Chapter 25:
Fluid, Electrolyte, and Acid / Base Balance

Body Fluids:
1) **Water**: (universal solvent)

Body water varies based on age, sex, mass, and body composition

\[ H_2O \sim 73\% \text{ body weight} \]
\[ \text{Low body fat} \]
\[ \text{Low bone mass} \]

\[ H_2O (♂) \sim 60\% \text{ body weight} \]
\[ H_2O (♀) \sim 50\% \text{ body weight} \]
\[ ♀ = \uparrow \text{ body fat} / \downarrow \text{ muscle mass} \]

\[ H_2O \sim 45\% \text{ body weight} \]
Body Fluids:
1) Water: (universal solvent)

Total Body Water
Volume = 40 L
(60% body weight)

Intracellular Fluid (ICF)
Volume = 25 L
(40% body weight)

Interstitial Fluid
Volume = 12 L

Extracellular Fluid (ECF)
Volume = 15 L
(20% body weight)

Body Fluids:
2) Solutes:

A) Non-electrolytes
(do not dissociate in solution – neutral)
- Mostly organic molecules
  (e.g., glucose, lipids, urea)

B) Electrolytes
(dissociate into ions in solution – charged)
- Inorganic salts
- Inorganic / organic acids
- Proteins

Although individual [solute] are different between compartments, the osmotic concentrations of the ICF and ECF are usually identical…
2) **Solute**

What happens to ICF volume if we increase osmolarity of ECF?

IV bags of varying osmolarities allow for manipulation of ECF / ICF levels...

**Water Balance:**

For proper hydration: \( \text{Water}_{\text{intake}} = \text{Water}_{\text{output}} \)

<table>
<thead>
<tr>
<th>Water Intake</th>
<th>Water Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolism (10%)</td>
<td>Feces (2%)</td>
</tr>
<tr>
<td>Solid foods (30%)</td>
<td>Sweat (8%)</td>
</tr>
<tr>
<td>Ingested liquids (60%)</td>
<td>Skin / lungs (30%)</td>
</tr>
</tbody>
</table>

2500 ml/day

2500 ml/day

\(< 0\)  
Osmolarity rises:  
- Thirst  
- ADH release

\(> 0\)  
Osmolarity lowers:  
- Thirst  
- ADH release  

\(= 0\)
Thirst Mechanism:

- ↓ osmolarity / ↑ volume of extracellular fluid
- ↓ saliva secretion → Dry mouth
- Osmoreceptors stimulated (Hypothalamus) → ↓ volume / ↑ osmolarity of extracellular fluid → Sensation of thirst → Drink

Water Balance Disorders:
1) **Dehydration** (long-term water deficiency)
   - a) Injury (e.g., burn, hemorrhage)
   - b) Exercise (profuse sweating)
   - c) Drugs (e.g., diuretic abuse)

2) **Hypotonic hydration** (water intoxication)
   - Leads to dilution of electrolytes
   - ↑ capillary hydrostatic pressure
   - ↑ capillary permeability

3) **Edema** (↑ fluid in interstitial space)
Electrolyte Balance:

**Importance:**
1) Total [electrolyte] directly affects water balance
2) Individual [electrolyte]s affect cell functions

**Uptake into System:**
- Across digestive epithelium
- Through metabolic activity

**Release from System:**
- Through digestive tract / kidney
  - Through perspiration
  - Gastrointestinal disorders

Electrolyte Balance:

**A) Sodium Balance:**

- Most abundant cation in ECF (~ 280 mosm)

**Importance:**
1) Contributes to osmotic pressure
2) Maintains neuron / muscle function

<table>
<thead>
<tr>
<th>Osmoreceptors stimulated</th>
<th>Osmoreceptors inhibited</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑ [Na⁺] in ECF</td>
<td>↓ [Na⁺] in ECF</td>
</tr>
<tr>
<td>↑ ADH release; ↑ thirst</td>
<td>↓ ADH release; ↓ thirst</td>
</tr>
<tr>
<td>Additional water dilutes ECF</td>
<td>Decreased water concentrates ECF</td>
</tr>
</tbody>
</table>

**Physiological Changes:**
- Eat salty potato chips: ↑ [Na⁺] in ECF
- Drink pure water: ↓ [Na⁺] in ECF

- Most common ion associated with electrolyte balance problems:
  - Hyponatremia = ↓ [Na⁺]
  - Hypernatremia = ↑ [Na⁺]

**Estrogens Enhance:**
- Na⁺ reabsorption; thus, edema during menstrual cycle / pregnancy
Electrolyte Balance:

Baroreceptor-initiated reflexes also affect \([\text{Na}^+]\) in body

Chapters 25: Fluid / Electrolyte / Acid-Base Balance

Electrolyte Balance:

B) Potassium Balance:

Importance:
1) Maintains neuron / muscle function
2) Assists in maintenance of pH

- As a rule, \(\text{K}^+\) levels in ECF sufficiently high that \(\text{K}^+\) needs to be secreted
  - Rate lost at kidney depends on:
    1) Changes in \([\text{K}^+]\) of ECF (\(\uparrow [\text{K}^+]\) = \(\uparrow\) rate of secretion)
    2) Changes in pH (\(\downarrow \text{pH}\) = \(\downarrow\) rate of secretion)
    3) Aldosterone levels (\(\uparrow\) aldosterone = \(\uparrow\) rate of secretion)

C) Calcium Balance:

Importance:
1) Maintains neuron / muscle function
2) Allows for normal blood clotting

- Levels in ECF regulated primarily by parathyroid hormone:
  1) \(\uparrow\) PTH = \(\uparrow\) bone desorption
  2) \(\uparrow\) PTH = \(\uparrow\) intestinal \(\text{Ca}^{++}\) absorption
  3) \(\uparrow\) PTH = \(\uparrow\) renal \(\text{Ca}^{++}\) reabsorption

Chvostek's sign

Hypokalemia = \(\downarrow [\text{K}^+]\)
Hyperkalemia = \(\uparrow [\text{K}^+]\)

Hypocalcemia = \(\downarrow [\text{Ca}^{++}]\)
Hypercalcemia = \(\uparrow [\text{Ca}^{++}]\)
Acid-Base Balance:

Critical for body to maintain pH between 7.35 – 7.45

Problems Encountered:
1) Disruption of cell membrane stability
2) Alteration of protein structure
3) Enzymatic activity change

Acid Types:
1) Volatile Acids: Acids that can leave solution and enter the atmosphere
   
   \[ \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{HCO}_3^- + \text{H}^+ \]
   
   carbonic acid

2) Fixed Acids: Acids that do not leave solution
   - Result from metabolism (e.g., phosphoric acid / lactic acid / ketone bodies)
   - Can only be eliminated via kidneys

Acid-Base Balance:

H⁺ Gain:
- Across digestive epithelium
- Cell metabolic activities

H⁺ Loss:
- Release at lungs
- Secretion into urine

Chemical Buffering Systems:
Dissolved compounds that neutralize H⁺ during transport by binding H⁺ when pH drops and releasing H⁺ when pH rises

1) Bicarbonate Buffer System: (primary ECF buffer)
   
   \[ \text{H}_2\text{CO}_3 \rightleftharpoons \text{HCO}_3^- + \text{H}^+ \]
   
   - Limitation: Can't protect system from pH changes resulting from elevated / depressed CO₂ levels
   
   Respiratory system must be working normally
Acid-Base Balance:

2) **Phosphate Buffer System**: (primary ICF buffer)

\[ \text{H}_2\text{PO}_4^- \rightleftharpoons \text{HPO}_4^{2-} + \text{H}^+ \]

- Also an important buffer in urine

3) **Protein Buffer System**: (both ECF and ICF buffer)

If pH rises

\[ \text{R} - \text{COOH} \rightarrow \text{R} - \text{COO}^- + \text{H}^+ \]

\[ \text{R} - \text{NH}_2 + \text{H}^+ \rightarrow \text{R} - \text{NH}_3^+ \]

- Proteins are most plentiful and powerful source of buffers in body

Buffers are a short-term fix to the problem; In the long term, H\(^+\) must be removed from the system...

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**Maintenance of Acid-Base Balance:**

1) **Respiratory Regulation**:

\[ \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \]

- Bicarbonate buffer system

\[ \text{H}_2\text{CO}_3 \rightleftharpoons \text{HCO}_3^- + \text{H}^+ \]

- Doubling / halving of areolar ventilation can raise / lower blood pH by 0.2 pH units

**If H\(^+\) begins to rise in system, respiratory centers excited**

\[ \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \]

**If H\(^+\) begins to fall in system, respiratory centers depressed**

\[ \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \]
Maintenance of Acid-Base Balance:

2) Renal Regulation:

Kidneys focus on maintaining adequate HCO₃⁻ levels in body

A) Bicarbonate 'reabsorption':

Filtrate in tubule lumen

- Process continues until majority of HCO₃⁻ 'reabsorbed'

- HCO₃⁻ + H⁺ → H₂CO₃
- H₂CO₃ → H⁺ + HCO₃⁻
- H₂O + CO₂

H⁺ not excreted from body (H₂O usually reabsorbed)

B) Bicarbonate generation:

- If low pH (high [H⁺]) exists in blood
- HCO₃⁻ can be secreted by PCT cells

Mechanism #1

Filtrate buffer

- HPO₄²⁻ + H⁺ → H₂PO₄⁻
- (cleared in urine)

Mechanism #2

Glutamine

- NH₄⁺ + HCO₃⁻ → NH₄⁺ + HCO₃⁻
- (cleared in urine)

If high pH (low [H⁺]) exists in blood

Mechanism #2

- CO₂ in blood due to ↑ H⁺
Disturbances of Acid-Base Balance:

1) Respiratory Acid / Base Disorders:
   - **A)** Respiratory Acidosis: 
     - \( \uparrow \text{CO}_2 \) retained in body  
     - **Cause:** 
       - Hypoventilation (e.g., emphysema)  
       - (Most common acid / base disorder)
   - **B)** Respiratory Alkalosis: 
     - \( \downarrow \text{CO}_2 \) retained in body  
     - **Cause:** 
       - Hyperventilation (e.g., stress)  
       - (Rarely persists long enough to cause clinical emergency)

2) Metabolic Acid / Base Disorders:
   - **A)** Metabolic Acidosis: 
     - \( \uparrow \) fixed acids generated in body  
     - **Causes:** 
       - Starvation (\( \uparrow \) ketone bodies)  
       - Alcohol consumption (\( \uparrow \) acetic acid)  
       - Excessive \( \text{HCO}_3^- \) loss (e.g., chronic diarrhea)
   - **A)** Metabolic alkalosis: 
     - \( \uparrow \) \( \text{HCO}_3^- \) generated in body  
     - **Causes:** 
       - Repeated vomiting (alkaline tide ‘amped’)  
       - Antacid overdose (Rare in body)

In the short term, respiratory / urinary system will compensate for disorders…