Sodium and Water in Endurance Cyclists-the Myths and the Truths

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A disease is not a disease unless it affects the kidneys

Joel Chinitz M.D. Philadelphia, 1996
Exercise Associated Hyponatremia and Encephalopathy History

- First case in a female runner in South Africa in 1981, next four case reports also from South Africa (1985) and had ingestion of large amounts of water and/or sports drinks as the common feature.
- Prior to this runners were not encouraged to drink excessively


Nothing good ever follows...

- Oh by the way doc (now for the real reason the patient came in)...
- I looked this up online (or) I googled this and found...
Exercise Associated Hyponatremia and Exercise (EAH) Associated Hyponatremic Encephalopathy (EAH-E)

Definition: EAH is the occurrence of hyponatremia during or up to 24 hours after prolonged activity and define as a serum or plasma Sodium below the normal reference range of the lab performing the test (<135 mg/dl)

EAH Definition (2)

- EAH is a dilutional hyponatremia caused by an [RAPID] increase in total body water relative to the amount of total body exchangeable sodium. The primary etiological factor is the consumption of fluids (water and sports drinks) in excess to total body fluid losses: insensible (transcutaneous, respiratory and GI) and renal losses.

2nd Conference on Exercise Associated Hyponatremia 2007 (2nd Conference EAH)  
EAH-Encephalopathy (EAH-E)

Definition

Neurological changes associated with ingestion of large quantities of water and/or hypotonic fluids. These changes are a direct result of cerebral edema. Manifestation may include: headache, dizziness, clouded sensorium, confusion, obtundation, coma, myoclonus, seizures and death.

2nd Conference EAH 2007

Doping circa 1920’s
J. Robert Cade M.D.
James Robert Cade M.D.

- U. of Florida nephrologist
- Inventor of Gatorade
- Generated a number of studies supporting its use and “alternative physiology”
- Sodium plus potassium content=23 mEq/l
- Serum Sodium =136-144 mEq/l

Faith begins where reason ends.
J. Frank Norris
Dr. Cade (2)

“Sports drinks are medicine that must be ingested during exercise in order to prevent heat illness and optimum performance (by preventing or alleviating fatigue) and that the more that is ingested the better.”

Taylor, Nature 2005; 437:1070-1

Bad advice and Parenteral Guilt

Thirst is a poor indicator of your child’s need for fluids. By the time most active kids become thirsty, they have already lost important fluids and electrolytes and may be dehydrated. While a cool drink of water may feel satisfying, it doesn’t supply the energy kids need to keep playing hard and having fun. A sports drink like Gatorade is the best way to keep kids cooled and fueled.

Noakes T, Waterlogged, Human Kinetics Champaign, IL, 2012 p. 209
Sporting Tradition-and Free Advertising

Athletic Dreams

The Dream  The Reality
Be Like Mike

How to be like Jens
Money doesn’t talk, it screams.
Bob Dylan

Influence of Gatorade/Pepsi and GSK

1996 American College of Sports Medicine*
- Recommended that athletes drink as much as tolerated during exercise.
- Sports drinks were a better alternative to water
- Tried to correlate professional endurance cyclist’s and runner’s fluid and electrolyte needs to that of the amateur athlete.
- Large body of flawed, biased research

*Gatorade and Gatorade Sports Institute were “Platinum Sponsors” of ACSM that year

Noakes T, Br J Sport Med; 40, 567-72, 2006
The Medical Urban Legends of Salt and Water

1. All fluid losses during an activity must be replaced for optimal performance
2. Thirst is a poor indicator of actual fluid depletion
3. Excess fluid ingestion is harmless and simply eliminated through the kidneys or sweat
4. Excess fluid ingestion (esp. sports drinks) will prevent heatstroke.
5. Fluid, electrolyte and nutritional requirements are the same for professional athletes and amateur athletes

The greater the ignorance, the greater the dogmatism.
Sir William Osler
Did evolution get it wrong?

• This assumes that the body does not know when there is fluid loss!

Training Adaptations

**Neuromuscular**: for more efficient and powerful body movements

**Cardiovascular**: for better endurance and oxygen utilization

**Metabolic**: training the body’s physiology for more efficiency and to rely more on fat as an energy source and sparing glucose/carbohydrate. This also include salt and water utilization.

**Mental**
How Does the Body Respond to Volume Loss?

Goals
- Maintain blood pressure and cardiac output
- Organ perfusion

A good heart and set of kidneys can withstand all but the most woefully incompetent fluid regime

What IS Blood Pressure?

Blood Pressure = CO \times SVR \ (afterload)

CO = HR \times SV

SV = EDV \ (preload) – ESV

CO=Cardiac Output, SVR=Systemic Vascular Resistance, SV=Stroke volume, EDV=End Diastolic volume, ESV=End Systolic Volume

What is Blood Pressure?

Preload
(Blood Volume Venous Tone)

Afterload
(Arterial Compliance)

Cardiac Factors
(Ventricular Function, Ischemia, Shunts, etc.)

Blood Pressure
Cardiac Output Distribution at Rest and Exercise


<table>
<thead>
<tr>
<th>Organ</th>
<th>Rest %</th>
<th>Exercise %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Splanchnic</td>
<td>24%</td>
<td>1%</td>
</tr>
<tr>
<td>Skeletal Muscle</td>
<td>20</td>
<td>88</td>
</tr>
<tr>
<td>Kidneys</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Brain</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Skin</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Heart</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Other organs</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

Renal Perfusion and Urine

- Normal Resting Cardiac output 4-6 l/min.
- Kidney- 20% of resting C.O.
- 800-1200 ml/min.
- 400-600 ml/kidney/min.
- Normal Glomerular filtration rate 120 ml/min (~60 ml/min/kidney)
- Normal urine production ~1-2 ml/min.
- When exercising there is decreased renal perfusion, GFR and urine production
Sodium and Water in the Kidney

• 99% of filtered sodium is reabsorbed
• 1% excreted
• 99% of filtered water is reabsorbed
• 1% excreted
• In states of excess sodium and water-more excretion
• In dehydration-body holds onto sodium and water

Sweat

• 700-1000 ml loss respiratory and sweat/day non exertional
• 30-50 mEq/l Sodium
• Minimal Potassium loss
• Sodium content decreases with acclimation
• Sodium and water losses in sweat and urine are proportional to intake

Sweat (2)

• Regulated by neural contraction of sweat glands independent of skin perfusion and cardiovascular response.
• The slight increase in body temperature in exercise not d/t increased sweat rate until uncompensated fluid losses are > 2.5 litre
• No evidence for loss of thermal homeostasis in those who abstain or limit fluids during exercise

Sweat (3)

• As sodium and water content changes the body strives to maintain normal sodium and osmolarity
• No need for excess sodium or salt supplementation (salt tablets)
• “Salty Sweater” canard

Noakes, *Waterlogged*, 138, 145
Baldwin’s Law of Physiology

The body always seeks a steady state—steady state good or bad, but a steady state

Role of Sodium

• Major extracellular cation (+)
• Major determinant of Osmolarity
• Membrane balance for neuromuscular function
• Blood pressure and cardiovascular function
• Cellular pumps e.g. Na/K-ATPase
Sodium Sensitivity and Blood Pressure

- Gospel for decades but recently has been reexamined
- Still applies to certain groups: CHF, CKD, liver disease, West African heritage-APOL-1 gene
- Normal saline is still fluid of choice for initial fluid resuscitation

What about Chloride?

- Major extracellular anion (-)
- Contributes ~70% of anions
- To exert effect sodium must combine with chloride NaCl
Role of Chloride in BP

• 5 men with controlled hypertension on a restricted sodium diet
• Given 5.52 gm Sodium Chloride for 7 days
• >SBP 16 mmHg, DBP 8mmHg
• When equimolar amt. of Sodium Citrate substituted BP normalized
• Both increased volume, sodium retention, and suppressed PRA and Aldosterone


Water Distribution

[Diagram showing fluid compartments]

- Human body is approximately 60% water

- Total body water 42fl
- Intracellular fluid (28fl)
- Extracellular fluid (14fl)
- Transcellular fluid (7%) 1fl
- Plasmas (23%) 3fl
- Interstitial fluid (70%) 10fl
Water Distribution (2)

Water Distribution (3)
Extra and Intracellular Electrolyte Concentrations

Osmolarity

- An osmole is a solute (sodium, glucose, ethylene glycol, etc) which causes the passive movement of water across a semi permeable membrane down its concentration gradient
How Does the Body Respond to Volume Loss?

Goals
- Maintain blood pressure and cardiac output
- Organ perfusion
Body’s response to salt and water loss

- Increased Catecholamine secretion
- Increased Renin Angiotensin Aldosterone Activity
- Increased Antidiuretic Hormone secretion (Vasopressin)

- All in an attempt to restore cardiac output/blood pressure and organ perfusion

Renal Hormones

[Diagram showing the relationship between BP, PG, Renin, ANP, and other hormones]
1. Catecholamines

- Epi/NE
- \( \downarrow \text{BP/CO} \)
- HR/Contraction
- VC
- SVR
- \( \uparrow \text{CO/BP} \)
- RAA

2. Stimulation of the Renin Angiotension Aldosterone System

- Low flow into the kidney
- Low sodium content in renal filtrate
- Increased Sympathetic activity
- Stimulation of baroreceptors
Renin-Angiotensin-Aldosterone

Angiotensin II

- Vasoconstriction
- Increased Sodium/Water reabsorption
- Stimulation of Sympathetic N.S.
- Stimulates ADH secretion
- Stimulates Thirst
- Stimulates Aldosterone secretion
Aldosterone

- Stimulates Sodium/Water reabsorption
- Secretion of Potassium and Hydrogen

3. Antidiuretic hormone
Other factors for ADH secretion

- Intense exercise
- NSAID use
- Nausea and/or vomiting
- Hypoglycemia
- Stresses e.g. pain or emotions
- Release of muscle derived Interleukin-6 (IL-6)
In Summary

• The body is very efficient in maintaining osmolarity, sodium and water conservation
• With increased activity, less blood flow goes to the kidneys, hence less urinary loss as compared to fluid loading at rest
• Thirst is stimulated early by multiple mechanisms

In any disorder of Sodium and/or Water, the most critical factor is to determine the patient’s volume status.
“Curbside” evaluation of volume status

- Mental status
- Color
- Skin turgor
- Perspiration or lack of
- Axillary moisture
- Heart rate and blood pressure
- Orthostasis

A Poor Man’s Swan-Ganz Catheter
Pathophysiology of EAH/EAHE

• Rapid diffusion of water into cells leading to cellular edema
• Acute dilution of serum (extracellular) sodium content
• Alteration of Sodium-Potassium balance on either side on the cell membranes leading to membrane instability and irritability
• May progress onto Central Pontine Myelinolysis

Cellular Response to Water
EAH-E Fatalities

- 1993 unnamed female
- 1998 Dr. Kelly Barrett in Chicago Marathon
- 2002 Dr. Cynthia Lucero in Boston Marathon
- Hilary Bellamy 2002 Marine Corps Marathon
- 3 unnamed military recruits
- All had received isotonic saline not 3%

1st International Exercise Associated Hyponatremia Consensus

Central Pontine Myelinolysis
EAH Incidence

- Ranges from 0-18% depending on the sample
- In a 2010 report there was a 51% incidence of EAH in a 161 km endurance race lasting over 24 hours


Risk Factors for EAH/EAH-E

Rate of fall of sodium level*
Athlete related
Drinking behavior
Weight gain during activity
Lower body weight
Female
Slower pace
Event inexperience

* Most critical factor
Clinical Presentation of EAH/EAHE

- Depend upon the extent of cerebral edema present
- Weakness, dizziness, headache, lethargy, bloating, nausea, vomiting, confusion, myoclonus
- Generalized edema, periorbital,
- Neck vein distention, SOB, orthopnea, rales, pulmonary edema may be present
- Seizures, coma and death in severe cases

Clinical Presentation

- Blood pressure normal or may be elevated
- If a portable blood sodium analyzer is available, the sodium concentration will be < 135. Generally the lower the value, the more pronounced the symptoms but it is the rapid rate of fall not the absolute value that is most critical.
Principles of Treatment

• Remember the patient has too much water on board, hence IV isotonic saline will have a deleterious effect
• In asymptomatic or mildly symptomatic patients (no neurological signs) fluid restriction is the only treatment

Sodium Content in IV Fluids

<table>
<thead>
<tr>
<th>Fluid Type</th>
<th>Sodium Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal (isotonic) Saline</td>
<td>154 mEq/litre</td>
</tr>
<tr>
<td>½ Normal Saline</td>
<td>75 mEq/l</td>
</tr>
<tr>
<td>3% Saline</td>
<td>513 mEq/l</td>
</tr>
</tbody>
</table>
Principles of Treatment 3% Saline

- A SMALL correction can lead to a good outcome. (2-3 mEq/l initially) Do not over correct or normalize.
- Do not correct unless evidence of hyponatremia is present or compelling clinical situation e.g. seizure, myoclonus, confusion, coma, etc.
- 100 ml of 3% saline should provide some improvement, if none it may be repeated every 10 min. for a total of 3 doses or clinical improvement
- Fluid restriction
- 2nd Conference EAH

Principles of Treatment

- Once in hospital, serial measurements of not only sodium, but also potassium and magnesium with correction of their deficits as needed
- The patient will spontaneously diurese the excess water
- Diuretics are not indicated unless there is pulmonary edema
- Baseline neurological imaging: CT or MRI
- Close neurological monitoring is essential, if any uncertainty admission to ICU or Neuro ICU
Tolvaptan

• Vasopressin Receptor 2 antagonist
• Induces a temporary nephrogenic diabetes insipidus and a free water diuresis
• Indicated for SIADH and CHF
• Not approved for EAH/EAH-E
• May cause too rapid increase in sodium content

A Tale of Two Races
2002 Boston Marathon

- 766 runners
- 488 provided a blood sample at the finish line
- 13% had a serum sodium <135 mg/dl
- 0.6% had a critical sodium level <120 mg/dl
- Fluid available every mile (1.6 km) and aggressive hydration promoted

2002 Boston Marathon (2)

Associated features:
- weight gain
- female sex
- consumption of >3 l of fluid
- time>4 hours
- decreased body mass index

2002 City of Christchurch Marathon

- 134 runners
- Fluid stations every 3 miles (5 km)
- Aggressive hydration NOT promoted
- NO cases of hyponatremia reported


Recommendations

- For events less than 2 hours supplemental fluids are usually not needed
- Drink to thirst, no need to excessively “prehydrate” water or sports drinks
- Salt tablets are not necessary
- Sports drinks are fine in moderation
- Face it: Most of us are not a pro cyclists or runners, so you don’t need to drink or eat like one
Event Planning

• Education: Drink When Thirsty
• Don’t Over-hydrate—More weight to pedal uphill with!
• Space rest stops/ hydration areas