Learning Objectives

• Explain regulation of electrolytes in the body; major ions in the intracellular and extracellular fluid and units of concentration
• Describe common disturbances of water balance and pathogenesis
• Explain physiologic mechanisms in the control of pH
• Describe pathogenesis of 4 common disturbances of acid-base balance and body’s compensatory mechanisms
• Define role of kidneys and lungs in regulating acid–base balance

Body Water and Electrolytes

• Body water contains dissolved mineral salts or electrolytes that dissociate in solution, yielding
  – Cations: positively charged ions
  – Anions: negatively charged ions
• Body fluids: electrically neutral
• Sum of cations balanced by sum of anions
• In disease, ion concentrations may vary but the electrical neutrality is always maintained

Intracellular and Extracellular Fluid (1 of 5)

• Disturbances of body water are associated with corresponding change in electrolytes
• If electrolyte concentration changes, there is a corresponding change in body water and vice versa
• Body consists of 70% water
  – Intracellular water (inside cells)
  – Extracellular water (within interstitial tissues surrounding cells, blood plasma, and lymph)
  • "Rule of thirds"
    – 2/3 of body weight is H₂O
    – 2/3 of H₂O is within cells
    – 1/3 of H₂O is extracellular in tissues surrounding cells (interstitial fluid)

Intracellular and Extracellular Fluid (2 of 5)

• Adult female: water content is 10% lower than adult male due to higher body fat than water
• Fluids and electrolytes diffuse freely between the intravascular and interstitial fluids
• Because capillaries are impermeable to protein, the interstitial fluid contains very little protein
• Cell membrane: separates intracellular fluid from interstitial fluid by a cell membrane
  – Freely permeable to water
  – Impermeable to Na⁺ and K⁺ ions

Intracellular and Extracellular Fluid (3 of 5)

• Chief intracellular ions
  – K⁺ (potassium)
  – PO₄³⁻ (phosphate)
• Chief extracellular ions
  – Na⁺ (sodium)
  – Cl⁻ (chloride)
• Differences in concentration of ions on different sides of the cell membrane result from metabolic activity of the cell
• Amount of sodium in the body determines the volume of extracellular fluid as the chief extracellular cation
Intracellular and Extracellular Fluid (4 of 5)

- Amount of potassium in the body determines the volume of intracellular fluid as the chief intracellular cation.
- In electrolyte disturbances: primary concern is the concentration of various ions and the interrelation of positively and negatively charged ions with one another than the actual number.

Intracellular and Extracellular Fluid (5 of 5)

- Units of concentration of electrolytes.
- Expressed in units that define ability to combine with other ions.
- Equivalent weight: molecular weight of substance in grams divided by valence.
  - 1 equivalent weight dissolved in a liter equals one equivalent per liter (1Eq/L).
  - Units expressed in milliequivalents per liter (1000 mEq = 1Eq).

Regulation of Body Fluid and Electrolyte Concentration (1 of 3)

- Amount of H$_2$O and electrolytes in body: represents the balance between amounts ingested in food and fluids and amounts excreted via urine, GI tract, perspiration, and as H$_2$O vapor excreted by lungs.
- Disturbances of H$_2$O balance:
  - Dehydration: most common
    - Inadequate intake: diarrhea or vomiting
    - Excess H$_2$O loss: comatose or debilitated patients
  - Overhydration: less common
    - Excessive fluid intake when renal function is impaired: renal disease; excessive intake of fluids; excessive administration of IV fluids.

Regulation of Body Fluid and Electrolyte Concentration (2 of 3)

- Disturbances of electrolyte balance:
  - Conditions that produce H$_2$O imbalance also disturb electrolyte composition.
  - Most result from depletion of body electrolytes.
- Depletion of electrolytes:
  - Vomiting or diarrhea: sodium and potassium depletion
  - Excessive use of diuretics
  - Excessive diuresis in diabetic acidosis
  - Renal tubular disease

Regulation of Body Fluid and Electrolyte Concentration (3 of 3)

- Diuretics promote excretion of salt and H$_2$O by the kidneys while impairing reabsorption of these substances:
  - Patients with heart failure, liver cirrhosis, kidney disease.
- Uncontrolled diabetes: excessive loss of H$_2$O in urine from the diuretic effect of glucose.
- Renal tubular disease: regenerating renal tubules unable to conserve electrolytes and water.

Acid–Base Balance

- Body produces large amounts of acid from normal metabolic processes, such as breakdown of proteins and glucose or oxidation of fat.
- Body fluids remain slightly alkaline.
- pH is maintained within a narrow range: 7.38 to 7.42.
- Regulatory mechanisms maintain pH:
  - Neutralize and eliminate the acids as soon as they are produced to maintain normal pH
    - Blood buffers: resist pH change
    - Lungs: control carbonic acid (H$_2$CO$_3$) concentration
    - Kidneys: control bicarbonate concentration.
"Board-and-fulcrum" concept of normal bicarbonate-carbonic acid relationships

Blood Buffer System (1 of 2)
- Minimize change in hydrogen ion by converting strong acids and bases into weaker ones chemically
  - Weak acid and its salt
  - Weak base and its salt
- Respiratory control of carbonic acid
  - Carbonic acid (H₂CO₃): dissolved as CO₂ in plasma
  - Hyperventilation: lowers CO₂ and H₂CO₃ in plasma
  - Decreased or inadequate ventilation: raises CO₂ and H₂CO₃ in plasma

Blood Buffer System (2 of 2)
- Renal control of bicarbonate concentration
  - Kidneys selectively reabsorb filtered bicarbonate
  - Kidneys can manufacture bicarbonate to replace amounts lost in buffering acids from metabolic processes
- In any buffer system
  - pH depends on ratio of bicarbonate to H₂CO₃
  - Normal ratio: 20 parts Na bicarbonate: 1 part H₂CO₃

Disturbances in Acid–Base Balance
- Acidosis
  - Blood pH shifts to acidic side
  - From an excess of H₂CO₃
  - From a reduced amount of bicarbonate
- Alkalosis
  - Blood pH shifts to basic side
  - From a decrease in H₂CO₃
  - From an excess of bicarbonate

Classification of Acid–Base Disturbances (1 of 3)
- Metabolic: disturbance lies in bicarbonate member of the buffer pair
- Respiratory: disturbance lies in carbonic acid member of the buffer pair
- Metabolic acidosis: increased endogenous acid generated
  - Amount of acid generated exceeds body’s buffering capacity
  - Excess acid is neutralized by bicarbonate
  - Bicarbonate in plasma falls from being consumed in neutralizing excess acid
  - Uremia, ketosis, lactic acidosis
- Compensation: by hyperventilation to lower PCO₂ and increased bicarbonate production in kidneys

A. Derangement of acid-base balance in metabolic acidosis. B. Compensation by reduction of carbonic acid and formation of additional bicarbonate.
Classification of Acid–Base Disturbances (2 of 3)

- Respiratory acidosis: increased H₂CO₃ concentration
  - Inefficient excretion of CO₂ by lungs
  - Leads to retention of CO₂ and rise in H₂CO₃
  - Compensation: increased bicarbonate production in kidneys
- Metabolic alkalosis: increased plasma bicarbonate

Classification of Acid–Base Disturbances (3 of 3)

- Respiratory alkalosis: Reduced H₂CO₃ concentration
  - Hyperventilation lowers PCO₂ and H₂CO₃ level falls
  - Relative excess of bicarbonate
  - Compensation: excretion of bicarbonate by kidneys

Diagnostic Evaluation of Acid–Base Balance

- Clinical evaluation: determination of concentration of bicarbonate in plasma as an index of patient's overall status
- Laboratory studies
  - Blood pH
  - PCO₂
  - Bicarbonate

Discussion

- What is the difference between intracellular and extracellular fluid?
- What are the differences between metabolic acidosis and respiratory acidosis as to causes and compensatory mechanisms of the body?
- What are the differences between metabolic alkalosis and respiratory alkalosis as to causes and compensatory mechanisms of the body?