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?

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)

\[ \% \text{chPV} = \frac{\text{Hb}_1 \times (1 - \text{Hct}_2)}{\text{Hb}_2 \times (1 - \text{Hct}_1)} - 1 \times 100 \]

• Van Beaumont formula (hct only)

\[ \% \text{ch PV} = 100 \left( \frac{\text{Hct}_1 - \text{Hct}_2}{\text{Hct}_2} \right) \times \frac{1}{1 - \text{Hct}_1} \]

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

Fluid compartments and dehydration

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

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

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 dehydration
    - 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 ($> 2$hrs), 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_max 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 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

Dehydration and endurance

<table>
<thead>
<tr>
<th>Body Weight Loss</th>
<th>Exercise Environment</th>
<th>VO2 max Change</th>
<th>Endurance change</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2% HOT</td>
<td>-10%</td>
<td>-22%</td>
<td></td>
</tr>
<tr>
<td>-4% HOT</td>
<td>-27%</td>
<td>-48%</td>
<td></td>
</tr>
<tr>
<td>-5% MILD</td>
<td>-7%</td>
<td>-12%</td>
<td></td>
</tr>
<tr>
<td>-5% MILD</td>
<td></td>
<td>-17%</td>
<td></td>
</tr>
</tbody>
</table>

Armstrong, pg 26

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

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**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

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**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)

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**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

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**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°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