Terminal Learning Objective

- **Action:** Communicate knowledge of “Fluid, Electrolyte, and Acid-Base Imbalances”
- **Condition:** Given a lecture in a classroom environment
- **Standard:** Received a minimum score of 75% on the written exam IAW course standards

References

- *Pathophysiology for the Health Professions* (4th edition; 2011; Gould; Dyer)
Reason

As a medic, you will be responsible for identifying and managing life-threatening fluid and electrolyte imbalances in order to stabilize your patients. Maintaining a proper acid-base balance in your patients will prove invaluable in your attempt to maintain homeostasis.

Agenda

- Define the key terms related to fluid, electrolyte, and acid-base imbalances
- Communicate the fluid balance in homeostasis and the causes and effects of fluid excess (edema)
- Communicate the causes and effects of fluid deficit (dehydration) and the fluid shift that occurs in third spacing

Agenda

- Identify the body's various electrolytes and the imbalances that can occur
- Communicate the various buffer systems and how they maintain an acid-base balance
- Communicate the different types of acid-base imbalances and their effects
- Identify the treatments of fluid, electrolyte, and acid-base imbalances
Key Terms Related to Fluid, Electrolyte, and Acid-Base Imbalances

Vocabulary Development

- **Aldosterone** – a mineralcorticoid hormone that increases the reabsorption of sodium and water in the renal tubules
- **Anion** – a negatively charged ion such as chloride, Cl–
- **Antidiuretic hormone (ADH)** – increases absorption of water in the renal tubules
- **Ascites** – abnormal accumulation of fluid in the abdominal cavity

Vocabulary Development

- **Atrial natriuretic peptide** – a peptide secreted by the atrial tissue of the heart in response to an increase in blood pressure, increases the excretion of sodium and water in urine
- **Capillary permeability** – a condition of the capillary wall structure that allows blood elements and waste products to pass through the capillary wall to tissue spaces
- **Carpopedal spasm** – a strong muscle contraction of the hand or foot
- **Cation** – a positively charged ion such as sodium, Na+
Vocabulary Development

- **Diffusion** – the movement of molecules from an area of high concentration to low concentration
- **Diuretic** – an agent that increases urine output
- **Dysrhythmia** – abnormal, disordered, or disturbed rhythm
- **Electrocardiogram** – a record of conduction in the heart
- **Extracellular** – outside the cell
- **Filtration** – the process of removing particles from a solution by allowing the liquid portion to pass through a membrane or other partial barrier

Vocabulary Development

- **Hydrogen ions** – a positive ion containing one valence electron
- **Hydrostatic pressure** – pertaining to the pressure of liquids in equilibrium and to the pressure exerted on liquids
- **Hypertonic/hyper-osmolar** – a solution with a greater concentration of solutes or higher osmotic pressure than that inside the cells present in the solution
- **Hypovolemia** – decreased blood volume

Vocabulary Development

- **Interstitial fluid** – fluid lying between spaces within an organ or tissue
- **Intracellular** – within the cell
- **Intravascular fluid** – within the blood vessel
- **Isotonic/iso-osmolar** – a solution with the same osmotic pressure as a reference solution
- **Laryngospasm** – closure of the larynx obstructing the airway
- **Milliequivalent (mEq)** – the concentration of electrolytes in a certain volume of solution
Vocabulary Development

- **Nonvolatile metabolic acids** – an acid produced from sources other than carbon dioxide
- **Osmoreceptors** – sensory nerve receptors stimulated by changes in fluid and electrolyte concentrations
- **Osmosis** – the force that draws water through a semipermeable membrane from a solution of lower solute concentration to a solution of higher concentration

Vocabulary Development

- **Osmotic pressure** – the force with which a solvent, usually water, passes through a semipermeable membrane separating solutions of different concentrations
- **Paresthesias** – abnormal sensations
- **Skin turgor** – an abnormality in the skin’s ability to change shape and return to normal (elasticity)
- **Tetany** – repeated muscle contractions or spasms, seen in the extremities and face, related to increased irritability of the nerves often associated with hypocalcemia

Fluid Balance in Homeostasis and the Causes and Effects of Fluid Excess (Edema)
Homeostasis

- Fluid Compartments
  - Water comprises about 60% of body weight (about 70% in infants)
  - Intracellular fluid (ICF)
  - Extracellular fluid (ECF)
    - Intravascular fluid (IVF)
    - Interstitial fluid (ISF)
    - Cerebrospinal fluid (CSF)
    - Transcellular fluid

---

<table>
<thead>
<tr>
<th>VOLUME</th>
<th>APPROXIMATE PERCENTAGE OF BODY WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intracellular fluid</td>
<td>Adult Male (L)</td>
</tr>
<tr>
<td>28</td>
<td>40</td>
</tr>
<tr>
<td>Extracellular fluid</td>
<td>(15)</td>
</tr>
<tr>
<td>Plasma</td>
<td>(4.5)</td>
</tr>
<tr>
<td>Interstitial fluid</td>
<td>(10.5)</td>
</tr>
<tr>
<td>Other</td>
<td>(&lt;0.5)</td>
</tr>
<tr>
<td>Total water</td>
<td>43</td>
</tr>
</tbody>
</table>

---

Homeostasis

- Movement of Water
  - Maintaining fluid levels
    - Fluid sources
      - Solid food
      - Liquids
      - Cell metabolism
    - Fluid losses
      - Urine and feces
      - Insensible loss (e.g., perspiration, exhaled air, etc.)
### Homeostasis

#### Sources (mL) vs. Losses (mL)

<table>
<thead>
<tr>
<th>Sources</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquids</td>
<td>Urine</td>
</tr>
<tr>
<td>1200 mL</td>
<td>1400 mL</td>
</tr>
<tr>
<td>Solid foods</td>
<td>Feces</td>
</tr>
<tr>
<td>1000 mL</td>
<td>200 mL</td>
</tr>
<tr>
<td>Cell metabolism</td>
<td>Insensible losses</td>
</tr>
<tr>
<td>300 mL</td>
<td>Lungs</td>
</tr>
<tr>
<td></td>
<td>400 mL</td>
</tr>
<tr>
<td></td>
<td>Skin</td>
</tr>
<tr>
<td></td>
<td>500 mL</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
</tr>
<tr>
<td>2500 mL</td>
<td>2500 mL</td>
</tr>
</tbody>
</table>

#### Control of fluid balance

- **thirst mechanism**
  - located in the hypothalamus
  - osmoreceptors sense fluid volume/concentration

- **antidiuretic hormone (ADH)**
  - promotes reabsorption of water in kidneys

- **aldosterone**
  - promotes reabsorption of sodium ions and water in kidneys

- **atrial natriuretic peptide (ANP)**
  - inhibits water and electrolyte re-uptake

#### Movements in the microcirculation

- **filtration**
  - \( NFP = HP - \pi \)
  - greater on arteriole end due to high hydrostatic pressure and low osmotic pressure

- **diffusion**
  - movement of solutes from high to low concentrations

- **osmosis**
  - greater on the venule end due to low hydrostatic pressure and high osmotic pressure
**Homeostasis**

From arteriole to venule:
1. Filtration
2. Diffusion
3. Osmosis

**Edema**

- Definition
  - An excessive amount of fluid in the interstitial compartment, which causes a swelling or enlargement of the tissues

- Causes of Edema
  - High, capillary, hydrostatic pressure
  - Low, capillary, osmotic pressure
  - Lymphatic obstruction
  - Increased capillary permeability
Effects of Edema

- Visible swelling
- Pitting vs. non-pitting
- Increased body weight
- Impaired function
- Pain
- Impaired circulation
- Susceptible to tissue breakdown

Causes and Effects of Fluid Deficit (Dehydration) and the Fluid Shift that Occurs in Third Spacing
Dehydration

- Definition
  - Insufficient body fluid resulting either from inadequate intake or excessive loss of fluid or a combination of the two
- Considerations
  - More serious in elderly and infants
  - Often accompanied by loss of electrolytes
  - Hypovolemia?

Dehydration

- Causes of Dehydration
  - Vomiting and/or diarrhea
  - Excessive sweating
  - Polyuria
  - Insufficient intake
  - High solute concentration

Dehydration

- Direct Effects of Dehydration
  - Decreased skin turgor and dry mucosa
  - Hypotension
  - Increased hematocrit
  - Decreased mental status
- Compensatory Effects of Dehydration
  - Polydipsia and oliguria
  - Tachycardia
  - Peripheral vasoconstriction
Fluid Shift (Third Spacing)

- Fluid Deficit and Fluid Excess
  - Fluid shifts from intravascular space to interstitial space
  - Fluid is now physiologically non-functional
  - Examples include:
    - peritonitis
    - edema in burns
    - ascites
    - pleural effusions

The Body’s Various Electrolytes and the Imbalances that Can Occur

Sodium (Na⁺)

- Review of Sodium
  - Primary extracellular cation
  - Maintains extracellular osmotic gradient
  - Transport
    - sodium-potassium pump (active)
    - diffusion (passive)
  - Lost in secretions, perspiration, urine, & feces
  - Levels controlled by aldosterone in the kidneys
  - Essential to conduction (e.g., nerve, muscle, etc.)
Sodium (Na⁺)

- Hyponatremia (<135 mEq/L)
  - Causes of hyponatremia
    - excessive sweating, vomiting, diarrhea
    - diuretics + low-salt diets
    - low aldosterone and/or excess ADH
    - early chronic renal failure
    - excessive water intake

Sodium (Na⁺)

- Effects of hyponatremia
  - impaired nerve conduction
  - muscle cramps and fatigue
  - hypovolemia/hypotension (due to fluid shift)
  - confusion/HA/seizures
  - N/V

Sodium (Na⁺)

- Hypernatremia (>145 mEq/L)
  - Causes of hypernatremia
    - diabetes insipidus (i.e., insufficient ADH)
    - loss of thirst mechanism
    - watery diarrhea (e.g., gastroenteritis, cholera, etc.)
    - severe burns
    - Cushing's syndrome
Sodium (Na⁺)

- Effects of hypernatremia
  - thirst
  - weakness
  - agitation
  - hypervolemia/hypertension

Potassium (K⁺)

- Review of Potassium
  - Primary intracellular cation
  - Maintains intracellular osmotic gradient
  - Transport
    - sodium potassium pump
    - diffusion (acid-base balance)
      - acidosis (excess H⁺) shifts K⁺ out of cell
      - alkalosis (H⁺ deficit) shifts K⁺ into cell
  - Essential to conduction (e.g., nerve, muscle, etc.)
  - Levels have a significant effect on cardiac muscle!
Potassium (K⁺)

- Hypokalemia (<3.5 mEq/L)
  - Causes of hypokalemia
    - excessive diarrhea
    - excessive diuretic use (e.g., furosemide)
    - excessive release of aldosterone
    - excessive glucocorticoids present (e.g., Cushing's)
    - decreased intake (e.g., alcoholism, starvation, etc.)
    - treatment of DKA with insulin

- Effects of hypokalemia
  - cardiac arrhythmias
  - muscle cramps/fatigue (to include diaphragm)
  - paresthesias ("pins and needles")
  - anorexia and nausea
  - polyuria

- Hyperkalemia (>5 mEq/L)
  - Causes of hyperkalemia
    - renal failure
    - aldosterone deficit
    - traumatic crush injuries
    - severe burns
    - prolonged/severe acidosis
Potassium (K⁺)

- Effects of hyperkalemia
  - cardiac arrhythmias
  - muscle weakness and fatigue
  - nausea
  - paresthesias and/or paralysis
  - oliguria

---

Calcium (Ca²⁺)

- Review of Calcium
  - Closely monitored extracellular cation
  - Controlled by release of PTH and calcitonin
  - Influenced by vitamin D₃ (calcitriol)
  - Phosphate levels are inversely proportional
  - Control permeability at all nerve synapses
  - Required for all muscle contraction
  - Required for blood clotting
Calcium (Ca^{2+})

- Hypocalcemia
  - Causes of hypocalcemia
    - hypoparathyroidism
    - malabsorption
    - deficient serum albumin
    - increased serum pH

- Effects of hypocalcemia
  - Skeletal muscle
    - muscle twitches
    - carpopedal spasm
    - tetany
  - Cardiac muscle
    - weak contractions
    - arrhythmias
    - hypotension

Calcium (Ca^{2+})

- Hypercalcemia
  - Causes of hypercalcemia
    - uncontrolled release of calcium ions from the bones due to neoplasms
    - hyperparathyroidism
    - immobility (i.e., decrease bone stress leads to demineralization)
    - excessive calcium or vitamin D intake
    - excessive milk and antacid intake
Calcium (Ca$^{2+}$)
- Effects of hypercalcemia
  - loss of skeletal muscle strength
  - increased cardiac muscle strength (arrhythmias)
  - polyuria and hypovolemia
  - if caused by excessive PTH release, bone density decreases (i.e., spontaneous fractures could occur)

Other Electrolytes
- Magnesium (Mg$^{2+}$)
  - Intracellular ion
  - Hypomagnesemia usually associated with chronic alcoholism
- Phosphate (HPO$_4^{2-}$ and H$_2$PO$_4^-$)
  - Involved in cellular energy (e.g., ATP)
  - Opposes calcium
- Chloride (Cl$^-$)
  - Major extracellular anion
  - Hypochloremia (vomiting) results in alkalosis

Various Buffer Systems and How they Maintain an Acid-Base Balance
Buffer Systems

- Normal pH
  - Arterial blood – 7.40*
  - Venous blood – 7.35*
  - Interstitial fluid – 7.35
  - Intracellular fluid – 6.0-7.4
  - Urine – 4.5-8.0
  - Gastric HCl – 0.8*

Buffer Systems

- Mechanisms Controlling pH
  - Buffer pairs
    - immediate pH compensation
    - (sodium) bicarbonate - carbonic acid system
      - must maintain 20:1 ratio (HCO₃⁻ : H₂CO₃)
      - most powerful extracellular buffer
    - phosphate system
      - important buffer in the renal system
    - protein system
      - most plentiful buffer in the body
      - hemoglobin as a buffer (H⁺ + Hb)
Buffer Systems

➢ Respiratory system
  • relatively fast pH compensation
  • effect is directly related to pH
    ➢ increased resp. rate will increase pH
    ➢ decreased resp. rate will decrease pH
  • compensation is inversely related to pH
    ➢ as pH decreases, resp. rate will increase
    ➢ as pH increases, resp. rate will decrease
  • between 50-75% effective
    ➢ e.g., if pH falls from 7.4 to 7.0, the resp. system can return pH to about 7.2 to 7.3

Buffer Systems

➢ Renal system
  • relatively slow pH compensation
  • most effective in controlling pH
  • H+ and HCO3⁻ are excreted into the urine
    ➢ HCO3⁻ can be reabsorbed/produced
    ➢ If more H+ is secreted, the body’s pH rises
    ➢ If more HCO3⁻ is secreted, the body’s pH falls
Different Types of Acid-Base Imbalances and their Effects

Acid-Base Nomogram

Acid-Base Imbalances

- Acidosis
  - Respiratory causes
    - acute resp. distress
    - acute obstruction
    - chest injuries
    - opiate overdose
    - chronic resp. distress (COPD)
  - Respiratory effects
    - compensation by kidneys
    - secretion of more acids and less bicarbonate
    - urine with low pH
Acid-Base Imbalances

- Metabolic causes
  - decrease in available bicarbonate ions
    - excessive loss due to diarrhea
    - increased utilization due to large amounts of acids (e.g., lactic acids, ketoacids, etc.)
  - renal disease or failure
    - Decrease in acid secretion
    - Decrease in bicarbonate production
- Metabolic effects
  - Compensation by respiratory system
    - Kussmaul’s respirations
    - adequate only for short durations

- Alkalosis
  - Causes of alkalosis
    - respiratory – hyperventilation
    - metabolic – early vomiting, hypokalemia, excessive antacid ingestion
    - not as common as acidosis
  - Effects of alkalosis
    - decreased respiratory drive
    - alkalosis = irritable nervous system
    - acidosis = depressed nervous system

Acid-Base Nomogram
Enteral Treatments

- **Oral Rehydration Underuse**
  - If viable, *more effective* than standard IV therapy
  - Dehydration prevention is key
  - Thirst drive may not be adequate

- **Oral Rehydration Misuse**
  - Water is preferred in mild to moderate cases
  - Should be consumed before, during and after activity
  - Should be *cold*
Enteral Treatments

- Oral Rehydration Solutions
  - May be necessary to replace lost electrolytes
  - Beware of over-concentrated drinks!
    - Osmolarity should be <350 mol/L
    - E.g., regular Gatorade should be at least cut in half with water
  - Avoid carbonated beverages
  - If proper solutions are not available, make your own

Parenteral Treatments

- Isotonic Crystalloid IV Therapy
  - Recommended in patients that will not tolerate PO administration
  - E.g., 0.9% NS, LR, D5W
  - Each type has different pros/cons
  - Administer 1L bolus and attempt PO, repeat if necessary
Parenteral Treatments

- Considerations
  - Hyponatremia
    - most common electrolyte disorder in US
    - causes include burns, CHF, diarrhea, sweating, etc.
    - if possible treat PO
  - Hypo/hyperkalemia can easily lead to fatal dysrhythmias
  - IV isotonic crystalloid TKO recommended in any unstable patient
  - Always read the label on the bag carefully!

Questions?

Terminal Learning Objective

- Action: Communicate knowledge of “Fluid, Electrolyte, and Acid-Base Imbalances”
- Condition: Given a lecture in a classroom environment
- Standard: Received a minimum score of 75% on the written exam IAW course standards
Agenda

- Define the key terms related to fluid, electrolyte, and acid-base imbalances
- Communicate the fluid balance in homeostasis and the causes and effects of fluid excess (edema)
- Communicate the causes and effects of fluid deficit (dehydration) and the fluid shift that occurs in third spacing

Agenda

- Identify the body's various electrolytes and the imbalances that can occur
- Communicate the various buffer systems and how they maintain an acid-base balance
- Communicate the different types of acid-base imbalances and their effects
- Identify the treatments of fluid, electrolyte, and acid-base imbalances

Reason

As a medic, you will be responsible for identifying and managing life-threatening fluid and electrolyte imbalances in order to stabilize your patients. Maintaining a proper acid-base balance in your patients will prove invaluable in your attempt to maintain homeostasis.
Break