About this Chapter

- Fluid and electrolyte homeostasis
- Water balance
- Sodium balance and ECF volume
- Potassium balance
- Acid-base balance

Fluid and Electrolyte Homeostasis

Why we need to worry about ionic concentrations

<table>
<thead>
<tr>
<th>Ionic Concentration</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺ and water</td>
<td>ECF volume and osmolarity</td>
</tr>
<tr>
<td>K⁺</td>
<td>Neuron and Muscle function</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>Exocytosis, muscle contractions, and other functions</td>
</tr>
<tr>
<td>H⁺ and HCO₃⁻</td>
<td>pH balance</td>
</tr>
</tbody>
</table>

Body must maintain mass balance
Excretion routes: kidney and lungs

Water Balance (~ 50% of body weight)

<table>
<thead>
<tr>
<th>Water Gain</th>
<th>Water Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food and drink</td>
<td>2.2 L/day</td>
</tr>
<tr>
<td>Skin</td>
<td>0.3 L/day</td>
</tr>
<tr>
<td>Lungs</td>
<td>0.3 L/day</td>
</tr>
<tr>
<td>Metabolism</td>
<td>0.3 L/day</td>
</tr>
<tr>
<td>Urine</td>
<td>1.5 L/day</td>
</tr>
<tr>
<td>Feces</td>
<td>0.1 L/day</td>
</tr>
<tr>
<td>2.5 L/day</td>
<td>2.5 L/day</td>
</tr>
</tbody>
</table>

Intake 2.2 L/day + Metabolic production 0.3 L/day = Output 2.5 L/day

Water Balance

- The kidneys conserve volume but cannot replace lost volume

Figure 20-1a
Figure 20-1b
Figure 20-2
Figure 20-3
Urine Concentration

Osmolarity changes as filtrate flows through the nephron

1. Hydronephrosis: Fluid leaving the proximal tubule becomes concentrated in the descending limb.
2. Removal of solutes in the thick ascending limb creates hyposmotic fluid.
3. Hormones control distal nephron permeability to water and solutes.
4. Urine osmolality depends on reabsorption in the collecting duct.

Water Reabsorption and Vasopressin (ADH)

Without ADH

With ADH

Water Reabsorption

- Vasopressin causes insertion of water pores into the apical membrane

Factors Affecting Vasopressin Release

Osmolarity of filtrate and interstitial tissue

How do we maintain the concentration gradients for movement of water out of the tubule?

If water is to move out of tubule (be reabsorbed), osmolarity must be greater in interstitium than in tubule!!!!

Why doesn't interstitium become dilute if water keeps leaving tubule?

Countercurrent Heat Exchanger

Warm blood

Cold blood

Warm blood

Warm blood

Heat lost to external environment

Limb

Figure 20-6

Figure 20-7

Figure 20-8
Counter Current exchange system (medulla)

- Vasa recta removes water
- Urea also increases the osmolality of the medullary interstitium

How the ions are reabsorbed in ascending loop

- Active reabsorption
- Transport driven by Na+/K+ pump
  - Na+ moves down gradient from lumen to cell
  - K+ and 2Cl- symported with the Na+
- Cl- and K+ enter interstitium via channels or cotransport
- Note: cells not permeable to water here

Sodium Balance

- Homeostatic responses to salt ingestion

Aldosterone Controls Sodium Balance

Na+ reabsorption and K+ secretion

Renin-angiotensin-aldosterone system

- Natriuretic peptides promote Na+ and water excretion
- Does opposite of Aldosterone
**Potassium Balance (only 2% of K+ is in ECF)**

- Most K+ is reabsorbed in proximal tubule
- K+ is secreted in the Distal tube (= dietary intake)
- Regulatory mechanisms keep plasma potassium in narrow range
  - Aldosterone plays a critical role
- Hypokalemia
  - Muscle weakness and failure of respiratory muscles and the heart
  - Stop releasing aldosterone
- Hyperkalemia
  - Can lead to cardiac arrhythmias
  - Release aldosterone
- Causes include kidney disease, diarrhea, and diuretics

**Acid-Base Balance**

- Normal pH of plasma is 7.38–7.42
- H+ concentration is closely regulated
  - Changes can alter tertiary structure of proteins
- Abnormal pH affects the nervous system
  - Acidosis: neurons become less excitable and CNS depression
  - Alkalosis: hyperexcitable
- pH disturbances
  - Associated with K+ disturbances

**pH Homeostasis depends on**

- **Buffers**
  - Moderate changes in pH
  - Combines with or releases H+
  - Cellular proteins, phosphate ions, and hemoglobin
- **Ventilation**
  - Rapid response
  - 75% of disturbances
- **Renal regulation** (Slowest of the three mechanisms)
  1. Directly by excreting or reabsorbing H+
  2. Indirectly by change in rate at which HCO₃⁻ buffer is reabsorbed or excreted

**Acid-Base Balance**

- Hydrogen ion and pH balance in the body
- There are few dietary sources for bases
- 3 factors influence pH homeostasis
- Plasma H⁺ and pH (\(\text{pH}\))

**pH Disturbances**

- -- don't forget the reflex pathway for respiratory compensation of metabolic acidosis
- But were talking kidneys today

**Volume and Osmolarity (Dehydration)**

- Blood volume/
- Blood pressure
- Osmolarity

**Cardiovascular Mechanisms**

- Renin-Angiotensin system
- Hypothalamic mechanisms
- Carotid and aortic baroreceptors
- Hypothalamic osmoreceptors

**Acid-Base Balance**

- Fatty acids
- Amino acids
- CO₂ (+ H₂O)
- Lactic acid
- Ketoacids
- CO₂ (+ H₂O)
- H⁺ input
- H⁺ output

**pH Disturbances**

- – don’t forget the reflex pathway for respiratory compensation of metabolic acidosis
- But were talking kidneys today
**pH Disturbances (General)**

- What happens during acidosis (low pH)
  - H+ secreted is buffered in urine
  - Bicarbonate ions reabsorbed to buffer H+ in blood

- **Figure 20-20**

**Renal Compensation: Transporters**

- Apical Na\(^+\)-H\(^+\) exchanger (NHE)
- Basolateral Na\(^+\)-HCO\(_3^−\) symport
- H\(^+\)-ATPase
- H\(^+\)-K\(^+\)-ATPase
- Na\(^+\)-NH\(_4^+\) antiport

**Renal Compensation Proximal tubule**

H\(^+\) secretion and the reabsorption of filtered HCO\(_3^−\)

- **Figure 20-21**

**Intercalated Cells**

- Type A intercalated cells function in acidosis

- **Figure 20-22a**

**Intercalated Cells**

- Type B intercalated cells function in alkalosis

- **Figure 20-22b**

**Acid-Base Balance**

- **Table 20-2**

<table>
<thead>
<tr>
<th>DISTURBANCE</th>
<th>$P_{CO_2}$</th>
<th>H(^+)</th>
<th>PH</th>
<th>HCO(_3^−)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidosis</td>
<td>↑</td>
<td>↑</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>Metabolic</td>
<td>Normal* or</td>
<td>↑</td>
<td>↓</td>
<td>↑</td>
</tr>
<tr>
<td>Alkalosis</td>
<td>↓</td>
<td>↓</td>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>Metabolic</td>
<td>Normal* or</td>
<td>↑</td>
<td>↑</td>
<td>↓</td>
</tr>
</tbody>
</table>

* These values are different from what you would expect from the law of mass action because almost instantaneous respiratory compensation keeps $P_{CO_2}$ from changing significantly.
Summary

- Fluid and electrolyte homeostasis
- Water balance
  - Vasopressin, aquaporin, osmoreceptors, countercurrent multiplier, and vasa recta
- Sodium balance
  - Aldosterone, principal cells, ANG I and II, renin, angiotensinogen, ACE, and ANP
- Potassium balance
  - Hyperkalemia and hypokalemia

Summary

- Behavioral mechanisms
- Integrated control of volume and osmolarity
- Acid-base balance
  - Buffers, ventilation, and kidney
  - Acidosis and alkalosis
  - Intercalated cells