Chapter 18 - Water, Electrolyte, and Acid-Base Balance

18.1 Introduction

A. To be in balance, the quantities of fluids and electrolytes leaving the body should be equal to the amounts taken in. Electrolytes are molecules that release ions in water.

B. Anything that alters the concentrations of electrolytes will also alter the concentration of water, and vice versa.

18.2 Distribution of Body Fluids

A. Fluids occur in compartments in the body (intracellular and extracellular), and movement of water and electrolytes between compartments is regulated.

B. Fluid Compartments (Fig. 18.1)

1. The average adult female is 52% water by weight, while a male is 63% water; the difference is due to the female's additional adipose tissue.
2. The intracellular fluid compartment includes all the water and electrolytes within cells.
3. The extracellular fluid compartment includes all water and electrolytes outside of cells (interstitial fluid, plasma, and lymph).
4. Transcellular fluid includes the cerebrospinal fluid of the central nervous system, fluids within the eyeball, synovial fluid of the joints, serous fluid within body cavities, and exocrine gland secretions.

C. Body Fluid Composition (Fig. 18.2)

1. Extracellular fluids have high concentrations of sodium, chloride, and bicarbonate ions, and lesser amounts of potassium, calcium, magnesium, phosphate, and sulfate ions.
2. Intracellular fluid has high concentrations of potassium, phosphate, and magnesium ions, and lesser amounts of sodium, chloride, and bicarbonate ions.

D. Movement of Fluid between Compartments (Fig. 18.3)

1. Hydrostatic pressure and osmotic pressure regulate the movement of water and electrolytes from one compartment to another.
2. Although the composition of body fluids varies from one compartment to another, the total solute concentrations and water amounts are normally equal.
3. A net gain or loss of water will cause shifts affecting both the intracellular and extracellular fluids due to osmosis.

18.3 Water Balance

A. Water balance exists when water intake equals water output.

B. Water Intake (Fig. 18.4)

1. The volume of water gained each day varies from one individual to the next.
2. About 60% of daily water is gained from drinking, another 30% comes from moist foods, and 10% from the water of metabolism.
3. Regulation of Water Intake
   a. The thirst mechanism is the primary regulator of water intake.
   b. The thirst mechanism derives from the osmotic pressure of extracellular fluids and a thirst center in the hypothalamus.
   c. Once water is taken in, the resulting distention of the stomach will inhibit the thirst mechanism.

C. Water Output (Fig. 18.4b)

1. Water is lost in urine, feces, perspiration, evaporation from skin (insensible perspiration), and from the lungs during breathing.
2. The route of water loss depends on temperature, relative humidity, and physical exercise.
3. Regulation of Water Output

a. The distal convoluted tubules and collecting ducts of the nephrons regulate water output.
b. Antidiuretic hormone from the posterior pituitary causes a reduction in the amount of water lost in the urine.
c. When drinking adequate water, the ADH mechanism is inhibited, and more water is expelled in urine.

18.4 Electrolyte Balance

A. An electrolyte balance exists when the quantities of electrolytes gained equals the quantities of electrolytes lost.
B. Electrolyte Intake
   1. The electrolytes of greatest importance to cellular metabolism are sodium, potassium, calcium, magnesium, chloride, sulfate, phosphate, bicarbonate, and hydrogen ions.
   2. Electrolytes may be obtained from food or drink, or they may be produced as a by-product of metabolism.
   3. Regulation of Electrolyte Intake
      a. A person ordinarily obtains sufficient electrolytes from foods eaten.
      b. A salt craving may indicate an electrolyte deficiency.
D. Electrolyte Output
   1. Losses of electrolytes occur through sweating, in the feces, and in urine.
   2. Regulation of Electrolyte Output (Fig. 18.5)
      a. The concentrations of the cations, especially sodium, potassium, and calcium, are very important.
      b. Sodium ions account for 90% of the positively charged ions in extracellular fluids; the action of aldosterone on the kidneys regulates sodium reabsorption.
      c. Aldosterone also regulates potassium ions; potassium ions are excreted when sodium ions are conserved.
      d. Calcium concentration is regulated by parathyroid hormone, which increases the concentrations of calcium and phosphate ions in extracellular fluids and by calcitonin, which does basically the reverse.
      e. Generally, the regulatory mechanisms that control positively charged ions secondarily control the concentrations of anions.

18.5 Acid-Base Balance

A. Electrolytes that ionize in water and release hydrogen ions are acids; those that combine with hydrogen ions are bases.
B. Maintenance of homeostasis depends on the control of acids and bases in body fluids.
C. Sources of Hydrogen Ions (Fig. 18.6)
   1. Most hydrogen ions originate as by-products of metabolic processes, including: the aerobic and anaerobic respiration of glucose, incomplete oxidation of fatty acids, oxidation of amino acids containing sulfur, and the breakdown of phosphoproteins and nucleic acids.
D. Strengths of Acids and Bases
   1. Acids that ionize more completely are strong acids; those that ionize less completely are weak acids.
   2. Bases release hydroxyl and other ions, which can combine with hydrogen ions, thereby lowering their concentration.
E. Regulation of Hydrogen Ion Concentration
   1. Acid-base buffer systems, the respiratory center in the brain stem, and the kidneys regulate pH of body fluids.
   2. Acid-Base Buffer Systems (pTable 18.1)

a. The chemical components of a buffer system can combine with a strong acid and convert it to a weaker one.
b. The chemical buffer systems in body fluids include the bicarbonate buffer system, the phosphate buffer system, and the protein buffer system.

3. Respiratory Excretion of Carbon Dioxide (Fig. 18.7)
    a. The respiratory center in the brain stem helps to regulate hydrogen ion concentration by controlling the rate and depth of breathing.
    b. During exercise, the carbon dioxide, and thus the carbonic acid, levels in the blood increase.
    c. In response, the respiratory center increases the rate and depth of breathing, so the lungs excrete more carbon dioxide.
4. Renal Excretion of Hydrogen Ions
    a. Nephrons secrete excess hydrogen ions in the urine.
5. Time Course of Hydrogen Ion Regulation (Fig. 18.8)
    a. Chemical buffers are considered the body's first line of defense against shifts in pH; physiological buffer systems (respiratory and renal mechanisms) function more slowly and constitute secondary defenses.

18.6 Acid-Base Imbalances (Fig. 18.10)

A. Chemical and physiological buffer systems usually keep body fluids within very narrow pH ranges but abnormal conditions may prevent this.
    1. A pH below 7.35 produces acidosis while a pH above 7.45 is called alkalosis.

B. Acidosis (Figs. 18.10-11)
    1. Two major types of acidosis are respiratory and metabolic acidosis.
        a. Respiratory acidosis results from an increase of carbonic acid caused by respiratory center injury, air passage obstructions of problems with gas exchange.
        b. Metabolic acidosis is due to either an accumulation of acids or a loss of bases, and has many causes including kidney disease, vomiting, diarrhea and diabetes mellitus.
        c. Increasing either the respiratory rate or the amount of hydrogen ions released by the kidney can help compensate for acidosis.

C. Alkalosis (Fig. 18.13)
    1. Alkalosis also has respiratory and metabolic causes.
        a. Respiratory alkalosis results from hyperventilation causing an excessive loss of carbon dioxide.
        b. Metabolic alkalosis is caused by a great loss of hydrogen ions or a gain in base perhaps from vomiting or use of drugs.