Summary of Water, Electrolyte, & pH Balance

VIII. Distribution of Body's Fluids

A) Fluid Compartments

- Water occupies three main locations within the human body:
  1. Intracellular Fluid (ICF)
  2. Extracellular Fluid (ECF) compartments
     Plasma
     Interstitial fluid

- Must stay in relative abundances within the compartments.

B) Composition of Body Fluids

1. Nonelectrolytes
   Examples: glucose, lipids, and urea.

2. Electrolytes dissociate into ions (ionize) in water
   Examples: Mg\(^{+}\), Na\(^{+}\), Cl\(^{-}\), K\(^{+}\)

Electrolytes have a greater ability to cause fluid shift.

C) Movement of Fluids between Compartments

- Exchange of body fluids regulated by osmotic and/or hydrostatic pressures.

IX. Electrolyte Balance

- All of the ions in plasma contribute to the osmotic balance that controls the movement of water between cells and their environment.

- Six electrolytes are most important: sodium, potassium, chloride, bicarbonate, calcium, and phosphate.

- Excretion of ions occurs mainly through the kidneys.

A) Sodium

- Sodium's role in the body: the major cation of the extracellular fluid.

- Excretion of sodium is accomplished primarily by the kidneys.

- Hyponatremia: usually associated with excess water accumulation in the body
  * Also, sweating, vomiting, or diarrhea.
- Hypernatremia: abnormal increase of blood sodium.
  * Associated with dehydration (concentration of sodium goes up). Sometimes vomiting and excessive sweating.

B) Potassium

- Potassium’s roles in the body: the major intracellular cation. Potassium is part of the body’s buffer system.

- Potassium balance is maintained primarily by Aldosterone at the kidney.

- Hypokalemia: abnormally low potassium blood level.
  
  Vomiting or diarrhea.

- Hyperkalemia: high levels in the blood. It can result from increased dietary intake of potassium.
  * For the heart, this means that it won’t relax after a contraction, and will effectively “seize” and stop pumping blood, which is fatal within minutes.

C) Chloride

- Chloride is the predominant extracellular anion.

- Hypochloremia: lower-than-normal blood chloride levels, can occur because of kidney failure, vomiting, diarrhea.

- Hyperchloremia: higher-than-normal blood chloride levels. Usually, ingestion of something with Cl-.

D) Bicarbonate

See later section on “pH Balance”.

E) Calcium and Phosphate – stored in body in hydroxyapatites in skeleton.

- Calcium’s role in the body:
  * Incorporated into bones and teeth, with bone serving as a mineral reserve for these ions.
  * Calcium ions, Ca2+, are necessary for muscle contraction, including cardiac, enzyme activity, and blood coagulation.

- Calcium ion concentration is regulated by interaction of two hormones: parathyroid hormone and calcitonin. Also, Vitamin D.

- Hypocalcemia: low calcium blood levels.

- Hypercalcemia: abnormally high calcium blood levels.
- Hypophosphatemia, or abnormally low phosphate blood levels, occurs with heavy use of antacids.

- Hyperphosphatemia, or abnormally increased levels of phosphates in the blood, occurs if there is decreased renal function (kidney failure).

F) Proteins:

- Found mostly in the intracellular fluid. Then, next highest concentration is in the plasma. Of course, most physiological and structural functions of the body are performed by proteins.

- Here, we will focus on its role in pH and homeostasis of water balance.

X. The Body’s Water Balance

A) Overview

- Sensible water loss: you can sense (perceive) the loss (urine, sweat, feces)

- Insensible water loss: those you cannot detect (vapor in lungs, diffusion through skin)

B) Regulation of Water Output and Electrolyte Balance

1) Introduction

- Rise in plasma osmolarity (solute concentration) triggers:

  1. Thirst, provoking water intake.
  
     Regulation of Water Intake (Thirst Mechanism) – no detail

  2. ADH release, causing the kidneys to excrete concentrated urine

- Disorders of Water Balance

  Dehydration - water loss exceeds water intake

  Hypotonic hydration – ECF is diluted; increase in osmosis occurs and tissue cells swell (edema)

2) Regulation of Sodium Balance and Water Balance (sodium-water balance, BP, and Blood Volume)

- Sodium most abundant cation in the ECF. The only cation exerting a significant osmotic pressure

- Influence of ADH

  * Increase in ADH secretion = increase in water resorption.
  
  *Recall: for aquaporin on CD.

- Influence of Aldosterone

  * Aldosterone aids in actively reabsorbing remaining Na⁺ and Cl⁻ in distal convoluted tubule/collection tubule
NOTE: water reabsorption is high with ADH, very high with aldosterone + ADH

- Influence of Atrial Natriuretic Factor (ANF)
  
  * Reduces blood pressure and blood volume by inhibiting nearly all events that promote vasoconstriction and sodium and water retention

  * In essence, inhibits ADH and Aldosterone production

XI. Acid-Base Balance

- All biochemical reactions are influenced by pH of their fluid environment, therefore optimum conditions and balance (acid-base) is required. Also, proteins denature rapidly in high or low pH conditions.

- Changes in pH in blood: arterial blood >7.45 = alkalosis and <7.35 = physiologic acidosis

A) Chemical buffers:

- There are three chemical buffer systems:

  1. The protein buffer system is important in regulating blood plasma and intracellular fluid pH.

    If plasma or extracellular fluid pH drops, hydrogen ions bind to amine groups and pH rises.

    If plasma or extracellular fluid pH rises, acid groups dissociate and pH drops.

  2. The phosphate system is most important in regulating intracellular fluid pH.

  3. The carbonic acid - bicarbonate system is most important in regulating blood plasma pH.

    If plasma pH drops, carbonic acid is formed and plasma pH rises.

    If plasma pH rises, bicarbonate ions are formed and plasma pH drops.

B) The respiratory system can regulate blood pH by controlling the amount of carbon dioxide removed from the blood. (of course, it still involves chemicals). Carbonic anhydrase ties them together!

Review:

Hyperventilation – increased depth and rate of breathing that:

  Quickly flushes carbon dioxide from the blood
  Occurs in response to hypercapnia

Though a rise CO2 acts as the original stimulus, control of breathing at rest is regulated by the hydrogen ion concentration in the brain

Hypoventilation – slow and shallow breathing due to abnormally low PCO2 levels

Apnea (breathing cessation) may occur until PCO2 levels rise
C) Urinary Tract. (of course, it still involves chemicals)

- Tubular cells of the proximal convoluted tubule and collecting tubules can alter the pH of filtrate and therefore blood pH.

- These cells can affect blood pH with two coupled mechanisms: the reabsorption of bicarbonate ions and the secretion of hydrogen ions.

  * Notice that the body does not reabsorb H+ readily in order to control pH. It secretes H+ into the filtrate, and reabsorbs bicarb to control blood pH.

    If pH is low, reabsorb more bicarbonate and secrete more H+
    If pH is high, reabsorb less bicarbonate and secrete less H+

D). Imbalances in pH: distinguished according to their causes as **respiratory** and **metabolic**.

1. **Metabolic acidosis**:

   The most common cause presence of organic acids or excessive ketones in the blood. Also, diarrhea as they lose bicarbonate.

   Toxins can also cause metabolic acidosis. E.g.: An overdose of aspirin causes metabolic acidosis.

2. **Metabolic Alkalosis**:

   **This is rare**. Vomiting.
3. Respiratory Acidosis.

   Respiratory acidosis can result from **anything that interferes with respiration**, such as pneumonia, emphysema, or congestive heart failure.

4. Respiratory Alkalosis:

   This condition usually occurs when too much CO2 is exhaled from the lungs, as occurs in **hyperventilation**. Recall our discussion on **ANXIETY** in the endocrine chapter.

- Compensation Mechanisms

  1. Respiratory Compensation

     In metabolic acidosis, there is increased breathing.

     In metabolic alkalosis, the breathing rate is decreased.

  2. Metabolic Compensation

     In respiratory acidosis, the urine has a low pH.

     In respiratory alkalosis, the urine has a lot of bicarbonate, and is very alkaline.