Introduction

- Problems we are faced with - Why has the incidence of hyponatremia increased?
  - The EHS (Tc) and dehydration dilemma
  - Experimental versus Field Studies
- Major fluid regulating hormones
  - The body's response to low blood pressure
- Three forms of hyponatremia
- Electrolyte studies in FB and Ice Hockey
  - Na+ supplemented versus un-supplemented

Sodium Depletion Illness (Hypovolemic Hyponatremia)

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Professor/Director, The HEAT Institute
West Chester University of Pennsylvania

Introduction

- Critical questions to which we don't have all of the answers
- By the numbers - sweat sodium losses
- Hyponatremia versus heat exhaustion
- Hypovolemic hyponatremia
  - Signs/symptoms
  - Management and prevention

Problem - Which are Heat Illnesses?

- Heat Cramps (EAMC)?
- Heat Exhaustion?
  - Symptomatic dehydration
- Hyponatremia?
  - This can be prevented!!
- Exertional Heat Stroke (EHS) – YES
- A heat illness is defined as a condition in which the primary treatment is rapid cooling!!

Problem - What causes Exertional Heat stroke?? HS ATC Survey

"ATC rankings of 14 items that predispose athletes to EHS revealed they consider..."

1. Dehydration (2.6 rank)
2. High Humidity (3.4 rank)
3. High ambient temperature (4.3 rank)
4. Acclimatization (5.1 rank)
5. Physical fitness (5.7 rank)
6. History of heat illness (6.1 rank)
7. Exercise intensity (6.2 rank)
Problem - What causes Exertional Heat stroke??

- Dehydration was ranked significantly higher than all other factors except high humidity!!
- However – The overwhelming expert consensus is that metabolic rate (exercise intensity) is the single most important factor related to elevated core temperature
  - Dehydration at best has minimal affect
- So why do ATC’s still think this way??
  - Where does your information come from?

Is there a Significant correlation between $T_c$ and level of Hydration?

$$r = 0.198, p = 0.294$$

Runners during a Marathon

- When runners get hot, they slow down
- Some reach $T_{max}$ early
- Some at the end
- $T_c$ is not related to % dehydration
- $T_c$ max of 104 - 106 °F are common and well tolerated!!!

Byrne, Lee, Chew et al. MSSE 06
Conclusions

Byrne, Lee, Chew et al. 06

- 17 of the 18 runners had a $T_{\text{c max}} \geq 103 \, ^\circ\text{F}$
  - In my lab the experiment for them was ended
- 10 of the 18 runners had a $T_{\text{c max}} > 104 \, ^\circ\text{F}$
  - In any lab in this country the trial is done
- % dehydration ranged from 0.9% - 3.9%
- "Core temperature responses demonstrated no significant relationship to absolute $\Delta$ mass ....or % dehydration"

Triathletes during a Race

Byrne, Lee, Chew et al. 06

- Mean $T_c$ max = 38.1°C (100.6°F)
- Mean % dehy = 3%
- Change in mass was not related to finishing $T_c$
- "Body mass loss of 3% was found to be tolerated by well trained tri-athletes ...... without any evidence of thermoregulatory failure"

The EHS and Dehydration Dilemma

- It clouds the fluid/electrolyte balance issue and provides a false sense of security
- It promotes the thinking that drinking to replace all fluid losses will prevent EHS
- We don’t know what causes EHS but it is NOT dehydration
- 2 - 3% body mass loss during exercise is normal, expected and well tolerated

Major Hormones Involved in the control of Blood Volume (BP)

- Released when blood volume and blood pressure are low
  - Vasopressin (ADH)
  - Renin-Angiotensin
  - Aldosterone
- Released when blood volume and blood pressure are high
  - Naturetic Peptides
    - ANP
    - BNP
    - Urodilantin
The Body's Response to Low BP (Salt/blood volume Depletion)
- Kidneys release Renin
- Renin combines with Angiotensinogen to form Angiotensin I
- Angiotensin I is converted to Angiotensin II by ACE
- Angiotensin II stimulates several mechanisms that raise blood pressure

Angiotensin II
- Causes Vasoconstriction of Blood Vessels
- Stimulates Brain to release Vasopressin (ADH)
  - Increases H₂O reabsorption
  - Stimulates Thirst
- Stimulates adrenal cortex to release Aldosterone
  - Increases Na⁺ reabsorption

Body Fluids → Blood Volume → BP

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Body Fluids → Blood Volume → BP

What is Normal Body Mass?
- Blood Electrolytes?
- Blood Glucose?
- Body Temperature?
- 290 mOsm/kg
- AVP
- Aldosterone
- Thirst
- Natureline peptides
- No thirst
- 280 mOsm/kg

Hormone response to low blood volume
- Vasopressin (ADH)
  - Thirst
  - H₂O Uptake
- Angiotensinogen
- Angiotensin I
- Angiotensin II
- Renin
- Aldosterone
- Aldosterone promotes Na⁺ Uptake in Kidneys

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Body Fluids → Blood Volume → BP
What is Constitutes Normal Hydration?

<table>
<thead>
<tr>
<th>AVP</th>
<th>Aldosterone</th>
<th>Thrust</th>
</tr>
</thead>
<tbody>
<tr>
<td>290 mOsm/kg</td>
<td>290 mOsm/kg</td>
<td>148.3 kg</td>
</tr>
</tbody>
</table>

- 2.2% less of mass

With Sosm (285 mOsm/kg) body mass normally fluctuates between:
- 79.2 kg and 80.8 kg in a 80 kg (176 lb) male (5 lbs)
- 64.4 kg and 65.6 kg in a 65 kg (143 lb) female (~ 3 lbs)
- 29.7 kg and 30.34 kg in a 30 kg (66 lb) child (1.4 lbs)
- 148.3 kg and 151.7 kg in a 150 kg (330 lb) FB LM (~ 8 lbs)

Three forms of Hyponatremia

- Hypervolemic hyponatremia
- Normovolemic hyponatremia
- Hypovolemic hyponatremia

- There is probably a spectrum of etiology
- Hypovolemic hyponatremia
- Normovolemic hyponatremia
- Hypovolemic hyponatremia

Hyponatremia - Na+ Dilution

- Hypervolemic hyponatremia – blood volume expands and blood Na+ is diluted
  - This is primarily the marathon/ultra-distance athlete – water intoxication
  - Females may be more prone?
  - Probably linked much of the time to ISADH
  - Caused by drinking too much of ANYTHING (including CE drinks)!!

Hyponatremia – Na+ Depletion

- Hypovolemic hyponatremia – Low body sodium leads to a contracted blood volume
  - This is the heavy and/or salty sweaters
  - Probably occurs more in males
  - Exacerbated by drinking too much water and/or CE drinks
  - Detection of the hypovolemia in collegiate FB players during two-a-days was the key!

Changes in Plasma Volume

#### Aldosterone Mediated Na+ Re-absorption

<table>
<thead>
<tr>
<th>Urinary Sodium Excretion</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
</tr>
<tr>
<td>Day 1</td>
</tr>
</tbody>
</table>

*Significantly elevated, p < 0.05
*Significantly different from Days 1 and 4-6
Fluid and Electrolyte Studies 2003 - 2009

Blood Na⁺ in Pro FB Players

Blood Na⁺ maintained at low normal levels at expense of PV

Blood Na⁺ in College FB Players (2003 preseason)

A Problem

- What are the blood K⁺ concerns specifically in football?
- Hyperkalemia causes cardiac issues
- These guys are not the "average" male athlete
Blood K+ in Un-supplemented Pro FB Players in 2003

![Chart showing blood K+ levels in un-supplemented players in 2003 with significance notes.]

Oral Sodium Supplementation

- Six players with a history of heat-related problems
- Orally supplemented with 4331 mg Na+/day
  - ½ saline with meals
  - ½ saline between practices
- Equal to ~40% of average players Na+ losses

Blood Na+ with supplementation

![Chart showing blood Na+ levels with supplementation.]

PV in Un-Suppl versus Na+Suppl

- In Na+ Suppl PV expanded 18% by Day 3
- PV was never below BL
- Clinically different from unsupplemented players in 2003

2004, 4.5 g sodium Plasma Volume Increased Perfectly

- Rapid expansion of plasma volume
- There were no differences between groups

Na+ Supplementation in 2005

- Two groups of players were supplemented at and between meals with oral electrolyte solutions
  - Pickle Juice
  - Rehydralyte + Pedialyte
- All subjects received 4.5g of Na+ per day
- One group drank Pickle Juice
- One group drank Rehydrayle and Pedialyte

One group drank

Pickle juice
INSTITUTE
Heat Illness Evaluation, Assistance and Treatment

Blood Sodium with Supplementation

- Blood Na⁺ was not different between groups
- Blood Na⁺ did not change across days

These were awesome results!

INSTITUTE
Heat Illness Evaluation, Assistance and Treatment

BUT - Blood Potassium was Too High!

- Blood K⁺ was not different between groups
- Blood K⁺ was elevated from baseline (BL) to Day 5 and above normal range

p < 0.01

This is a BIG problem, especially for football players!

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Heat Illness Evaluation, Assistance and Treatment

Na⁺ supplementation with NO K⁺ in 2006

10 players representing all positions

INSTITUTE
Heat Illness Evaluation, Assistance and Treatment

Results

- PV expanded 12% by Day 11

INSTITUTE
Heat Illness Evaluation, Assistance and Treatment

Results

- No differences between days existed for blood Na⁺
- No differences between days existed for blood K⁺
- Both within normal clinical range

INSTITUTE
Heat Illness Evaluation, Assistance and Treatment

Results

- No differences between days existed for CI and they were within were normal clinical range
- No differences in pre-AM or pre-PM %Δmass
Individual Sodium Supplementation in 2007

One player received this much salt
While another player received this much
This over the counter juice contains no potassium

FB Players’ Urine Color is not Normal and it’s Heavy

Blood sodium, potassium and chloride were all perfect!

Better yet – the players felt great!

Why is blood and urine K+ high?

- Playing football in the heat causes muscle cell death (rhabdomyolysis)
- Eyles et al. JAT 2001
- Muscle cells have high [K+] inside
- When cells rupture they leak K+ into the blood
- The K+ has to be excreted

Critical Questions

- Can athletes really become sodium depleted?
- Does hyponatremia always have to involve at least some ISADH?
- Why can’t CE drinks prevent hyponatremia?
- Can high sweat losses replaced with hypotonic fluids on consecutive days causes hyponatremia?
FB Players Sweat Heavily

- Case study in a collegiate football player
  - Average sweat losses during practices (3 days and 6 practices) = 13.5 L per day
  - Maximal sweat loss = 14.8 L per day
    That’s 35 8 oz glasses!!!
  - Fluids consumed during practices = 8 L/day

Ice Hockey Players Sweat a lot

And they get hot—some over 103°F

Sweat and Sodium Losses in NHL Players during a Pre-season Practice and a Game

Introduction
- Many players in the National Hockey League (NHL) are larger than the average-sized athlete
- Additionally, they exercise in a micro-environment allowing only the face to be exposed for evaporation of sweat.
- The combination of a large body surface area (BSA) and equipment may result in high sweat rates (SwR), sweat losses and sodium (Na+) losses not only in games but in daily practices.

Purpose
- To measure SwR, sweat sodium content and total sodium losses in NHL players during a pre-season practice and compare these data to a pre-season game.
Subjects

- Ten players from the Philadelphia Flyers
- 4 defensemen and 6 line players
- Age = 28 ± 6 yr
  - Height = 189 ± 6 cm
  - Mass = 97 ± 8.5 kg
  - BSA = 2.24 ± 0.12 m²

Methods

- Sweat data was collected during one of the first pre-season practices and then in a pre-season game the following week
- Prior to dressing the skin of the right upper forearm was prepped
- A sweat patch was applied

SwR = (pre mass – post mass) - Uvol + Fluid
  time

Results

- WBGT and ambient temperatures were higher during the game (14 and 18 °C) versus the practice (11 and 13 °C)
  - 14 = 57°F
  - 18 = 64°F
  - 11 = 52°F
  - 13 = 55°F

Sweat Analysis
Results

• SwR were not different between the practice (1.3 ± .3 l/hr) and game (1.22 ± .3 l/hr).

• Gross sweat losses were higher in the game (3.7 ± 0.9 I) versus 2.6 ± 0.6 I.

Results

• Sweat sodium was not different between the practice 61 ± 31 mmol·L⁻¹ and game 67 ± 21 (range = 10 mmol·L⁻¹ to 104 mmol·L⁻¹).

• Players experienced greater total sodium losses in the game (252 ± 104 versus 168 ± 118 mmol) due to higher gross sweat losses.

Results

• Players consumed more fluids during the game.

• Body mass loss was not different:
  - 1.5 ± .7% (game)
  - 1.2 ± .5% (practice).

Results

• Mean sodium losses per game = 5.8 g (14.7 g NaCl or ~3 tsp salt).

• Mean sodium losses per practice = 3.9 g (9.9 g NaCl or ~2 tsp salt).

• But substantial variability.

By the Numbers

• Remember - all fluids that your athletes consume are hypotonic (not salty).
• CE drinks have Na⁺ ~ 20 mEq·L⁻¹.
• Sweat Na⁺ ranges from 10 – 100 mEq·L⁻¹.
• Just replacing fluids - even with a CE drink does not adequately replace salt in heavy sweaters.

What about CE Drinks?

• Why can’t we put all of the salt back with CE drinks??
• They are actually OK for a small population of athletes:
  - Average-sized males with average SwR and low sweat [Na⁺]
  - Female heavy sweaters
  - Kids??????? What about the childhood obesity epidemic?

This is non carbonated sugar and salt water.
Two Examples – Sweat Studies

How much CE is Needed? Ex. #1
• An NFL player who sweats 2.7 L · h⁻¹ and practices 4 h per day = 10.8 L of sweat loss
• At a sweat Na⁺ content of 86 mEq · L⁻¹ and 10.8 L per day he would lose 929 mEq or > 21 grams (21360 mg) of Na⁺ in one day
• Replacing ½ in food
• He needs to consume ~ 14 L of CE drink which will make him hyponatremic

How much CE is Needed? Ex. #2
• An NHL player who sweats 2 L · h⁻¹ in a 3 hr game = 6 L of sweat loss
• At a sweat Na⁺ content of 90 mEq · L⁻¹ and 6 L of fluid loss he would lose 540 mEq or 12.4 grams of Na⁺ in one game
• Replacing ½ in food
• He needs to consume ~ 24 L of CE drink which will make him hyponatremic

What else will you get??
• Remember – we are assuming ½ of the sodium is replaced with food intake
• 24 L of CE drink will likely promote hyponatremia – AND provide:
  - 4750 Kcals
  - 1344 g of CHO (glucose, fructose, sucrose)
  - 2880 mg of potassium

Sweat Na⁺ losses range considerably

<table>
<thead>
<tr>
<th>Sweat Rate (L/hr)</th>
<th>LR/QB (n=12)</th>
<th>LM (n=14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>.43</td>
<td>1.42</td>
</tr>
<tr>
<td>mean</td>
<td>1.43</td>
<td>2.0</td>
</tr>
<tr>
<td>high</td>
<td>2.22</td>
<td>3.16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low Na⁺ (mol/L)</th>
<th>Salt (mg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>222.5</td>
</tr>
<tr>
<td>mean</td>
<td>1645</td>
</tr>
<tr>
<td>high</td>
<td>4065</td>
</tr>
</tbody>
</table>

TeaH2O is here!!

8 Yrs of Research has resulted in a Healthy, All Natural Product Line
**What is Heat Exhaustion?**

- Water depletion
  - Symptomatic dehydration
  - Caused by inadequate replacement of water losses (dehydration beyond 3 - 4%)
  - Beginning a second bout of exercise hypohydrated
  - Untreated it can lead to heat stroke
  - Involves an elevated core temperature

**Salt/volume depletion Illness**

- Should not be classified as a Heat illness
  - Caused by low serum Na⁺ but may not clinically be classified as hyponatremia until Na⁺ ≤ 130 mmol·L⁻¹ (135 mmol·L⁻¹ is better)
  - Usually occurs in athletes who sweat heavily over several consecutive days
  - Water loss is replaced but Na⁺ is not
  - Does not involve hyperthermia
  - Athlete is hypovolemic

**Signs and Symptoms of Salt/Volume Depletion Illness**

- Weakness
- Fatigue
- Severe headache
- Muscle aches
- Anorexia
- Nausea
- Vomiting
- Diarrhea

This illness is probably under diagnosed or misdiagnosed as viral illness or food poisoning.

**Management**

- Rest – Do not let them play
- Administer high electrolyte drink orally
- Consider IV fluid replacement (saline)
- Monitor vital signs (blood pressure)
- Recovery usually within 24 hours
- Educate athletes about replacement of electrolytes (salt food liberally)

**Prevention**

- It is caused by consecutive days of large daily Na⁺ losses not replaced and drinking too much of anything
- Know your athletes’ sweat rate
- Know your salty sweaters
- Swt [Na⁺] and SwtR are extremely variable
- We have to get rid of consecutive days of two-a-day practices!!
Prevention
- Know your athletes who are hypertensive
  - Be aware of which athletes are on a low Na\(^+\) diet
  - Be aware of athletes on ACE inhibitors
  - Medication may need to be altered during preseason

Prevention
- Require weight charts and monitor them
- Be aware of athletes who are not maintaining body weight
- Think beyond pre-season fall sports

4 meals per day during Pre-season (football) and Playoffs (hockey)
- Eat foods high in Na\(^+\) and Mg\(^{++}\) and Cl\(^-\)
- Avoid too much potassium in these populations
- Can consume some Pedialyte or PJ
  - 2-3 bottles Pedialyte
  - 3-4 oz PJ

Breakfast Foods
- Cereals
  - Chex cereal
  - Golden graham
  - Maple and brown sugar oatmeal
  - Rice krispies
  - Total
  - Frosted wheaties
  - Basic 4
- Breads
  - Corn muffins
  - Bagels
  - Whole wheat English muffins
- Meats
  - Sausage
  - Canadian bacon
  - Ham
### Lunch and dinner foods

- **Hotdogs and Lunch meats**
- **Soups**
  - Chicken noodle
  - Onion
  - Vegetable
  - Tomato
  - Cream of chicken or mushroom
  - NE Clam Chowder
  - Chicken gumbo
  - Split pea and ham
- **Sauerkraut**
- **Cheese**
  - American
  - Cottage
  - Parmesan
  - Mozzarella
  - Pizza
  - Tomatoes
  - Salads with dressing
    - zesty Italian
    - French
    - Caesar

### Drinks

- **Snacks**
  - Pickles
  - Pretzels/chips
  - Cheese puffs
  - Chex mix
- **Drinks**
  - Tomato juice
  - V-8 juice
  - Pedialyte
  - Pickle juice

### How much CE is Needed? Ex. #1

- A football player who sweats 3.5 L · h⁻¹ and practices 4.5 h per day = 13.5 L sweat loss
- At a sweat Na⁺ content of 50 mEq · L⁻¹ and 13.5 L per day he would lose 675 mEq or 15.5 grams of Na⁺ in one day
- Replacing ½ in food (4 tsp salt)
- He needs to consume ~ 17 L of CE drink
- Won't this promote sodium dilution? Yes!

### Lunch and dinner foods

- **Sauces**
  - Marinara
  - Alfredo sauces
  - Beef or mushroom gravy
  - Stir-fry
    - teriyaki and soy sauces
  - Chili, stews
  - Chow mein vegetables
  - Navy beans, chic peas, baked beans
  - Peas and carrots
  - Pita bread

### Foods to avoid during pre-season

- Orange juice
- Bananas
- Dried fruits
- Baked potatoes
- Raisins
- Nuts
- Spinach
- Mushrooms
- Lima beans
- Black beans
- Lentils
- Cucumbers
- Squash
- Zucchini
- Brussel sprouts
- Gatorade Endurance