Chapter 2

Fluid, Electrolyte, and Acid-Base Imbalances
Review of Concepts and Processes

- The major component of the body is water in these compartments:
  - Intercellular fluid (ICF) compartment
  - Extracellular fluid (ECF) compartment
- Balance of water in the compartments essential for homeostasis
Fluid Compartments

- About 60% of an adult’s body weight is water.
- About 70% of an infant’s body weight is water.
- Females—higher percentage of fatty tissue, lower water content than males
- Older adults and obese persons—lower proportion of water
- Individuals with less fluid reserve are more likely to be adversely affected by any fluid or electrolyte imbalance.
Fluid Compartments (cont’d.)

- Intracellular compartment (ICF)

- Extracellular compartment (ECF)
  - Intravascular fluid (IVF) or blood
  - Interstitial fluid (ISF) or intercellular fluid
Fluid Compartments in the Body

70 kg male (154 pounds) as prototypic example

Intracellular  28 L

Extracellular  15 L
  - plasma      4.5 L
  - interstitial 10.5 L
Intake and Output of Water

- The amount of water entering the body should equal the amount of water leaving the body (approximately 2.5 L).

<table>
<thead>
<tr>
<th>In:</th>
<th>Out:</th>
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<tbody>
<tr>
<td>Liquid 1200 ml</td>
<td>Urine 1400 ml</td>
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<tr>
<td>Solid Food 1000 ml</td>
<td>Feces 200 ml</td>
</tr>
<tr>
<td>Cell 300 ml</td>
<td>Lungs* 400 ml</td>
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<tr>
<td>metabolism 300 ml</td>
<td>Skin* 500 ml</td>
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</table>

* Lungs and Skin are “Insensible fluid loss”
Movements of Water between Compartments

Hydrostatic (water) pressure: from blood pressure.

Osmotic Pressure: from protein concentration.

Fluid flows from high to low Hydrostatic pressure.

Hydrostatic Pushes

Fluid flows from low to high osmotic pressure.

Osmotic Pulls
**Arteriolar end of capillary bed:**
- Hydrostatic pressure moves fluid out of the vessels into the interstitium.

**Venous end of capillary bed:**
- Because fluid was lost on the arteriolar side, solute concentration is higher. This produces osmotic pressure that pulls the fluid back into the circulation.

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* = solute
High concentration due to water loss
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Fluid Imbalance

- Edema—excessive amount of fluid in the interstitial compartment.

- Dehydration – shortage of body fluid.
Causes of Edema

- Increased capillary hydrostatic pressure
  - Caused by higher blood pressure or increased blood volume
  - Forces increased fluid out of capillaries into tissue
- Loss of plasma proteins
  - Particularly albumin
  - Results in decreased plasma osmotic pressure
  - Tissue pulls fluid out of vessels to normalize blood protein concentration.

Also from:
Lymphatic Blockage
Local Inflammation
Effects of Edema

- Swelling
  - Pale or red in color

- Pitting edema
  - Presence of excess interstitial fluid
  - Moves aside when pressure is applied by finger
  - Depression—“pit” remains when finger is removed

- Increase in body weight
  - With generalized edema
Effects of Edema (cont’d.)
Fluid Deficit—Dehydration

Insufficient body fluid
- Inadequate intake
- Excessive loss (vomiting, diarrhea)
- Both

Vomiting loses acid (HCl) - hydrogen ions (H⁺)

Diarrhea loses base - bicarbonate ions (HCO₃⁻)
Effects of Dehydration

- Dry mucous membranes in the mouth
- Decreased skin turgor or elasticity
- Lower blood pressure, weak pulse, and fatigue
- Decreased mental function, confusion, loss of consciousness
Attempts to Compensate for Fluid Loss

- Increasing thirst
- Increasing heart rate
- Constriction of cutaneous blood vessels
- Producing less urine (retains fluid)
- Concentration of urine
**Distribution of Major Electrolytes (mEq/L)**

<table>
<thead>
<tr>
<th>Ion</th>
<th>Intracellular</th>
<th>Blood</th>
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<tbody>
<tr>
<td>Sodium (Na&lt;sup&gt;+&lt;/sup&gt;)</td>
<td>10</td>
<td>142</td>
</tr>
<tr>
<td>Potassium (K&lt;sup&gt;+&lt;/sup&gt;)</td>
<td>160</td>
<td>4</td>
</tr>
<tr>
<td>Calcium (Ca&lt;sup&gt;++&lt;/sup&gt;)</td>
<td>variable</td>
<td>5</td>
</tr>
<tr>
<td>Magnesium (Mg&lt;sup&gt;++&lt;/sup&gt;)</td>
<td>35</td>
<td>3</td>
</tr>
<tr>
<td>Bicarbonate (HCO3&lt;sup&gt;-&lt;/sup&gt;)</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>Chloride (Cl&lt;sup&gt;-&lt;/sup&gt;)</td>
<td>2</td>
<td>103</td>
</tr>
<tr>
<td>Phosphate (HPO4&lt;sup&gt;-&lt;/sup&gt;)</td>
<td>140</td>
<td>2</td>
</tr>
</tbody>
</table>

*Positive = cations; Negative = anions*
Major Ions

- Sodium (hyper, hyponatremia):
  - primary cation in blood and extracellular fluid
  - 90% of solute in extracellular fluid (affecting osmotic pressure).
  - Lost in sweat, vomiting and diarrhea.
  - Affected by water consumption and kidney function.

- Potassium (hyper, hypokalemia):
  - primary cation in intracellular fluid
  - blood levels have profound effect on heart
  - abnormal potassium levels cause changes in cardiac conduction and are *life-threatening!*
Relationship of Hydrogen and Potassium Ions

Acidosis (low blood pH) is characterized by increased hydrogen ions (H\(^+\)) in the blood.

H\(^+\) moves to interstitium then into cells pushing potassium (K\(^+\)) out.

K\(^+\) gets back into blood stream producing increased blood K\(^+\) (hyperkalemia)
Calcium Imbalance

- Review of calcium (hyper, hypocalcemia):
  - Stored in bone
  - Balance controlled by hormones:
    - parathyroid hormone (PTH) raises calcium in blood
    - calcitonin lowers calcium in blood (tones the bones).
  - Vitamin D promotes calcium absorption from intestine
    - Ingested or synthesized in skin in the presence of ultraviolet rays
    - Activated in kidneys
Functions of Calcium

- Provides structural **strength for bones** and teeth
- Maintenance of the stability of nerve membranes
- **Required for muscle contractions**
- Necessary for many metabolic processes and enzyme reactions
- **Essential for blood clotting**
Magnesium

- Intracellular ion
- Hyper, Hypomagnesemia

Phosphate

- Bone and tooth mineralization
- Phosphate buffer system—acid-base balance
- Reciprocal relationship with serum calcium
- Hyper, Hypophosphatemia

Chloride

- Major extracellular anion
- Chloride levels related to sodium levels
- Can shift in response to acid-base imbalances.
- Hyper, Hypochloremia
H+ concentration is pH but Cl⁻ and HCO₃⁻ are most important for acid-base balance in body.
Chloride Shift

1. Vomiting — Lose HCl

2. Low Cl⁻

3. Cl⁻ Moves from ISF to gastric secretions

4. Cl⁻ Shifts from plasma to ISF

5. HCO₃⁻ Bicarbonate ion moves out of erythrocyte to replace lost Cl⁻

6. Increased in blood leads to alkalosis

Blood

HCO₃⁻ HCO₃⁻ HCO₃⁻

Erythrocyte

HCO₃⁻

ISF

Stomach

Blood in capillary

Cl⁻ = CHLORIDE ION
HCO₃⁻ = BICARBONATE ION
ISF = INTERSTITIAL FLUID
Changes in Acids, Bicarbonate Ion, and Serum pH in Circulating Blood
Acid-Base Imbalance

- **Acidosis**
  - Excess hydrogen ions
  - Decrease in serum pH
- **Alkalosis**
  - Deficit of hydrogen ions
  - Increase in serum pH

Two ways to produce acidosis and alkalosis:
1. Respiratory
2. Metabolic

Ways to control:
1. Respiratory (quick but obtrusive)
2. Buffers
3. Kidneys (slowest but most effective).
Respiratory Acidosis

- Lungs are not getting rid of the CO$_2$, acid builds up in blood.
  - Acute problems
    - Pneumonia, airway obstruction, chest injuries
    - Drugs that depress the respiratory control center
  - Chronic respiratory acidosis
    - Common with chronic obstructive pulmonary disease

- Kidneys compensate respiratory acidosis by dumping H+ in urine (lowering urine pH) and retaining HCO$_3^-$ (increasing blood HCO$_3^-$)

- Body uses respiratory acidosis to compensate for metabolic alkalosis.
Respiratory Alkalosis

● Lungs getting rid of too much CO₂, depletes acid in blood

➢ Hyperventilation
  • Caused by anxiety, high fever, overdose of aspirin
  • Head injuries
  • Brainstem tumor

➢ Kidneys compensate respiratory alkalosis by retaining H+ from urine (raising urine pH) and dump HCO₃⁻ (decreasing blood HCO₃⁻)

➢ body uses respiratory alkalosis to compensate for metabolic acidosis.
Metabolic Acidosis

- Excessive loss of bicarbonate ions to buffer hydrogen \( (\text{HCO}_3^- \text{ levels decrease in blood}) \)
  - Diarrhea—loss of bicarbonate from intestines
- Renal disease or failure
  - Decreased excretion of acids
  - Decreased production of bicarbonate ions
- Metabolic imbalance
  - Lactic acidosis from anaerobic metabolism.
    - Hypoxia, hypoperfusion
    - Sepsis
    - Shock
    - Inborn errors in metabolism.
Metabolic Alkalosis

- Metabolic alkalosis
  - Increase in serum bicarbonate ion
    - Loss of hydrochloric acid from stomach (chloride lost from stomach compensated by chloride in blood, compensated by bicarbonate from red blood cells)
    - Hypokalemia (potassium going into cells, opposite of acidosis with potassium coming out of cells).
    - Excessive ingestion of antacids (bicarbonate).