

Chapter 27

Fluid, Electrolyte, and Acid-Base Balance

An Introduction to Fluid, Electrolyte, and Acid–Base Balance

- Water
 - Is 99% of fluid outside cells (extracellular fluid)
 - Is an essential ingredient of cytosol (intracellular fluid)
 - All cellular operations rely on water
 - As a diffusion medium for gases, nutrients, and waste products

27-1 Fluid, Electrolyte, and Acid–Base Balance

- The Body
 - Must maintain normal volume and composition of:
 - **Extracellular fluid (ECF)**
 - **Intracellular fluid (ICF)**

27-1 Fluid, Electrolyte, and Acid–Base Balance

- **Fluid Balance**
 - Is a daily balance between:
 - Amount of water gained
 - Amount of water lost to environment
 - Involves regulating content and distribution of body water in ECF and ICF
 - The Digestive System
 - Is the primary source of water gains
 - Plus a small amount from metabolic activity
 - The Urinary System
 - Is the primary route of water loss

27-1 Fluid, Electrolyte, and Acid–Base Balance

- **Electrolyte Balance**

- **Electrolytes** are ions released through dissociation of inorganic compounds
 - Can conduct electrical current in solution
- Electrolyte balance
 - When the gains and losses of all electrolytes are equal
 - Primarily involves balancing rates of absorption across digestive tract with rates of loss at kidneys and sweat glands

27-1 Fluid, Electrolyte, and Acid–Base Balance

- **Acid–Base Balance**

- Precisely balances production and loss of hydrogen ions (pH)
- The body generates acids during normal metabolism
 - Tends to reduce pH

27-1 Fluid, Electrolyte, and Acid–Base Balance

- The Kidneys

- Secrete hydrogen ions into urine
- Generate buffers that enter bloodstream
 - In distal segments of distal convoluted tubule (DCT) and collecting system

- The Lungs

- Affect pH balance through elimination of carbon dioxide

27-2 Fluid Compartments

- Fluid in the Body
 - Water accounts for roughly:
 - 60% of male body weight
 - 50% of female body weight
 - Mostly in intracellular fluid

27-2 Fluid Compartments

- Water Exchange
 - Water exchange between ICF and ECF occurs across plasma membranes by:
 - Osmosis
 - Diffusion
 - Carrier-mediated transport

27-2 Fluid Compartments

- Major Subdivisions of ECF
 - Interstitial fluid of peripheral tissues
 - Plasma of circulating blood
- Minor Subdivisions of ECF
 - Lymph, perilymph, and endolymph
 - Cerebrospinal fluid (CSF)
 - Synovial fluid
 - Serous fluids (pleural, pericardial, and peritoneal)
 - Aqueous humor

27-2 Fluid Compartments

- Exchange among Subdivisions of ECF
 - Occurs primarily across endothelial lining of capillaries
 - From interstitial spaces to plasma
 - Through lymphatic vessels that drain into the venous system

27-2 Fluid Compartments

- The ECF and the ICF
 - ECF Solute Content
 - Types and amounts vary regionally
 - Electrolytes
 - Proteins
 - Nutrients
 - Waste products

27-2 Fluid Compartments

- The ECF and the ICF
 - Are called **fluid compartments** because they behave as distinct entities
 - Are separated by plasma membranes and active transport
- Cations and Anions
 - In ECF
 - Sodium, chloride, and bicarbonate
 - In ICF
 - Potassium, magnesium, and phosphate ions
 - Negatively charged proteins

27-2 Fluid Compartments

- Membrane Functions
 - Plasma membranes are selectively permeable
 - Ions enter or leave via specific membrane channels
 - Carrier mechanisms move specific ions in or out of cell

27-2 Fluid Compartments

- The Osmotic Concentration of ICF and ECF
 - Is identical
 - Osmosis eliminates minor differences in concentration
 - Because plasma membranes are permeable to water

27-2 Fluid Compartments

- Basic Concepts in the Regulation of Fluids and Electrolytes
 1. *All homeostatic mechanisms that monitor and adjust body fluid composition respond to changes in the ECF, not in the ICF*
 2. *No receptors directly monitor fluid or electrolyte balance*
 3. *Cells cannot move water molecules by active transport*
 4. *The body's water or electrolyte content will rise if dietary gains exceed environmental losses, and will fall if losses exceed gains*

27-2 Fluid Compartments

- An Overview of the Primary Regulatory Hormones
 - Affecting fluid and electrolyte balance
 1. *Antidiuretic hormone*
 2. *Aldosterone*

3. *Natriuretic peptides*

27-2 Fluid Compartments

- Antidiuretic Hormone (ADH)
 - Stimulates water conservation at kidneys
 - Reducing urinary water loss
 - Concentrating urine
 - Stimulates thirst center
 - Promoting fluid intake

27-2 Fluid Compartments

- ADH Production
 - **Osmoreceptors** in hypothalamus
 - Monitor osmotic concentration of ECF
 - Change in osmotic concentration
 - Alters osmoreceptor activity
 - Osmoreceptor neurons secrete ADH

27-2 Fluid Compartments

- ADH Release
 - Axons of neurons in anterior hypothalamus
 - Release ADH near fenestrated capillaries
 - In neurohypophysis (posterior lobe of pituitary gland)
 - Rate of release varies with osmotic concentration
 - Higher osmotic concentration increases ADH release

27-2 Fluid Compartments

- Aldosterone
 - Is secreted by adrenal cortex in response to:
 - Rising K^+ or falling Na^+ levels in blood
 - Activation of renin–angiotensin system
 - Determines rate of Na^+ absorption and K^+ loss along DCT and collecting system

27-2 Fluid Compartments

- “Water Follows Salt”
 - High aldosterone plasma concentration
 - Causes kidneys to conserve salt
 - Conservation of Na^+ by aldosterone
 - Also stimulates water retention

27-2 Fluid Compartments

- Natriuretic Peptides
 - ANP and BNP are released by cardiac muscle cells
 - In response to abnormal stretching of heart walls
 - Reduce thirst
 - Block release of ADH and aldosterone
 - Cause diuresis
 - Lower blood pressure and plasma volume

27-3 Fluid Movement

- Movement of Water and Electrolytes
 - When the body loses water:

- Plasma volume decreases
- Electrolyte concentrations rise
- When the body loses electrolytes:
 - Water is lost by osmosis
- Regulatory mechanisms are different

27-3 Fluid Movement

- Fluid Balance
 - Water circulates freely in ECF compartment
 - At capillary beds, hydrostatic pressure forces water out of plasma and into interstitial spaces
 - Water is reabsorbed along distal portion of capillary bed when it enters lymphatic vessels
 - ECF and ICF are normally in osmotic equilibrium
 - No large-scale circulation between compartments

27-3 Fluid Movement

- Fluid Movement within the ECF
 - Net hydrostatic pressure
 - Pushes water out of plasma
 - Into interstitial fluid
 - Net colloid osmotic pressure
 - Draws water out of interstitial fluid
 - Into plasma

27-3 Fluid Movement

- Fluid Movement within the ECF
 - ECF fluid volume is redistributed

- From lymphatic system to venous system (plasma)
- Interaction between opposing forces
 - Results in continuous filtration of fluid
- ECF volume
 - Is 80% in interstitial fluid and minor fluid compartment
 - Is 20% in plasma

27-3 Fluid Movement

- *Edema*
 - The movement of abnormal amounts of water from plasma into interstitial fluid
- *Lymphedema*
 - Edema caused by blockage of lymphatic drainage

27-3 Fluid Movement

- Fluid Gains and Losses
 - *Water losses*
 - Body loses about 2500 mL of water each day through urine, feces, and insensible perspiration
 - Fever can also increase water loss
 - Sensible perspiration (sweat) varies with activities and can cause significant water loss (4 L/hr)

27-3 Fluid Movement

- Fluid Gains and Losses
 - *Water gains*
 - About 2500 mL/day
 - Required to balance water loss
 - Through:

- Eating (1000 mL)
- Drinking (1200 mL)
- **Metabolic generation** (300 mL)

27-3 Fluid Movement

- Metabolic Generation of Water
 - Is produced within cells
 - Results from oxidative phosphorylation in mitochondria

27-3 Fluid Movement

• Fluid Shifts

- Are rapid water movements between ECF and ICF
 - In response to an osmotic gradient
- *If ECF osmotic concentration increases:*
 - Fluid becomes hypertonic to ICF
 - Water moves from cells to ECF
- *If ECF osmotic concentration decreases:*
 - Fluid becomes hypotonic to ICF
 - Water moves from ECF to cells

27-3 Fluid Movement

• Fluid Shifts

- ICF volume is much greater than ECF volume
 - ICF acts as water reserve
 - Prevents large osmotic changes in ECF

27-3 Fluid Movement

- Allocation of Water Losses
- **Dehydration** (*Water Depletion*)
 - Develops when water loss is greater than gain
 - If water is lost, but electrolytes retained:
 - ECF osmotic concentration rises
 - Water moves from ICF to ECF
 - Net change in ECF is small

27-3 Fluid Movement

- Severe Water Loss
 - Causes:
 - Excessive perspiration
 - Inadequate water consumption
 - Repeated vomiting
 - Diarrhea
 - Homeostatic responses
 - Physiologic mechanisms (ADH and renin secretion)
 - Behavioral changes (increasing fluid intake)

27-3 Fluid Movement

- Distribution of Water Gains
 - If water is gained, but electrolytes are not:
 - ECF volume increases
 - ECF becomes hypotonic to ICF
 - Fluid shifts from ECF to ICF
 - May result in **overhydration** (*water excess*)
 - Occurs when excess water shifts into ICF
 - Distorting cells
 - Changing solute concentrations around enzymes
 - Disrupting normal cell functions

27-3 Fluid Movement

- Causes of Overhydration
 - Ingestion of large volume of fresh water
 - Injection of hypotonic solution into bloodstream
 - Endocrine disorders
 - Excessive ADH production
 - Inability to eliminate excess water in urine
 - Chronic renal failure
 - Heart failure
 - Cirrhosis

27-3 Fluid Movement

- Signs of Overhydration
 - Abnormally low Na^+ concentrations (*hyponatremia*)
 - Effects on CNS function (*water intoxication*)

27-4 Electrolyte Balance

- Electrolyte Balance
 - Requires rates of gain and loss of each electrolyte in the body to be equal
 - *Electrolyte concentration directly affects water balance*
 - *Concentrations of individual electrolytes affect cell functions*

27-4 Electrolyte Balance

- Sodium

- Is the dominant cation in ECF
- Sodium salts provide 90% of ECF osmotic concentration
 - Sodium chloride (NaCl)
 - Sodium bicarbonate (NaHCO₃)

27-4 Electrolyte Balance

- Normal Sodium Concentrations
 - In ECF
 - About 140 mEq/L
 - In ICF
 - Is 10 mEq/L or less

27-4 Electrolyte Balance

- Potassium
 - Is the dominant cation in ICF
 - Normal potassium concentrations
 - In ICF
 - About 160 mEq/L
 - In ECF
 - 3.5–5.5 mEq/L

27-4 Electrolyte Balance

- Rules of Electrolyte Balance
 1. *Most common problems with electrolyte balance are caused by imbalance between gains and losses of sodium ions*
 2. *Problems with potassium balance are less common, but more dangerous than sodium imbalance*

27-4 Electrolyte Balance

- Sodium Balance

- Total amount of sodium in ECF represents a balance between two factors
 1. Sodium ion uptake across digestive epithelium
 2. Sodium ion excretion in urine and perspiration

27-4 Electrolyte Balance

- Sodium Balance

- Typical Na^+ gain and loss
 - Is 48–144 mEq (1.1–3.3 g) per day
- If gains exceed losses:
 - Total ECF content rises
- If losses exceed gains:
 - ECF content declines

27-4 Electrolyte Balance

- Sodium Balance and ECF Volume

- Changes in ECF Na^+ content
 - Do not produce change in concentration
 - Corresponding water gain or loss keeps concentration constant
- Na^+ regulatory mechanism changes ECF volume
 - Keeps concentration stable
- When Na^+ losses exceed gains:
 - ECF volume decreases (increased water loss)
 - Maintaining osmotic concentration

27-4 Electrolyte Balance

- Large Changes in ECF Volume
 - Are corrected by homeostatic mechanisms that regulate blood volume and pressure
 - If ECF volume rises, blood volume goes up
 - If ECF volume drops, blood volume goes down

27-4 Electrolyte Balance

- Homeostatic Mechanisms
 - A rise in blood volume elevates blood pressure
 - A drop in blood volume lowers blood pressure
 - Monitor ECF volume indirectly by monitoring blood pressure
 - Baroreceptors at carotid sinus, aortic sinus, and right atrium

27-4 Electrolyte Balance

- *Hyponatremia*
 - Body water content rises (overhydration)
 - ECF Na⁺ concentration <136 mEq/L
- *Hypernatremia*
 - Body water content declines (dehydration)
 - ECF Na⁺ concentration >145 mEq/L

27-4 Electrolyte Balance

- ECF Volume
 - If ECF volume is inadequate:
 - Blood volume and blood pressure decline
 - Renin–angiotensin system is activated

- Water and Na^+ losses are reduced
- ECF volume increases

27-4 Electrolyte Balance

• Plasma Volume

- If plasma volume is too large:
 - Venous return increases
 - Stimulating release of natriuretic peptides (ANP and BNP)
 - Reducing thirst
 - Blocking secretion of ADH and aldosterone
 - Salt and water loss at kidneys increases
 - ECF volume declines

27-4 Electrolyte Balance

• Potassium Balance

- 98% of potassium in the human body is in ICF
- Cells expend energy to recover potassium ions diffused from cytoplasm into ECF

• Processes of Potassium Balance

1. Rate of gain across digestive epithelium
2. Rate of loss into urine

27-4 Electrolyte Balance

• Potassium Loss in Urine

- Is regulated by activities of ion pumps
 - Along distal portions of nephron and collecting system
 - Na^+ from tubular fluid is exchanged for K^+ in peritubular fluid

- Are limited to amount gained by absorption across digestive epithelium (about 50–150 mEq or 1.9–5.8 g/day)

27-4 Electrolyte Balance

- Factors in Tubular Secretion of K^+
 1. *Changes in K^+ concentration of ECF*
 2. *Changes in pH*
 3. *Aldosterone levels*

27-4 Electrolyte Balance

- *Changes in Concentration of K^+ in ECF*
 - Higher ECF concentration increases rate of secretion
- *Changes in pH*
 - Low ECF pH lowers peritubular fluid pH
 - H^+ rather than K^+ is exchanged for Na^+ in tubular fluid
 - Rate of potassium secretion declines

27-4 Electrolyte Balance

- *Aldosterone Levels*
 - Affect K^+ loss in urine
 - Ion pumps reabsorb Na^+ from filtrate in exchange for K^+ from peritubular fluid
 - High K^+ plasma concentrations stimulate aldosterone

27-4 Electrolyte Balance

- Calcium Balance
 - Calcium is most abundant mineral in the body
 - A typical individual has 1–2 kg (2.2–4.4 lb) of this element
 - 99% of which is deposited in skeleton

27-4 Electrolyte Balance

- Functions of Calcium Ion (Ca^{2+})
 - Muscular and neural activities
 - Blood clotting
 - Cofactors for enzymatic reactions
 - Second messengers

27-4 Electrolyte Balance

- Hormones and Calcium Homeostasis
 - Parathyroid hormone (PTH) and calcitriol
 - Raise calcium concentrations in ECF
 - Calcitonin
 - Opposes PTH and calcitriol

27-4 Electrolyte Balance

- Calcium Absorption
 - At digestive tract and reabsorption along DCT
 - Is stimulated by PTH and calcitriol
- Calcium Ion Loss
 - In bile, urine, or feces

- Is very small (0.8–1.2 g/day)
- Represents about 0.03% of calcium reserve in skeleton

27-4 Electrolyte Balance

• *Hypercalcemia*

- Exists if Ca^{2+} concentration in ECF is >5.5 mEq/L
- Is usually caused by *hyperparathyroidism*
 - Resulting from oversecretion of PTH
- Other causes
 - Malignant cancers (breast, lung, kidney, bone marrow)
 - Excessive calcium or vitamin D supplementation

27-4 Electrolyte Balance

• *Hypocalcemia*

- Exists if Ca^{2+} concentration in ECF is <4.5 mEq/L
- Is much less common than hypercalcemia
- Is usually caused by chronic renal failure
- May be caused by *hypoparathyroidism*
 - Undersecretion of PTH
 - Vitamin D deficiency

27-4 Electrolyte Balance

• Magnesium Balance

- Is an important structural component of bone
- The adult body contains about 29 g of magnesium
- About 60% is deposited in the skeleton
- Is a cofactor for important enzymatic reactions
 - Phosphorylation of glucose

- Use of ATP by contracting muscle fibers
- Is effectively reabsorbed by PCT
- Daily dietary requirement to balance urinary loss
 - About 24–32 mEq (0.3–0.4 g)

27-4 Electrolyte Balance

- Magnesium Ions (Mg^{2+})
 - In body fluids are primarily in ICF
 - Mg^{2+} concentration in ICF is about 26 mEq/L
 - ECF concentration is much lower

27-4 Electrolyte Balance

- Phosphate Ions (PO_4^{3-})
 - Are required for bone mineralization
 - About 740 g PO_4^{3-} is bound in mineral salts of the skeleton
 - Daily urinary and fecal losses about 30–45 mEq (0.8–1.2 g)
 - In ICF, PO_4^{3-} is required for formation of high-energy compounds, activation of enzymes, and synthesis of nucleic acids
 - In plasma, PO_4^{3-} is reabsorbed from tubular fluid along PCT
 - Plasma concentration is 1.8–2.9 mEq/L

27-4 Electrolyte Balance

- Chloride Ions (Cl^-)
 - Are the most abundant anions in ECF
 - Plasma concentration is 97–107 mEq/L
 - ICF concentrations are usually low

- Are absorbed across digestive tract with Na⁺
- Are reabsorbed with Na⁺ by carrier proteins along renal tubules
- Daily loss is small 48–146 mEq (1.7–5.1 g)

27-5 Acid–Base Balance

- Acid–Base Balance
 - pH of body fluids is altered by addition or deletion of acids or bases
 - Acids and bases may be strong or weak
 - *Strong acids and strong bases*
 - Dissociate completely in solution
 - *Weak acids or weak bases*
 - Do not dissociate completely in solution
 - Some molecules remain intact
 - Liberate fewer hydrogen ions
 - Have less effect on pH of solution

27-5 Acid–Base Balance

- Carbonic Acid
 - Is a weak acid
 - In ECF at normal pH:
 - Equilibrium state exists



27-5 Acid–Base Balance

- The Importance of pH Control
 - pH of body fluids depends on dissolved:
 - Acids
 - Bases

- Salts
- pH of ECF
 - Is narrowly limited, usually 7.35–7.45

27-5 Acid–Base Balance

- **Acidosis**

- Physiological state resulting from abnormally low plasma pH
- *Acidemia* plasma pH < 7.35

- **Alkalosis**

- Physiological state resulting from abnormally high plasma pH
- *Alkalemia* plasma pH > 7.45

27-5 Acid–Base Balance

- Acidosis and Alkalosis

- Affect all body systems
 - Particularly nervous and cardiovascular systems
- Both are dangerous
 - But acidosis is more common
 - Because normal cellular activities generate acids

27-5 Acid–Base Balance

- Types of Acids in the Body

1. **Fixed acids**
2. **Organic acids**
3. **Volatile acids**

27-5 Acid–Base Balance

• **Fixed Acids**

- Are acids that do not leave solution
- Once produced they remain in body fluids
 - Until eliminated by kidneys
- Sulfuric acid and phosphoric acid
 - Are most important fixed acids in the body
 - Are generated during catabolism of:
 - Amino acids
 - Phospholipids
 - Nucleic acids

27-5 Acid–Base Balance

• **Organic Acids**

- Produced by aerobic metabolism
 - Are metabolized rapidly
 - Do not accumulate
- Produced by anaerobic metabolism (e.g., lactic acid)
 - Build up rapidly

27-5 Acid–Base Balance

• **Carbonic Acid**

- A **volatile acid** that can leave solution and enter the atmosphere
- At the lungs, carbonic acid breaks down into carbon dioxide and water
 - Carbon dioxide diffuses into alveoli

27-5 Acid–Base Balance

- Carbon Dioxide
 - In solution in peripheral tissues:
 - Interacts with water to form carbonic acid
 - Carbonic acid dissociates to release:
 - Hydrogen ions
 - Bicarbonate ions

27-5 Acid–Base Balance

- *Carbonic Anhydrase*
 - Enzyme that catalyzes dissociation of carbonic acid
 - Found in:
 - Cytoplasm of red blood cells
 - Liver and kidney cells
 - Parietal cells of stomach
 - Other cells

27-5 Acid–Base Balance

- CO₂ and pH
 - Most CO₂ in solution converts to carbonic acid
 - Most carbonic acid dissociates
 - P_{CO₂} is the most important factor affecting pH in body tissues
 - P_{CO₂} and pH are inversely related

27-5 Acid–Base Balance

- CO₂ and pH
 - When CO₂ levels rise:
 - H⁺ and bicarbonate ions are released

- pH goes down
- At alveoli:
 - CO₂ diffuses into atmosphere
 - H⁺ and bicarbonate ions in alveolar capillaries drop
 - Blood pH rises

27-5 Acid–Base Balance

- Mechanisms of pH Control
 - To maintain acid–base balance:
 - The body balances gains and losses of hydrogen ions
 - And gains and losses of bicarbonate ions

27-5 Acid–Base Balance

- Hydrogen Ions (H⁺)
 - Are gained
 - At digestive tract
 - Through cellular metabolic activities
 - Are eliminated
 - At kidneys and in urine
 - At lungs
 - Must be neutralized to avoid tissue damage
 - Acids produced in normal metabolic activity
 - Are temporarily neutralized by buffers in body fluids

27-5 Acid–Base Balance

- *Buffers*
 - Are dissolved compounds that stabilize pH
 - By providing or removing H⁺

- Weak acids
 - Can donate H⁺
- Weak bases
 - Can absorb H⁺

27-5 Acid–Base Balance

• **Buffer System**

- Consists of a combination of:
 - A weak acid
 - And the anion released by its dissociation
- The anion functions as a weak base
- In solution, molecules of weak acid exist in equilibrium with its dissociation products

27-5 Acid–Base Balance

- Three Major Buffer Systems
 1. **Protein buffer systems**
 - Help regulate pH in ECF and ICF
 - Interact extensively with other buffer systems
 2. **Carbonic acid–bicarbonate buffer system**
 - Most important in ECF
 3. **Phosphate buffer system**
 - Buffers pH of ICF and urine

27-5 Acid–Base Balance

• **Protein Buffer Systems**

- Depend on amino acids
- Respond to pH changes by accepting or releasing H⁺

- If pH rises:
 - Carboxyl group of amino acid dissociates
 - Acting as weak acid, releasing a hydrogen ion
 - Carboxyl group becomes carboxylate ion

27-5 Acid–Base Balance

- Protein Buffer Systems
 - At normal pH (7.35–7.45)
 - Carboxyl groups of most amino acids have already given up their H⁺
 - If pH drops:
 - Carboxylate ion and amino group act as weak bases
 - Accept H⁺
 - Form carboxyl group and amino ion

27-5 Acid–Base Balance

- Protein Buffer Systems
 - Carboxyl and amino groups in peptide bonds cannot function as buffers
 - Other proteins contribute to buffering capabilities
 - Plasma proteins
 - Proteins in interstitial fluid
 - Proteins in ICF

27-5 Acid–Base Balance

- The **Hemoglobin Buffer System**
 - CO₂ diffuses across RBC membrane
 - No transport mechanism required
 - As carbonic acid dissociates:
 - Bicarbonate ions diffuse into plasma

- In exchange for chloride ions (*chloride shift*)
- Hydrogen ions are buffered by hemoglobin molecules

27-5 Acid–Base Balance

- The Hemoglobin Buffer System
 - Is the only intracellular buffer system with an immediate effect on ECF pH
 - Helps prevent major changes in pH when plasma P_{CO_2} is rising or falling

27-5 Acid–Base Balance

- The **Carbonic Acid–Bicarbonate Buffer System**
 - Carbon dioxide
 - Most body cells constantly generate carbon dioxide
 - Most carbon dioxide is converted to carbonic acid, which dissociates into H^+ and a bicarbonate ion
 - Is formed by carbonic acid and its dissociation products
 - Prevents changes in pH caused by organic acids and fixed acids in ECF

27-5 Acid–Base Balance

- The Carbonic Acid–Bicarbonate Buffer System
 1. *Cannot protect ECF from changes in pH that result from elevated or depressed levels of CO_2*
 2. *Functions only when respiratory system and respiratory control centers are working normally*
 3. *Ability to buffer acids is limited by availability of bicarbonate ions*

27-5 Acid–Base Balance

- The Carbonic Acid–Bicarbonate Buffer System
 - Bicarbonate ion shortage is rare
 - Due to large reserve of *sodium bicarbonate*
 - Called the **bicarbonate reserve**

27-5 Acid–Base Balance

- The **Phosphate Buffer System**
 - Consists of anion H_2PO_4^- (a weak acid)
 - Works like the carbonic acid–bicarbonate buffer system
 - Is important in buffering pH of ICF

27-5 Acid–Base Balance

- Limitations of Buffer Systems
 - Provide only temporary solution to acid–base imbalance
 - Do not eliminate H^+ ions
 - Supply of buffer molecules is limited

27-5 Acid–Base Balance

- Maintenance of Acid–Base Balance
 - For homeostasis to be preserved, captured H^+ must:
 1. Be permanently tied up in water molecules
 - Through CO_2 removal at lungs
 2. Be removed from body fluids
 - Through secretion at kidney

27-5 Acid–Base Balance

- Maintenance of Acid–Base Balance
 - Requires balancing H^+ gains and losses
 - Coordinates actions of buffer systems with:
 - Respiratory mechanisms
 - Renal mechanisms

27-5 Acid–Base Balance

- Respiratory and Renal Mechanisms
 - Support buffer systems by:
 1. Secreting or absorbing H^+
 2. Controlling excretion of acids and bases
 3. Generating additional buffers

27-5 Acid–Base Balance

- **Respiratory Compensation**
 - Is a change in respiratory rate
 - That helps stabilize pH of ECF
 - Occurs whenever body pH moves outside normal limits
 - Directly affects carbonic acid–bicarbonate buffer system

27-5 Acid–Base Balance

- Respiratory Compensation
 - Increasing or decreasing the rate of respiration alters pH by lowering or raising the P_{CO_2}

- When P_{CO_2} rises:
 - pH falls
 - Addition of CO_2 drives buffer system to the right
- When P_{CO_2} falls:
 - pH rises
 - Removal of CO_2 drives buffer system to the left

27-5 Acid–Base Balance

• Renal Compensation

- Is a change in rates of H^+ and HCO_3^- secretion or reabsorption by kidneys in response to changes in plasma pH
- The body normally generates enough organic and fixed acids each day to add 100 mEq of H^+ to ECF
- Kidneys assist lungs by eliminating any CO_2 that:
 - Enters renal tubules during filtration
 - Diffuses into tubular fluid en route to renal pelvis

27-5 Acid–Base Balance

• Hydrogen Ions

- Are secreted into tubular fluid along:
 - Proximal convoluted tubule (PCT)
 - Distal convoluted tubule (DCT)
 - Collecting system

27-5 Acid–Base Balance

• Buffers in Urine

- The ability to eliminate large numbers of H^+ in a normal volume of urine depends on the presence of buffers in urine
- Carbonic acid–bicarbonate buffer system

- Phosphate buffer system
- Ammonia buffer system

27-5 Acid–Base Balance

- Major Buffers in Urine
 - Glomerular filtration provides components of:
 - Carbonic acid–bicarbonate buffer system
 - Phosphate buffer system
 - Tubule cells of PCT
 - Generate ammonia

27-5 Acid–Base Balance

- Renal Responses to Acidosis
 1. Secretion of H^+
 2. Activity of buffers in tubular fluid
 3. Removal of CO_2
 4. Reabsorption of $NaHCO_3^-$

27-5 Acid–Base Balance

- Renal Responses to Alkalosis
 1. Rate of secretion at kidneys declines
 2. Tubule cells do not reclaim bicarbonates in tubular fluid
 3. Collecting system transports HCO_3^- into tubular fluid while releasing strong acid (HCl) into peritubular fluid

27-6 Acid–Base Balance Disturbances

- Acid–Base Balance Disturbances
 - Disorders
 - Circulating buffers
 - Respiratory performance
 - Renal function
 - Cardiovascular conditions
 - Heart failure
 - Hypotension
 - Conditions affecting the CNS
 - Neural damage or disease that affects respiratory and cardiovascular reflexes

27-6 Acid–Base Balance Disturbances

- *Acute Phase*
 - The initial phase
 - pH moves rapidly out of normal range
- *Compensated Phase*
 - When condition persists
 - Physiological adjustments occur

27-6 Acid–Base Balance Disturbances

- *Respiratory Acid–Base Disorders*
 - Result from imbalance between:
 - CO₂ generation in peripheral tissues
 - CO₂ excretion at lungs
 - Cause abnormal CO₂ levels in ECF

- *Metabolic Acid–Base Disorders*
 - Result from:
 - Generation of organic or fixed acids
 - Conditions affecting HCO_3^- concentration in ECF

27-6 Acid–Base Balance Disturbances

- **Respiratory Acidosis**
 - Develops when the respiratory system cannot eliminate all CO_2 generated by peripheral tissues
 - Primary sign
 - Low plasma pH due to **hypercapnia**
 - Primary cause
 - Hypoventilation

27-6 Acid–Base Balance Disturbances

- **Respiratory Alkalosis**
 - Primary sign
 - High plasma pH due to **hypocapnia**
 - Primary cause
 - Hyperventilation

27-6 Acid–Base Balance Disturbances

- **Metabolic Acidosis**
 - Three major causes
 1. Production of large numbers of fixed or organic acids
 - H^+ overloads buffer system
 - **Lactic acidosis**
 - Produced by anaerobic cellular respiration
 - **Ketoacidosis**

- Produced by excess ketone bodies
2. Impaired H^+ excretion at kidneys
 3. Severe bicarbonate loss

27-6 Acid–Base Balance Disturbances

- Combined Respiratory and Metabolic Acidosis
 - Respiratory and metabolic acidosis are typically linked
 - Low O_2 generates lactic acid
 - Hypoventilation leads to low P_{O_2}

27-6 Acid–Base Balance Disturbances

- **Metabolic Alkalosis**
 - Is caused by elevated HCO_3^- concentrations
 - Bicarbonate ions interact with H^+ in solution
 - Forming H_2CO_3
 - Reduced H^+ causes alkalosis

27-6 Acid–Base Balance Disturbances

- The Detection of Acidosis and Alkalosis
 - Includes blood tests for pH, P_{CO_2} , and HCO_3^- levels
 - Recognition of acidosis or alkalosis
 - Classification as respiratory or metabolic

27-7 Age and Fluid, Electrolyte, and Acid–Base Balance

- Fluid, Electrolyte, and Acid–Base Balance in Fetuses and

Newborns

- Fetal pH Control
 - Buffers in fetal bloodstream provide short-term pH control
 - Maternal kidneys eliminate generated H⁺
- Newborn Electrolyte Balance
 - Body water content is high
 - 75% of body weight
 - Basic electrolyte balance is same as adult's

27-7 Age and Fluid, Electrolyte, and Acid–Base Balance

- Aging and Fluid Balance
 - Body water content, ages 40–60
 - Males 55%
 - Females 47%
 - After age 60
 - Males 50%
 - Females 45%

27-7 Age and Fluid, Electrolyte, and Acid–Base Balance

- Aging and Fluid Balance
 - Decreased body water content reduces dilution of waste products, toxins, and drugs
 - Reduction in glomerular filtration rate and number of functional nephrons
 - Reduces pH regulation by renal compensation
 - Ability to concentrate urine declines
 - More water is lost in urine
 - Insensible perspiration increases as skin becomes thinner

27-7 Age and Fluid, Electrolyte, and Acid–Base Balance

- Aging and Fluid Balance
 - Maintaining fluid balance requires higher daily water intake
 - Reduction in ADH and aldosterone sensitivity
 - Reduces body water conservation when losses exceed gains
 - Muscle mass and skeletal mass decrease
 - Cause net loss in body mineral content

27-7 Age and Fluid, Electrolyte, and Acid–Base Balance

- Aging and Acid–Base Balance
 - Loss is partially compensated by:
 - Exercise
 - Dietary mineral supplement
 - Reduction in vital capacity
 - Reduces respiratory compensation
 - Increases risk of respiratory acidosis
 - Aggravated by arthritis and emphysema
 - Disorders affecting major systems increase