

i. Fundamentals of human physiology and cellular function

Introduction to Human Physiology

1. Definition and Scope

- **Physiology** studies the mechanical, physical, and biochemical functions of living organisms.
- **Human physiology** focuses on how cells, tissues, and organs coordinate to maintain health and respond to internal and external challenges.

2. Homeostasis

- Coined by Walter Cannon, **homeostasis** refers to the body's ability to maintain stable internal conditions (e.g., temperature, pH, ion concentrations) despite external fluctuations.
- Involves **feedback loops**—negative feedback (common; opposes change) and positive feedback (less common; amplifies an initial stimulus, e.g., in blood clotting or labor contractions).

3. Levels of Organization

- **Cellular → Tissues → Organs → Organ Systems**
- Specialized cell types form tissues with distinct structures and functions, which integrate into larger organ systems (e.g., nervous, cardiovascular, respiratory).

Cellular Architecture and Function

1. Cell Membrane and Fluid Compartments

- **Phospholipid Bilayer**: Embedded with proteins (channels, transporters, receptors) and cholesterol (stabilizes fluidity).
- **Intracellular Fluid (ICF)**: High K^+ , low Na^+ , abundant proteins and organelles.
- **Extracellular Fluid (ECF)**: Composed of interstitial fluid and plasma, higher Na^+ , lower K^+ , crucial for nutrient delivery and waste removal.

2. Organelles

- **Nucleus**: Houses genetic material (DNA), site of transcription, cell cycle control.
- **Mitochondria**: Powerhouse for ATP production via oxidative phosphorylation, also key in apoptosis and calcium buffering.
- **Endoplasmic Reticulum (ER)**:
 - **Rough ER**: Synthesizes membrane-bound and secretory proteins.
 - **Smooth ER**: Lipid metabolism, detoxification, calcium storage.
- **Golgi Apparatus**: Modifies, sorts, and packages proteins/lipids for secretion or organelle targeting.
- **Lysosomes/Peroxisomes**: Degradation and recycling of cellular waste; detoxification of reactive oxygen species.

3. Cytoskeleton

- **Microfilaments (Actin)**: Cell shape, motility, muscle contraction (in concert with myosin).
- **Intermediate Filaments**: Structural integrity (e.g., keratins, neurofilaments).
- **Microtubules**: Intracellular transport, mitotic spindle, ciliary/flagellar motility (with dynein, kinesin).

Membrane Transport and Electrochemical Gradients

1. Passive Transport

- **Simple Diffusion**: Movement of small or lipid-soluble molecules down their concentration gradient.
- **Facilitated Diffusion**: Movement down a gradient via carrier proteins or ion channels (e.g., glucose transporter, ion-specific channels).

2. Active Transport

- **Primary Active Transport**: Directly uses ATP (e.g., Na^+/K^+ ATPase pumping Na^+ out, K^+ in).
- **Secondary Active Transport**: Coupled transport (e.g., Na^+ -glucose symport) uses the gradient established by a primary pump.

3. Vesicular Transport

- **Endocytosis** (phagocytosis, pinocytosis, receptor-mediated) and **Exocytosis** (secretion of hormones, neurotransmitters) require membrane remodeling and ATP.

4. Membrane Potential

- **Resting Membrane Potential (RMP):** Cells maintain an electrical potential difference (usually -70 mV in neurons) due to ion gradients and selective permeability.
- **Excitable Cells:** Neurons and muscle cells can rapidly alter membrane potential (action potentials, signaling).

Intercellular Communication

1. Chemical Messengers

- **Hormones (Endocrine Signaling):** Released into the bloodstream by glands, act on distant targets (e.g., insulin, cortisol).
- **Paracrine Factors:** Local signaling molecules (e.g., nitric oxide, growth factors).
- **Neurotransmitters:** Released by neurons into synaptic clefts for rapid, localized signaling (e.g., acetylcholine, dopamine).

2. Receptors

- **Cell-Surface Receptors:** G protein-coupled receptors (GPCRs), ion channels, enzyme-linked receptors.
- **Intracellular Receptors:** For lipophilic molecules (e.g., steroid hormones); alter gene transcription directly in the nucleus.

3. Signal Transduction Cascades

- **Second Messengers** (cAMP, Ca^{2+} , IP₃, DAG) amplify signals.
- **Protein Kinase Cascades** (e.g., MAPK, PKA, PKC) modulate cellular processes—gene expression, metabolism, cell division.

Tissue Organization and Function

1. Epithelial Tissue

- Covers body surfaces and lines cavities (e.g., intestines, kidney tubules).
- Functions in protection, absorption, secretion.
- Tight junctions form selectively permeable barriers.

2. Connective Tissue

- Provides structural support (extracellular matrix, collagen, elastin).
- Includes bone, cartilage, blood, adipose tissues.
- Fibroblasts, osteoblasts, chondrocytes produce and maintain ECM.

3. Muscle Tissue

- **Skeletal Muscle:** Voluntary control, striated fibers, multinucleated.
- **Cardiac Muscle:** Involuntary, striated, intercalated discs for synchronized contraction.
- **Smooth Muscle:** Involuntary, non-striated, present in walls of hollow organs (e.g., intestines, blood vessels).

4. Nervous Tissue

- **Neurons:** Excitable cells that transmit electrical impulses.
- **Glial Cells:** Support and protect neurons (astrocytes, oligodendrocytes/Schwann cells for myelin formation).

Integration into Organ Systems

1. Neural Control

- Central (brain and spinal cord) and peripheral nervous systems coordinate rapid communication.
- **Reflex arcs** integrate sensory inputs with motor outputs for immediate responses.

2. Endocrine Regulation

- Hormone-secreting glands (pituitary, thyroid, adrenals, pancreas) orchestrate slower, long-term regulation (e.g., growth, metabolism, reproduction).

3. Cardiovascular and Respiratory Systems

- Work together to supply oxygen, remove CO_2 , circulate nutrients, and maintain tissue perfusion.
- **Homeostatic Mechanisms:** Blood pressure control (baroreceptor reflex), regulation of blood gases (chemoreceptors).

4. Renal and Digestive Systems

- **Kidneys** filter blood, maintain electrolyte balance and pH, excrete waste (urea).
- **Gastrointestinal Tract** breaks down nutrients, absorbs them into circulation, eliminates undigested residues.

5. Immune and Lymphatic Systems

- Defend against pathogens, clear damaged cells, involve both innate (macrophages, neutrophils) and adaptive immunity (T/B lymphocytes).

Concluding Perspectives

Human physiology is fundamentally anchored in **cellular function**—how cells harness chemical gradients, respond to signals, generate electrical impulses, and coordinate their activities to sustain life. The human body relies on a delicate **equilibrium** maintained by feedback mechanisms across organ systems. Advances in molecular and cellular biology continue to deepen our knowledge, informing disciplines from **medicine** and **pharmacology** to **bioengineering** and **systems biology**. Understanding these foundational principles is essential for exploring disease pathology (when regulation fails) and designing novel therapeutic interventions.

Key Takeaways

- **Cellular organization** underpins tissue and organ function.
- **Membrane physiology** (transport, potentials) drives excitability, communication, and metabolism.
- **Tissue specialization** (epithelial, connective, muscle, nervous) enables the diverse roles of organ systems.

Homeostatic feedback loops and **signal transduction** unify processes across systems, ensuring adaptability and stability in a changing environment.