Chapter 27: Fluid, Electrolyte and Acid-Base Homeostasis

Chapter Objectives

**FLUID COMPARTMENTS AND FLUID BALANCE**

1. Describe the various fluid compartments of the body and tell where fluid can move between them.
2. Discuss the effect of osmolarity on water movement between compartments.
3. Define water intoxication and describe possible causes.
4. Discuss the sources of water gain and its avenues for loss.
5. Define the processes available for fluid intake and how they are regulated.
6. Indicate how ADH, Angiotensin II, Aldosterone and ANP act on organ systems to control the rate of fluid loss.

**ELECTROLYTES IN BODY FLUID**

7. Discuss the four general functions of electrolytes in the body.
8. Contrast the electrolyte concentrations of the three major fluid compartments.
9. Discuss the functions and the primary fluid compartment location of sodium.
10. Examine the functions and the primary fluid compartment location of chloride.
11. Examine the functions and the primary fluid compartment location of potassium.
12. Examine the functions and the primary fluid compartment location of bicarbonate.
13. Examine the functions and the primary fluid compartment location of calcium.
14. Examine the functions and the primary fluid compartment location of phosphate.
15. Examine the functions and the primary fluid compartment location of magnesium.

**ACID-BASE BALANCE**

17. List the three primary mechanisms to maintain the concentration of H+ within a very limited range of pH.
18. List the three buffer systems and describe how each buffer system works to prevent large changes in the H+ concentration.
19. Define acid-base imbalances, their effects on the body, and the methods the body normally employs to compensate for excesses in acid and base.
20. Discuss respiratory acidosis/alkalosis in terms of the partial pressure of CO₂.
21. Discuss metabolic acidosis/alkalosis in terms of HCO₃⁻ levels.

Chapter Lecture Notes

Introduction
In lean adults body fluids comprise about 55-60\% of total body weight. *(Fig 27.1)*

**Fluid compartments**

- **Intracellular fluid (ICF)** - fluid located in cells
  - about two-thirds of the body’s fluid
- **Extracellular fluid (ECF)** – fluid located outside of cells
  - about one-third of the body’s fluid
- **Interstitial fluid** (fluid between cells and lymph fluid) - 80\% of the ECF
- **Blood plasma** - 20\% of the ECF

Only 2 places for exchange between compartments:

- cell membranes separate and allow exchange between intracellular and interstitial fluid
- capillary walls allow exchange between blood plasma and interstitial fluids

**Fluid and Solute Balance**

Fluid balance - the various body compartments contain the required amount of water, proportioned according to their needs.

Fluid balance primarily means water balance, but also implies electrolyte balance; the two are inseparable.

Osmosis is the primary way in which water moves in and out of body compartments.

The concentrations of solutes in the fluids are major determinants of fluid balance.

Intracellular and interstitial fluids normally have the same osmolarity, so cells neither swell nor shrink.

**Water intoxication** - $Na^+$ concentration of plasma falls below normal *(Fig 27.5)*

- drinking plain water faster than kidneys can excrete it
- replace water lost from diarrhea or vomiting with plain water
- osmolarity of plasma and interstitial fluid falls below cells, cells may swell and burst

**Body Water Gain and Loss**

Body water = 45-75\% body weight
declines with age since fat contains almost no water

Normally loss = gain (Fig 27.2)

dehydration - water loss is greater than water gain

Mechanisms of body water gain (Fig 27.2)

- ingest liquids – largest gain amount
- ingest foods
- metabolic water – water made by burning sugars

Regulation of fluid gain is by regulation of thirst (Fig 27.3)

One mechanism for stimulating the thirst center in the hypothalamus is the renin-angiotensin II pathway

Mechanisms of body water loss (Fig 27.2)

- urine production by the kidneys – largest loss amount
- sweating through the skin
- breathing water vapor out of the lungs
- water in digestive tract solid waste

Regulation of fluid loss depends mainly on regulating how much is lost in the urine

Under normal conditions, urine production fluid output (loss) is adjusted by (Fig 27.4 & Table 27.1)

- antidiuretic hormone (ADH)
- atrial natriuretic peptide (ANP)
- aldosterone

Electrolytes in Body Fluids (Table 27.2)

Electrolytes serve four general functions in the body

- electrolytes control the osmosis of water between body compartments because they are more numerous than nonelectrolytes
- maintain the acid-base balance required for normal cellular activities
electrolytes carry electrical current
production of action potentials
production of graded potentials
control of secretion of some hormones and neurotransmitters
electrolytes can be cofactors needed for optimal activity of enzymes.

Intracellular fluid, interstitial fluid and blood plasma differ considerably from each other in electrolyte concentrations. (Fig 27.6 & Table 27.2)

Blood plasma contains many proteins, but interstitial fluid does not produce blood colloid osmotic pressure.

Interstitial fluid and blood plasma contains Na\(^+\) and Cl\(^-\)

Intracellular fluid contains K\(^+\) and phosphates (HPO\(_4\)\(^{2-}\))

Sodium (Na\(^+\))

Most abundant extracellular ion

Hormonal that control sodium levels

Aldosterone

ADH

ANP

Sodium retention causes water retention

Caused by renal failure or hyperaldosterone

Edema - abnormal accumulation of interstitial fluid

Excessive loss of sodium causes excessive loss of water

Due to inadequate secretion of aldosterone or too many diuretics

hypovolemia=low blood volume

Chloride (Cl\(^-\))

Most prevalent extracellular anion

Moves easily between compartments due to Cl\(^-\) leakage channels
Helps balance anions in different compartments

Chloride shift across red blood cells with buffer movement

It plays a role in forming HCl in the stomach

Regulation

passively follows Na$^+$ so it is regulated indirectly by aldosterone levels

ADH helps regulate Cl$^-$ in body fluids because it controls water loss in urine

Potassium (K$^+$)

The most abundant cation in intracellular fluid.

It is involved in

- maintaining fluid volume
- nerve impulse conduction
- muscle contraction

Exchanged for H$^+$ to help regulate pH in intracellular fluid

The plasma level of K$^+$ is under the control of mineralocorticoids, mainly aldosterone.

Bicarbonate (HCO$_3^-$)

It is a significant plasma anion in electrolyte balance (Fig 27.8)

It is a major component of the plasma acid-base buffer system

Kidneys are main regulator of plasma levels

Calcium (Ca$^{2+}$)

The most abundant ion in the body, principally an extracellular ion

It is a structural component of bones and teeth.

Important role in

- blood clotting
- neurotransmitter release
- muscle tone
- nerve and muscle function
Regulated by parathyroid hormone

- stimulates osteoclasts to release calcium from bone
- increases production of calcitriol (Ca\(^{2+}\) absorption from GI tract and reabsorption from glomerular filtrate)

**Phosphate**

Present as calcium phosphate in bones and teeth, and in phospholipids, ATP, DNA and RNA

HPO\(_4\)^{2-}\) is important intracellular anion and acts as buffer of H\(^+\) in body fluids and in urine

Plasma levels are regulated by parathyroid hormone & calcitriol

**Magnesium (Mg\(^{2+}\))**

Primarily an intracellular cation

Activates several enzyme systems involved in the metabolism of carbohydrates and proteins

Needed for operation of the sodium-potassium pump

It is also important in
- neuromuscular activity
- neural transmission within the central nervous system
- myocardial functioning

Several factors regulate magnesium ion concentration in plasma

- blood magnesium levels
- blood calcium levels
- changes in extracellular fluid volume
- changes in parathyroid hormone levels
- blood pH - acidosis or alkalosis

**Acid-Base Balance**

The overall acid-base balance of the body is maintained by controlling the H\(^+\) concentration of body fluids, especially extracellular fluid

3 major mechanisms to regulate pH (Table 27.3)
buffer systems

exhalation of CO₂ (respiratory system)

kidney excretion of H⁺ (urinary system)

Buffer systems prevent rapid, drastic changes in pH in body fluids

3 principal buffer systems

protein buffer system

  hemoglobin very good at buffering H⁺ in RBCs

  albumin is main blood plasma protein buffer

carbonic acid-bicarbonate buffer system

  bicarbonate ion (HCO₃⁻) can act as a weak base

    holds excess H⁺

  carbonic acid (H₂CO₃) can act as weak acid

    dissociates into H⁺ ions

phosphate buffer system

  most important intracellularly, but also acts to buffer acids in the urine

  dihydrogen phosphate ion acts as a weak acid that can buffer a strong base

  monohydrogen phosphate acts a weak base by buffering the H⁺ released by a strong acid

Acid-Base Imbalances

Acidosis - blood pH below 7.35

  Acidosis causes depression of CNS - coma

Alkalosis - blood pH above 7.45

  Alkalosis causes excitability of nervous tissue - spasms, convulsions & death

Respiratory acidosis and respiratory alkalosis are primary disorders of blood P_{CO₂} (Table 27.4)

Metabolic acidosis and metabolic alkalosis are primary disorders of bicarbonate concentration

Compensation - physiological response to an acid-base imbalance (Fig 27.7)

Either renal or respiratory system will compensate for disorder of opposite system