Methods Introduced in the "heat lab"

- How did we measure core temp?
  - What was the termination Tc?
- How did we measure skin temp? Sites?
  - Calculate mean skin temp
  - Calculate mean body temp
- What is the WBGT?
  - Wet bulb, dry bulb, globe temp
- Did you see how we measured air flow?
  - What is an anemometer
- What is uncompensible heat stress?

Hydration and Exercise

Who was that man??

Water and Survival

- Water is more important than food when it comes to survival
  - death in weeks, even months, w/o food
  - death in days w/o water (100 hr rule)
- Humans can not acclimate to lack of water
  - with heat acclimation, ↓ sweat threshold
  - training, ↑ sweat for a given Tcore
  - natives, are more "efficient sweaters"—genetics or adaptation?

Fluid and salt control

- Water and salt intake vary greatly
  - 1 L/d for old, sedentary
  - 10 L/d for camel drivers in the Sahara
  - 3-30 g/d salt intake
- Plasma volume and sodium content are controlled within ~1%
  - PV, maintained ± 50 ml
  - Na^+, maintained 135-145 mequiv/L

Body fluid imbalances

- Over-hydration is rare
  - water and salt will be excreted with too much intake
  - water intoxication is very rare
- Under-hydration is very common
  - dehydration with exercise
  - dehydration in the elderly (lack of thirst)
  - dehydration with fever and diarrhea (children most susceptible)
  - Hypo-hydration in astronauts

Dehydration vs. Hypohydration

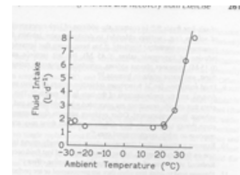
- Dehydration
  - reduced plasma volume
  - increased plasma osmolality
- Hypohydration
  - Isotonic loss of water without increased plasma osmolality

Normal fluid balance

- Intake (2550 ml)
  - drink 1200 ml
  - food 1000 ml
  - metabolically produced 350 ml
- Output (2550 ml)
  - insensible 900 ml
  - sweat 50 ml
  - feces 100 ml
  - urine 1500 ml

Obligatory Water loss

- Humans lose water (minimum 1000-1200 mL) due to:
  - elimination of metabolic byproducts (500 mL/d)
  - insensible water loss (600 mL/d temperate climate, 1000 mL/d hot/humid)
  - sensible sweating
    - begin at Ta > 25°C
    - 1.5 to 3.0 L/hr



Human kidneys

- Concentrating ability of kidneys
  - human, urine can be 2/3 as concentrated as seawater
  - sand rat, urine is 5 times seawater
- Humans do not store water
  - human, 2-3 liters stored in stomach and intestines
  - camel, > 50 liters

Obligatory Water Intake

- Humans must have 1000-1200 mL/d fluid intake to avoid a progressive dehydration

Body fluid compartments

- Human body is 60% water (42 liters)
  - TBW
    - 55% Intracellular fluid
    - 45% Extracellular fluid (19 L)
      - 2/3 interstitial
      - 1/3 blood vol (6 L)
        - » RCM
        - » PV (3L)

What is dehydration?

- Loss of body water
  - > 2% body weight loss
- Loss of plasma volume
  - Estimated from changes in hct and hb
- Increased urine osmolality and specific gravity
  - Color > 3, Sg > 1.030, osm > 800 mosm/kg
- Increased serum osmolality
  - > 290 mosm/kg

% change in PV

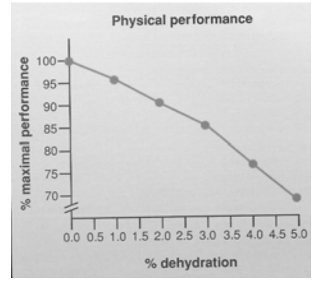
- Dill and Costill (hct and hb)

$$\% \text{ chPV} = \left[\frac{[Hb1] \times (1 - Hct2)}{[Hb2] \times (1 - Hct1)} - 1 \right] \times 100$$

- Van Beaumont formula (hct only)

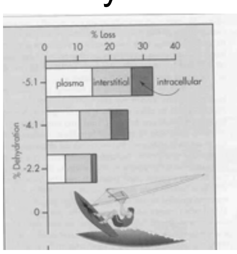
$$\% \text{ ch PV} = 100\,(Hct_1 - Hct_2)/Hct_2 \times 1/(1 - Hct_1)$$

Effect of dehydration on "physical performance"



Aerobic endurance events are most affected

Fluid compartments and dehydration



Fluid loss in sweat is shared by all compartments, but, look at the unproportionate loss of PV

Plasma volume changes with exercise

- Exercise Mode
  - Greater loss of PV with cycle vs treadmill exercise
    - More anaerobic, > loss
- Exercise intensity
  - Mild exercise, expand PV
  - heavy exercise, decrease PV
- Ambient temp
  - Hotter environments, greater decrease PV
- Training and heat acclimation
  - Greater loss of PV with equal drinking
  - Usually however, trained people drink more

PV and Fitness

- PV expands with training and heat acclimation. How?
  - Piantadosi
    - sweating causes increased sodium concentration in PV
    - water moves into PV to equalize sodium
  - Senay
    - with exercise, protein moves from the lymph into the PV
    - each g of protein binds 15 ml of water

Components of Plasma

- 96% of osmolality is determined by Na^+ and its associated anions.
  - Plasma osmolality is 280 mosm/l
  - Na+, 136 mequiv/l, (NaCl, 272 mosom/l)
  - Electrolytes easily move through the capillary wall
- oncotic pressure is determined by proteins
  - [total protein] is about 7.4 g/dl in plasma
    - albumin (4-5 g/dl) smallest and most influential in terms of fluid movement
  - Proteins can move in and out of the PV with posture, exercise
  - New proteins are produced with training, heat acclimation

Thirst

- Regulated in the hypothalamus. Thirst stimuli:
  - plasma osmolality >295
  - water loss > 2 liters
  - renin-angiotension-angiotension II
  - dry mouth and throat receptors
- Humans normally stop drinking before replacing all fluid lost
  - stomach distention
  - drop in plasma osmolality

ADH

- Acts to retain water (kidneys, sweat glands)
- Release from posterior pituitary is stimulated by:
  - osmoreceptors (brain, liver, others?)
  - SNS, stress
  - elevated temperature
  - cardiac atrial receptors (Henry Gauer reflex?)
    - Role in humans?
  - arterial baroreceptors

Other hormones

- Aldosterone acts to conserve sodium
  - conserving Na+, conserves water
- Atrial natriuretic factor (peptide)
  - released from the cardiac atria with distention to cause sodium excretion
    - less distention in dehydraton
    - less ANF is released
    - less sodium is excreted

Early studies of dehydration and heat tolerance

- Effects of dehydration first studied in coal miners in England (JS Haldane)
  - voluntary water restriction
  - afraid of water toxicity
- Importance of heat acclimation shown in gold miners in S. Africa (Wyndham, Strydom)

Stomach emptying and dehydration

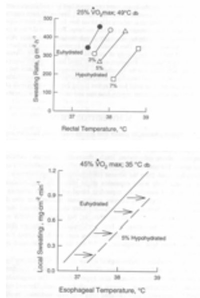
- **Sweat loss during exercise is typically 0.8 to 1.4 l/h**
- **The rate of stomach emptying during exercise is 0.8 to 1.2 liters/min**
  - will be slower with increased osmolality of the drinking solution
- **Prolonged severe exercise in heat can lead to progressive dehydration even with excessive drinking? (Gisolfi, very rare)**

Hydromiosis

- Sweat gland fatigue?
  - sweating is reduced under conditions where sweating is not effective
    - with prolonged sweating in humid conditions (> 2hrs), SR will decline
    - mechanism proposed to be swelling of the epidermal cells around the sweat gland pores
    - drying of the skin can lead to return of sweating

Dehydration and heat responses

- Dehydration
  (decreased PV and increased osmolality)
  - increase thresholds for sweating and FBF
  - decreased maximal SR and FBF
  - faster rise in body temperature
  - conserves body water



Other effects of dehydration

- Cardiovascular
  - increased HR and decreased SV
  - reduced CO and increases in a-v(O2 diff)
  - decreased splanchnic bf
  - decreased muscle bf *(controversial)*
- Muscular
  - > 5% dehydration--loss of strength
  - increased lactate
    - reduced clearance and increased production?
  - decreased endurance

Dehydration and exercise

- Decrease in body weight
  - 1%, cardiovascular effects
  - 3%, decrease VO_2max in cool
  - 5%, loss of strength
  - 2-8%, common during competition and training
  - 12%, often fatal
  - 25%, Pablo syndrome, 1906 *(pg 83, Piantadosi)*

Am I the good, the bad, or the ugly guy??

Dehydration and endurance

Body Weight Loss	Exercise Environment	VO2 max Change	Endurance change
-2%	HOT	-10%	-22%
-4%	HOT	-27%	-48%
-5%	MILD	-7%	-12%
-5%	MILD		-17%

Armstrong, pg 26

Dehydration and Survival

- Loss of 12% body mass
  - clinical shock
  - plasma osmolality of 350 mosm/liter
  - loss of 8.4 liters of sweat
  - loss of 33% of PV (1 liter)
- With no fluid intake and an obligatory water loss of 1200 ml/d, 8.4 liters will be lost in 7 days (168 hrs), with no exertion

100 hr rule

- Humans can survive about 100hrs without water
  - shorter than 168 hrs because more water is lost due to heat, activity
  - shorter yet with increased activity and heat exposure

Hydration Solutions

- Adolf (early 40s)
  - importance of fluid ingestion to reduce cardiovascular and thermoregulatory effects of dehydration
  - slows development of fatigue
- Gisolfi (90s)
  - studied effect of weak carbohydrate (6%) and electrolyte solutions

Water vs. electrolyte solutions?

- Add carbohydrates
  - when exercise is intense (>70%) and prolonged (> 1 hr)
- Add electrolytes
  - when sweating is profuse and prolonged (> 4 hrs)
- Water
  - empties best from the stomach and is most effective in shorter duration exercises
  - For most individuals (except athletes, military or spec. occup.) water is enough

How much fluid intake?

- Current ACSM recommendation
  - drink to maintain body weight
- Noakes
  - prolonged drinking to maintain wt can lead to hyponatremia (Na^+ < 130 mequiv/l)

Increase sodium intake?

- Americans typically eat 6-17 g NaCl/d
  - Recommended to reduce to 6 g
- People who live in hot climates and eat less than us don't have hyponatremia-
  - Masai, < 5g NaCl/d
  - Galilean naturalists, 1.9 g NaCl/d
- Lab studies have shown successful heat acclimation with 4-6 g NaCl/d
  - Typical sweat losses are 0.8-2.0 g in acc and 3-4 g NaCl/l in unacclimated humans
  - 1 Tsp salt (8g NaCl) can easily replace sweat loss

Rehydration

- Drink water?
  - water will empty from the stomach quickly
  - water will lower sodium concentration
  - lower sodium will inhibit drinking before fluid is totally replaced
  - delay rehydration?
- Nose:
  - add sodium to the rehydration solution to get more rapid and complete rehydration

Over-hydration to improve exercise performance?

- A controversy over semantics?
- Over-hydration (Sawka)
  - is not effective
  - drink before & replace fluids during exercise
  - is no better than controls drinking during exercise
- Over-hydration (Moroff)
  - is effective
  - drink before & no fluids during exercise
  - is better than controls not drinking during exercise
  - extra fluid before exercise delays dehydration.

Glycerol Hydration Controversy

- Riedesel, Montner
  - pre-hydration with glycerol and hydration during exercise reduces cv and tr strain
  - expanding the ICF and ISF allows > reservoir to maintain PV
- Sawka
  - glycerol hydration solutions offered no benefit. Expands TBW but does not increase PV and therefore is not effective
- Robergs
  - Negative findings with glycerol are related to the method of administration. Must start the night before and continue during exercise

ACSM Position Stand on Exercise and Fluid Replacement, 2000

- drink 500 ml of fluid 2 hr before exercise
- during exercise, drink early, drink to maintain body wt, or max rate tolerated (600-1200 ml/hr)
- cool fluids (15-22^{o}C)
- with few exceptions, water is the replacement of choice
- unless the exercise bout lasts > 60-90 min. there is little advantage to supplementing carbs