Electrolyte and Water Balance

Dr Sarama Saha
A 55-year-old man was brought to the emergency with severe multiple injuries in a road traffic accident and crush injuries, fractures of the legs and scalp lacerations. He was conscious and breathing spontaneously. Pulse 130/min, BP 60/40 mm Hg, serum sodium 142 mmol/L, potassium 7.9 mmol/L, chloride 110 mmol/L, Blood urea 40 mg/dL, and serum creatinine 1.2 mg/dL.

• Interpret the laboratory data?
• What is the basis of the changes?
The body water compartments

Total body water (42 L) (60% of body weight)

- Intracellular (28 L) (40% of body weight)
  - Intravascular (4%) (2.8 L)
  - Extravascular (16%) (11.2 L)
- Extracellular (14 L) (20% of body weight)
During oxidation of foodstuffs,
  • 1 g carbohydrate produces
    • 0.6 mL of water,
  • 1 g protein releases
    • 0.4 mL water and
  • 1 g fat generates
    • 1.1 mL of water.

major factors controlling the intake:
  • thirst and
  • the rate of metabolism.
# Water balance in the body

<table>
<thead>
<tr>
<th>Intake per day</th>
<th>Output per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water in food</td>
<td>Urine</td>
</tr>
<tr>
<td>1250 mL</td>
<td>1500 mL</td>
</tr>
<tr>
<td>Oxidation of food</td>
<td>Skin</td>
</tr>
<tr>
<td>300 mL</td>
<td>500 mL</td>
</tr>
<tr>
<td>Drinking water</td>
<td>Lungs</td>
</tr>
<tr>
<td>1200 mL</td>
<td>700 mL</td>
</tr>
<tr>
<td></td>
<td>Feces</td>
</tr>
<tr>
<td></td>
<td>50 mL</td>
</tr>
<tr>
<td><strong>2750 mL</strong></td>
<td><strong>2750 mL</strong></td>
</tr>
</tbody>
</table>
• Osmolarity means osmotic pressure exerted by the number of moles per liter of solution.

• Osmolality is the osmotic pressure exerted by the number of moles per kg of solvent.

• osmotic balance is mainly maintained by
  • Albumin

• the major determinant factor of osmolality is
  • the sodium

• The osmolality of plasma varies from
  • 285 to 295 mosm/kg
Gamblegrams showing composition of fluid compartments
## Electrolyte and Water Composition of Body Fluid Compartments

<table>
<thead>
<tr>
<th>Components</th>
<th>Plasma</th>
<th>Interstitial fluid</th>
<th>Intracellular fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume, H2O (TBW = 42 L)</td>
<td>3.5 L</td>
<td>10.5 L</td>
<td>28 L</td>
</tr>
<tr>
<td>Na+</td>
<td>142</td>
<td>145</td>
<td>12</td>
</tr>
<tr>
<td>K+</td>
<td>4</td>
<td>4</td>
<td>156</td>
</tr>
<tr>
<td>Ca+2</td>
<td>2.4</td>
<td>2-3</td>
<td>2.3</td>
</tr>
<tr>
<td>Mg2+</td>
<td>2</td>
<td>1-2</td>
<td>26</td>
</tr>
<tr>
<td>Trace elements</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total cations</td>
<td>155</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl−</td>
<td>103</td>
<td>114</td>
<td>4</td>
</tr>
<tr>
<td>HCO−</td>
<td>27</td>
<td>31</td>
<td>12</td>
</tr>
<tr>
<td>Protein−</td>
<td>16</td>
<td>-</td>
<td>55</td>
</tr>
<tr>
<td>Organic acids−</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPO2 −</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO2 −</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total anions</td>
<td>154</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Formulas for Estimating Serum Osmolality and Effective Osmolality

<table>
<thead>
<tr>
<th>Osmolality</th>
<th>Effective Osmolality</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2 \times [\text{Na}^+ \text{ mEq/L}]$</td>
<td>$2 \times [\text{Na}^+ \text{ mEq/L}]$</td>
</tr>
<tr>
<td>$+ \frac{[\text{glucose mg/dL}]}{18}$</td>
<td>$+ \frac{[\text{glucose mg/dL}]}{18}$</td>
</tr>
<tr>
<td>$+ \frac{[\text{BUN mg/dL}]}{2.8}$</td>
<td></td>
</tr>
<tr>
<td>$= \text{Sosm (mosm/Kg H}_2\text{O)}$</td>
<td>$= \text{Sosm (mosm/Kg H}_2\text{O)}$</td>
</tr>
</tbody>
</table>
Regulation of Sodium and Water balance

• ADH

• Renin-Angiotensin system

• Autoregulation
Disturbances in Fluid and Electrolyte balance

• Isotonic contraction- Loss of fluid that is isotonic with plasma--Loss of GI fluid

• Hypotonic contraction—Predominant Na loss– Infusion of fluids with low sodium content like dextrose

• Hypertonic contraction ---Predominantly water depletion---Diarrhoea
• Isotonic expansion---Secondary to hypertension

• Hypotonic expansion---ADH excess

• Hypertonic expansion---Conns syndrome & Cushings syndrome_ Excess mineralocorticoid- sodium retention
Hyponatremia typically manifests clinically as
(1) nausea,
(2) generalize weakness, and
(3) mental confusion.

<120 mmol/L: mental confusion
<110 mmol/L : Ocular palsy
90-105 mmol/L: Severe mental impairment

Reference interval of Sodium:
136-145 mmol/L (Adult)
128-148 mmol/L (New born at 48 h)
Approx 127 mmol/L (From Umbilical cord)

Urinary sodium excretion = 120-240 mmol/day with large diurnal variation
At night = 20% of the peak
Algorithm for the differential diagnosis of hyponatremia.

- **Plasma Osmolality**
  - Normal (280-295 mOsm/kg)
    - Pseudohyponatremia:
      - Hyperlipidemia
      - Hyperproteinaemia
  - Decreased
    - Hyperglycemia
    - Mannitol
    - Uremia
  - Increased

- **Volume Status**
  - Hypervolemia: water excess with normal, ↓, or ↑ NaCl
  - Euvolemia: isolated NaCl deficit
  - Hypovolemia: dehydration with a large NaCl deficit
Hypernatremia  Plasma sodium > 150 mmol/L

Symptoms are primarily neurologic
(because of neuronal cell loss of H2O into the ECF)

1. Tremors
2. Irritability
3. Ataxia
4. Confusion
5. Coma
Hypernatremia

Volume Status

- Hypervolemia: water excess with a large NaCl excess
  - Hyperaldosteronism
  - Cushing syndrome
  - Hypertonic IV fluid therapy

- Euvolemia: isolated NaCl excess
  - Urine Na⁺ variable

- Hypovolemia: dehydration with or without NaCl excess
  - Urine Na⁺ (mmol/L)

  - >20
    - >800
      - Central or nephrogenic diabetes insipidus
    - <800
      - Insensible loss
        - Lung
        - Skin
  - <10
    - <800
      - Isotonic or hypotonic
      - Osmotic diuresis
      - Diuretic therapy and ↓ water intake
    - >800
      - GI loss and ↓ water intake
      - Skin loss and ↓ water intake
**HYPOKALEMIA**

1. Muscle weakness
2. Irritability
3. Paralysis
4. Tachycardia
5. Cardiac conduction defect
6. Flattened T wave
7. Cardiac arrest

Reference interval of K+:
- Serum = 3.5-5.0 mmol/L (Adult)
- Plasma = 3.4-4.8 mmol/L (Adult)
- 3.7-5.9 mmol/L (Newborn)
- CSF = 70% that of plasma
Hypokalemia

K⁺ Redistribution

- Insulin response
- Alkalosis
- Catecholamine or β-adrenergic excess
- Pseudohypokalemia due to ↑ WBC
- Hypothermia
- Hypokalemic periodic paralysis

True K⁺ deficit

24-Hour urine K⁺

>25 mmol/day
- Renal loss
  - GI: diarrhea, fistula
  - Skin: excessive sweating

<25 mmol/day
- Extrarenal loss
  - ↓ Dietary intake (for example, starvation)
- Metabolic acidosis
  - Renal tubular acidosis, type I or II

- Metabolic alkalosis
  - Acute tubular necrosis, diuretic phase
  - Amphotericin B toxicity
  - Hypomagnesemia
Hypokalemia (continued)

Metabolic Alkalosis

24-Hour urine Cl⁻

>10 mmol/day

• Mineralocorticoid excess, primary or secondary
• Glucocorticoid excess, primary (for example, Cushing syndrome) or iatrogenic

<10 mmol/day

• Diuretics
• Vomiting or NG suction
• Penicillins
HYPERKALEMIA

1. Mental confusion
2. Weakness
3. Tingling
4. Flaccid paralysis of the extremities
5. Weakness of the respiratory muscles
6. Bradicardia
7. Conduction defects
8. Peripheral vascular collapse: Prolonged severe hyperkalemia >7 mmol/L
9. Cardiac arrest
MCQ 1

• A patient with diarrhoea may have all the following abnormalities except:
  • A. Metabolic acidosis
  • B. Hypertonic contraction of ECF
  • C. Urine with a high specific gravity
  • D. Isotonic contraction of ECF
MCQ 2

• Which of the following is the major intracellular cation?
• A. Magnesium
• B. Sodium
• C. Calcium
• D. Potassium
MCQ 3

• All 5 the following hormones affect fluid and electrolyte balance except:
  • A. Aldosterone
  • B. ADH
  • C. Cortisone
  • D. Thyroxine
References

• DM Vasudevan, textbook of medical biochemistry, 7th Edition,
• Tietz fundamentals of clinical chemistry and molecular diagnostics, 7th edition