Systematic Physiology

TOPIC: Acid-Base Balance

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Acid-base Balance

♦ The importance of pH control

• The pH of the ECF remains between 7.35 and 7.45
• If plasma levels fall below 7.35 (acidemia), acidosis results
• If plasma levels rise above 7.45 (alkalemia), alkalosis results
• Alteration outside these boundaries affects all body systems
• Can result in coma, cardiac failure, and circulatory collapse

Types of acids in the body

• Volatile acid
  • Can leave solution and enter the atmosphere (e.g. carbonic acid)
• Fixed acids
  • Acids that do not leave solution (e.g. sulfuric and phosphoric acids)
• Organic acids
  • Participants in or by-products of aerobic metabolism

Common Acids

• Carbonic acid is most important factor affecting pH of ECF
  • CO₂ reacts with water to form carbonic acid
  • Inverse relationship between pH and concentration of CO₂
• Sulfuric acid and phosphoric acid
  • Generated during catabolism of amino acids
• Organic acids
  • Metabolic byproducts such as lactic acid, ketone bodies
  • Buffer system consists of a weak acid and its anion

♦ Three major buffering systems:
♦ Protein buffer system
  • Amino acid
♦ Hemoglobin buffer system
  • $\text{H}^+$ are buffered by hemoglobin
♦ Carbonic acid-bicarbonate
  • Buffers changes caused by organic and fixed acids
♦ Minor buffering system
  • Phosphate
    • Buffer pH in the ICF

The Basic Relationship between $P_{\text{CO}_2}$ and Plasma pH
Protein buffer system

- If pH climbs, the carboxyl group of amino acid acts as a weak acid
- If the pH drops, the amino group acts as a weak base
- Hemoglobin buffer system
  - Prevents pH changes when $P_{CO_2}$ is rising or falling

Amino Acid Buffers

![Amino Acid Buffers](image)

In alkaline medium, amino acid acts as an acid and releases $H^+$

Neutral pH

In acidic medium, amino acid acts as a base and absorbs $H^+$

Carbonic Acid-Bicarbonate Buffering System

- Carbonic acid-bicarbonate buffer system
  - $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + CO_3^-$
- Has the following limitations:
  - Cannot protect the ECF from pH changes due to increased or depressed $CO_2$ levels
  - Only functions when respiratory system and control centers are working normally
  - It is limited by availability of bicarbonate ions (bicarbonate reserve)
The Carbonic Acid-Bicarbonate Buffer System

Maintenance of acid-base balance

- Lungs help regulate pH through carbonic acid - bicarbonate buffer system
  - Changing respiratory rates changes $P_{CO_2}$
  - Respiratory compensation
- Kidneys help regulate pH through renal compensation
Kidney tubules and pH Regulation

**Diagram (a):**
- **Carbonic anhydrase**
- **Lumen**
- **Capillary**
- **Metabolic generation in tubule cell**
- **Cells of PCT, DCT, and collecting system**

**Diagram (b):**
- **NH₃**
- **NH₄⁺**
- **Glutaminase**
- **HCO₃⁻**
- **HCO₃⁻** (from Glutaminase)

**Diagram (c):**
- **Renal response to alkalosis**
- **Cl⁻**
- **HCO₃⁻**
- **CO₂ + H₂O → H₂CO₃** (from carbonic anhydrase)
- **H⁺**
- **HCO₃⁻ → H⁺ + CO₂ + H₂O**

**Key:**
- Leak channel
- Countertransport
- Active transport
- Exchange pump
- Cotransport
- Diffusion
- Reabsorption
- Secretion

**Steps:**
1. **H₂CO₃** → **CO₂ + H₂O**
2. **H₂CO₃** → **H⁺ + HCO₃⁻**
3. **NH₄⁺** + **Na⁺** → **NH₃** + **Na⁺**
4. **NH₃** → **NH₄⁺** + **H⁺**
5. **H⁺** + **HCO₃⁻** → **H₂CO₃**
6. **H₂CO₃** → **CO₂ + H₂O**

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**Legend:**
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**Explanation:**
- The diagram illustrates the process of pH regulation in the kidney tubules, involving transport mechanisms and chemical reactions to maintain pH homeostasis.

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**Further reading:**
- Understanding the role of carbonic anhydrase and its importance in the renal tubule system.
- The mechanisms of transport and reabsorption in the proximal convoluted tubule (PCT) and distal convoluted tubule (DCT).
- The role of ammonia in maintaining and regulating blood pH.
Disturbances of Acid-base Balance

Acid-base balance maintained by

- Buffer systems
- Respiration
- Renal function
  - Maintain tight control within range 7.35 – 7.45

The Central Role of the Carbonic Acid-Bicarbonate Buffer System in the Regulation of Plasma pH
Acid-Base Disorders

- Respiratory acid base disorders
  - Result when abnormal respiratory function causes rise or fall in CO₂ in ECF
- Metabolic acid-base disorders
  - Generation of organic or fixed acids
  - Anything affecting concentration of bicarbonate ions in ECF

Respiratory acidosis

- Results from excessive levels of CO₂ in body fluids
Respiratory Acid-Base Regulation

(a) Hypoventilation causing increased $P_{CO_2}$
- Respiratory acidosis
  - H$^+$ secretion; HCO$_3^-$ generation
  - Buffer systems other than carbonic acid-bicarbonate system accept H$^+$ ions
- Increased respiratory rate
- Renal compensation
- Decreased $P_{CO_2}$

(b) Hyperventilation causing decreased $P_{CO_2}$
- Respiratory alkalosis
  - H$^+$ generation; HCO$_3^-$ secretion
  - Inhibition of arterial and CSF chemoreceptors
- Decreased respiratory rate
- Renal compensation
- Increased $P_{CO_2}$

Homeostasis restored in both cases.
**Respiratory alkalosis**

- Relatively rare condition
- Associated with hyperventilation

**Metabolic acidosis**

- Major causes are:
  - Depletion of bicarbonate reserve
  - Inability to excrete hydrogen ions at kidneys
  - Production of large numbers of fixed / organic acids
  - Bicarbonate loss due to chronic diarrhea

**The Response to Metabolic Acidosis**
Metabolic alkalosis

- Occurs when $\text{HCO}_3^-$ concentrations become elevated
  - Caused by repeated vomiting
Detection of acidosis and alkalosis

- Diagnostic blood tests
  - Blood pH
  - $P_{CO_2}$
  - Bicarbonate levels
- Distinguish between respiratory and metabolic

A Diagnostic Chart for Acid-Base Disorders
Aging and Fluid, Electrolyte, and Acid-base Balance

Changes with age include

- Reduced total body water content
- Impaired ability to perform renal compensation
- Increased water demands
  - Reduced ability to concentrate urine
  - Reduced sensitivity to ADH/aldosterone
- Net loss of minerals
- Inability to perform respiratory compensation
- Secondary conditions that affect fluid, electrolyte, acid-base balance

You should now be familiar with:

- What is meant by “fluid balance,” “electrolyte balance,” and “acid-base balance”
- The compositions of intracellular and extracellular fluids
- The hormones that play important roles in regulating fluid and electrolyte balance
- The movement of fluid that takes place within the ECF, between the ECF and the ICF, and between the ECF and the environment
- How sodium, potassium, calcium and chloride ions are regulated to maintain electrolyte balance
- The buffering systems that balance the pH of the intracellular and extracellular fluids
- The compensatory mechanisms involved in acid-base balance