Chapter 26
Fluid, Electrolyte, and Acid-Base Balance
Body Water Content

- Infants: 73% or more water (low body fat, low bone mass)
- Adult males: ~60% water
- Adult females: ~50% water (higher fat content, less skeletal muscle mass)
- Water content declines to ~45% in old age
Total body water
Volume = 40 L
60% of body weight

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

Interstitial fluid (IF)
Volume = 12 L
80% of ECF

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

Plasma
Volume = 3 L, 20% of ECF
Figure 26.2 Electrolyte composition of blood plasma, interstitial fluid, and intracellular fluid.

Blood plasma
Interstitial fluid
Intracellular fluid

<table>
<thead>
<tr>
<th>Ion</th>
<th>Blood Plasma (mEq/L)</th>
<th>Interstitial Fluid (mEq/L)</th>
<th>Intracellular Fluid (mEq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺</td>
<td>154</td>
<td>142</td>
<td>125</td>
</tr>
<tr>
<td>K⁺</td>
<td>15</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>25</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>106</td>
<td>92</td>
<td>76</td>
</tr>
<tr>
<td>HPO₄²⁻</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Total solute concentration (mEq/L)

0  20  40  60  80  100  120  140  160
Electrolyte Concentration

• Expressed in milliequivalents per liter (mEq/L), a measure of the number of electrical charges per liter of solution

\[
m\text{Eq/L} = \frac{\text{ion concentration (mg/L)}}{\text{atomic weight of ion (mg/mmol)}} \times \text{# of electrical charges on one ion}
\]

• For single charged ions (e.g. Na\(^+\)), 1 mEq = 1 mOsm

• For bivalent ions (e.g. Ca\(^{2+}\)), 1 mEq = 1/2 mOsm
Predicting Osmolality

- Normal osmolality of body fluids is ????
- Sodium accounts for one-half of osmolality
- Estimate osmolality by doubling the sodium value in mEq/L
Fluid Movement Among Compartments

• Regulated by osmotic and hydrostatic pressures
• Water moves freely by osmosis; osmolalities of all body fluids are almost always equal
• Two-way osmotic flow is substantial
• Ion fluxes require active transport or channels
• Change in solute concentration of any compartment leads to net water flow
Figure 26.4  Major sources of water intake and output.

- **Metabolism**: 10% (250 ml)
- **Foods**: 30% (750 ml)
- **Beverages**: 60% (1500 ml)
- **Feces**: 4% (100 ml)
- **Sweat**: 8% (200 ml)
- **Insensible loss via skin and lungs**: 28% (700 ml)
- **Urine**: 60% (1500 ml)

**Average intake per day**: 2500 ml

**Average output per day**: 1500 ml
Figure 26.5 The thirst mechanism for regulating water intake.

- Initial stimulus:
  - ECF osmolality increases.

- Physiological response:
  - Plas achieve osmolality decreases by 5-10%.
  - Plasma volume reduces, inhibits.
  - Blood pressure decreases.
  - Granular cells in kidney and renin-angiotensin-aldosterone mechanism.
  - Angiotensin II increases.

- Result:
  - Hypothalamic thirst center.
  - Sensation of thirst; person takes a drink.
  - Water moistens mouth, throat; stretches stomach, intestine.
  - Water absorbed from GI tract.
  - ECF osmolality decreases.
  - Plasma volume increases.

- 10/15/13
Electrolyte Balance

- Electrolytes are salts, acids, and bases
- Electrolyte balance usually refers only to salt balance
- Importance of salts
  - Controlling fluid movements
  - Excitability
  - Secretory activity
  - Membrane permeability
Regulation of Potassium Balance

• Importance of potassium:
  • Affects RMP in neurons and muscle cells (especially cardiac muscle)
    • $\uparrow$ ECF $[K^+] \rightarrow \downarrow$RMP $\rightarrow$ depolarization $\rightarrow$ reduced excitability
    • $\downarrow$ ECF $[K^+] \rightarrow$ hyperpolarization and nonresponsiveness
Regulation of Potassium Balance

- Hyperkalemia and hypokalemia can:
  - Disrupt electrical conduction in the heart
  - Lead to sudden death
- Hydrogen ions shift in and out of cells
  - Leads to corresponding shifts in potassium in the opposite direction
  - Interferes with activity of excitable cells
Regulation of Potassium Balance

- K⁺ balance is controlled in the cortical collecting ducts by changing the amount of potassium secreted into filtrate.
- High K⁺ content of ECF favors principal cell secretion of K⁺.
- When K⁺ levels are low, type A intercalated cells reabsorb some K⁺ left in the filtrate.
Regulation of Potassium Balance

• Influence of aldosterone
  • Stimulates $K^+$ secretion (and $Na^+$ reabsorption) by principal cells
  • Increased $K^+$ in the adrenal cortex causes
    • Release of aldosterone
    • Potassium secretion
Regulation of Calcium

- Ca$^{2+}$ in ECF is important for
  - Neuromuscular excitability
  - Blood clotting
  - Cell membrane permeability
  - Secretory activities
Regulation of Calcium

• Hypocalcemia $\rightarrow$ ↑ excitability and muscle tetany

• Hypercalcemia $\rightarrow$ Inhibits neurons and muscle cells, may cause heart arrhythmias

• Calcium balance is controlled by parathyroid hormone (PTH) and calcitonin
Figure 16.13 Effects of parathyroid hormone on bone, the kidneys, and the intestine.

- **Initial stimulus**
  - Hypocalcemia (low blood Ca\(^{2+}\))
  - PTH release from parathyroid gland

- **Physiological response**
  - Osteoclast activity in bone causes Ca\(^{2+}\) and PO\(_4\)\(^{3-}\) release into blood
  - Ca\(^{2+}\) reabsorption in kidney tubule
  - Activation of vitamin D by kidney
  - Ca\(^{2+}\) absorption from food in small intestine

- **Result**
  - Ca\(^{2+}\) in blood
Central Role of Sodium

• Most abundant cation in the ECF
• Sodium salts in the ECF contribute 280 mOsm of the total 300 mOsm ECF solute concentration
• Na⁺ leaks into cells and is pumped out against its electrochemical gradient
• Na⁺ content may change but ECF Na⁺ concentration remains stable due to osmosis
Regulation of Sodium Balance: Aldosterone

- Na\(^+\) reabsorption
  - 65% is reabsorbed in the proximal tubules
  - 25% is reclaimed in the loops of Henle
- Aldosterone $\rightarrow$ active reabsorption of remaining Na\(^+\)
- Water follows Na\(^+\) if ADH is present
Figure 26.8 Mechanisms and consequences of aldosterone release.

- **↑K⁺ concentration in the ECF**
- **↓Body Na⁺ content triggers renin release, increasing angiotensin II**

- Stimulates
  - Adrenal cortex
    - Releases
      - Aldosterone
        - Targets
          - Kidney tubules
            - Effects
              - **↑Na⁺ reabsorption**
              - **↑K⁺ secretion**

- Restores
  - Homeostatic plasma levels of Na⁺ and K⁺
Influence of Other Hormones

- Estrogens: $\uparrow$ NaCl reabsorption (like aldosterone)
  - $\rightarrow$ H$_2$O retention during menstrual cycles and pregnancy
- Progesterone: $\downarrow$ Na$^+$ reabsorption (blocks aldosterone)
  - Promotes Na$^+$ and H$_2$O loss
- Glucocorticoids: $\uparrow$ Na$^+$ reabsorption and promote edema
Acid-Base Balance

- pH affects all functional proteins and biochemical reactions
- Normal pH of body fluids ______
  - Arterial blood: ______
  - Venous blood and IF fluid: pH ______
  - ICF: pH ______
- Alkalosis or alkalemia: arterial blood pH >____
- Acidosis or acidemia: arterial pH <____
Abnormalities of Acid-Base Balance

- Respiratory acidosis and alkalosis
- Metabolic acidosis and alkalosis
Acidosis

- Accumulation of too much H+ or loss of HCO3
- Major effects
  - Depression of CNS
  - Deep and rapid breathing
  - Weak and irregular heart contractions
  - Systemic vasodilation
Alkalosis

• Due to loss of $H^+$ or accumulation of $HCO_3^-$
  • Hyperexcitability of nervous system
  • Nervous
  • Breathing is slow or shallow
  • Leads to convulsions and death
  • Role of $Ca^{++}$???
Identifying the acidosis or alkalosis

• Respiratory Acidosis - #1 most common acid-base imbalance
• Metabolic Acidosis – 2nd most common
• Respiratory Alkalosis – 3rd most common
• Metabolic Alkalosis – rarest
Causes of Acid-Base Imbalance

• Hyperventilation due to emotions would cause..

• Excessive vomiting of stomach contents would cause..

• Excessive ingestion of sodium bicarb would cause..

• Aspirin overdose would cause..

• COPD late stages would cause..

• Uncontrolled Diabetes mellitus would cause..
Causes of Acid-Base Imbalance

- Partial heart failure would cause..
- Alcohol or narcotics overdose causing hypoventilation would cause..
- Kidney failure due to antifreeze poisoning would cause..
- Diuretics that deplete K\(^+\) from ECF
- Severe diarrhea would cause....
What if....?????

For each scenario identify
- osmolarity change
- fluid shift
- result
- hormonal response

• You consume high sodium foods?
• You lose 5-10% of your blood by hemorrhage?
Practical Application

• IV solutions
  • Isotonic – 0.9 % Normal Saline, D5W, lactate ringers
  • Hypotonic - .45% Normal Saline
  • Hypertonic – Mannitol