Water Balance: Hypo- and Hypernatremia

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Clinical Relevance

Mortality after Hospitalization with Mild, Moderate, and Severe Hyponatremia

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Preoperative Hyponatremia and Perioperative Complications

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Learning Objectives (5)

• Define serum osmolality
• Review ADH release and action on the kidney
• Define Hyponatremia and discuss causes
• Define Hypernatremia and discuss causes
• Distinguish between disorders of water and salt
Serum Osmolality

\[ \text{Posm} = 2\text{Na} + \frac{\text{Glucose}}{18} + \frac{\text{BUN}}{2.8} \]
Serum Osmolality

\[ \text{Posm} = 2Na + \frac{\text{Glucose}}{18} + \frac{\text{BUN}}{2.8} \]

Effective \( \text{Posm} = 2Na \)
Serum Osmolality

\[ \text{Posm} = 2\text{Na} + \frac{\text{Glucose}}{18} + \frac{\text{BUN}}{2.8} \]

Effective Posm = 2Na

Na concentration \([\text{Na}] = \frac{\text{Na}}{\text{H2O}}\)
Serum Osmolality

\[ \text{Posm} = 2\text{Na} + \frac{\text{Glucose}}{18} + \frac{\text{BUN}}{2.8} \]

Effective Posm = 2Na

\[ \text{Na concentration} \ [\text{Na}] = \frac{\text{Na}}{\text{H2O}} \]

If Sodium amount changes or H2O water changes then [Na] changes
Osmolality is a force...
Serum Osmolality

Cell: 280

Blood Vessel: 280
Serum Osmolality

280

280

280

260
Serum Osmolality
Osmotic sensors in the Hypothalamus (H)

ADH Release
• Paraventricular Neurons
• Supraoptic Nuclei
ADH Release

Graph A: Normal subjects (n=25), primary polyuria (n=2), nephrogenic diabetes insipidus (n=2), pituitary diabetes insipidus (n=8).

Graph B: Isotonic volume depletion, isovolemic osmotic increase.

Plasma ADH (pg/ml) vs. Plasma Osmolality (mOsm/kg) vs. Percent Change.
ADH Action

Low Uosm = 100-200 mOsm
ADH Release

H

280

310
ADH Action

High Uosm = 1000-1200 mOsm

NaCl transport
 Passive H₂O diffusion
ADH Release
ADH Action

High Uosm = 1000-1200 mOsm

Cortex
- 285
- Medulla
- 400
- 600
- 800
- 1000
- 1200

Loop of Henle
- 400
- 400
- 200
- 400
- 600
- 800
- 1000
- 1200

Collecting tubule
- 400
- 600
- 800
- 1000
- 1200

Interstitium

Papilla

NaCl transport
Passive H₂O diffusion

High ADH
Hyponatremia

- Defined as a plasma sodium concentration of $< 135$ mEq/L
- Implies hypo-osmolality
- Na/ECF (water)
ADH Release
Decreased effective arterial blood volume

“Appropriate” ADH release

Heart failure
Cirrhosis
Nephrotic syndrome
Volume depletion
Normal effective arterial blood volume

SIADH

Heart failure
Cirrhosis
Nephrotic syndrome
Volume depletion

ADH Release
Hyponatremia

- SIADH
- Tumors (brain/lung)
- Medications

- Heart Failure
- Cirrhosis
- Nephrotic syndrome
- Volume depletion
Diuretics and Water Balance

• Do thiazide diuretics predispose to hyponatremia?

• Do loop diuretics predispose to hyponatremia?
ADH Action

High Uosm = 100 mOsm

<table>
<thead>
<tr>
<th>Cortex</th>
<th>Medulla</th>
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<tbody>
<tr>
<td>285</td>
<td>400</td>
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<td>600</td>
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<td>1000</td>
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<tr>
<td>1200</td>
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</tbody>
</table>

Diagram showing the movement of water and solutes in response to high ADH levels.

- **Interstitium**
  - Cortex: 285 mOsm
  - Medulla: 400 mOsm
  - Loop of Henle:
    - Down: 400 mOsm
    - Up: 200 mOsm
  - Collecting tubule:
    - 400 mOsm
    - 600 mOsm
    - 800 mOsm
    - 1000 mOsm
    - 1200 mOsm

- **Papilla**
  - NaCl transport
  - Passive H₂O diffusion

- **High ADH**
Diuretics and Water Balance

• Do thiazide diuretics predispose to hyponatremia? **Yes**
  – Sodium reabsorbed in distal convoluted tubule with no concomitant water reabsorption
  – ADH can be increased if patient has volume depletion due to diuretics

• Do loop diuretics predispose to hyponatremia? **No**
  – Sodium reabsorbed in thick limb of loop of Henle with no concomitant water reabsorption, but....
  – ADH can’t work because NKCC2 required for generation and maintenance of hyperosmotic medulla, i.e. nothing for ADH to act on
Hypernatremia

- Na concentration [Na] = Na/H2O
Hypernatremia

- No access to water
- Kidney losing water
ADH Release

H

310
ADH Release
What if the kidney is losing water?
No effective ADH Action

Low Uosm = 100-200 mOsm
Case

- 47 year old Asian female with past history of breast CA
- Admitted to the hospital with pneumonia
- Required mechanical ventilation
- Her plasma osmolality began rising
  - P osm of 280 on admission
  - Increased to 290, then 300, then 310
Case

• Despite the rise in her Posm, her urine output was excessive and dilute
• The urine osm was only 100 mOsm/L
What if the kidney is losing water?

- Diabetes insipidus
  - Central
    - Tumor that disrupts ADH release
    - Ischemia (e.g. Sheehan’s syndrome)
Case

- 52 y/o male with a past psychiatric history presents with an acute gallbladder attack and is taken to the operating room.

- His serum sodium is 145 meq/L preoperatively and rises to 160 meq/L by the next morning. The nurses note a large urine output.
• Serum sodium = 160 meq/L
• Urine osm = 140 mOsm/kg

• The physicians administer subcutaneous vasopressin (ADH) and there is no change in the Urine osm.

• Diagnosis?
Principal Cell of the Distal Nephron
Principal Cell of the Distal Nephron
The periodic table of the elements

- Metals
- Metalloids
- Non-metals
- Transition Metals
- Gases
Principal Cell of the Distal Nephron
What if the kidney is losing water?

• Diabetes insipidus
  – Central
    • Tumor that disrupts ADH release
    • Ischemia
    • Alcohol
  – Nephrogenic
    • Lithium
The Difference between Salt and Water

- Salt: Disorders of Volume
  - e.g. salt-sensitive hypertension (too much salt and water; but isotonic)

- Salt concentration: Disorders of Water
  - e.g. hyponatremia (too much water RELATIVE to salt)

- A patient can have one, the other, or both
The Difference between Salt and Water

NORMAL

HYPOVoleMIA

HYPoNaTREMIA

HYPoNaTREMIA

HYPERVoleMIA

HYPERNATREMIA
The Difference between Salt and Water

NORMAL

HYPOVOLEMIA

HYPERNATREMIA

HYPERNATREMIA

EUVOLEMIA

HYPERNATREMIA

HYPERVOLEMIA
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