

CHAPTER 27

LECTURE OUTLINE

I. INTRODUCTION

- A. Body fluid refers to body water and its dissolved substances.
- B. Regulatory mechanisms insure homeostasis of body fluids since their malfunction may seriously endanger nervous system and organ functioning.

II. FLUID COMPARTMENTS AND FLUID BALANCE

A. Introduction

1. In lean adults body fluids comprise about 55-60% (Figure 27.1) of total body weight.
2. Water is the main component of all body fluids.
3. About two-thirds of the body's fluid is located in cells and is called intracellular fluid (ICF).
4. The other third is called extracellular fluid (ECF).
 - a. About 80% of the ECF is interstitial fluid and 20% is blood plasma.
 - b. Some of the interstitial fluid is localized in specific places, such as lymph; cerebrospinal fluid; gastrointestinal tract fluids; synovial fluid; fluids of the eyes (aqueous humor and vitreous body) and ears (endolymph and perilymph); pleural, pericardial, and peritoneal fluids between serous membranes; and glomerular filtrate in the kidneys.
5. Selectively permeable membranes separate body fluids into distinct compartments. Plasma membranes of individual cells separate intracellular fluid from interstitial fluid. Blood vessel walls divide interstitial fluid from blood plasma. Although fluids are in constant motion from one compartment to another, the volume of fluid in each compartment remains fairly stable – another example of homeostasis.
6. Fluid balance means that the various body compartments contain the required amount of water, proportioned according to their needs.
 - a. Osmosis is the primary way in which water moves in and out of body compartments. The concentrations of solutes in the fluids is therefore a major determinant of fluid balance.
 - b. Most solutes in body fluids are electrolytes, compounds that dissociate into ions.
 - c. Fluid balance, then, means water balance, but also implies electrolyte balance; the two are inseparable.

B. Sources of Body Water Gain and Loss

1. Water is the largest single constituent in the body, varying from 45% to 75% of body weight, depending on age and the amount of fat present.

2. Fluid intake (gain) normally equals fluid output (loss), so the body maintains a constant volume (Figure 27.2).

C. Regulation of Water Gain

1. Metabolic water volume depends mostly on the level of aerobic cellular respiration, which reflects the demand for ATP in body cells.
2. The main way to regulate body water balance is by adjusting the volume of water intake.
3. When water loss is greater than water gain, dehydration occurs (Figure 27.3).
4. The stimulus for fluid intake (gain) is dehydration resulting in thirst sensations; one mechanism for stimulating the thirst center in the hypothalamus is the renin-angiotensin II pathway, which responds to decreased blood volume (therefore, decreased blood pressure) (Figure 27.3).

D. Regulation of Water and Solute Loss

1. Although increased amounts of water and solutes are lost through sweating and exhalation during exercise, loss of body water or excess solutes depends mainly on regulating how much is lost in the urine (Figure 27.4).
2. Under normal conditions, fluid output (loss) is adjusted by antidiuretic hormone (ADH), atrial natriuretic peptide (ANP), Angiotensin II and aldosterone, all of which regulate urine production.
3. Table 27.1 summarizes the factors that maintain body water balance.

E. Movement of Water Between Body Fluid Compartments

1. A fluid imbalance between the intracellular and interstitial fluids can be caused by a change in their osmolarity.
2. Most often a change in osmolarity is due to a change in the concentration of Na⁺.
3. When water is consumed faster than the kidneys can excrete it, water intoxication may result (Figure 27.5).
4. Repeated use of enemas can increase the risk of fluid and electrolyte imbalances. (Clinical Connection)

III. ELECTROLYTES IN BODY FLUIDS

- A. Electrolytes serve four general functions in the body.
 1. Because they are more numerous than nonelectrolytes, electrolytes control the osmosis of water between body compartments.
 2. They help maintain the acid-base balance required for normal cellular activities.

3. They carry electrical current, which allows production of action potentials and graded potentials and controls secretion of some hormones and neurotransmitters. Electrical currents are also important during development.
4. Several ions are cofactors needed for optimal activity of enzymes.

B. Concentrations of Electrolytes in Body Fluids

1. To compare the charge carried by ions in different solutions, the concentration is typically expressed in milliequivalents/liter (mEq/Liter), which gives the concentration of cations or anions in a solution.
2. The chief difference between plasma and interstitial fluid is that plasma contains quite a few protein anions, where interstitial fluid has hardly any since plasma proteins generally cannot move out of impermeable blood vessel walls. Plasma also contains slightly more sodium ions but fewer chloride ions than the interstitial fluid. In other respects, the two fluids are similar.
3. Intracellular fluid (ICF) differs considerably from extracellular fluid (ECF), however.
4. Figure 27.6 compares the concentrations of the main electrolytes and protein anions in plasma, interstitial fluid, and intracellular fluid.

C. Sodium (Na⁺)

1. It is the most abundant extracellular ion.
2. It is involved in impulse transmission, muscle contraction, and participates in fluid and electrolyte balance by creating most of the osmotic pressure of extracellular fluid.
3. The average daily intake of sodium far exceeds the body's normal daily requirements. The kidneys excrete excess sodium and conserve it during periods of sodium restriction.
4. Its level in the blood is controlled by aldosterone, antidiuretic hormone, and atrial natriuretic peptide.
5. Excess Na⁺ in the body can result in edema. Excess loss of Na⁺ causes excessive loss of water, which results in hypovolemia, an abnormally low blood volume. (Clinical Connection)

D. Chloride (Cl⁻)

1. It is the major extracellular anion.
2. It plays a role in regulating osmotic pressure between compartments and forming HCl in the stomach.
3. Regulation of Cl⁻ balance in body fluids is indirectly controlled by aldosterone. Aldosterone regulate sodium reabsorption; the negatively charged chloride follows the positively charged sodium passively by electrical attraction.

E. Potassium (K⁺)

1. It is the most abundant cation in intracellular fluid.

2. It is involved in maintaining fluid volume, impulse conduction, muscle contraction, and regulating pH.
3. The plasma level of K^+ is under the control of mineralocorticoids, mainly aldosterone.

F. Bicarbonate (HCO_3^-)

1. It is a prominent ion in the plasma.
2. It is a significant plasma anion in electrolyte balance.
3. It is a major component of the plasma acid-base buffer system.
4. The kidney reabsorbs or secretes bicarbonate to make the final balance for acid-base conditions.

G. Calcium (Ca^{+2})

1. Is the most abundant ion in the body, is principally an extracellular ion.
2. It is a structural component of bones and teeth. It also functions in blood coagulation, neurotransmitter release, maintenance of muscle tone, and excitability of nervous and muscle tissue.
3. The level of calcium in plasma is regulated principally by parathyroid hormone and calcitonin.

H. Phosphate

1. present as calcium phosphate salts
2. Phosphates contribute about 100 mEq/liter of anions to intracellular fluid. HPO_4^{2-} is an important buffer of H
3. The same two hormones that govern calcium homeostasis—parathyroid hormone (PTH) and calcitriol— also regulate the level of HPO_4^{2-} in blood plasma
 - a. PTH increases urinary excretion of phosphate and lowers blood phosphate level
 - b. Calcitriol promotes absorption of both phosphates and calcium from the gastrointestinal tract

I. Magnesium (Mg^{+2})

1. It is primarily an intracellular cation.
2. It activates several enzyme systems involved in the metabolism of carbohydrates and proteins and is needed for operation of the sodium pump. It is also important in neuromuscular activity, neural transmission within the central nervous system, and myocardial functioning.
3. Several factors regulate magnesium ion concentration in plasma. They include hypo- or hypercalcemia, hypo- or hypermagnesemia, an increase or decrease in extracellular fluid volume, an increase or decrease in parathyroid hormone, and acidosis or alkalosis.

4. Table 27.2 describes the imbalances that result from the deficiency or excess of several electrolytes.
5. Individuals at risk for fluid and electrolyte imbalances include those dependent on others for fluid and food needs; those undergoing medical treatment involving intravenous infusions, drainage or suction, and urinary catheters, those receiving diuretics, and post-operative individuals, burned individuals, individuals with chronic disease, and those with altered states of consciousness.

IV. ACID-BASE BALANCE

- A. The overall acid-base balance of the body is maintained by controlling the H⁺ concentration of body fluids, especially extracellular fluid.
 1. The normal pH of extracellular fluid is 7.35-7.45.
 2. Homeostasis of pH is maintained by buffer systems, exhalation of carbon dioxide, and kidney excretion.

B. The Actions of Buffer Systems

1. Most buffer systems of the body consist of a weak acid and the salt of that acid (which functions as a weak base); together they function to prevent rapid, drastic changes in the pH of a body fluid by changing strong acids and bases into weak acids and bases. Buffers work within fractions of a second.
2. The important buffer systems include the protein system, the carbonic acid-bicarbonate system, and the phosphate system.
 - a. The protein buffer system is the most abundant buffer in body cells and plasma. Inside red blood cells the protein hemoglobin is an especially good buffer for carbonic acid.
 - b. The carbonic acid-bicarbonate buffer system is an important regulator of blood pH and is based on the bicarbonate ion.
 - c. The phosphate buffer system is an important regulator of pH, both in red blood cells and in the kidney tubular fluids.

C. Exhalation of Carbon Dioxide

1. The pH of body fluids may be adjusted by a change in the rate and depth of respirations, which usually takes from 1 to 3 minutes.
 - a. An increase in the rate and depth of breathing causes more carbon dioxide to be exhaled, thereby increasing pH.
 - b. A decrease in respiration rate and depth means that less carbon dioxide is exhaled, causing the blood pH to fall.

2. The pH of body fluids, in turn, affects the rate of breathing (Figure 27.7).

D. Kidney excretion of H⁺

1. Cells in the PCT and collecting ducts secrete hydrogen ions into the tubular fluid.
2. In the PCT Na⁺/H⁺ antiporters secrete H⁺ and reabsorb Na⁺ (Figure 26.13).
3. The apical surfaces of some intercalated cells include proton pumps (H⁺ ATPases) that secrete H⁺ into the tubular fluid and HCO₃⁻ antiporters in their basolateral membranes to reabsorb HCO₃⁻ (Figure 27.8).
4. Other intercalated cells have proton pumps in their basolateral membranes and Cl⁻/HCO₃⁻ antiporters in their apical membranes.
5. These two types of cells help maintain body fluid pH by excreting excess H⁺ when pH is too low or by excreting excess HCO₃⁻ when the pH is too high.

E. Table 27.3 summarizes the mechanism that maintains pH of body fluids.

F. Acid-Base Imbalances

1. The normal pH range of systemic arterial blood is between 7.35-7.45.
 - a. Acidosis is a blood pH below 7.35. Its principal effect is depression of the central nervous system through depression of synaptic transmission.
 - b. Alkalosis is a blood pH above 7.45. Its principal effect is overexcitability of the central nervous system through facilitation of synaptic transmission.
 - c. A change in blood pH that leads to acidosis or alkalosis can be compensated to return pH to normal. Compensation refers to the physiological response to an acid-base imbalance.
 - d. Respiratory acidosis and respiratory alkalosis are primary disorders of blood PCO₂. On the other hand, metabolic acidosis and metabolic alkalosis are primary disorders of bicarbonate concentration.
2. Respiratory acidosis is characterized by an elevated PCO₂ and decreased pH and is caused by hypoventilation or other causes of reduced gas exchange in the lungs.
3. Respiratory alkalosis is characterized by a decreased arterial blood PCO₂ and increased pH and is caused by hyperventilation.
4. Metabolic acidosis is characterized by a decreased bicarbonate level and decreased pH, and results from an abnormal increase in acid metabolic products (other than CO₂), loss of bicarbonate, or failure of the kidneys to excrete H⁺ ions derived from metabolism of dietary proteins
5. Metabolic alkalosis is characterized by increased bicarbonate concentration and results from nonrespiratory loss of acid (e.g., excessive vomiting) or excess intake of alkaline drugs.
6. A summary of acidosis and alkalosis is presented in Table 27.4.

G. Clinical Connection: Diagnosis of acid-base imbalances employs a general four-step process.

1. Note whether the pH is high or low relative to the normal range.
2. Decide which value of PCO₂ or HCO₃⁻ could cause the abnormality.
3. Specify the problem source as respiratory or metabolic.
4. Look at the noncausative value and determine if it is compensating for the problem

V. AGING AND FLUID, ELECTROLYTE, AND ACID-BASE HOMEOSTASIS

- A. Infants experience more problems than adults with respect to fluid distribution, regulation of fluid and electrolyte balance, and acid-base homeostasis.
- B. The differences are related to proportion and distribution of water, metabolic rate, functional development of the kidneys, body surface area, breathing rate, and ion concentration.
- C. Older adults often have impaired ability to maintain fluid, electrolyte, and acid-base balance due to declining skeletal muscle mass and increasing mass of adipose tissue (which includes very little water), age-related respiratory and renal diseases, and both sensible and insensible water loss from the skin. Older adults are susceptible to dehydration and hypernatremia, hyponatremia, hypokalemia, and acidosis.