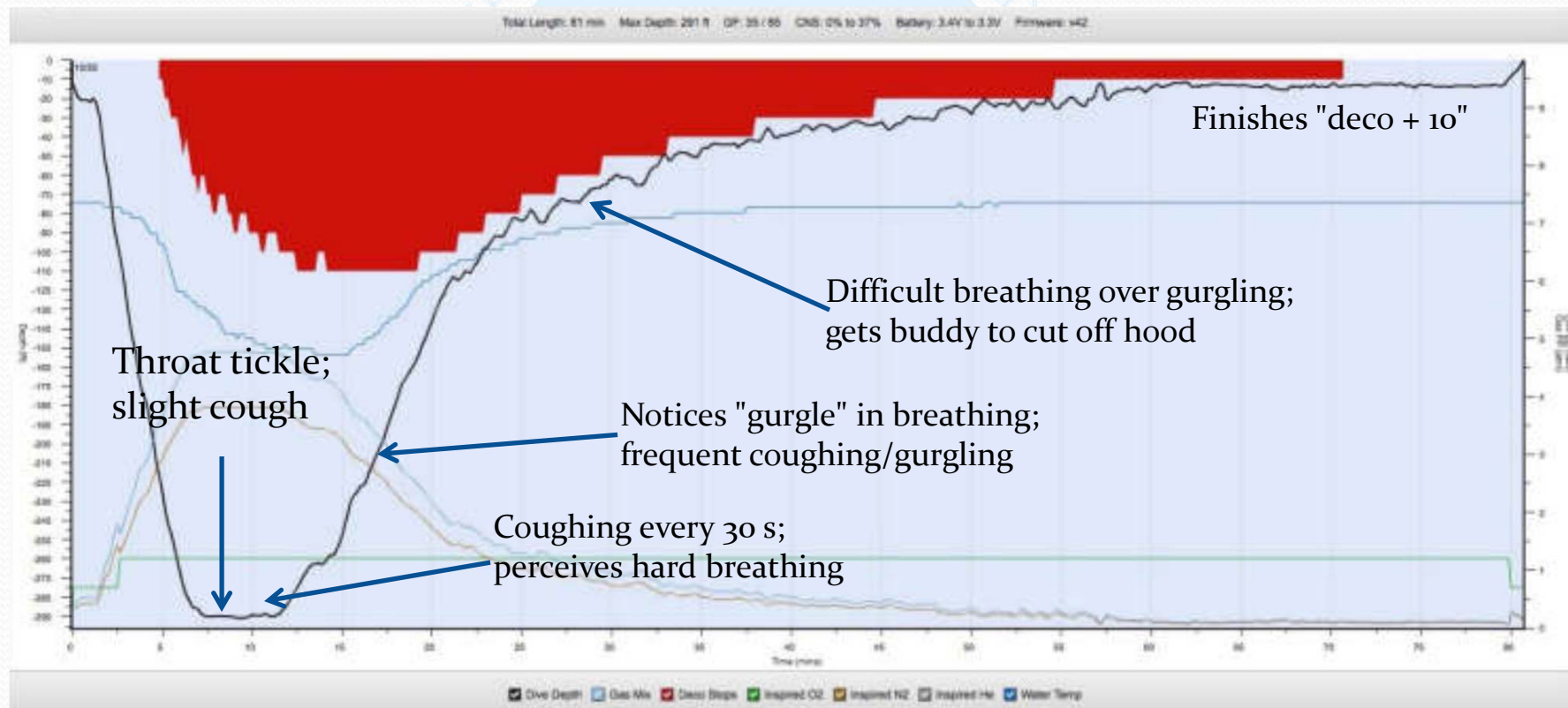
# MEMORY & COGNITIVE FUNCTION

- 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
  - O<sub>2</sub> 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
  - O<sub>2</sub>, 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 O<sub>2</sub>, 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?

