FLUID, ELECTROLYTE, & ACID-BASE BALANCE
Intracellular and Extracellular Fluid

Extracellular fluid (37%)

Intracellular fluid (63%)
Fluid Separation by Cell Membranes

Total body of water

Intracellular fluid (63%)

Membranes of body cells

Interstitial fluid
Plasma
Lymph
Transcellular fluid
Extracellular fluid (37%)
Ion Concentrations

Relative concentrations and ratios of ions in extracellular and intracellular fluids

Extracellular fluid
Intracellular fluid

<table>
<thead>
<tr>
<th>Ion</th>
<th>Concentration (m Eq/L)</th>
<th>Ratio (Extracellular: Intracellular)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺</td>
<td>140</td>
<td>14:1</td>
</tr>
<tr>
<td>K⁺</td>
<td>140</td>
<td>1:28</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>60</td>
<td>5:1</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>10</td>
<td>1:19</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>20</td>
<td>26:1</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>50</td>
<td>3:1</td>
</tr>
<tr>
<td>PO₄³⁻</td>
<td>10</td>
<td>1:19</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>10</td>
<td>1:2</td>
</tr>
</tbody>
</table>
Fluid Movement between Compartments

- Transcellular fluid
- Interstitial fluid
- Plasma
- Blood vessel
- Capillary wall
- Intracellular fluid
- Lymph
- Lymphatic vessel

Equilibrium
Blood hydrostatic pressure
Osmotic pressure

Cell membrane
Serous membrane
Blood flow
Interstitial fluid
Lymphatic vessel
Average daily intake of water

Major Sources of Body Water

Total intake (2,500 mL)

- Water of metabolism (250 mL or 10%)
- Water in moist food (750 mL or 30%)
- Water in beverages (1,500 mL or 60%)
Average daily output of water

Water Output

Total output (2,500 mL)

- Water lost in sweat (150 mL or 6%)
- Water lost in feces (150 mL or 6%)
- Water lost through skin and lungs (700 mL or 28%)
- Water lost in urine (1,500 mL or 60%)
Electrolyte Balance

- Foods
- Fluids
- Metabolic reactions

Electrolyte intake

Electrolyte output

- Perspiration
- Feces
- Urine
Potassium/Sodium Balance

Potassium ion concentration increases

Adrenal cortex is signaled

Sodium ions are conserved and potassium ions are excreted

Renal tubules increase reabsorption of sodium ions and increase secretion of potassium ions

Aldosterone is secreted
Important Electrolytes

• Sodium Ions (Na\(^+\))
  – Low = Hyponatremia
  – High = Hypernatremia

• Potassium Ions (K\(^+\))
  – Low = Hypokalemia
  – High = Hyperkalemia
Regulation of Electrolyte Output

Calcium ion concentration decreases

Parathyroid glands are stimulated

Parathyroid hormone is secreted

Intestinal absorption of calcium increases

Renal tubules conserve calcium and increase secretion of phosphate

Activity of bone-resorbing osteocytes and osteoclasts increases

Increased phosphate excretion in urine

Addition of phosphate to bloodstream

Calcium ion concentration returns toward normal

Normal phosphate concentration is maintained
Hydrogen Ion Sources

- Aerobic respiration of glucose
- Anaerobic respiration of glucose
  - Carbonic acid
  - Lactic acid
- Hydrolysis of phosphoproteins and nucleic acids
- Oxidation of sulfur-containing amino acids
  - Sulfuric acid
- Phosphoric acid
  - Acidic ketone bodies
- Incomplete oxidation of fatty acids
Hydrogen Ion Regulation

- High intake of proteins
  - Increased metabolism of amino acids
  - Increased formation of sulfuric acid and phosphoric acid
  - Increased concentration of $H^+$ in body fluids
    - Increased secretion of $H^+$ into fluid of renal tubules
    - Concentration of $H^+$ in body fluids returns toward normal
Chemical and Physiological Buffers

First line of defense against pH shift
- Chemical buffer system

Secondary line of defense against pH shift
- Physiological buffers

- Bicarbonate buffer system
- Phosphate buffer system
- Protein buffer system
- Respiratory mechanism ($CO_2$ excretion)
- Renal mechanism ($H^+$ excretion)
Bicarbonate Buffer System

- Present in intra & extracellular body fluids
- Consists of:
  - sodium bicarbonate (NaHCO₃) for strong acids
    \[ \text{HCl} + \text{NaHCO}_3 \rightarrow \text{H}_2\text{CO}_3 + \text{NaCl} \]
  - carbonic acid (H₂CO₃) for strong bases
    \[ \text{NaOH} + \text{H}_2\text{CO}_3 \rightarrow \text{NaHCO}_3 + \text{H}_2\text{O} \]
Phosphate Buffer System

- Present in intra & extracellular body fluids
  - Imp. in nephrons
- Consists of:
  - sodium monohydrogen phosphate (Na$_2$HPO$_4$)
    \[ \text{HCl} + \text{Na}_2\text{HPO}_4 \rightarrow \text{NaH}_2\text{PO}_4 + \text{NaCl} \]
  - sodium dihydrogen phosphate (NaH$_2$PO$_4$)
    \[ \text{NaOH} + \text{NaH}_2\text{PO}_4 \rightarrow \text{Na}_2\text{HPO}_4 + \text{H}_2\text{O} \]
- Turns one into the other
Protein Buffer System

- Consists of plasma proteins (Ex. albumins), & certain proteins within cells
- Proteins can function as acids or bases
  - H+ released from carboxyl groups
  - H+ accepted onto amino groups
- Ex. Hemoglobin
  - Accept H+ released into blood minimizing pH change
Arterial Blood pH

Normal pH range

Acidosis
Alkalosis

pH scale
6.8 7.0 7.35 7.45 7.8 8.0

Survival range
Carbon Dioxide Balance

- CO$_2$ reacts with H$_2$O to produce H$_2$CO$_3$
- Cells increase production of CO$_2$
- H$_2$CO$_3$ releases H$^+$
- Respiratory center is stimulated
- Rate and depth of breathing increase
- More CO$_2$ is eliminated through lungs
- Normal CO$_2$ and H$^+$ concentration is maintained
Acidosis and Alkalosis

- Accumulation of acids
- Loss of bases

Increased concentration of $H^+$

Acidosis
  - pH drops
  - pH scale: 7.4

Alkalosis
  - pH rises

Decreased concentration of $H^+$

- Loss of acids
- Accumulation of bases
Respiratory Acidosis Factors

- Decreased rate and depth of breathing
- Obstruction of air passages
- Decreased gas exchange

Accumulation of CO₂

Respiratory acidosis
Respiratory Alkalosis Factors

- Fever
- Poisoning
- Anxiety
- High altitude

Hyperventilation → Excessive loss of CO₂ → Decrease in concentration of H₂CO₃ → Decrease in concentration of H⁺ → Respiratory alkalosis
Metabolic Acidosis Factors

- Kidney failure to excrete acids
- Excessive production of acidic ketones as in diabetes mellitus

- Accumulation of nonrespiratory acids

- Metabolic acidosis

- Excessive loss of bases

- Prolonged diarrhea with loss of alkaline intestinal secretions
- Prolonged vomiting with loss of intestinal secretions