AP 150

Integrative Anatomy and Physiology with Laboratory Exercises

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Integrative Anatomy and Physiology with Laboratory Exercises

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Section 1 – Cells, Tissues, and Skin

Cellular Anatomy

Plasma Membrane

Mammalian cells are surrounded by the **plasma membrane** that encloses the cell and regulates passage of substances into and out of the cell. The plasma membrane often has extensions, such as **cilia** and **microvilli.**

- Composed of a single phospholipid bilayer and various proteins.
- Encloses cell and regulate passage of substances.
- Membrane permeability depends on integral and carrier proteins, lipid solubility, molecular size and ionic charge.

Cilia

- Are relatively large extensions of the plasma membrane that contain cytoplasm and microtubules.
- Secrete mucus and move.

Microvilli

- Are relatively small extensions of the plasma membrane that increase surface area.

Cytoplasm

All of the material inside of the cell (except sometimes the **nucleus)** is called the **cytoplasm**. The **cytosol** is the cytoplasm minus the **membranous organelles.**

- The cytosol includes 80% to 90% water plus various electrolytes.

Membranous Organelles

The membranous organelles include the mitochondria, nucleus, endoplasmic reticulum, Golgi complex, lysosomes, and peroxisomes.

Mitochondria

- Composed of a double phospholipid bilayer forming an outer membrane and an inner membrane.
- Much of the inner membrane forms deep folds called **cristae**.
- Site for cellular energy production.

Nucleus

- Surrounded by the nuclear membrane that is composed of a double phospholipid bilayer with pores.
- Contain Chromatin – DNA and protein.
- Contains the Nucleolus – RNA and protein.

Endoplasmic reticulum (ER)

- Consists of interconnected membranes, and tubules between the membranes, that connect to the nucleus.
- The membranes and tubules are composed of a single phospholipid bilayer.
- Act as transportation pathways and storage sites.
- Rough ER – ribosomes on membranes, synthesize proteins.
- Smooth ER – no ribosomes, synthesize lipids.

Golgi apparatus

- Consists of membranous sacs continuous with ER.
- The membranous sacs are composed of a single phospholipid bilayer.
- Acts in cellular secretion through production of Vesicles.
- Synthesize carbohydrate compounds.

Vesicles

- Consists of membranous sacs used for storage in the cell and secretion out of the cell.
- The membranous sacs are composed of a single phospholipid bilayer.

Secretory Vesicles

- Vesicles containing substances that are secreted out of the cell.
- Responsible for secretion of neurotransmitter and most hormones, as well as many other secretions.

Lysosomes

- Vesicles containing digestive enzymes, common in phagocytic cells.
- Digest cellular debris and pathogens.

Peroxisomes

- Vesicles containing enzymes that produce and breakdown hydrogen peroxide.
- Oxidize cellular debris and pathogens.

Non-Membranous Organelles

The non-membranous organelles are molecular clusters in the cell that are not surrounded by phospholipid bilayers. These include the ribosomes, the cytoskeleton, and other structures such as fibrils and the centrioles.

Ribosomes

- Free of or attached to ER; composed of RNA and protein.
- Site for building proteins using messenger and transfer RNA.

Cytoskeleton

- Composed largely of **Fibrils** and **Microtubules** (small protein fibers and tubes) in the cell that serve as an internal skeleton.
- Some Fibrils are specialized, such as Myofibrils in muscle that are responsible for contraction.
- Microtubules transport macromolecules.

Centrioles

- 9 evenly spaced bundles of 3 microtubules per bundle.
- Act in separation of chromatids during cell division.

Cellular Anatomy – Laboratory

Using the terms in the left box, draw and then label the structures. Alternatively, you may paste pictures and then label the structures. If you need more space use separate sheets of paper.

Model / Diagram of Cell

Plasma membrane • Phospholipid Bilayer • Cilia • Microvilli Cytoplasm	

Membranous Organelles
 	
• Cytoplasm
• Mitochondria
• Nucleus
• Endoplasmic reticulum (ER)
  ○ Smooth
  ○ Rough
• Golgi apparatus
• Secretory Vesicles
• Lysosomes
• Peroxisomes	

Non-membranous Organelles • Ribosomes • Cytoskeleton • Centrioles	

Cellular Control and Transport

Plasma Membrane

The plasma membrane is composed of a phospholipid bilayer.

- The surface facing the outside of the cell is phosphate based and hydrophilic.
- The surface facing the inside of the cell is also phosphate based and hydrophilic.
- The interior of plasma membrane is lipid and cholesterol based and hydrophobic.
    - Water soluble ions and molecules cannot enter this hydrophobic region.

Integral (Transmembrane) Transport Proteins

Because the phospholipid bilayer is relatively impermeable to water and water soluble substances, integral (transmembrane) proteins play a central role in transport across the cell membranes. Some integral proteins function in membrane transport. Other integral proteins function in cellular communication.

Channels

Channels are transmembrane proteins that form passageways in the cell membrane. Channels allow for the diffusion of water and small water soluble substances (such as ions) through the cell membrane. Substances move from a region of high concentration to a region of lower concentration. Movement through channels is often classified as **passive transport**.

- Passive Channels are passageways in the cell membrane that are always open.
- Gated Channels are passageways in the cell membrane that can open or close in response to chemical, electrical, or other types of signals. Accordingly, gated channels also function as receptors.

Facilitative Transporters

Facilitative transporters are transmembrane proteins that are often called **carrier proteins**. These proteins allow for the movement of larger water soluble substances (such as glucose) through the cell membrane. Substances move from a region of high concentration to a region of lower concentration. The carrier proteins are not enzymatically active and move substances by spontaneous conformational changes. Movement by facilitative transporters is classified as **passive transport**.

Co-Transporters and Counter-Transporters

Co-transporters and counter-transporters are transmembrane proteins. These proteins can move substances from a region of high concentration to a region of low concentration, or from a region of low concentration to a region of high concentration. Although, these transporter proteins are

not enzymatically active, they depend on energy derived from the concentration gradient of another substance, most commonly sodium ions, to cause conformational changes and transport. Movement by co-transporters and counter-transporters is classified as **secondary active transport**.

- Co-Transporters will move a substance (such as glucose) through the cell membrane in the same direction as the substance (such as sodium ions) with the concentration gradient that is providing the needed energy.
- Counter-Transporters will move a substance (such as hydrogen ions) through the cell membrane in the opposite direction to the substance (such as sodium ions) with the concentration gradient that is providing the needed energy.

Pumps

Active transport pumps are transmembrane proteins. These proteins can move substances from a region of high concentration to a region of low concentration, or from a region of low concentration to a region of high concentration. Pumps are enzymatically active and obtain the energy for transport from the breakdown of ATP, to cause conformational changes and transport. Movement by pumps is classified as **primary active transport**.

Passive Transport

Diffusion in general

Diffusion is the movement of substances from an area of high concentration to an area of low concentration due to the random activity of molecules.

- The concentration gradient is the difference in concentration between the region of high concentration and the region of low concentration.

Diffusion across cell membranes: Lipids and Lipid Soluble Substances

Permeability is a measure of the extent that substances can diffuse across the plasma membrane. Cell membranes are generally selectively permeable; only certain substances can diffuse across the membrane.

Because of the composition and organization of the phospholipid bilayer, lipid soluble substances (such as steroid and thyroid hormones) *can* readily diffuse through the cell membrane without the use of channels or other transmembrane proteins.

- The plasma membrane is permeable to lipids and lipid soluble substances.

Diffusion across cell membranes: Water and Water Soluble Substances

In contrast, water and water soluble substances (such as Na+, K+, Ca+, and Cl-) depend on the use of channels to diffuse through the plasma membrane.

- Specific channels allow for the diffusion of water and many water soluble substances through the plasma membrane.

Water and water soluble substances can pass through channels only if:

- The substances are smaller than the channels.
- The charge of the channel permits passage of the substance.
- The channel is specifically constructed to allow passage of the substance.
- There is a concentration gradient for the substance.

For example, water passes through water channels. Na^+ ions pass through sodium channels. K^+ ions pass through potassium channels. Ca^+ ions pass through calcium channels. Cl^- ions pass through chloride channels.

Osmosis and Dialysis

Osmosis is the diffusion of water across a cell membrane. Dialysis is the diffusion of solutes across a cell membrane. However, water and solute (soluble substances) diffuse independently. Water moves from the region of high water concentration to the region of low water concentration through water channels. Solute (such as Na^+, K^+, Ca^+, and Cl^-) moves from the region of high solute concentration to the region of low solute concentration through specific solute channels.

- The concentration of water and solute are codependent and inversely related. As solute concentration increases, water concentration decreases, and vice versa.

  - Osmolarity is a measure of the concentration of dissolved solutes and determines the concentration of the water. As the osmolarity increases, water concentration decreases, and vice versa.

- A solution that is **iso-osmotic** (isotonic) has the same solute and water concentration as the intracellular fluid.
- A solution that is **hypo-osmotic** (hypotonic) has a lower solute concentration and a higher water concentration than the intracellular fluid.
- A solution that is **hyper-osmotic** (hypertonic) has higher solute concentration and a lower water concentration than the intracellular fluid.

As the osmolarity of a solution increases, the **osmotic pressure** increases. Because the osmolarity increases, the water concentration decreases. The decrease in water concentration of the solution generates a concentration gradient for water that will cause water movement from a region of higher to the region of lower water concentration.

- The osmotic pressure of a solution is a measure of water movement into a solution due to the water concentration gradient.

Filtration

In addition to the concentration gradient moving water and water soluble substances through the plasma membrane, **hydrostatic pressure** (water pressure) can move water through the membrane. This process is called filtration.

"Facilitated Diffusion" across cell membranes: Role of facilitative transporters

Some substances (such as glucose) that are not lipid soluble or are too large to pass through the membrane channels can be transported through the cell membrane using **facilitative transporters** (carrier proteins) that bind to the substances. These transporters appear to spontaneously change conformation.

Active Transport

Secondary Active Transport

The energy released when one molecule moves with the electrochemical gradient is coupled with the movement of another molecule against the electrochemical gradient (refer to transporters and counter-transporters discussed earlier).

The most common mechanisms are co-transport and counter-transport.

- **Co-transport** is when two molecules move in the same direction, generally into the cell (for example, Na^+ linked Glucose transport).
- **Counter-transport** is when two molecules move in opposite directions, one molecule into the cell and the other out of the cell (for example, Na^+ linked H^+ exchange).

Primary Active Transport

Primary active transport involves the movement of substances across a cell membrane using an Active Transport Protein (pump) and energy from the breakdown of ATP (refer to pumps earlier in the chapter).

- Primary active transport allows for the movement of a substance from a region of low concentration to a region of high concentration.

The most common active transport pumps are Ion and Exchange Pumps.

- **Ion pumps** actively transport a single ion, such as calcium ions.
- **Exchange pumps** actively transport a particular ion in one direction and another ion in the opposite direction. The sodium-potassium exchange pump is an example; three sodium ions are moved out of the cell and two potassium ions are moved into the cell.

Integral (Transmembrane) Receptor Proteins

Integral (transmembrane) receptor proteins are proteins imbedded in cell membranes with the receptors on the exterior of the cell membrane. Water soluble chemical messengers bind to these receptors, which include channel linked receptors, tyrosine kinase linked receptors, and G-protein coupled receptors.

Channel linked Receptors

Channel linked receptors (also called fast ligand gated channels) are transmembrane proteins that function as both receptor and ion channel. Commonly, the receptor faces the exterior of the cell and the channel passes through the plasma membrane. In other instances the receptor faces the interior of the cell and the channel may pass through the plasma membrane or through an intracellular membrane (such as the endoplasmic reticulum).

- The binding of an appropriate water soluble chemical messenger usually causes the channel to open and allows the diffusion of certain ions (such as sodium, chloride, or calcium).

Tyrosine Kinase linked Receptors

The tyrosine kinase linked receptors (also called fast ligand gated channels) are transmembrane proteins that function as both receptor and enzyme. The receptor faces the exterior of the cell and the enzyme (tyrosine kinase) faces the cytoplasm.

- The binding of an appropriate water soluble chemical messenger activates the enzyme.

G-protein coupled Receptors

The G-protein coupled receptors are transmembrane proteins that function as a receptor and as a coupling to intracellular G-proteins. The receptor faces the exterior of the cell and the coupling end faces the cytoplasm.

- The binding of an appropriate water soluble chemical messenger causes the coupled G-protein to release GDP and bind GTP, causing the G-protein to separate.

Transmembrane potential

Due to the sodium-potassium exchange pumps and chloride pumps the concentrations of several ions vary considerably between the extracellular and intracellular fluid.

- Extracellular fluid contains large numbers of sodium and chloride ions.
- Intracellular fluid contains large numbers of potassium ions and negatively charged proteins.

This uneven distribution of charges, and the fact that potassium ions diffuse out of the cell through leaky potassium channels faster than sodium ions diffuse into the cells, generate a transmembrane potential of about -70 mV. We will be returning to this issue in relation to muscles and nerves.

Tissues

Clusters of similar cells are referred to as tissues. Although there are probably as least two hundred different types of tissues, four major categories of tissues are commonly discussed. These categories include epithelial, connective, muscle and nervous tissues and are summarized in the accompanying table on the next page.

Epithelial Tissues

Epithelial tissues are composed of cells tightly bonded together by glycoprotein deposits, desmosomes, and tight junctions.

- Anatomically, epithelial tissues are avascular (do not contain blood vessels), are connected to underlying tissue by a basement membrane, and contain germinative cells (cells that undergo mitosis).
- Functionally, epithelial tissues act as a **barrier**, line body cavities or other openings, and produce secretions (function as glands).

Connective Tissues

Connective tissues are composed of widely separated secretory cells and of the substances secreted from these cells (the matrix).

- Anatomically, connective tissues are vascular and contain fibers composed mainly of protein and/or contain a gelatin like substance (ground substance).
- Functionally, connective tissues provide **structure**, support and protection.

Muscle Tissues

Muscle tissues are composed of cells with large quantities of actin and myosin.

- Anatomically, muscle tissues are vascular and cells vary from long and spaghetti shaped to short and spindle shaped.
- Functionally, muscle tissues are specialized to contract and provide **movement**.

Nervous Tissues

Nervous tissue is composed of intermingling neurons and glial cells.

- Anatomically, nervous tissue is vascularly isolated and cells vary from long, stringy and branched to short and compact.
- Functionally, nervous tissue is specialized to **process** and transmit signals.

Summary of the four major categories of tissues

Tissue	Cell Structure	Vasculature	Function
Epithelial	small cells tightly bonded together	no blood vessels	act as a **barrier** and produce **secretions**
Connective	small cells widely separated and surrounded by secreted substances	blood vessels intermingle with cells	provide **structure**, **support** and protection
Muscle	vary from long and spaghetti shaped to short and spindle shaped	blood vessels intermingle with cells	**contract** and provide **movement**
Nervous	vary from long, stringy and branched to short and compact	blood vessels are isolated from neurons	**process** and **transmit** signals

Epithelial Tissues

Classification of Epithelial Tissues and Cells

- Simple Epithelial Tissues – single layer of cells.
- Non-Simple Epithelial Tissues – multiple layers of cells (Stratified, Transitional) or falsely appearing to be multiple layers of cells (Pseudostratified).
- The shapes of the cells varies – Squamous (flat), Cuboidal (cube-like), Columnar (tall), oval (seen in Transitional Epithelium).

Simple Epithelial Tissues

Simple Squamous

- Cover visceral organs, line body cavities and vessels.
- Permit diffusion and filtration (easiest to pass through).

Simple Cuboidal

- Line exocrine glands, ducts, renal tubules, cover ovaries.
- Permit secretion (glandular, see next page), excretion, or absorption.

Simple Columnar

- Line digestive tract.
- Provide protection, permit absorption and secretion (glandular, see next page).

Non-Simple Epithelial Tissues

Stratified Squamous

- Cover skin (keratinized), ends of GI tract (non-keratinized).
- Provide protection.

Transitional

- Line ureter and bladder.
- Permit distension.

Pseudostratified Ciliated Columnar

- Line respiratory airways.
- Provide protection, permit secretion (glandular, see below), ciliary movement (sweep away debris).

Epithelial Tissues – Laboratory

Using the terms in the left box, draw and then label the tissues, cells, or structures. Alternatively, you may paste pictures and then label the tissues, cells, or structures. If you need more space use separate sheets of paper.

Simple Squamous Epithelium	
Simple Cuboidal Epithelium	
Simple Columnar Epithelium	

Histology of Non-Simple Epithelial Tissues

Stratified Squamous Epithelium	
Transitional Epithelium	
Pseudostratified Ciliated Columnar Epithelium	

Connective Tissues

Classification of Connective Tissues and Cells

Fibrous Connectie Tissues

Fibroblasts / fibrocytes produce a matrix composed mainly of protein fibers.

Areolar Connective Tissue

- Matrix is composed of collagen fibers and thin elastin fibers.
- Often contain Mast cells that produce histamine.
- Located around nerves and blood vessels, in skin, between muscles, and other organs.
- Attach epithelial tissues, permit diffusion, binds organs.

Dense Irregular Connective Tissues

- Matrix is composed of thick collagen fibers that are randomly organized.
- Located in skin, fibrous capsules of organs and joints.
- Provides strong support in all directions.

Dense Regular Connective Tissues

- Matrix is composed of thick collagen fibers that are organized in parallel.
- Located in tendons and ligaments.
- Provides strong support in the longitudinal direction.

Adipose Tissue

Adipocytes do not produce a matrix – they store lipids in their cytoplasm

- Store fat droplets.
- Found under skin, around heart, kidneys, eyeballs, joints.
- Provides protection, stores fat, insulates.

Cartilage Tissues

Chondroblasts / chondrocytes produce a matrix composed of a thick gelatin-like protein.

Hyaline Cartilage

- Matrix is composed of thick protein gelatin.
- Located in joint surfaces of bones, nose, respiratory airways.
- Provides flexible support.
- Is a precursor to bone.

Osseous Tissues

Osteoblasts / osteocytes produce a matrix composed mainly of calcium phosphate.

Bone

- Matrix is composed calcium phosphate deposits and collagen fibers.
- Found in skeleton.
- Provides rigid support.
- Involved in storage and release of calcium and phosphate (mineral metabolism).

Connective Tissues – Laboratory

Using the terms in the left box, draw and then label the tissues, cells, or structures. Alternatively, you may paste pictures and then label the tissues, cells, or structures. If you need more space use separate sheets of paper.

Histology of Connective tissues

Areolar Connective Tissue • Fibroblasts / Fibrocytes • fine Collagen fibers • Elastic fibers • Mast cells	
Dense Irregular Connective Tissue • Fibroblasts / Fibrocytes • thick Collagen fibers	
Dense Regular Connective Tissue • Fibroblasts / Fibrocytes • thick Collagen fibers	

Adipose Tissue • Adipocytes • Lipids	
Hyaline Cartilage • Chondrocytes • Chondroitin Sulfate	
Osseous Tissue • Osteocytes • Calcium Phosphate	

Muscle and Nervous Tissues

Muscle Tissues

General Function

- Cells are specialized to contract.
- (Anatomical Features and Organization of Muscle Tissues are considered with the Muscular System).

Nervous Tissues

General Function

- Cells are specialized to transmit signals.
- (Anatomical features and Organization of Nervous Tissues are considered with the Nervous System).

Integumentary System

Layers of the Integument

Epidermis

- Composed of Stratified Squamous Epithelium organized in the following layers (Strata).
    - Stratum Corneum – dead cell residue and Keratin – TOP stratum.
    - Stratum Lucidum – organelles completely disappear.
    - Stratum Granulosum – keratinization begins here and organelles begin to disappear.
    - Stratum Spinosum – cells attached by spine like projections.
    - Stratum Basale (Germinativum) – Cells are cuboidal and mitotically active – BOTTOM stratum.
- Controls skin–permeability, provides a barrier to pathogens, and synthesizes vitamin-D.

Dermis

- Commonly consists of two major layers.

    Papillary Layer

    - Composed of Areolar Connective Tissue.
    - Contain many Blood Capillaries and Lymphatic vessels.
    - Contain Tactile Receptors (Meissner's Corpuscles) for detecting light touch.

    Reticular Layer

    - Composed of Dense Irregular Connective Tissue.
    - Contain Blood Vessels, Lymph Nodes and Lymphatic Vessel.
    - Contain Lamellated Corpuscles (Pacinian Corpuscles) for detecting deep pressure.
- Nourishes epidermis, restricts and destroys pathogens, stores lipids, attaches skin to underlying tissue, provides for sensory detection, assists in thermoregulation by way of blood vessels.

Hypodermis (Subcutaneous Layer)

- Composed of Adipose Tissue.
- Contains areolar connective tissue and blood vessels.
- Provides cushioning and storage of fat.

Skin Thickness

Thick skin

- Stratum lucidum is *distinct.*
- Stratum corneum is *thick.*
- Papillary layer is *thin.*

Thin skin

- Stratum lucidum is *absent.*
- Stratum corneum is *thin.*
- Papillary layer is *distinct.*

Accessory Structures of the Skin

Hair Follicles

- Are formed by invagination of the epidermis into the dermis.
- Protects skull and other structures and assists in sensory detection.

Papilla – Connective tissue of the dermis that extends into the lower end of the follicle.

Matrix – Epithelial cells that surround the papilla.

- These cells are mitotically active and are responsible for the growth of Hair.

Hair Shaft and Root – Exposed and deep portions of a hair.

Arrector Pili Muscles

- Smooth Muscle connecting to hair follicle.
- Straighten hair.

Sebaceous Glands (Oil Glands)

- Associated with hair follicles.
- Secrete sebum (mainly a lipid) into hair follicles, function to lubricate and protect hair shaft and surrounding skin.
- Anatomically are simple branched acinar glands.
- Functionally are Holocrine Glands (secrete via whole cell secretion).

Sudoriferous Glands (Sweat Glands)

Merocrine (Eccrine) Sweat Glands – Associated with epidermis in most parts of the body.

- Secrete sweat onto surface of epidermis, widely distributed throughout the body, function to excrete salts, water, and organic wastes.
- Anatomically are simple coiled tubular glands.
- Functionally are Merocrine Glands (secrete via transmembrane transport).

Apocrine Sweat Glands – associated with hair follicles in axillary and pubic regions

- Secrete into hair follicle, most common in axillary and pubic region, function to provide an odorous secretion.
- Anatomically are simple coiled tubular glands.
- Functionally are Apocrine Glands (secrete via membrane pinching).
- (Mammary Glands are specialized apocrine sweat glands).

Thermoregulation

- By increasing blood flow in dermis heat is dissipated through convection.
- By increasing perspiration heat is dissipated through evaporation.
- Fluid from sweat glands is referred to as sensible perspiration.
- Fluid from capillary leakage is referred to as insensible perspiration.

Integumentary System – Laboratory

Using the terms in the left box, draw and then label the structures. Alternatively, you may paste pictures and then label the structures. If you need more space use separate sheets of paper.

Model of Skin

Epidermis • Stratum Corneum • Stratum Lucidum • Stratum Granulosum • Stratum Spinosum • Stratum Germinativum	
Dermis • Papillary Layer • Reticular Layer • Tactile (Meissner's) Corpuscle • Sebaceous glands • Merocrine sweat glands	
Hypodermis • Lamellated (Pacinian) corpuscle	
Hair Follicles • Papilla • Matrix • Hair • Arrector Pili muscle	

Histology of Skin

Thick Skin

Epidermis • Stratum Corneum • Stratum Lucidum • Stratum Granulosum • Stratum Spinosum • Stratum Germinativum	

Dermis
 	
• Papillary Layer
  ○ Tactile Corpuscles
• Reticular Layer
  ○ Merocrine sweat glands	

Hypodermis • Lipids • Lamellated Corpuscles	

Thin Skin / Scalp

Epidermis • Stratum Corneum • Stratum Granulosum • Stratum Germinativum	

Dermis
 	
• Papillary Layer
  ○ Tactile Corpuscles
• Reticular Layer
  ○ Merocrine sweat glands
  ○ Sebaceous glands	

Hypodermis	
Hair Follicles • Papilla • Matrix • Hair	

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Practice Questions – Cells, Tissues, and Skin

Choices may be used more than once or not at all.

1-5. Matching

A)	Nucleus	transport synthesized substances throughout the cell	1) _____
B)	Ribosomes	package synthesized substances for secretion	2) _____
C)	Mitochondria	produce ATP from glucose and fatty acids	3) _____
D)	Golgi Apparatus	site for protein synthesis in the cytoplasm	4) _____
E)	Endoplasmic Reticulum	contains the genetic DNA code	5) _____

6-10. Matching

A)	Endoplasmic reticulum	contains channels	6) _____
B)	Cell membrane	site for synthesis of channels	7) _____
C)	Nucleus	contains genetic code for proteins	8) _____
		contains genetic code for channels	9) _____
		site for synthesis of proteins and other substances	10) _____

11-15. Matching

A)	Edge of plasma membrane facing extracellular fluid	is hydrophilic	11) _____
B)	Edge of plasma membrane facing intracellular fluid	contains lipids	12) _____
C)	Interior core of plasma membrane	is hydrophobic	13) _____
D)	None of the above	faces cytoplasm	14) _____
E)	A and B	contains phosphate groups	15) _____

16-20. Matching

A)	Interstitial fluid	found in cells	16) _____
B)	Vascular fluid	found in capillaries	17) _____
C)	Cytoplasm	found in fibrous CT	18) _____
		found in muscle cells	19) _____
		found in epithelial tissues	20) _____

21-25. Matching

A)	Integral transport proteins	may be pumps	21) _____
B)	Integral receptor proteins	may be channels	22) _____
C)	None of the above	act as extracellular receptors	23) _____
D)	A and B	include G-protein coupled receptors	24) _____
		imbedded within the phospholipid bilayer	25) _____

26-30. Matching

A)	Osmosis	movement in general along a concentration gradient	26) _____
B)	Diffusion	diffusion of large molecules using a carrier protein	27) _____
C)	Facilitated diffusion	diffusion of water along a concentration gradient	28) _____
D)	Primary active transport	movement of ions using a co-transporter	29) _____
E)	Secondary transport active	movement of ions using ATP	30) _____

31-35. Matching

A) Hypertonic	osmolality is low	31) _____
B) Hypotonic	osmolality is high	32) _____
C) Isotonic	solute concentration low	33) _____
	solute concentration high	34) _____
	solute concentration normal	35) _____

36-40. Matching

A) Sodium pumps	allow diffusion of water molecules	36) _____
B) Water channels	Integral transport proteins	37) _____
C) Sodium channels	may be passive or gated	38) _____
D) A, B, and C	allow diffusion of sodium ions	39) _____
E) A and B	Move sodium from low to high concentration	40) _____

41-45. Matching

A) Neurons	cells are specialized to conduct signals	41) _____
B) Muscle cells	cells have semipermeable membranes	42) _____
C) Epithelial cells	cells are tightly connected together	43) _____
D) Connective tissue cells	cells are specialized to shorten	44) _____
E) All of the above	cells secrete a matrix material	45) _____

46-50. Matching

A) Pseudostratified Ciliated Columnar Epithelium	sweep away debris	46) _____
B) Simple Squamous Epithelium	provide(s) a barrier	47) _____
C) Simple Columnar Epithelium	most easily allows diffusion	48) _____
D) Simple Cuboidal Epithelium	often involved in nutrient absorption	49) _____
E) All of the above	commonly secrete of glandular substances	50) _____

51-55. Matching

A) Simple Squamous	line exocrine glands, ducts, renal tubules	51) _____
B) Simple Cuboidal	line body cavities and blood vessels	52) _____
C) Simple Columnar	line respiratory airways	53) _____
D) Transitional	line ureter and bladder	54) _____
E) Pseudostratified Ciliated Columnar	line digestive tract	55) _____

56-60. Matching (CT = connective tissue)

A) Dense irregular CT	accumulates lipids	56) _____
B) Hyaline cartilage	found under most epithelium	57) _____
C) Osseous tissue	often found under areolar CT	58) _____
D) Adipose tissue	found at end of joints and in trachea	59) _____
E) Areolar CT	matrix composed of calcium phosphate	60) _____

61-65. Matching

A) Dense irregular fibrous connective tissue	contains lipids	61) _____
B) Areolar connective tissue	contains Mast cells	62) _____
C) Hyaline cartilage	contains chondroitin	63) _____
D) Adipose tissue	contains calcium phosphate	64) _____
E) None of the above	contains large scattered collagen fibers	65) _____

66-70. Matching

A) Chondrocytes	found in areolar CT	66) _____
B) Osteoblasts	found in 'fatty' tissue	67) _____
C) Adipocytes	produce bone matrix	68) _____
D) Fibroblasts	produce collagen fibers	69) _____
	produce cartilage matrix	70) _____

71-75. Matching

A) Hypodermis	does not contain blood vessels	71) _____
B) Epidermis	composed mainly of adipose tissue	72) _____
C) Dermis	composed of stratified squamous epithelium	73) _____
	composed mainly of fibrous connective tissue	74) _____
	major location of tactile receptors for light touch	75) _____

76-80. Matching

A) Stratum Lucidum	cells attached by spine like projections	76) _____
B) Stratum Corneum	nuclei and organelles disappear	77) _____
C) Stratum Spinosum	dead cells filled with Keratin	78) _____
D) Stratum Granulosum	keratohyalin formed here	79) _____
E) Stratum Germinativum	mitotically active	80) _____

81-85. Matching

A) Papillary layer of dermis	contain lymph nodes	81) _____
B) Reticular layer of dermis	contain many blood capillaries	82) _____
C) Hypodermis	composed of areolar connective tissue	83) _____
	composed of dense irregular connective Tissue	84) _____
	contain lamellated corpuscles for detecting pressure	85) _____

86-90. Matching

A) Merocrine sweat glands	secrete into hair follicles	86) _____
B) Sebaceous glands	invagination of epidermis into dermis	87) _____
C) Hair follicles	secrete sweat onto surface of epidermis	88) _____
D) A and B	anatomically are simple coiled tubular glands	89) _____
	anatomically are simple branched acinar glands	90) _____

91-95. Matching

A) Fluid from capillary leakage	dissipates heat	91) _____
B) Fluid from sweat glands	sensible perspiration	92) _____
C) A and B	insensible perspiration	93) _____
	increases with elevated body temperature	94) _____
	increases with increased skin blood flow rate	95) _____

Short Essays

1. Describe the role of membrane channels in allowing substances to pass into or out of a cell. Comment on the significance of the process of diffusion in allowing substances to move through a cell membrane.

2. Describe the role of DNA and RNA in protein synthesis. Comment on the role of proteins in controlling the function and behavior of a cell.

3. Compare and contrast the organization and function of epithelial tissues and connective tissues.

4. Describe the life cycle of cells of the epidermis of the skin. Include the names and characteristics of the various layers of cells.

5. Describe the role of blood vessels and sweat glands in the control of body temperature.

Section 2 –Osseous Tissue, Bone, and the Skeleton

Osseous Tissue and Bone

General organization of a long bone

Diaphysis

- The shaft of a bone.
- Composed mainly of dense bone.

Epiphysis

- The heads of a bone.
- Composed mainly of spongy bone.

Marrow Cavity

- Open interior of a bone.
- Lined by the endosteum.

Endosteum

- Lining of the marrow cavity.
- Composed of: an epithelial cellular layer with Osteoblasts and Osteoclasts.

Bone Marrow

- Adipose tissue and hemopoietic tissue (blood cells) in marrow cavity.

Periosteum

- Covering around the outside of a bone.
- Composed of Dense Irregular (Fibrous) Connective Tissue.

Joint Capsule

- Continuation of the periosteum around a joint.

Articular Cartilage

- Covering at end of the epiphysis.
- Composed of Hyaline cartilage.

Ligaments

- Continuation of the periosteum that connects bone to bone.
- Composed of dense regular connective tissue.

Tendons

- Continuation of the periosteum that connects bone to muscle.
- Composed of dense regular connective tissue.

Dense (Compact) Bone

Located mainly in the diaphysis of a bone

Osteon – The cylindrical unit of dense bone growing around a blood vessel.

Central Canal – The space in the center of the osteon that houses blood vessels.

Lamellae – Circularly arranged layers of bone matrix (calcium phosphate) within the osteon.

Lacunae – The spaces in the bone matrix that house the osteocytes.

Osteocytes – The bone cells in the lacunae.

Canaliculi – Channels in the bone matrix that connect the lacunae to the central canal.

Interstitial Lamellae – Layers of bone matrix between adjacent osteons.

Circumferential Lamellae – Layers of bone matrix between the osteons and the periosteum.

Periosteum

- Covering around the outside of a bone.
- Composed of: Dense Irregular (Fibrous) Connective Tissue.

Spongy (Cancellous) Bone

Located mainly in the heads of bone and near the marrow cavity.

Trabeculae

- Random flakes of bone that grow between blood vessels.

Lacunae

Osteocytes

Endosteum

- Lining of marrow cavity or spaces inside a bone.
- Composed of an epithelial-like layer consisting of various cells.
    - Simple Squamous Epithelial cells – Act as a barrier.
    - Osteoblasts – Cells responsible for producing new bone matrix.
    - Osteoclasts – Cells responsible for destroying old bone matrix.

Compact and Spongy Bone

Using the terms in the left box, draw and then label the structures, cells, or tissues. Alternatively, you may paste pictures and then label the structures, cells, or tissues. If you need more space use separate sheets of paper.

Bone Sectioned

Long Bone • Diaphysis • Epiphysis • Epiphyseal plate • Epiphyseal line • Endosteum • Marrow cavity • Periosteum	

Model of Bone

Compact Bone • Perforating canals • Central canals • Osteons • Calcium phosphate • Lacunae • Osteocytes • Lamellae • Canaliculi • Interstitial lamellae • Circumferential Lamellae • Periosteum	

Spongy Bone • Trabeculae • Lacunae • Osteocytes • Endosteum • Marrow Cavity	

Histology of Bone

Compact Bone • Osteons • Central canals • Calcium phosphate • Osteocytes in Lacunae • Lamellae • Canaliculi	

Spongy Bone / Developing Bone
 	
• Trabeculae
• Osteocytes in Lacunae
• Marrow Cavity
• Endosteum
  ○ Simple Squamous Epithelial Cells
  ○ Osteoblasts
  ○ Osteoclasts
• Hyaline cartilage
• Epiphyseal plate
• Articular Cartilage	

Bone growth and Metabolism

Development and Growth

Ossification – replacing other tissue with bone.

Calcification – deposition of calcium within a tissue.

Mineral metabolism

Parathyroid Hormone

Parathyroid hormone is ecreted in response to low blood levels of calcium.

- Stimulates osteoclast activity.
- Decreases rate of calcium excretion by kidney.

Calcitriol

Calcitriol is secreted in response to low blood levels of calcium.

- Increases rate of intestinal absorption of calcium.

Calcitonin

Calcitonin is secreted in response to very elevated blood levels of calcium.

- Inhibits osteoclast activity.
- Decreases rate of intestinal absorption of calcium.
- Increases rate of calcium excretion by kidney.

Bone remodeling

About one-fifth of skeleton is demolished and rebuilt each year.

Osteocytes maintain matrix by removing and replacing calcium salts.

Osteoclasts dissolve bone matrix.

Osteoblasts synthesize the new bone matrix.

Skeletal Organization, Bone, and Skull Markings

Organization of skeleton

Axial Skeleton

Skull

Hyoid bone

Vertebrae

Ribs and Sternum

Appendicular Skeleton

Upper Appendicular Skeleton

Shoulder girdle – clavicle and scapula

Arms – humerus, ulna, radius

Hands and Fingers – carpals, metacarpals, phalanges

Lower Appendicular Skeleton

Pelvic girdle – coxa

Thighs – femur

Legs – tibia and fibula

Feet and Toes – tarsals, metatarsals, phalanges

Shapes of bones

Flat bone – Flattened, such as bones of the roof of the skull.

Sutural bones – Grow between flat bones of skull.

Irregular bone – Complex, such as vertebrae.

Long bone – Elongated; such as bones of the limbs.

Short bone – Cube-like; such as bones of the wrist and ankles.

Sesamoid bone – Develop inside tendons, such as knee cap.

Bone Markings

- Projections or elevations where tendons and ligaments attach.
- Perforations or depressions where blood vessels and nerves pass.

General

Process – Any projection or bump.

Ramus – An extension making an angle.

Attachments for tendons or ligaments

Trochanter – Large, rough projection.

Tuberosity – Smaller, rough projection.

Tubercle – Small, round projection.

Crest – Prominent ridge.

Line – Low ridge.

For joints

Head – Expanded articular end.

Condyle – Smooth, rounded articular process.

Trochlea – Smooth, grooved articular process.

Facet – Small, flat articular process.

Spine – Pointed process.

Depressions

Fossa – Shallow depression.

Sulcus – Narrow grove.

Openings

Foramen – Rounded passageway.

Fissure – Cleft.

Meatus – Canal.

Sinus – Chamber.

Features and Foramen of the Skull

Occipital Bone

- Occipital Condyles – Joint surfaces for articulating with the first cervical vertebra (C1, atlas).
- Foramen Magnum – for medulla/spinal column; vertebral arteries.
- Jugular Foramen – for vagus and glossopharyngeal nerves; internal jugular veins.

Parietal bones

- Lambdoidal Suture – Joint between the parietal bones and the occipital bone.
- Sagittal Suture – Joint between the parietal bones.
- Coronal Suture – Joint between the parietal bones and the frontal bone.

Frontal Bone

- Orbit – The eye socket.
- Frontal Sinus – Marrow cavities in the frontal bone.

Maxillary Bone

- Maxillary Sinus – Marrow cavities of the maxillary bones.

Ethmoid Bone

- Crista Galli – Anterior attachment site for the dura mater of the brain.
- Cribriform Plate – For olfactory nerves.
- Superior and Middle Nasal Conchae – Extensions of bone into the nasal cavity.
- Perpendicular Plate – A sheet of bone that forms the superior part of the nasal septum.

Vomer Bone – A sheet of bone that forms the inferior part of the nasal septum.

Sphenoid Bone

- Sella Turcica - Forms a protective barrier for the pituitary gland.
- Optic Foramen (Canal) – For optic nerve.
- Superior Orbital Fissure – For 3 cranial nerves to eye muscles.
- Foramen Rotundum – For maxillary branch of trigeminal nerve.
- Foramen Ovale – For mandibular branch of trigeminal nerve.
- Foramen Spinosum – For vessels to membranes around CNS.
- Sphenoid Sinus – Marrow cavity of the sphenoid bone.

Temporal Bone

- Squamous Suture – Joint between the temporal bone and the parietal bone.
- External Acoustic Meatus – External entry for the ear.
- Internal Acoustic Meatus – For Vestibulocochlear nerve).
- Carotid Foramen (Canal) – For internal carotid artery).
- Foramen Lacerum – For internal carotid artery).
- Mandibular Fossa – Joint surface for mandible.
- Styloid Process – Muscle attachment site.
- Mastoid Process – Muscle attachment site.

Mandible

- Coronoid Process – Muscle attachment site.
- Mandibular Condyles – Joint surface for articulating with the temporal bone.

Skull – Laboratory

Using the terms in the left box, draw and then label the bones and features. Alternatively, you may paste pictures and then label the bones and features. If you need more space use separate sheets of paper.

Bones and Features of the Skull

Occipital bone • Occipital Condyles • Foramen Magnum • Jugular Foramen	
Parietal bones • Lambdoidal Suture • Sagittal Suture • Coronal Suture	
Frontal bone • Orbit • Frontal Sinuses	
Nasal bones	

Maxillary bones (Maxilla) • Maxillary Sinus	
Lacrimal bones	
Ethmoid bone • Crista Galli • Cribriform Plate • Superior and Middle Nasal Conchae • Perpendicular Plate	
Inferior nasal conchae	

Vomer bone • Nasal Septum (formed by the vomer bone, the perpendicular plate of the ethmoid bone, and cartilage)	
Palatine bones	
Sphenoid bone • Sella Turcica • Optic Foramen (Canal) • Superior Orbital Fissure • Foramen Rotundum • Foramen Ovale • Foramen Spinosum • Sphenoid Sinus	

Zygomatic bones • Zygomatic Arch • Temporal Process (of Zygomatic Bone)	
Temporal bones • Zygomatic Process of Temporal Bone • Squamous Suture • External Acoustic Meatus (External Auditory Canal) • Internal Acoustic Meatus (Internal Auditory Canal) • Mastoid Process • Styloid Process • Mandibular Fossa • Carotid Foramen (Canal) • Foramen Lacerum	
Mandible • Ramus • Coronoid Process • Condylar Processes (Mandibular Condyles)	

Features and Foramen of the Vertebrae

General Features

- Body – Anterior weight bearing portion.
- Vertebral foramen – Central opening for spinal cord.
- Spinal Processes – Posterior muscle attachment sites.
- Transverse Processes – Lateral muscle attachment sites.
- Superior and Inferior Articular Processes – Articulations between adjacent vertebrae posterior to bodies.
- Intervertebral Discs – Joint cushions between adjacent bodies.
- Intervertebral foramen – For spinal nerves.

Cervical vertebrae (C1-C7)

- Transverse foramen – For vertebral arteries).
- C1 (Atlas)
- C2 (Axis)
- Odontoid process (Dens) – Pivot on C2 for rotation of C1.

Thoracic vertebrae (T1-T12)

- Facets on transverse processes of T1-T10 – For joints with tubercle of ribs.
- Facets on body of T1-T12 – For joints with head of ribs.

Ribs

- Fixed ribs (1-10) – Contain tubercle and head and articulate with thoracic T1-T10.
- Floating ribs (11-12) – Contain head only and articulate with thoracic T11-T12.

Sternum

- Manubrium – Articulates with the clavicle bones and with ribs 1 and 2.
- Body – Articulates with ribs 3-10.
- Xiphoid process

Lumbar vertebrae (L1-L5)

Sacrum (S1-S4)

- Sacral canal – Contains anterior and posterior roots from the spinal cord.
- Sacral foramen – For spinal nerves.

Vertebrae – Laboratory

Using the terms in the left box, draw and then label the bones and features. Alternatively, you may paste pictures and then label the bones and features. If you need more space use separate sheets of paper.

General Features • Body • Vertebral foramen • Spinal process • Transverse processes • Superior and Inferior Articular processes • Intervertebral foramen • Intervertebral discs	
Cervical vertebrae (C1-C7) • Transverse foramen • C1 (Atlas) • C2 (Axis) ○ Odontoid process (Dens)	

Thoracic vertebrae (T1-T12)
 	
• Facets (on transverse processes, T1-T10)
  [for tubercle of rib]
• Facets / Demifacets (on body, T1-T12)
  [for head of rib]	

Ribs • Fixed ribs (1-10) • Floating ribs (11-12) • Tuberculum (Tubercle) (ribs 1-10) • Capitulum (Head) (ribs 1-12)	
Sternum • Manubrium • Body • Xiphoid process	
Lumbar vertebrae (L1-L5)	
Sacrum and Coccyx • Sacral canal • Sacral foramen	

Articulations

Upper Appendicular Skeleton

Clavicle

- Sternal end – Articulates with manubrium of sternum.
- Acromial end – Articulates with acromion process of scapula.

Scapula

- Acromion process – Articulates with acromial end of clavicle.
- Glenoid fossa – Articulates with head of humerus.

Humerus

- Head – Articulates with glenoid fossa of scapula.
- Trochlea – Articulates with trochlear notch of ulna.
- Coronoid fossa – Depression for coronoid process of ulna.
- Olecranon fossa – Depression for olecranon process of ulna.
- Capitulum – Articulates with head of radius.

Ulna

- Trochlear notch – Articulates with trochlea of humerus.
- Coronoid process – Articulates with coronoid fossa of humerus.
- Olecranon process – Articulates with olecranon fossa of humerus.
- Head – Articulates with Lunate bone of wrist.

Radius

- Head of radius – Articulates with capitulum of humerus.
- Styloid process of radius – Articulates with Scaphoid bone of wrist.

Carpus

- Lunate – Articulates with head of Ulna.
- Scaphoid – Articulates with styloid process of radius.

Metacarpals

- Metacarpals – Articulate with Proximal Phalanges.

Phalanges

- Digits (fingers)
    - Proximal Phalanges – Articulate with Middle Phalanges.
    - Middle Phalanges – Articulate with Distal Phalanges.
    - Distal Phalanges
- Pollex (thumb)
    - Proximal Phalanx – Articulates with Distal Phalanx.
    - Distal Phalanges

Lower Appendicular Skeleton

Ilium

- Sacroiliac Joint – Articulates with sacrum.

Pubis

- Pubic tubercle – Articulates with public tubercle.

Coxa

- Acetabulum – Articulates with head of femur.

Femur

- Head – Articulates with acetabulum of coxa.
- Lateral and Medial Condyles – Articulate with lateral and medial condyles of tibia.
- Intercondylar Fossa – dDepression for Intercondylar eminence of tibia.

Tibia

- Lateral and Medial Condyles – Articulate with lateral and medial condyles of femur.
- Margin of Lateral Condyle – Articulates with head of the fibula.
- Intercondylar Eminence – Articulates with the Intercondylar fossa of the femur.
- Medial Malleolus – Articulates with Talus bone of ankle.

Fibula

- Head of Fibula – Articulates with Margin of Lateral Condyle of femur.
- Lateral Malleolus – Articulates with talus bone of ankle.

Tarsus

- Talus – Articulates with medial malleolus of tibia and lateral, malleolus of fibula – articulates with Calcaneus.
- Calcaneus – Articulates with Navicular and Cuboid.

Metatarsals

- Metatarsals – Articulate with Proximal Phalanges.

Phalanges

- Digits (little toes).
    - Proximal Phalanges – Articulate with Middle Phalanges.
    - Middle Phalanges – Articulate with Distal Phalanges.
    - Distal Phalanges
- Hallux (big toe)
    - Proximal Phalanx – Articulates with Distal Phalanx.
    - Distal Phalanges

Structure of a Synovial Joint

Articular cartilage – Hyaline cartilage without perichondrium.

Synovial membrane – Lines joint cavity.

Joint capsule – Continuation of the periosteum that surrounds a joint.

Synovial fluid – Lubricates joint.

Menisci – Fibrocartilage pads between articular surfaces.

Fat pads – Around edges of joint.

Accessory ligaments – Localized thickenings of joint capsule.

- Extracapsular ligaments – Continuations of the periosteum exterior to a joint.
- Intracapsular ligaments – Continuations of the periosteum in the interior of a joint.

Bursae – Pockets of synovial fluid around tendons and ligaments.

Upper Appendicular Skeleton – Laboratory

Using the terms in the left box, draw and then label the bones and features. Alternatively, you may paste pictures and then label the bones and features. If you need more space use separate sheets of paper.

Pectoral girdle

Sternum • Manubrium	
Clavicle • Sternal end • Acromial end	
Scapula • Superior border • Glenoid fossa (cavity) • Coracoid process • Acromial process • Scapular spine	

Arm

Humerus • Head • Deltoid tuberosity • Trochlea • Capitulum • Coronoid fossa • Olecranon fossa	
Ulna • Trochlear notch • Olecranon • Coronoid process • Head of ulna • Styloid process of ulna	
Radius • Head of radius • Radial tuberosity • Styloid process of radius	

Wrist and Hand

Carpus • Lunate • Scaphoid	
Hand • Metacarpals – 1 thru 5 • Phalanges – 1 thru 5 • thumb – Pollex o Proximal and Distal Phalanx – 1 • fingers – Digits o Proximal, Middle, and Distal Phalanges – 2 thru 5	

Lower Appendicular Skeleton – Laboratory

Using the terms in the left box, draw and then label the bones and features. Alternatively, you may paste pictures and then label the bones and features. If you need more space use separate sheets of paper.

Coxa

Ilium • Anterior inferior iliac spine • Anterior superior iliac spine • Iliac crest • Posterior superior iliac spine • Posterior inferior iliac spine • Greater sciatic notch	
Ischium • Ischial spine • Lesser sciatic notch • Ischial tuberosity • Ischial ramus	
Pubis • Inferior ramus • Pubic body • Pubic Symphysis • Superior ramus	

Coxa • Acetabulum • Obturator foramen • Sacroiliac joint	

Thigh and Leg

Femur • Head • Greater trochanter • Lesser trochanter • Gluteal tuberosity (tubercle) • Linea aspera • Lateral condyle • Medial condyle • Intercondylar fossa	
Patella	
Tibia • Lateral condyle • Medial condyle • Intercondylar eminence • Tibial tuberosity • Anterior crest • Medial malleolus	

Fibula • Head of fibula • Lateral malleolus	

Ankle and Foot

Tarsus • Talus • Calcaneus	
Foot • Metatarsals – 1 thru 5 • Phalanges – 1 thru 5 • big toe – Hallux o Proximal and Distal Phalanx – 1 • Little toes – Digits o Proximal, Middle, and Distal Phalanges – 2 thru 5	

Practice Questions – Skeleton

Choices may be used more than once or not at all.

1-5. Matching

A)	Diaphysis	composed of Osteoblasts and Osteoclasts	1) _____
B)	Epiphysis	adipose tissue and hemopoietic tissue	2) _____
C)	Endosteum	lined by the endosteum	3) _____
D)	Bone Marrow	the heads of a bone	4) _____
E)	Marrow Cavity	the shaft of a bone	5) _____

6-10. Matching

A)	Articular Cartilage	connects bone to bone	6) _____
B)	Joint Capsule	composed of Hyaline cartilage	7) _____
C)	Periosteum	covering at end of the epiphysis	8) _____
D)	Ligaments	covering around the outside of a bone	8) _____
E)	Tendons	continuation of the periosteum around a joint	10) _____

11-15. Matching

A)	Lacunae	channels in the bone for nourishing bone cells	11) _____
B)	Canaliculi	covering around the outside of a bone	12) _____
C)	Periosteum	spaces within the cartilage matrix	13) _____
D)	Perichondrium	spaces within the bone matrix	14) _____
		covering around cartilage	15) _____

16-20. Matching

A)	Trabeculae	cells responsible for destroying old bone matrix	16) _____
B)	Osteocytes	cells responsible for producing new bone matrix	17) _____
C)	Osteoblasts	the cartilage producing cells in the lacunae	18) _____
D)	Osteoclasts	the bone cells in the lacunae	19) _____
E)	Chondrocytes	basic unit of spongy bone	20) _____

21-25. Matching

A)	Found in compact bone	lacunae	21) _____
B)	Found in spongy bone	canaliculi	22) _____
C)	A and B	osteocytes	23) _____
D)	None of the above	central canal	24) _____
		bone marrow	25) _____

26-30. Matching

A)	Ligaments	continuation of the “periosteum” around a joint	26) _____
B)	Endosteum	covering around the outside of a bone	27) _____
C)	Periosteum	contains osteoblasts and osteoclasts	28) _____
D)	Articular capsule	separates bone marrow from bone	29) _____
E)	None of the above	connect(s) bone to bone	30) _____

31-35. Matching

A)	Calcitonin	produced in response to low blood calcium	31) _____
B)	Parathormone	produced by parathyroid 'chief'cells	32) _____
C)	None of the above	produced by thyroid 'C' cells	33) _____
		stimulate osteoclasts	34) _____
		inhibit osteoblasts	35) _____

36-40. Matching

A)	Temporal bones	contains sella turcica	36) _____
B)	Sphenoid bone	articulates with the atlas	37) _____
C)	Occipital bone	contains the mandibular fossa	38) _____
D)	Ethmoid bone	contains superior and middle concha	39) _____
E)	Maxilla	forms a major part of the roof of the mouth	40) _____

41-45. Matching

A)	Foramen ovale	for nerves for eye movement	41) _____
B)	Optic foramen	for trigeminal nerve	42) _____
C)	Jugular foramen	for jugular veins	43) _____
D)	Foramen magnum	for optic nerve	44) _____
E)	Superior orbital fissure	for spinal cord	45) _____

46-50. Matching

A)	Forms part of the orbits (eye sockets)	vomer bone	46) _____
B)	Forms part of nasal septum	frontal bone	47) _____
C)	None of the above	sphenoid bone	48) _____
		maxillary bones	49) _____
		perpendicular plate of Ethmoid bone	50) _____

51-55. Matching

A)	Cervical vertebra	contain facets for ribs	51) _____
B)	Thoracic vertebra	contain vertebral foramen	52) _____
C)	Tumbar vertebra	contain spinous processes	53) _____
D)	All of these	contain transverse foramen	54) _____
		contain intervertebral foramen (notch)	55) _____

56-60. Matching

A)	Cervical vertebrae	contain facets on bodies	56) _____
B)	Thoracic vertebrae	contain articular processes	57) _____
C)	Tumbar vertebrae	contain transverse foramen	58) _____
D)	All of the above	contain transverse processes	59) _____
		have large bodies with stout spinous processes	60) _____

61-65. Matching

A)	Non-floating ribs	ribs 1- 7	61) _____
B)	Floating ribs	ribs 8-10	62) _____
		ribs 11-12	63) _____
		contain capitulum only	64) _____
		contain capitulum and tuberculum	65) _____

66-70. Matching

A)	Ribs 1-10	are called the floating ribs	66) _____
B)	Ribs 11 and 12	contain head and tubercle	67) _____
C)	None of the above	contain head and no tubercle	68) _____
		connect to the vertebrae only at the bodies	69) _____
		connect to vertebrae at the bodies and transverse processes	70) _____

71-75. Matching

A)	Radius	articulates with the scaphoid bone	71) _____
B)	Ulna	articulates with the lunate bone	72) _____
C)	None of the above	articulates with the capitulum	73) _____
		articulates with the trochlea	74) _____
		contains the radial notch	75) _____

76-80. Matching

A)	Humerus	connects at the glenoid fossa (cavity)	76) _____
B)	Manubrium	connects with medial end of clavicle	77) _____
C)	Coracoid process	connects with lateral end of clavicle	78) _____
D)	Coranoid process	found in the scapula	79) _____
E)	Acromion process	found in the ulna	80) _____

81-85. Matching

A)	Ulna	contains the greater trochanter	81) _____
B)	Tibia	contains the deltoid tuberosity	82) _____
C)	Femur	contains the gluteal tuberosity	83) _____
D)	Fibula	contains the lateral malleolus	84) _____
E)	Humerus	contains the linea aspera	85) _____

86-90. Matching

A)	Ilium	most posterior and inferior coxal bone	86) _____
B)	Pubis	most anterior and inferior coxal bone	87) _____
C)	Ischium	connects with the head of the femur	88) _____
D)	Acetabulum	most superior coxal bone	89) _____
E)	Oobturator foramen	connects with the sacrum	90) _____

91-95. Matching

A)	Fibular articular surface of tibia	connects to tibia	91) _____
B)	Lateral and medial malleolus	connects to fibula	92) _____
C)	Condyles of femur	connects to talus bone	93) _____
D)	Acetabulum	connects to the calcaneus bone	94) _____
E)	Talus bone	connects to the head of the femur	95) _____

Short Essays

1. Describe the mechanisms responsible for the maintenance of relatively constant levels of calcium in the blood. Include the role of hormones, osteoblasts and osteoclasts
2. Compare and contrast the structures and functions of the connective tissues found in bone. Include osseous tissues, fibrous connective tissues, and adipose tissue.
3. Relate differences in the anatomical structure of various joints to the movements that these joints permit. Use three examples.

Section 3 – Muscle Tissue and Skeletal Muscles

Muscle and Muscle Tissues

Classification of Muscle Tissues

Skeletal Muscle

Extrafusal muscle

- Cells are long, ribbon shaped with multiple nuclei, and are arranged in parallel.
- Cells are connected side by side with fibrous connective tissue.
- Skeletal muscle cells are responsible for the contraction of skeletal muscles.

Intrafusal Muscle

- Short cells with single nuclei that are surrounded by sensory nerve receptors.
- The cells are attached in parallel to the Skeletal muscle cells.
- The intrafusal muscle cells and their associated receptors are responsible for detecting the degree of skeletal muscle stretch.

Cardiac Muscle

- Cells are short, rectangular shaped with a single nucleus.
- cells are connected together end to end by interdigitations of the cell membranes, visible as the Intercalated Discs.
- Cells are connected side by side with fibrous connective tissue.
- Cardiac muscle cells are responsible for contraction of the heart.

Smooth Muscle

- Cells are small, spindle shaped cells with a single nucleus.
- The cells are connected end to end and side by side with fibrous connective tissue.
- Smooth muscle cells are responsible for contraction of blood vessels, the respiratory airways, the gastrointestinal tract, and other internal organs.

General Organization of Skeletal Muscles

Fascia

- Dense irregular (fibrous) connective tissue that surrounds groups of skeletal muscles.

Epimysium

- Dense irregular (fibrous) connective tissue that surrounds an individual skeletal muscle.

Fascicles

- Within an individual skeletal muscle, the skeletal muscle cells are organized in bundles.

Perimysium

- Dense irregular (fibrous) connective tissue that surrounds the fascicles.

Endomysium

- Dense irregular (fibrous) connective tissue that surrounds individual skeletal muscle cells.
- Intrafusal Muscle Cells are attached in parallel to groups of one or more skeletal muscle cells by the endomysium.

Organization of individual skeletal muscle cells (muscle fibers)

Sarcolemma – The plasma membrane that surrounds the muscle cell.

Neuromuscular Junction – The communication point between neurons and skeletal muscle that includes.

- Motor End Plate – Specialized region of sarcolemma for receiving signals from neurons.
- Synaptic Bulbs – The terminal ends of neurons that send signals to the motor end plate.

Sarcoplasm – The cytoplasm of skeletal muscle cells.

Myofibrils – Bundles of alternating and partially overlapping protein myofilaments in the interior of a muscle cell consisting of.

- Thin filaments (especially the protein Actin).
- Thick filaments (especially the protein Myosin).

Sarcoplasmic reticulum – A structure similar to the endoplasmic reticulum that surrounds the myofibrils.

Transverse tubules – Invaginations of the sarcolemma that carry signals to the sarcoplasmic reticulum.

Sarcomeres – Groups of myofibrils that include Actin-Myosin-Myosin-Actin and form functional units for muscle shortening.

Organization of Sarcomeres in a longitudinal view

A-band – The presence of the thick filaments (Myosin) makes the A-band appear dark.

I-band – In the absence of the thick filaments the thin filaments (Actin) of the I-band appear light.

M-line – The junction between adjacent thick filaments (myosin) in the center of the sarcomere.

H-zone – The central region of the A-band where there is no actin.

Zone of overlap – The region where thick filaments (myosin) and thin filaments (actin) overlap.

Z-line – The junctions between adjacent thin filaments (actin) at the ends of the sarcomere.

Skeletal Muscle Tissue – Laboratory

Using the terms in the left box, draw and then label the structures. Alternatively, you may paste pictures and then label the structures. If you need more space use separate sheets of paper.

Model of Skeletal Muscle

Cable • Epimysium • Fascicles • Perimysium • Endomysium	

Models of Skeletal Muscle Cell

Muscle Cell in cross section • Endomysium • Sarcolemma • Motor End Plate • Synaptic Bulbs • Myofibrils	
Myofibrils in longitudinal section • A-band • I-band • M-line • Z-line • H-zone • Zone of overlap • Thin filaments (the protein Actin) • Thick filaments (the protein Myosin) • Sarcomeres • Sarcoplasmic reticulum • Transverse Tubules	

Histology of Skeletal Muscle

Skeletal Muscle Fascicles and Cells in cross section • Fascicles • Perimysium • Endomysium • Myofibrils	
Skeletal Muscle Cells in longitudinal section • I-Band • A-Band • Sarcomere	
Neuromuscular Junction • Skeletal Muscle Cells • Motor End Plate • Synaptic Bulbs	

Muscle Contraction

Anatomy of Sliding Filament mechanism

Actin Chain

- Composed of round strands of chains of actin molecules.
- Active Sites – binding sites on the actin molecules.
- Tropomyosin – protein chain that parallels the actin chain and covers the active sites.
- Troponin – protein that binds to both actin and tropomyosin, holding the tropmyosin in place.

Myosin Chain

- Composed of helical array of myosin molecules.
- Globular Heads (cross bridges) – enlarged end of myosin molecule that projects away from the center of the thick filament.
- ADP and phosphate – bound to the cross bridges (the cross bridge of the myosin chain acts as an ATPase, breaks down ATP, and stores the energy).

Sarcomere

- Repeating unit of the myofibrils consisting of actin, myosin, myosin, actin.

Transverse Tubules

- Begin at the sarcolemma, travels perpendicular to the sarcolemma and encircles the sarcomeres and comes in close contact with the sarcoplasmic reticulum.
- Conducts action potential from the sarcolemma toward the sarcoplasmic reticulum.

Sarcoplasmic reticulum

- Surrounds each sarcomere and is similar in structure to the endoplasmic reticulum.
- Stores calcium by way of a calcium ion pump.

Contraction cycle

Generation of an action potential

- The sarcolemma has the ability to conduct an electrical impulse (excitable membrane).
- A massive change in membrane permeability causes a depolarization that sweeps across the cell (the action potential.).
- A neurotransmitter binds to receptors on the motor end-plate and causes the opening of chemically gated sodium channels.

Conduction of an action potential

- The action potential is immediately conducted across the cell and travels down each of the transverse tubules to act on the sarcoplasmic reticulum.
- The influx of sodium causes the opening of voltage gated sodium channels.
- The sequential opening and closing of sodium channels along the membrane is the action potential.

Action on sarcoplasmic reticulum to release calcium

- Arrival of the action potential activates and opens calcium channels in the membrane of the sarcoplasmic reticulum, permitting release of the stored calcium.

Action of calcium

- Calcium binds to the troponin molecule, moving the troponin-tropomyosin complex and exposing the active sites.
- Myosin cross bridges bind to the active sites using the energy stored in the myosin molecule.
- The globular head pivots toward the center of the sarcomere (ADP and phosphate is released).
- Cross bridges detach when the myosin head binds another ATP molecule.
- Free myosin head breaks down the ATP, retaining the ADP and phosphate, and storing the energy.
- Myosin cross bridges bind to the active sites and the cycle repeats until calcium concentration returns to normal (by way of active transport into the sarcoplasmic reticulum).

Muscular Organization for Movement

Overview

- An observable movement of the body generally involves muscles pulling on bones, skin or muscle.
- Muscles produce movements by pulling (shortening or contracting) *not* by pushing.

Muscle Connections

- Muscles pull on bones, skin or other muscles by way of cord like extensions commonly called tendons.

  Tendons –The connective tissue that intermingles with muscle cells and surrounds a muscle, and that in turn extends away from the muscle.

  Origin – The connection at the end of the tendon that anchors the muscle to a bone.

  Insertion – The connection at the end of the tendon that attaches to the bone (or skin) that moves.

Reciprocal Control

- Movements in opposing directions are caused by different muscles connecting to complementary portions of a bone.

  Agonist – The muscle that, by way of contraction, can cause the movement of interest.

  Antagonist – The muscle that, by way of contraction, can cause an opposing movement.

Head and Trunk Muscles

Muscles of Facial Expresssion			
Action	*Muscle*	*Origin*	*Insertion*
Scalp			
Raise eyebrow	Frontalis	aponeurosis	eyebrow
Tense scalp	Occipitalis	occipital	aponeurosis
Eye			
Close eyes	Orbicularis oculi	medial orbit	eyelids
Mouth			
Compress / Pucker lips	Orbicularis Oris	maxillae mandible	lips
Elevate lips	Levator Labii	maxillae	orbicularis oris
Depress lips	Depressor Labii	mandible	lower lip
Protude lips	Mentalis	mandible	skin of chin
Compress cheeks	Buccinator	maxillae mandible	orbicularis oris
Elevate angle of Mouth	Zygomaticus	zygomatic	angle of mouth

Muscles of Chewing and Swallowing			
Action	*Muscle*	*Origin*	*Insertion*
Muscles of Mastication			
Elevate jaw	Temporalis	temporal	coronoid mandible
	Masseter	zygomatic arch	lateral mandible
Compress cheeks	Buccinator	maxillae mandible	orbicularis oris
Muscles of the Tongue			
Depress tongue	Genioglossus	mandible, medial	body of tongue
Extrinsic Muscles of the Larynx			
Elevate larynx	Digastricus	mastoid, mandible	hyoid bone
	Stylohyoid	styloid process	hyoid
Depress larynx	Omohyoid	clavicle	hyoid, scapula

Muscles of the Spine and Trunk			
Action	*Muscle*	*Origin**	*Insertion*
Muscles of the Spine			
Extend head	Semispinalis capitis	c t vertebrae	occipital bone
	Splenius capitis	c vertebrae	mastoid occipital
Flex head	Sternocleidomastoid	manubrium, clavicle	mastoid
Extend spine	Spinalis	t l vertebrae	t vertebrae
	Longissimus	t l vertebrae	t l vertebrae
	Iliocostalis	ileum, t l vertebrae	ribs
Oblique and Rectus Muscles			
Elevate ribs, Expand ribcage	Scalene	c vertebrae	1-2 ribs
	Ext. Intercostals	inferior ribs	superior ribs
Expand lower ribcage (?)	Serratus Posterior	T11-L2	9-12 ribs
Contract ribcage	Int. Intercostals	superior ribs	inferior ribs
Depress ribs, Flex waist / spine	Rectus Abdominus	5-7 ribs xiphoid	pubis
Compress abdomen	External Oblique	5th to 12th ribs	ilium linea alba
	Internal Oblique	ilium	lower ribs
	Transverse Abdominus	lower ribs	pubis linea alba
Expand chest	Diaphragm	xiphoid 4-10 ribs	tendon sheet

*c = cervical, t = thoracic; l = lumbar

Head and Trunk Muscles – Laboratory

Using the terms in the left box, draw and then label the muscles. Alternatively, you may paste pictures and then label the muscles. If you need more space use separate sheets of paper.

Muscles of Facial Expression

Scalp and Eye

Elevate Eyebrow • Frontalis Tense Scalp • Occipitalis Close Eye • Orbicularis oculi	

Mouth

Close Mouth • Orbicularis Oris Elevate Lips • Levator Labii Depress Lips • Depressor Labii Protrude Lips • Mentalis Compress Cheeks • Buccinator Smile • Zygomaticus	

Muscles of Chewing and Swallowing

Muscles of Mastication

Elevate Jaw • Temporalis • Masseter Compress Cheek • Buccinator	

Muscles of the Tongue

Depress Tongue • Genioglossus	

Extrinsic Muscles of the Larynx

Elevate Larynx • Digastricus • Stylohyoid Depress Larynx • Omohyoid	

Muscles of the Spine and Trunk

Muscles of the Spine

Flex Head/Neck • Sternocleidomastoid Extend Head/Neck • Semispinalis capitis • Splenius capitis Flex Back • Quadratus Lumborum Extend Back • Spinalis • Longissimus • Iliocostalis Lumborum	

Oblique and Rectus Muscles

Elevate Ribs • Scalene Contract (Compress) Ribcage • Ext. Intercostals Expand Ribcage • Int. Intercostals Depress Ribs • Rectus Abdominus Compress Abdomen • External Oblique • Internal Oblique • Transverse Abdominus Depress Diaphragm • Diaphragm Muscle	

Upper Body Muscles

Muscles of the Shoulder and Upper Arm			
Action	*Muscle*	*Origin*	*Insertion*
Muscles that move the Shoulder Girdle			
Elevator	Levator Scapulae	cervical 1-4	scapula, medial
	Trapezius	occipital thoracic	scapula, clavicle
Depressor	Pectoralis Minor	3-5 ribs	scapula, coracoid
Abductor	Serratus Anterior	1-9 ribs	scapula, medial
Adductor	Rhomboideus Major	thoracic	scapula, medial
Muscles that move the Upper Arm			
Abductors	Deltoid	scapula, acromion	humerus deltoid
Adductors	Pectoralis Major	ribs sternum clavicle	humerus greater tubercle
	Latissimus Dorsi	thoracic lumbar	humerus lesser tubercle
Flexors	Pectoralis Major	ribs sternum clavicle	humerus greater tubercle
Extensors	Latissimus Dorsi	thoracic lumbar	humerus lesser tubercle
	Triceps (long)	scapula	ulna, olecranon

Muscles of the Lower Arm and Wrist			
Action	*Muscle*	*Origin*	*Insertion*
Muscles that move the Lower Arm			
Flexors	Biceps Brachii	scapula	radius, radial
	Brachioradialis	humerus	radius, styloid
Extensors	Triceps (lat/med)	humerus	ulna, olecranon
Muscles that move the Wrist			
Flexors	Palmaris Longus	humerus, medial	palm
	Flexor Carpi Radialis	humerus, medial	metacarpal 2
	Flexor Carpi Ulnaris	humerus ulna	metacarpal 3-5
Extensors	Extensor Carpi Radialis Longus	humerus, lateral	metacarpal 2
	Extensor Carpi Ulnaris	humerus ulna	metacarpal 5

Muscles of the Fingers			
Action	*Muscle*	*Origin*	*Insertion*
Muscles that move the Fingers			
Flexors	Flexor Digitorum Profundus	ulna	phalanges 2-5
	Flexor Digitorum Superficialis	humerus radius	phalanges 2
Extensors	Extensor Digitorum	humerus	phalanges 2-5

Upper Body Muscles – Laboratory

Using the terms in the left box, draw and then label the muscles. Alternatively, you may paste pictures and then label the muscles. If you need more space use separate sheets of paper.

Muscles of the Shoulder and Upper Arm

Muscles that move the Shoulder Girdle (Scapula)

Elevate Scapula • Levator Scapulae • Trapezius Depress Scapula • Pectoralis Minor Abduct Scapula • Serratus Anterior Adduct Scapula • Rhomboideus Major	

Muscles that move the Shoulder Girdle (Scapula)

Abduct Humerus • Deltoid Adduct Humerus • Pectoralis Major • Latissimus Dorsi Flex Humerus • Pectoralis Major Extend Humerus • Latissimus Dorsi • Triceps (long)	

Muscles of the Lower Arm and Wrist

Muscles that move the Lower Arm (Radius / Ulna)

Flexor Radius / Ulna • Biceps Brachii • Brachioradialis Extend Radius / Ulna • Triceps (lat/med)	

Muscles that move the wrist (Carpus)

Flex Carpus • Palmaris Longus • Flexor Carpi Radialis • Flexor Carpi Ulnaris Extend Carpus • Extensor Carpi Radialis Longus • Extensor Carpi Ulnaris	

Muscles of the Fingers and Thumb

Muscles that move the Fingers (Digits)

Flex Digits • Flexor Digitorum Profundus • Flexor Digitorum Superficialis Extend Digits • Extensor Digitorum	

Lower Body Muscles

Muscles of the Hip and Thigh			
Action	*Muscle*	*Origin*	*Insertion*
Muscles that Move the Thigh			
Flexors	Iliopsoas	ilium	femur
Extensors	Gluteus Maximus	ilium, crest	femur, gluteal tuberosity
Abductors	Gluteus Medius	ilium, crest	femur, greater trochanter
	Tensor Fasciae Latae	ilium, crest	iliotibial
Adductors	Adductor Magnus	pubis, inferior ramus	femur, linea aspera
	Adductor Longus	pubis, inferior ramus	femur, linea aspera

Muscles of the Leg and Ankle			
Action	*Muscle*	*Origin*	*Insertion*
Muscles that Move the Leg			
Flexors (Hamstrings)	Biceps Femoris	ischium femur	fibula tibia
	Semitendinosus	ischium, tuberosity	tibia, posterior
	Semimembranosus	ischium, tuberosity	tibia, posterior
	Gracilis	pubis ischium	tibia, medial
	Sartorius	ilium, anterior inferior.	tibia, medial
Extensors (Quadriceps)	Rectus Femoris	ilium, anterio inferior	tibia, tuberosity
	Vastus Intermedius	femur, linea aspera distal.	tibia, tuberosity
	Vastus Lateralis	femur, linea aspera proximal.	tibia, tuberosity
	Vastus Medialis	femur, linea aspera	tibia, tuberosity.
Muscles that Move the Ankle			
Dorsiflexors	Tibialis anterior	tibia, lateral	1st metatarsal
Plantar flexors	Gastrocnemius	femur	calcaneus
	Soleus	fibula tibia	calcaneus

Muscles of the Toes			
Action	*Muscle*	*Origin*	*Insertion*
Muscles that Move the Little Toes			
Flexors	Flexor Digitorum Longus	tibia, posterior medial	2-5 phalanges
Extensors	Extensor Digitorum Longus	tibia fibula, anterior	2-5 phalanges

Lower Body Muscles – Laboratory

Using the terms in the left box, draw and then label the muscles. Alternatively, you may paste pictures and then label the muscles. If you need more space use separate sheets of paper.

Muscles of the Hip and Thigh

Muscle that move the Thigh (Femur)

Flex Femur • Iliopsoas Extend Femur • Gluteus Maximus Abduct Femur • Gluteus Medius • Tensor Fasciae Latae Adduct Femur • Adductor Magnus • Adductor Longus	

Muscle that move the Leg (Tibia / Fibula)

Flex Tibia / Fibula • Biceps Femoris • Semitendinosus • Semimembranosus • Gracilis • Sartorius Extend Tibia / Fibula • Rectus Femoris • Vastus Intermedius • Vastus Lateralis • Vastus Medialis	

Muscles that move the Ankle (Tarsus)

Dorsiflex Tarsus • Tibialis anterior Plantar Flex Tarsus • Gastrocnemius • Soleus	

Muscles of the Toes

Muscles that move the Little Toes (Digits)

Flex Digits • Flexor Digitorum Longus Extend Digits • Extensor Digitorum Longus	

Muscle Tension and Muscle Metabolism

Muscle twitches and tension development

Twitch

- A single stimulus-contraction-relaxation sequence in a muscle cell.
- Latent period – about 10 msec in duration, as the action potential sweeps across the sarcolemma and calcium ions are released.
- Contraction phase – about 40 msec in duration, as cross bridges are interacting with active sites on the actin filaments.
- Relaxation phase – about 50 msec, as the cross bridges detach.

Sarcomere length-tension relationships

- Tension developed increases as the the number of cross bridges increase. (When sarcomeres are too shortened, tension decreases as the.
- Thick filaments run into the Z-line).

Effects of repeated stimulation

Treppe

- Stimulations repeating immediately after the relaxation phase lead to twitches that increase in tension, and reach a plateau..
- Movements will be very jerky.

Wave summation

- Stimulations repeating before the relaxation phase has ended lead to twitches that increase in tension, and reach a plateau.
- Movements will be moderately jerky.

Complete tetanus

- Stimulations repeating before the relaxation phase begins do not lead to twitches. The tension will increase and reach a plateau.
- Movements will be smooth.

Recruitment

- By increasing the number of motor units activated the total tension of a muscle can be increased.

Isometric and isotonic contractions

- Isotonic – length of muscle shortens as tension is developed.
- Isometric – length of muscle remains constant as tension is developed.

Energetics of muscle activity

Aerobic metabolism

Resting muscle

- Fatty acids are catabolized using oxygen to produce ATP.
- ATP is used to store glucose as glycogen.
- excess ATP is stored as creatine phosphate:

$$\text{ATP + creatinine} \rightarrow \text{ADP + creatine phosphate}$$

$$\text{ADP + creatinine phosphate} \rightarrow \text{ATP + creatine}$$

Moderate activity in muscle

- Glycogen, Glucose and fatty acids catabolized using oxygen to produce ATP
- Involves sarcoplasmic breakdown of glucose:

$$\text{glucose} \rightarrow \text{2 pyruvic acid + 2 ATP}$$

- And mitochondrial breakdown of pyruvic acid:

$$O_2 + \text{2 pyruvic acid} \rightarrow CO_2, H_2O + \text{34 ATP}$$

Anaerobic metabolism

Peak activity in muscle

- Glycogen, glucose is catabolized without oxygen to produce ATP.
- Involves sarcoplasmic breakdown of glucose:

$$\text{glucose} \rightarrow \text{2 pyruvic acid + 2 ATP}$$

- And conversion of pyruvic acid to lactic acid.

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Practice Questions – Skeletal Muscle

Choices may be used more than once or not at all.

1-5. Matching

A)	Endomysium	continues as tendons	1) _____
B)	Perimysium	bundles of muscle cells	2) _____
C)	Epimysium	surrounds skeletal muscles	3) _____
D)	Fascicles	surrounds muscle fascicles	4) _____
		surrounds individual skeletal muscle cells	5) _____

6-10. Matching

A)	Sarcomere	neurotransmitter sensitive portion of cell membrane	6) _____
B)	Sarcolemma	unit of Actin-Myosin-Myosin-Actin	7) _____
C)	Sarcoplasm	cytoplasm of muscle cell	8) _____
D)	Motor end plate	muscle cell membrane	9) _____
E)	Sarcoplasmic reticulum	stores calcium	10) _____

11-15. Matching

A)	Actin	contains binding sites for myosin	11) _____
B)	Myosin	is short in contracted muscle	12) _____
C)	Troponin-tropomyosin	covers binding sites on actin	13) _____
D)	None of the above	is phosphorylated by ATP	14) _____
		is long in relaxed muscle	15) _____

16-20. Matching

A)	Z-line	contains myosin and myosin overlapping with actin	16) _____
B)	I-band	contains only myosin overlapping with actin	17) _____
C)	M-line	composed mainly of actin	18) _____
D)	A-band	site for joining of myosin	19) _____
E)	zone of overlap	site for joining of actin	20) _____

21-25. Matching

A)	Origin	a muscle that opposes the action of another muscle	21) _____
B)	Agonist	a muscle primarily responsible for a movement	22) _____
C)	Insertion	the end of a muscle that acts as the anchor	23) _____
D)	Antagonist	the end of the muscle that usually moves	24) _____
E)	None of the above	the humerus is the _____ for the deltoid	25) _____

26-30. Matching

A)	Elevate mandible	Masseter	26) _____
B)	Compress cheeks	Buccinator	27) _____
C)	Depress tongue	Temporalis	28) _____
D)	Compress lips	Genioglossus	29) _____
E)	None of these	Orbicularis Oris	30) _____

31-35. Matching

A) Elevate larynx
B) Depress larynx
C) Elevate ribs / expand ribcage
D) Depress ribs /contract ribcage

External Intercostals 31) _____
Internal Intercostals 32) _____
Stylohyoid 33) _____
Omohyoid 34) _____
Scalenes 35) _____

36-40. Matching

A) Compress ribcage
B) Expand ribcage
C) Compress abdomen
D) None of these

External Intercostals 36) _____
Internal Intercostals 37) _____
Internal Oblique 38) _____
Splenius Capitis 39) _____
Scalene 40) _____

41-45. Matching

A) Flex head
B) Flex waist
C) Elevate jaw
D) Extend head
E) None of these

sternocleidomastoid 41) _____
semispinalis capitis 42) _____
rectus abdominus 43) _____
masseter 44) _____
splenius 45) _____

46-50. Matching

A) Abduct shoulder (scapula)
B) Adduct shoulder (scapula)
C) Depress shoulder (scapula)
D) Elevate shoulder (scapula)
E) None of these (scapula)

Levator Scapulae 46) _____
Latissimus dorsi 47) _____
Pectoralis Minor 48) _____
Rhomboideus Major 49) _____
Serratus Anterior 50) _____

51-55. Matching

A) Extend wrist
B) Flex wrist
C) Extend lower arm
D) Flex lower arm
E) None of these

Extensor Carpi Radialis Longus 51) _____
Extensor Digitorum Ulnaris 52) _____
Flexor Carpi Ulnaris 53) _____
Palmaris Longus 54) _____
Brachioradialis 55) _____

56-60. Matching

A) Abduct upper arm
B) Adduct/extend upper arm
C) Adduct/flex upper arm
D) Extend lower leg
E) Flex lower leg

Latissimus Dorsi 56) _____
Pectoralis Major 57) _____
Biceps Femoris 58) _____
Rectus Femoris 59) _____
Deltoid 60) _____

61-65. Matching

A) Plantar flex foot
B) Dorsiflex foot
C) None of these

Soleus 61) _____
Gastrocnemius 62) _____
Rectus Femoris 63) _____
Tibialis Anterior 64) _____
Extensor Digitorum Longus 65) _____

66-70. Matching

A) Extend thigh
B) Flex thigh
C) Abduct thigh
D) Adduct thigh

Tensor Facia Latae 66) _____
Gluteus Maximus 67) _____
Gluteus Medius 68) _____
Iliopsoas 69) _____
Gracilis 70) _____

71-75. Matching

A) Abduct upper arm (humerus)
B) Adduct upper arm (humerus)
C) Abduct thigh (femur)
D) adduct thigh (femur)
E) none of the above

Deltoid 71) _____
Gluteus Medius 72) _____
Adductor Magnus 73) _____
Tensor Facia Latae 74) _____
Lattisimus Dorsi / Pectoralis Major 75) _____

76-80. Matching

A) flex thigh (femur)
B) extend thigh (femur)
C) flex lower leg (tibia)
D) extend lower leg (tibia)
E) none of the above

Gluteus Maximus 76) _____
Semitendinosus 77) _____
Rectus Femoris 78) _____
Biceps Femoris 79) _____
Iliopsoas 80) _____

Short Essays

1. Describe the mechanism for transmission of excitable signals along the membrane of a muscle cell and along the transverse tubules. Describe how these excitable signals lead to the release of calcium from the sarcoplasmic reticulum.

2. Describe the mechanism allowing calcium to initiate muscle contraction. Describe how actin and myosin interact to cause contraction of muscle cells.

3. Describe the major muscles that are involved in standing up from a sitting position. Include a description of the agonists and antagonists involved.

Section 4 – Nervous Tissue and Nervous System

Nervous System, Neurons, Nerves, and Glial Cells

Overview

Sensory (Afferent) – Carry signals toward nervous system.

Motor (Efferent) – Carry signals out of nervous system.

Central Nervous System [CNS] – Inside dorsal body cavity.

Peripheral Nervous System [PNS] – Outside of dorsal body cavity.

Somatic Nervous System – Control skeletal muscle.

Autonomic Nervous System – Control smooth muscle or glands.

Enteric Nervous System – Within the smooth muscle of the gastrointestinal tract; influenced by the autonomic nervous system.

Ganglion vs. Nucleus

Ganglion (Ganglia – pleural) – Group of neuron cell bodies in the peripheral nervous system (PNS).

Nucleus (Nuclei – pleural) – Group of neuron cell bodies in the central nervous system (CNS).

Types of Neurons

Unipolar neurons

- *Commonly are sensory neurons*.
- Cell bodies are in the PNS within Ganglia.

Bipolar neurons – occur in retina of eye.

Multipolar neurons

- *Commonly are motor neurons*.
- Cell bodies are in the CNS within nuclei.

Unipolar (Sensory) Neuron structure

Dendrite / Sensory Receptors

- Detects sensory signals.
- Generates nervous signals.
- Transfer nervous signals to axon.

Axon (Peripheral Process)

- Conducts signals from the dendrites to the vicinity of the cell body.

Cell Body

- Usually located in the peripheral nervous system along the route of the axon.
- Contain Nissl granules (RNA that shows with Nissl stain).

Axon (Central Process)

- Conducts signals from the vicinity of the cell body toward the synaptic bulbs.
- Contain neurotubules that facilitate transport within axons.

Axon Collaterals – Major branches of the axon.

Synaptic Bulbs – Release neurotransmitters.

- Synaptic Vesicles – Store the neurotransmitters.
- Presynaptic Membrane

Multipolar (Motor or Interneuron) Neuron structure

Dendrites

- Receive signals from other neurons and transfer signals to the cell body.
- RNA and ribosomes (Nissl granules) extend into dendrites.

Cell Body

- Usually located in the central nervous system.
- Contain Nissl granules (RNA that shows with Nissl stain).

Axon Hillock

- Narrowing of the cell body that connects to the axon.
- Site for formation of action potentials.
- Do not contain Nissl granules.

Axon

- Continuation of the axon hillock.
- Conduct signals (action potentials) away from the cell body / axon hillock.
- Contain neurotubules that facilitate transport within axons.

Axon Collaterals – major branches of the axon.

Synaptic Bulbs – Release neurotransmitters.

Synaptic Vesicles – Store the neurotransmitters.

Synapse

Synaptic Bulbs – Release neurotransmitters.

- Synaptic Vesicles – Store the neurotransmitters.
- Presynaptic Membrane – the portion of the synaptic bulb that faces the synaptic cleft.

Synaptic Cleft – S thin space between the pre- and postsynaptic membranes.

Dendrite – Receive signals from other neurons.

- Postsynaptic Membrane – Contain receptors that respond to neurotransmitters.

Neuroglial Cells

Schwann cells

- Flat cells that produce myelin and wrap around axons in PNS to provide an insulating myelin sheath.

Nodes of Ranvier – gaps between adjacent Schwann cells.

Oligodendrocytes

- Octopus-like cells with tentacles that produce myelin and wrap around axons in CNS to provide an insulating myelin sheath.

Myelin Sheath –layers of the plasma membrane of Schwann cells and Oligodendrocytes around axons that insulate the axons.

Astrocytes

- Star-like cells positioned between neurons and blood capillaries.
- Provide a structural framework.
- Provide a filtration barrier between the blood and neurons (blood-brain barrier).
- Contribute to growth and integrity of synapses and may function somewhat like neurons.

Microglia

- Phagocytic cells that migrate through CNS.
- Provide an intrinsic immune system for the brain.

Ependymal cells

- Line cavities in the CNS (such as central canal of spinal cord and the ventricles of the brain).
- Provide a barrier and a means for chemical communication between the cerebral spinal fluid and neurons in the central nervous system.

Peripheral nerves

Peripheral Nerves are bundles of axons outside of that CNS surrounded by fibrous connective tissue.

Epineurium – Fibrous connective tissue that surrounds the nerve.

Perineurium – Fibrous connective tissue that separates the nerve into smaller bundles and surrounds these bundles.

Nerve Fascicles – Smaller bundles of axons within the nerve.

Endoneurium – Fibrous connective tissue that surrounds individual Schwann Cells wrapped around the axons within a fascicle.

Neurons, Glial Cells, and Nerves – Laboratory

Using the terms in the left box, draw and then label the cells and structures. Alternatively, you may paste pictures and then label the cells and structures. If you need more space use separate sheets of paper.

Models

Unipolar Neuron
 	
• Cell Body
  ○ Nucleus
  ○ Nucleolus
• Peripheral Axons
• Central Axons	

Multipolar Neuron
 	
• Cell Body
  ○ Nucleus
  ○ Nucleolus
• Dendrites
• Axons Hillock
• Axons
• Schwann Cells
• Myelin Sheath
• Nodes of Ranvier	

Synaptic Bulb • Axon • Synaptic Bulb • Synaptic Vesicles • Presynaptic Membrane	

Peripheral Nerve • Perineurium • Nerve Fascicle • Epineurium • Endoneurium • Schwann Cell • Axon	

Spinal Cord, Spinal Nerves and Meninges

Spinal Cord

Cervical Enlargement – Expanded region giving rise to Brachial Plexus.

Lumbar Enlargement – Expanded region giving rise to Lumbar Plexus.

- Located inside of lower thoracic vertebrae.

Conus Medullaris – End of spinal cord.

Filum Terminale – Continuation of the pia mater of the spinal cord from the conus medullaris to the coccyx.

Cauda Equina – Dorsal and ventral roots within spinal column.

Spinal Nerve Plexi and Nerves

Cervical Plexus – Group of nerves passing through upper cervical vertebrae, distribute to neck and diaphragm.

- Phrenic Nerve – Nerve to diaphragm.

Brachial Plexus – Group of nerves passing through lower cervical vertebrae, distribute to arms.

- Thoracic Spinal Nerves – Individual nerves passing through thoracic vertebrae, distribute to the trunk.

Lumbar Plexus – Group of nerves passing through lumbar vertebrae, distribute to thigh.

- Femoral Nerve – nerve to thigh.

Sacral Plexus – Group of nerves passing through sacrum, distribute to leg.

- Sciatic Nerve – Nerve to leg.

Dermatomes

Trigeminal (V1-V3) – Anterior and lateral head.

Cervical (C2-C8) – Posterior head, shoulders, and anterior arm.

Thoracic (T2-T12) – Posterior arm and trunk.

Lumbar (L1-L5) – Lumbar trunk and anterior thigh, leg, and foot.

Sacral (S1-S5) – Gluteal region and posterior thigh, leg, and foot.

Spinal Meninges

Dura Mater – Fibrous connective tissue sac around spinal cord.

Epidural Space – Outside of dura mater.

Subdural Space – Under dura mater, contains cerebrospinal fluid.

Arachnoid – Vascular regions between pia mater and dura mater.

Pia Mater – Epithelium adhering to spinal cord.

Denticulate Ligaments – Connections between the pia and dura mater.

Central Canal – Located in the commissure and contains cerebrospinal fluid.

Sensory and Motor Organization

Afferent (sensory)

Posterior (Dorsal) Horns – Entry point for sensory neurons.

Posterior (Dorsal) Root – Contain axons of sensory neurons.

Posterior (Dorsal) Root Ganglia – Contain cell bodies of sensory neurons.

Commissure – Connects the right and left sides of the Horns.

Posterior Columns and Lateral Columns – Carry axons of sensory neurons up to the brain.

Efferent (motor)

Somatic

Anterior (Ventral) Horns – Contain cell bodies of somatic motor neurons.

Anterior (Ventral) Root – Axons of somatic motor neurons.

Lateral horns – Contain cell bodies of autonomic motor neurons.

Lateral Columns and Anterior Columns – Carry axons from neurons in the brain down to motor neurons in the spinal cord.

Spinal Cord, Spinal Neurons – Laboratory

Using the terms in the left box, draw and then label the structures and nerves. Alternatively, you may paste pictures and then label the structures and nerves. If you need more space use separate sheets of paper.

Models and Specimens

Spinal Cord (longitudinal) • Cervical Enlargement • Thoracic Region • Lumbar Enlargement • Sacral Region • Conus Medullaris • Filum Terminale • Cauda Equina • Anterior Median Fissure	

Spinal Nerve Plexi and Nerves
• Cervical Plexus (C1-C5)
  ○ Phrenic Nerve
• Brachial Plexus (C5-T1)
• Thoracic Spinal Nerves (T1-T12)
• Lumbar Plexus (T12-L4)
  ○ Femoral Nerve
• Sacral Plexus (L4-S4)
  ○ Sciatic Nerve	

Spinal Cord and Meninges (cross) • Dura Mater • Epidural Space • Subdural Space • Arachnoid • Pia Mater • Denticulate Ligaments • Central Canal	

Spinal Cord • Spinal Commissure • Central Canal • Anterior Horns • Anterior Root • Posterior Horns • Posterior l Root • Posterior Root Ganglia • Anterior Columns • Lateral Columns • Posterior Columns (Axons)	

Histology of the Spinal Cord

Spinal Meninges • Anterior Median Fissure • Dura Mater • Subdural Space • Arachnoid • Subarachnoid Space (Interstitial Space) • Pia Mater	
Spinal Cord • Spinal Commissure • Central Canal • Anterior Horns • Anterior Root • Posterior Horns • Posterior l Root • Posterior Root Ganglia • Anterior Columns • Lateral Columns • Posterior Columns (Axons)	

Neuron Physiology

Transmembrane Potential

Electrochemical Gradient

- Sum of all the chemical and electrical forces across the membrane.

Resting Potential

- At this transmembrane potential an equilibrium exists between the electrochemical forces and the sodium–potassium exchange pump.

Membrane Channels

- Passive Channels – always open and permit leakage of ions.
- Gated Channels – open or close in response to specific stimuli.
- Chemically Regulated Channels – open or close in response to binding to specific extracellular chemicals.
- Voltage Regulated Channels – open or close in response to changes in the transmembrane potential.

Generation of an action potential

- An action potential occurs in response to a graded potential that leads to a threshold depolarization of the cell membrane, about -60 mV to -55 mV in an axon.

activation of voltage regulated sodium channels

- The threshold depolarization opens the sodium channels permits sodium ions to enter the cytoplasm, decreasing the transmembrane potential to about +30 mV.

sodium channel inactivation

- The decrease in transmembrane potential closes the sodium channels.

activation of voltage regulated potassium channel

- The decease in transmembrane potential opens the potassium channels and permits potassium to leave the cytoplasm, increasing the transmembrane potential toward -70 mV.

return to normal permeability

- Repolarization of the membrane returns the sodium channels to their normal state (closed and capable of opening) and closes the potassium channels, leading to a brief hyperpolarization.

Conduction of an action potential

- An action potential is conducted in only one direction.
- The site of an action potential cannot produce another action potential during the period between activation of the sodium channels and inactivation of the sodium channels (absolute refractory period).

Conduction velocity

Myelinization

- Continuous conduction – action potential leads to a wave of depolarization across the membrane surface.
- Saltatory conduction – local currents can depolarize the membrane only at uninsulated nodes, thus the action.

Axon diameter

- Larger axons allow faster movement of ions through the membrane and permit faster conduction of action potentials.

Synaptic Communication

Neuromuscular Control

Skeletal muscle contraction depends on the stimulation of muscle cells by motor neurons. Neurotransmitters released from synaptic bulbs of the motor neurons bind to receptors on the motor end-plate of the muscle cell. The binding of the neurotransmitter, typically acetylcholine, leads to the opening of chemically gated sodium channels.

- Neuromuscular communication normally occurs at a neuromuscular junction (synapse) from the synaptic bulbs of a motor neuron to a motor endplate (Presynaptic Membrane to Postsynaptic Membrane).

The majority of the synaptic communication between motor neurons and skeletal muscle cells involve the release of acetylcholine from the synaptic bulbs. Synapses utilizing acetylcholine as a neurotransmitter are often referred to as cholinergic synapses.

Activation of sodium and calcium channels in presynaptic membrane

- The action potential depolarizes the presynaptic membrane and opens calcium channels, permitting calcium ions to enter the synaptic knob.

Release of neurotransmitter stored in synaptic vesicles

- The increased calcium concentration in the synaptic knob causes the fusion of synaptic vesicles with the presynaptic membrane and permits diffusion of ACh.

Activation of sodium channels in postsynaptic membrane

- The acetylcholine binds to chemically regulated sodium channels, causing a graded depolarization.

Inactivation of neurotransmitter

- Acetylcholinesterase hydrolyzes the ACh and permits only a transient effect on the postsynaptic membrane.

Neuron to Neuron Control

Synaptic communication at the axodendritic junction

Central neuron activity depends on the stimulation of central neurons by peripheral sensory neurons or by central interneurons. Neurotransmitters released from synaptic bulbs of the sensory neurons or interneurons typically bind to receptors on the dendrites of the central neurons. Many different neurotransmitters are involved in central synaptic communication. The binding of one neurotransmitter, for example, may lead to the opening of chemically gated sodium channels. A second neurotransmitter may lead to the opening of chemically gated potassium channels. A third neurotransmitter may lead to the opening of chemically gated chloride channels.

Neurotransmitters released from synaptic bulbs typically diffuse onto the dendrites of target neurons and change the postsynaptic potential of the affected neurons.

- Dendrites and the soma express changes in postsynaptic potentials but do not initiate action potentials.
- The potential at the axon hillock determines whether or not an action potential will develop from the neuron.

Dendritic postsynaptic potentials

A neurotransmitter may cause either depolarization (an increase in positive charge) or hyperpolarization (an increase in negative charge) of the postsynaptic membrane of the dendrite.

- Excitatory Postsynaptic Potential (EPSP) – depolarization caused by a neurotransmitter (usually via opening of sodium channels).
- Inhibitory Postsynaptic Potential (IPSP) – hyperpolarization caused by a neurotransmitter (usually via opening of potassium channels or chloride channels).

Axon hillock potentials

The sum of the excitatory post synaptic potentials (EPSPs) and the inhibitory postsynaptic potentials (IPSPs) will determine the potential at the axon hillock. A sufficient depolarization will stimulate the generation of an action potential.

- Temporal summation – changing depolarization (or hyperpolarization) caused by rapid release of neurotransmitters at a single synapse.
- Spatial summation – changing depolarization (or hyperpolarization) caused by release of neurotransmitter at different synapses.

Spinal Reflexes

Tendon reflex

- Prevent unusually high tension in a muscle, triggered by high tension in a tendon.

Golgi tendon organs : sensory neurons

- Inhibitory interneurons are stimulated by the sensory neurons.
- Motor neurons responsible for tension are inhibited by the inhibitory interneurons, leading to relaxation of the skeletal muscles responsible for the high tension.

Stretch reflexes

- Provide for automatic adjustment of muscle tone, triggered by changes in muscle tone.

Muscle Spindles: sensory neurons

- Extrafusal Muscle – The skeletal muscle that makes up the bulk of the entire muscle.
- Intrafusal Muscle – Specialized skeletal muscle fibers that make the muscle spindle.
- Nuclear bag region – A region central to the intrafusal fibers that is monitored by receptors of sensory neurons.
- Alpha Motor Neurons – Neurons responsible for contraction of the extrafusal muscle.
- Gamma Motor Neurons – Neurons responsible for contraction of the intrafusal muscle.
- Alpha motor neurons are stimulated directly by activation of the sensory neurons of the muscle spindle, leading to contraction of the affected extrafusal skeletal muscle.

Relaxation of the muscle spindle decreases the stimulation of alpha motor neurons, leading to relaxation of the affected extrafusal skeletal muscle.).

- Gamma motor neurons are stimulated by neurons in the brainstem and cerebral and cerebellar cortex.
- Stimulation of gamma motor neurons causes contraction of intrafusal muscle fibers, causing stretch of the muscle spindles, leading to a reflex contraction of skeletal muscle.

Regulation of posture

- Stretch reflexes play a major role in maintaining posture by reflex countering inappropriate muscle contraction or relaxation.

Brain and Cortex

Cranial meninges

Dura Mater

Dural Sinuses – Act as veins.

Arachnoid

Pia mater

Falx Cerebri – Dura mater between cerebral hemispheres.

Tentorium Cerebelli – Dura mater between cerebellum and cerebrum.

Ventricles

Septum Pellucidum – Separates lateral ventricles.

Lateral Ventricles – Wing like spaces under cerebral hemispheres.

Interventricular Foramen – Connects lateral ventricles with third ventricle.

Third Ventricle – Slit like space in center of diencephalon.

Midbrain Aqueduct (Cerebral Aqueduct) – Connects third ventricle with fourth ventricle.

Fourth Ventricle – Space under cerebellum.

Choroid Plexus – Produces cerebrospinal fluid.

Cerebellum – Cerebellar Cortex

Anterior and Posterior Lobes – Involved in monitoring and timing of motor events.

Cerebrum – Cerebral Cortex

Longitudinal Fissure

Central Sulcus

- Frontal Lobe – Generally motor in function.
  - Precentral Gyrus (Primary Motor Cortex) – Control of fine movement.
  - Pre-Frontal Cortex – Involved in decision making; direction of attention.
- Parietal Lobe – Generally sensory in function.
  - Postcentral Gyrus (Primary Somatosensory Cortex) – Perception of sensation from skin (Cutaneous) and muscle (proprioceptive).
  - Posterior Parietal Cortex – Involved in determination of presence and location of body regions and structures.
  - Sensory Association Cortex – Integration of sensory signals; direction of sensory attention.
    - Left Association Cortex – Involved in production of meaning to language; (Wernicke's area).
    - Right Association Cortex – Involved in production of meaning to spatial relationships.

Parieto-occipital Sulcus

- Occipital Lobe – Generally sensory in function.
- Visual Cortex – Perception of visual sensation.

Lateral Sulcus

- Temporal Lobe – Generally sensory in function.
  - Primary Auditory Cortex – Perception of auditory sensation.
  - Gustatory and Olfactory Cortex – Perception of gustatory and olfactory sensation.
  - Insular Cortex [at deep extent of lateral sulcus] – Involved in providing knowledge about outcome of events.
  - Parahippocampal Gyrus – Overlies hippocampus.

Brain and Cortex – Laboratory

Using the terms in the left box, draw and then label the structures. Alternatively, you may paste pictures and then label the structures. If you need more space use separate sheets of paper.

Models and Specimens of Cranial and Meninges

Cranial meninges • Dura Mater • Dural Sinuses • Falx Cerebri • Tentorium Cerebelli	

Models and Specimens of Cerebral Cortex

Fissures and Sulci • Longitudinal Fissure • Central Sulcus • Parieto-occipital Sulcus • Lateral Sulcus	
Frontal Lobe • Precentral Gyrus (Primary Motor Cortex) • Pre-Frontal Cortex	

Parietal Lobe • Postcentral Gyrus (Primary Somatosensory Cortex) • Posterior Parietal Cortex • Sensory Association Cortex	
Occipital Lobe • Visual Cortex	
Temporal Lobe • Primary Auditory Cortex • Insular Cortex • Parahippocampal Gyrus	

Cranial Nerves, Brainstem and Subcortical Structures

Cranial Nerves

Olfactory nerve (I) – Special sensory, smell.

Optic nerve (II) – Special sensory, vision.

Oculomotor nerve (III) – Motor, eye movement (remaining four muscles of the eye).

Trochlear nerve (IV) – Motor, eye movement (superior oblique muscle).

Trigeminal nerve (V) – Mixed sensory and motor; face, mouth, mastication.

Abducens nerve (VI) – Motor, eye movement (lateral rectus muscle).

Facial nerve (VII) – Mixed sensory and motor; anterior 2/3 tongue, facial expression.

Vestibulocochlear nerve (VIII) – Special sensory, balance and hearing.

Glossopharyngeal nerve (IX) – Mixed sensory and motor; posterior 1/3 tongue, carotid arteries, swallowing.

Vagus nerve (X) – Mixed sensory and motor; visceral organs.

Spinal Accessory nerve (XI) – Motor, neck.

Hypoglossal nerve (XII) – Motor, tongue movements.

Brain Stem

Medulla Oblongata – Involved, in part, in respiration, blood pressure and heart rate.

Medullary Pyramid – Ventrally located, contains pyramidal tracts from motor cortex.

Pons – Involved in interconnection and integration of cerebral cortex, cerebellar cortex and brainstem.

Midbrain (Mesencephalon) – Involved in interconnection and integration of cerebral cortex, and brainstem.

Cerebral Peduncles (Crus Cerebri) – Connect midbrain to cerebral cortex.

Colliculi – Involved in reflex head and eye movements.

Hypothalamus – Site for major neural autonomic and endocrine integration and control.

Optic Chiasm – Site of crossing of optic nerves.

Pituitary Gland – Anterior and posterior pituitary hormones.

Thalamus – Filter and select sensory information; the "Gateway" to the cerebral cortex.

Subcortical Structures

Corpus Callosum – Connects right with left cerebral hemispheres.

Hippocampus – Involved in formation of long term memory.

Amygdala – Involved with feeling of emotion.

Basal Nuclei (ganglia) – Modifies cerebral cortical commands after evaluating signals from cerebral cortex, cerebellum, and brainstem; disturbed in Parkinsonism.

Cranial Nerves, Subcortical Structures, and Brainstem – Laboratory

Using the terms in the left box, draw and then label the nervess and structures. Alternatively, you may paste pictures and then label the nerves and structures. If you need more space use separate sheets of paper.

Models and Specimens of Cranial Nerves

Cranial Nerves I through VI • Olfactory nerve (I) • Optic nerve (II) • Oculomotor nerve (III) • Trochlear nerve (IV) • Trigeminal nerve (V) • Abducens nerve (VI)	
Cranial Nerves VII through XII • Facial nerve (VII) • Vestibulocochlear nerve (VIII) • Glossopharyngeal nerve (IX) • Vagus nerve (X) • Spinal Accessory nerve (XI) • Hypoglossal nerve (XII)	

Models and Specimens of Subcortical, Limbic Structures, and Ventricles

Subcortical • Corpus Callosum • Basal Nuclei (ganglia) ○ Caudate Nucleus	
Limbic • Hippocampus • Amygdala	
Ventricles • Septum Pellucidum • Lateral Ventricles • Interventricular Foramen • Third Ventricle • Midbrain Aqueduct (Cerebral Aqueduct) • Fourth Ventricle ○ Choroid Plexus	

Models and Specimens of Brainstem

Medulla Oblongata • Medullary Pyramid	
Pons	
Midbrain (Mesencephalon) • Cerebral Peduncles • Colliculi	

Hypothalamus • Optic Chiasm • Pituitary Gland	
Thalamus • Pineal Gland • Thalamus	

Practice Questions – Nervous System

Choices may be used more than once or not at all.

1-5. Matching

A) Central nervous system
B) Peripheral nervous system

posterior root ganglion 1) _____
muscle receptor 2) _____
spinal nerves 3) _____
spinal cord 4) _____
brain 5) _____

6-10. Matching

A) Peripheral nervous system
B) Central nervous system

brain stem 6) _____
spinal cord 7) _____
sacral plexus 8) _____
dorsal root ganglion 9) _____
sympathetic chain ganglia 10) _____

11-15. Matching

A) Somatic
B) Efferent
C) Afferent
D) Peripheral
E) Visceral

refers to integumentary and muscular systems 11) _____
refers to visceral (internal) organ systems 12) _____
refers to outside of the skull and vertebrae 13) _____
refers to incoming or sensory signals 14) _____
refers to outgoing or motor signals 15) _____

16-20. Matching

A) Motor neurons
B) Sensory neurons
C) None of the above

commonly are multipolar neurons 16) _____
commonly are unipolar neurons 17) _____
commonly are bipolar neurons 18) _____
found in dorsal root ganglia 19) _____
found in anterior horn 20) _____

21-25. Matching (motor neurons)

A) Axon
B) Dendrite
C) Axon hillock

responsible for receiving incoming signals 21) _____
responsible for conducting action potentials 22) _____
responsible for integrating <u>incoming</u> signals 23) _____
responsible for carrying signals away from the neuron 24) _____
responsible for initiating action potentials in motor neurons 25) _____

26-30. Place in the order that signals will pass into, through and out of a <u>motor neuron</u>.

A) Axon 26) _____
B) Cell body 27) _____
C) Dendrites 28) _____
D) Axon hillock 29) _____
E) Synaptic bulbs 30) _____

31-35. Matching (motor neurons)

A) Axons
B) Dendrites

conduct signals toward cell body 31) _____
conduct signals away from cell body 32) _____
usually do not support action potentials 13) _____
usually contain voltage gated channels 34) _____
usually contain ligand (chemically) gated channels 35) _____

36-40. Matching (sensory neurons)

A) Peripheral axons
B) Central axons
C) A and B

are often very long 36) _____
are often quite short 37) _____
extend from the ventral horn to skeletal muscles 38) _____
extend from the dorsal root ganglia into the spinal cord 39) _____
extend from sensory receptors to the dorsal root ganglia 40) _____

41-45. Matching

A) Myelin
B) Epineurium
C) Perineurium
D) Endoneurium
E) None of the above

fibrous connective tissue around bundles of axons 41) _____
fibrous connective tissue around Schwann cells 42) _____
fibrous connective tissue around a nerve 43) _____
insulation around axons 44) _____
bundles of axons 45) _____

46-50. Matching (during the resting period)

A) Higher inside than outside of neuron
B) Higher outside than inside of neuron

sodium ions 46) _____
calcium ions 47) _____
chloride ions 48) _____
potassium ions 49) _____
positive charge 50) _____

51-55. Matching (multipolar neurons)

A) Postsynaptic membrane
B) Presynaptic membrane

located on dendrites 51) _____
located on cell bodies 52) _____
located on synaptic bulbs 53) _____
releases neurotransmitters 54) _____
responds to neurotransmitters 55) _____

56-60. Matching

A) Voltage gated Na^+ channels
B) Chemical gated Na^+ channels
C) A and B
D) None of the above

found in axon 56) _____
found in axon hillock 57) _____
found in motor end plates 58) _____
found in dendrites and cell bodies 59) _____
found in post-synaptic membranes 60) _____

61-65. Matching

A) Mechanically gated channels
B) Chemically gated channels
C) Voltage gated channels

found in axon hillock 61) _____
found in motor end plates 62) _____
found in postsynaptic membranes 63) _____
found in muscle spindle receptors 64) _____
found in dendrites of sensory neurons 65) _____

66-70. Matching

A)	Excitatory neurotransmitters	usually open sodium channels	66) _____
B)	Inhibitory neurotransmitters	make cytoplasm more positive	67) _____
		often open potassium channels	68) _____
		depolarize postsynaptic membrane	69) _____
		hyperpolarize postsynaptic membrane	70) _____

71-75. Matching

A)	Acetylcholine	opens chloride channels	71) _____
B)	Acetylcholinesterase	excites skeletal muscle	72) _____
C)	Gamma amino butyric acid	destroys acetylcholine	73) _____
D)	None of the above	often excites neurons	74) _____
		inhibits neurons	75) _____

76-80. Matching

A)	Anterior horn	contains cell bodies of sensory neurons	76) _____
B)	Anterior root	contains cell bodies of motor neurons	77) _____
C)	Posterior horn	contains axons of sensory neurons	78) _____
D)	Posterior root	dorsal gray matter of spinal cord	79) _____
E)	Posterior root ganglion	contains axons of motor neurons	80) _____

81-85. Matching

A)	Pia mater	thick connective tissue covering the brain and spinal cord	81) _____
B)	Arachnoid	attaches directly to brain and spinal cord	82) _____
C)	Dura mater	supports numerous fine blood vessels	83) _____
D)	Epidural space	outside of spinal cord	84) _____
E)	Subdural space	under dura mater	85) _____

86-90. Matching

A)	Originates from the cervical plexus	sciatic nerve	86) _____
B)	Originates from the brachial plexus	phrenic nerve	87) _____
C)	Originates from the lumbar plexus	femoral nerve	88) _____
D)	Originates from the sacral plexus	thoracic nerve	89) _____
E)	None of the above	nerves of the arms	90) _____

91-95. Matching

A)	Postcentral gyrus	location of the visual cortex	91) _____
B)	Precentral gyrus	involved in acting out of emotions	92) _____
C)	Occipital cortex	location of the primary motor cortex	93) _____
D)	Parietal lobe	location of the primary sensory cortex	94) _____
E)	Frontal lobe	location of the sensory association cortex	95) _____

96-100. Matching

A)	Frontal lobe	involved in making things happen (action / movement)	96) _____
B)	Farietal lobe	involved in memory and emotion	97) _____
C)	Occipital lobe	contains primary visual cortex	98) _____
D)	Temporal lobe	involved in decision making	99) _____
E)	B and C	receive sensory signals	100) _____

101-105. Matching

A)	Medulla oblongata	connects to the pituitary	101) _____
B)	Hypothalamus	is located below the 4th ventricle	102) _____
C)	Midbrain	critical for respiration and blood pressure	103) _____
D)	Pons	located between the midbrain and medulla	104) _____
E)	A and D	is located just posterior to the hypothalamus	105) _____

106-110. Matching

A)	Cranial nerve I	optic nerve	106) _____
B)	Cranial nerve II	trochlear nerve	107) _____
C)	Cranial nerve III	olfactory nerve	108) _____
D)	Cranial nerve IV	trigeminal nerve	109) _____
E)	Cranial nerve V	oculomotor nerve	110) _____

111-115. Matching

A)	Vagus nerve	motor, eye movement (superior oblique muscle	111) _____
B)	Optic nerve	mixed sensory and motor; visceral organs	112) _____
C)	Trochlear nerve	special sensory, vision	113) _____
D)	Olfactory nerve	special sensory, smell	114) _____
E)	Oculomotor nerve	motor, eye movement	115) _____

116-120. Matching

A)	Facial nerve	branch passes through foramen ovale	116) _____
B)	Trigeminal nerve	sensory for posterior tongue	117) _____
C)	Hypoglossal nerve	sensory for anterior tongue	118) _____
D)	Glossopharyngeal nerve	motor for chewing	119) _____
		motor for tongue	120) _____

121-125. Matching

A)	Interventricular foramen	produces cerebrospinal fluid	121) _____
B)	Spinal commissure	connects right and left cerebrum	122) _____
C)	Cerebral aqueduct	connects third and fourth ventricle	123) _____
D)	Corpus callosum	connects third and lateral ventricle	124) _____
E)	Choroid plexus	connects left and right spinal horns	125) _____

126-130. Matching

A)	Pons	monitors and times contraction of muscles	126) _____
B)	Thalamus	carry signals to and from cerebellum	127) _____
C)	Cerebellum	critical for long term memory	128) _____
D)	Hippocampus	filters sensory information	129) _____
E)	Hypothalamus	controls pituitary gland	130) _____

Short Essays

1. Describe the mechanisms responsible for the conductions of action potentials. Include the roles of sodium and potassium channels.

2. Describe the mechanisms responsible for the release of neurotransmitters. Include the roles of sodium and calcium channels and of synaptic vesicles.

3. Describe the integration of synaptic signals at the axon hillock that leads to the generation of an action potential.

4. Compare and contrast the mechanisms for excitatory and inhibitory postsynaptic potentials

5. Describe the neural pathways and mechanisms involved in the stretch reflex.

6. Compare and contrast the organization and function of the posterior and anterior portions of the cerebral cortex

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Section 5 – Cardiovascular System

Cardiovascular Organization

Cardiovascular Circuits

Pulmonary circuit

- Pulmonary circuit – Carries blood to and from the lungs.
- Pulmonary Arteries – Carry blood away from the heart to the lungs.
- Pulmonary Veins – Carry blood from the lungs to the heart

Systemic circuit

- Systemic circuit – Carries blood to and from the rest of the body.
- Systemic Arteries – Carry blood from heart to other organs.
- Systemic veins – Carry blood from other organs to the heart.

Lymphatic vessels

- Carry lymph from tissues to systemic veins.

Blood Vessels

Arteries

- Carry blood from the heart and toward the capillaries.
- Contain a prominent layer of smooth muscle that is under the control of the autonomic nervous system and various hormones.
- Arterioles – small arteries that connect to the capillaries.

Capillaries

- Serve as the site for transfer between blood and interstitial space.
- Consist of a layer of simple squamous epithelium (endothelium).

Veins

- Carry blood away from capillaries and to the heart.
- Contain extensions of the endothelium that serve as valves.
- Venules – small veins that connect to the capillaries.

Lumen – Open space inside of vessel.

Relationship between the Heart and Blood Vessels

Right side of the heart

Right atrium

- Receives blood from the systemic circuit mainly via the Inferior and Superior Vena Cava.

Right ventricle

- Discharges blood into pulmonary circuit via the Pulmonary Trunk and Arteries.

Right atrioventricular valve (tricuspid valve)

- Controls movement of blood between the right atrium and right ventricle.

Pulmonary semilunar valve

- Controls movement of blood between the right ventricle and the pulmonary circuit.

Left side of the heart

Left atrium

- Receives blood from the pulmonary circuit via the Pulmonary Veins.

Left ventricle

- Discharges blood into systemic circuit via the Aorta.

Left atrioventricular valve (bicuspid valve, mitral valve)

- Controls movement of blood between the left atrium and the left ventricle.

Aortic semilunar valve

- Controls movement of blood between the left ventricle and the systemic circuit.

The Heart

Superficial Anatomy

Pericardial cavity – Located between the heart and the pericardial sac.

Parietal pericardium – Lines the pericardial sac.

Visceral pericardium (epicardium) – Covers the heart.

Base – Region where the major arteries and veins connect.

Apex – Tip of the heart.

Coronary sulcus – Groove between the atria and the ventricles.

Interventricular sulcus – Depression between the ventricles.

Right atrium – Receives blood from the systemic circuit.

Right ventricle – Discharges blood into pulmonary circuit.

Left atrium – Receives blood from the pulmonary circuit.

Left ventricle – Discharges blood into systemic circuit.

Superior Vena Cava – Returns blood from upper systemic organs to the right atrium.

Inferior Vena Cava – Returns blood from lower systemic organs to the right atrium.

Pulmonary Trunk – Carries blood to the lungs from the right ventricle.

Pulmonary Veins – Returns blood from the lungs to the left atrium.

Ascending Aorta – Carries blood to systemic organs from the left ventricle.

Aortic Arch – A bend in the aorta that allows vessel to branch to the upper body before descending to the lower body.

Ligamentum Arteriosus – Remnant of the fetal vascular connection between the pulmonary trunk and the aortic arch.

Sectional Anatomy

Interventricular Septum – Heart wall between left and right ventricles.

Right atrioventricular valve (tricuspid valve) – Controls movement of blood between the right atrium and right ventricle.

Pulmonary semilunar valve – Controls movement of blood between the right ventricle and the pulmonary circuit.

Left atrioventricular valve (bicuspid valve, mitral valve) – Controls movement of blood between the left atrium and the left ventricle.

Aortic semilunar valve – Controls movement of blood between the left ventricle and the systemic circuit.

Chordae tendinae – Tendonous fibers that brace the Cusps of the atrioventricular valves.

Papillary muscles – Cardiac muscle connect to the chordae tendinae.

Trabeculae carnae – Deep groves and folds in the ventricles.

Fossa ovale – Remnant of the fetal opening between right and left atria.

Fetal Heart and Circulation

Foramen ovale – Opening between right and left atria.

Fossa ovale – Remnant of the fetal opening between right and left atria.

Ductus arteriosus – Vascular connection between pulmonary trunk and aortic arch.

Ligamentum Arteriosus – Remnant of the fetal vascular connection between pulmonary trunk and aortic arch.

Umbilical artery – Carries oxygen poor blood from the fetal Internal Iliac arteries to the placenta of the mother.

Umbilical vein – Carries oxygen rich blood from the placenta of the mother to the Inferior Vena Cava of the fetus.

Placenta – Contains two parallel and separate blood capillary networks. One network connects to the mother; the other connects to the fetus.

Coronary Circulation

Coronary Arteries

- Originate at the base of the ascending aorta.

  Right Coronary artery – Follows coronary sulcus.

  Marginal branch – Extends along right border.

  Posterior Descending artery (Posterior Interventricular) – Within the posterior interventricular sulcus.

  Left Coronary artery – Follows coronary sulcus.

  Anterior Descending artery (Anterior Interventricular) – Within the anterior interventricular sulcus.

  Circumflex branch – Follows coronary sulcus; part fuses with right coronary artery.

Coronary (Cardiac) Veins

- Empty into the Coronary Sinus and then right atrium.

  Anterior cardiac veins – Adjacent to marginal branch arteries.

  Small cardiac Vein – Lateral to Anterior cardiac veins; empties into the coronary sinus.

  Posterior Descending vein (Middle Cardiac vein) – Adjacent to posterior descending arteries.

  Great cardiac vein – Adjacent to anterior descending arteries; empties into the coronary sinus.

  Coronary Sinus – In posterior coronary sulcus; empties into the right atrium.

Heart Wall

Epicardium (visceral pericardium).

- Covers exterior of heart
- Consists of a mesothelial (simple squamous) layer and a connective tissue layer.

Myocardium

- Muscular wall of the heart.
- Contains cardiac muscle, connective tissue, blood vessels, nerves.

Endocardium

- Covers interior of heart.
- Consists of an endothelial (simple squamous) layer.

Cardiac Muscle

Cardiac muscle cells – Short cells with single nuclei.

Intercalated discs – Sites of membrane bonding at ends of adjacent cardiac muscle cells.

Endomysium – Fibrous connective tissue connecting cardiac muscle cells together side by side.

Heart – Laboratory

Using the terms in the left box, draw and then label the structures. Alternatively, you may paste pictures and then label the structures. If you need more space use separate sheets of paper.

Models and Specimens of Heart

Superficial Anatomy

Heart • Pericardial Cavity • Pericardial Sac • Parietal pericardium • Visceral pericardium (Epicardium • Base • Apex	
Major Veins • Superior vena cava • Inferior vena cava • Pulmonary veins (right and left)	
Major arteries • Ascending aorta • Pulmonary trunk • Pulmonary arteries (right and left)	

Chambers • Right Atria and Auricle (Atrial Appendage) • Left Atria and Auricle (Atrial Appendage) • Right Ventricle • Left Ventricle	

Sectional Anatomy

Right side • Right Atrioventricular (AV) (tricuspid) valve • Fossa ovale • Chordae tendinae • Papillary muscles • Trabeculae carnae • Pulmonary semilunar valve	
Left side • Left Atrioventricular (AV) (bicuspid valve, Mitra) valve • Fossa ovale • Chordae tendinae • Papillary muscles • Trabeculae carnae • Aortic Semilunar valve	

Coronary Circulation

Coronary Arteries • Right Coronary artery • Marginal branch • Posterior Descending • Left Coronary artery • Anterior Descending • Circumflex branch	
Coronary Veins • Anterior cardiac veins • Small cardiac Vein • Middle cardiac vein • Great cardiac vein • Posterior cardiac vein • Coronary Sinus	

Fetal Heart and Circulation

• Foramen ovale (becomes the fossa ovale after birth) • Ductus arteriosus (becomes the ligamentum arteriosus after birth) • Umbilical artery • Umbilical vein • Placenta	

Histology of the Heart

Heart Wall • Epicardium (visceral pericardium) • Myocardium • Endocardium	
Cardiac Muscle • Cardiac muscle cells • Intercalated discs • Endomysium	

Cardiac Pumping

Cardiac cycle

The cardiac cycle corresponds to the period between one heart beat and the next, and is usually viewed starting with atrial contraction.

- Atrial contraction is followed by atrial relaxation which continues until the next atrial contraction.
- After the atria contract the ventricles contract.
- Ventricular contraction is followed by ventricular relaxation which continues until the next ventricular contraction.
- Blood moves from an area of higher pressure to an area of lower pressure.

Pumping actions of the heart

Atrial Relaxation

- Causes a decrease in atrial pressures.
- As the atrial pressures become less than the venous pressures, blood moves from the veins to the atria.

Ventricular Relaxation (Diastole)

- Causes a rapid decrease in ventricular pressure.
- As the ventricular pressures become less than the arterial pressures, the semilunar valves close.
- As the ventricular pressures become less than the atrial pressures, the atrioventricular valves open and blood moves from the atria to the ventricles.
- The diastolic pressure differences between the atria and the ventricles causes about 70% of ventricular filling.

Atrial Contraction

- causes a rapid increase in atrial pressures.
- As the atrial pressures increase, more blood moves from the atria to the ventricles.

Ventricular Contraction (Systole)

- Causes a rapid increase in ventricular pressure.
- As the ventricular pressures exceed the atrial pressures, the atrioventricular valves close.
- As the ventricular pressures exceed the arterial pressures, the semilunar valves open and blood moves to the arteries.

Coordination of Cardiac Muscle Contraction

Cardiac conduction system

- The atria must contract from the appendages toward the AV valves.
- The ventricles must contract from the apex toward the semilunar valves.
- The contraction is coordinated by specialized cells.

Nodal cells

- Membranes depolarize spontaneously and cyclically.
- Pacemaker cells – Those that cycle fastest.
    - Sinoatrial node – In posterior wall of right atrium – produces intrinsically about 80-100 action potentials per minute.
    - Atrioventricular node – In floor of right atrium near ventricle – Produces intrinsically about 40-60 action potentials per minute.

Conduction Fibers

- Conducting fibers in the atrial wall.
- atrioventricular node.
- AV bundle (of His) – Travels along interventricular septum.
- Bundle Branches – Divide along interventricular septum and radiate across the inner surface of the right and left ventricles.
- Purkinje fibers – Branches to contractile cells.

Conduction pathway:

SA node → atrial conduction fibers → AV node → AV bundle → bundle branches → Pacemaker potentials

Generation of cardiac pacemaker activity

- Voltage gated "F" channels which are Na^+ / K^+ channels that respond to repolarization (not depolarization) by opening briefly and then closing (the movement of Na^+ dominates causing an early depolarization).
- In response to the initial depolarization voltage-gated Ca^{++} T-channels open briefly causing a further depolarization.
- In responses to this further depolarization voltage-gated Ca^{++} L-channels open. (The channels are most likely dihydropyridine channels.)
- The Ca^{++} entry leads to the opening calcium gated calcium channels in the sarcoplasmic reticulum and further movement of Ca^{++} into the cytosol. (The channels are most likely ryanodine channels.)
- The final depolarization opens voltage-gated K^+ channels.
- The escape of K^+ leads to a repolarization that closes the Ca^{++} channels and subsequently closes the K^+ channels.
- The repolarization causes the cycle to repeat.

Pacemaker control of cardiac muscle contraction

Cardiac muscle cells are mainly activated by diffusion of cations through gap junctions in the intercalated discs.

- The influx of sodium and calcium through the **connexon** of the gap junction between the pacemaker and contractile cell leads to the opening of voltage gated Na^+ channels in the sarcolemma of the contractile cell.
- The sequential opening and closing of Na^+ channels and K^+ channels along the membrane produces an action potential like that seen in axons.
- The action potential is conducted across the sarcolemma and down each of the transverse tubules.
- The action potential activates voltage sensitive Ca^{++} L-channels in the transverse tubules and allows calcium to diffuse from the extracellular fluid into the sarcoplasm. (The channels are most likely dihydropyridine channels.)
- The entry of calcium seems to activate some of the calcium sensitive calcium channels in the sarcoplasmic reticulum and allows calcium to diffuse out of the sarcoplasmic reticulum (SR) and into the cytosol. (The channels are most likely ryanodine channels.)
- Voltage gated K^+ channels open in response to the prolonged depolarization, and subsequently close.
- The Ca^{++} that enters the sarcoplasm binds to troponin and moves tropomyosin away from the binding sites on actin, allows the myosin heads to bind to actin, and causes muscle contraction.

Electrocardiogram (EKG)

The electrocardiogram reflects the changes in membrane potential of the cardiac muscle (contractile cell potentials) during the cardiac cycle, as shown below (Pacemaker and Contractile Potentials). The changes in membrane potential of the cardiac muscle cells are measured from the surface of the body.

Standard Limb Leads

Measurement of EKG is based on potential differences between the three combinations of two points around a triangle as worked out by Einthoven.

- Lead I measures the potential difference between the Right Arm and the Left Arm.
- Lead II measures the potential difference between the Right Arm and the Left Leg.
- Lead III measure the potential difference between the Left Arm and the Left Leg.

An example of a normal EKG with lead I, II, and III measurements is shown below. (Lead I, II, III Electrocardiogram - Normal). The significance of Einthoven's triangle is that the sum of the voltages of leads I and III equals that in lead II (Einthoven's law). Hence, if the voltages of two of the standard leads are recorded, that of the third lead can be determined mathematically.

Twelve lead measurements from the skin of the chest are common in the clinical setting. However, the underlying mechanisms remain the same.

EKG waves

In the EKG tracing several waves are prominent.

- The P wave reflects depolarization of the atria.
- The QRS waves reflect depolarization of the ventricles.
- The T wave reflects repolarization of the ventricles.

The timing of the intervals between the waves is of diagnostic importance. The most useful intervals are the RR interval, PR interval, QRS interval, and the QT interval.

- RR interval
    - The time between the one R wave and the next R wave.
    - The time is inversely related to the heart rate.
    - Is 0.857 sec (857 msec) at a heart rate of 70 beats / min

$$\text{Heart Rate} = \frac{60 \text{ sec}}{\text{RR interval (sec)}}$$

- PR interval
    - The time between the beginning of the P wave and the beginning of the R wave.
    - Represents the time between the beginning of atrial depolarization and ventricular depolarization.
    - Corresponds to the time of atrial contraction.
    - Usually about 0.17 sec (170 msec).
    - A longer interval may suggest a partial AV heart block caused by damage to the AV node.
    - In total heart block, no impulses are transmitted through the AV node, and the atria and ventricles beat independently of one another.
- QRS interval
    - The time between the Q wave and the S wave.
    - Represents the time for the depolarization of the ventricles.
    - Usually about 0.08 sec (80 msec).
    - Prolonged by a right or left bundle branch block in which one ventricle is contracting later than the other.
- QT interval
    - The time between the Q wave and the end of the T wave.
    - The Q-T interval is the period from the beginning of ventricular depolarization through repolarization.
    - The S-T segment corresponds to the time of ventricular contraction.
    - Usually about 0.35 sec (350 msec) at a heart rate of 70 beats / min.
    - As the rate increases, this interval becomes shorter; conversely, when the heart rate drops, the interval is longer.
    - Prolonged by damage to conduction fibers, ischemia or myocardial damage.
- TQ interval
    - The time between the end of the T wave and the Q wave.
    - The T-Q interval is the period from the end of ventricular depolarization through the end of atrial depolarization.
    - Corresponds to the time of ventricular relaxation.
- QP interval
    - Corresponds to the time of atrial relaxation.

Electrocardiogram – Laboratory

One student in each group will be instrumented for measurement of EKG.

- Obtain EKG under resting conditions.
- Exercise by walking up and down the stairs several times.
- Obtain EKG immediately after exercise.
- Obtain EKG two minutes after exercise.

Each student in a group will obtain copies of the three charts.

- Label all of the waves during a cardiac cycle on each chart.
- Determine the PR interval for each chart.
- Determine the heart rate for each chart.
- Determine the duration of the QRS complex for each chart.
- Determine the duration of ventricular systole for each chart.

Each student will answer the following questions.

1. The cells with the fastest spontaneous cycle of depolarization are located in the _____.
2. Indicate the electrical events that produce the following waves:
   P wave _____.
   QRS wave _____.
   T wave _____.
3. An occasional extra beat, which can be seen as an ectopic QRS complex, is called a _____.
4. An abnormally long P-R interval indicates a condition called _____.
5. A condition where the ventricles are unable to contract as a pump and a circus rhythm of electrical activity may be present is known as _____.
6. Explain why the SA node functions as the normal pacemaker. _____.
7. The ECG wave that occurs at the beginning of ventricular systole is the _____ wave.
8. The ECG wave that occurs at the end of systole and beginning of diastole is the _____ wave.
9. The ECG wave that occurs at the end of ventricular diastole is the _____ wave.
10. Describe the regulatory mechanisms that produce an increase in cardiac rate during exercise. Explain how these changes affect the ECG.
    _____

Cardiac Output

The purpose of the heart is to pump blood to the lungs, back to the heart, to the rest of the body, and back to the heart. The amount of blood pumped out of the heart (left ventricle) each minute is called **cardiac output**. A normal cardiac output is about 7% of body weight in kg. For an average person of about 70 kg, their cardiac output would be about 4.9 L / min (or 4900 mL / min).

Cardiac output is influenced by two major factors, the stroke volume and the heart rate.

Cardiac output (CO) = Stroke volume (SV) x Heart rate (HR)

- Stroke volume (SV) is the amount of blood pumped out of the heart (left ventricle) with each contraction.
- Heart rate (HR) is the number of contractions per minute.

With a heart of 70 beats / min we can seen that the stroke volume would be 70 mL.

4900 mL / min = 70 mL x 70 beats / min

However, stroke volume is influenced by two major factors, the end diastolic volume and the end systolic volume.

Stroke volume (SV) = End Diastolic Volume (EDV) – End Systolic Volume (ESV)

- End Diastolic Volume (EDV) is the ventricular volume at the end of ventricular relaxation.
- End Systolic Volume (ESV) is the ventricular volume at the end of ventricular contraction.

In turn, the end diastolic volume and the end systolic volume are influenced by vascular factors, as well as by cardiac factors.

- End Diastolic Volume (EDV) is increased by elevated central venous pressure (preload) and by increased filling time.
- End Systolic Volume (ESV) is increased by elevated arterial pressure (afterload) and is decreased by increased force of ventricular contraction.

Control of stroke volume, heart rate and cardiac output

Together we can see that cardiac output is influenced by heart rate, end diastolic volume and end diastolic volume:

$$CO = (EDV – ESV) \times HR$$

- Increased central venous pressure will increase cardiac filling during ventricular relaxation and increase EDV, and by itself increase CO.
- Increased arterial pressure will decrease cardiac emptying during ventricular contraction and increase ESV, and by itself decrease CO.
- Increased force of ventricular contraction will increase cardiac emptying during ventricular contraction and decrease ESV, and by itself increase CO.
- Increased HR will by itself increase CO.
- Decreased HR will by itself decrease CO.

Neural and Hormonal Control of the Heart

Modulation of Cardiac pacemakers and muscle

Pacemaker cells not only have an intrinsic rhythm generator, their rhythms are modulated by parasympathetic nerves, by sympathetic nerves and by various hormones, such as epinephrine. As we noted earlier, a typical resting heart rate is about 70 beats / minute although the intrinsic rate of the SA node is about 80 – 100 beats / minute. This difference is largely due the activity of the parasympathetic nervous system

The parasympathetic nervous system controls heart rate. Parasympathetic postganglionic neurons secrete acetylcholine which acts on muscarinic-2 receptors to hyperpolarize the pacemaker cells causing a decrease in heart rate.

The sympathetic nervous system controls heart rate. Sympathetic postganglionic neurons secrete norepinephrine which acts on Beta-1 receptors to further depolarize the pacemaker cells causing an increase in heart rate.

Cardiac muscle cells are not only controlled by the cardiac conduction system, they are modulated by the sympathetic nervous system and various hormones, for example by epinephrine. The sympathetic nervous system controls cardiac force.. Sympathetic postganglionic neurons secrete norepinephrine which acts on Beta-1 receptors to increase movement of calcium into the cytosol and increase the force of cardiac contraction.

Baroreceptor Reflexes – cardiac control

The cardiovascular system contains sensory receptors that monitor blood pressures in the neck, trunk, and heart. Signals from these sensory receptor travel to the brainstem where they are compared to reference values. When necessary, cardiovascular responses are generated to normalize the pressures.

- Carotid sinus baroreceptors respond to pressure changes in the carotid arteries going to the head.
- Aortic arch baroreceptors respond to pressure changes in the aorta.
- Cardiac atrial stretch receptors respond to pressure changes in the cardiac atria.

Baroreceptor control of heart rate is mediated in part by the parasympathetic nervous system. Increases in carotid artery pressure stimulate the carotid sinus baroreceptors. The glossopharyngeal nerve carries the baroreceptor signal into the medulla of the brainstem and further stimulates the parasympathetic nervous system which decreases heart rate.

In a complementary manner, decreases in carotid artery pressure "de-stimulate" the carotid sinus baroreceptors. This results in inhibition of the parasympathetic nervous system and stimulation of the sympathetic nervous system, causing an increase in heart rate.

Blood Vessels, Microcirculation and Lymphatic Vessels

Blood Vessels

- Arteries carry blood away from the heart.
- Arteries branch to form more numerous but smaller arterioles.
- Arterioles branch to form more numerous but smaller capillaries.
- Capillaries come together to form venules.
- Venules come together to form veins.
- Veins carry blood back to the heart.

Arteries and arterioles have a relatively thick wall with a thick layer of smooth muscle (tunica media). Arteries generally have more elastic connective tissue than arterioles. Capillaries are composed of just endothelium. Veins have a relatively thin wall with a thin layer of smooth muscle (tunica media) and venules have little if any smooth muscle.

Arteries

Tunica Interna

- Endothelial lining (endothelium) – simple squamous epithelium.
- Elastic connective tissue (internal elastic lamina).

Tunica Media

- Thick layer of concentric sheets of smooth muscle.
- Under the control of the autonomic nervous system and various hormones.

Tunica Externa

- Connective tissue sheath.
- Elastic connective tissue (external elastic lamina).

Capillaries

Tunica Interna

- Endothelial lining (endothelium) – simple squamous epithelium.

Veins

Tunica Interna

- Endothelial lining (endothelium) – simple squamous epithelium.

Tunica Media

- Thin layer of smooth muscle.

Tunica Externa

- connective tissue sheath.

Microcirculation

The microcirculation refers to the capillaries and surrounding structures involved in fluid, nutrient and gas exchange. Fluid moves between vascular space (blood) and the interstitial space (interstitial fluid), and between the interstitial space and the intracellular space (intracellular fluid).

Blood Capillaries

- Thin walled vessels between the arterioles and the venules where exchange of oxygen, nutrients, wastes and other.
- Exchange occurs between the blood and the interstitial fluid.

Lymphatic Capillaries

- Recover plasma lost from the blood capillaries for return to the systemic venous circulation.

Vascular space

- Space in the lumen of blood vessels that contains the blood.

Interstitial space

- Space between cells and between cells and the capillaries that contains the Interstitial fluid.

Intracellular space

- Space inside of cells that contains the Intracellular fluid (cytosol / cytoplasm).

Lymphatic vessels

Lymphatic vessels recover fluid that leaks out of the blood capillaries and returns it to the systemic venous circulation.

Lymphatic capillaries

- Recover interstitial fluid.
- Composed of endothelial cells with no basement membrane.
- Overlapping endothelial cells act as one way valves.

Lymphatic nodules

- Filter and destroy pathogens in the lymphatic fluid.
- Composed of reticular tissue and lymphocytes.
- Interspersed along the lymphatic vessels.

Thoracic duct

- Collects lymph from the body below the diaphragm and from the left half of the body above the diaphragm.
- Empties into the venous system at the junction of the left internal jugular vein and the left subclavian vein.

Right lymphatic duct

- Collects lymph from the right side of the body above the diaphragm.
- Empties into the venous system at the junction of the right internal jugular vein and the right subclavian vein.

Blood Vessels – Laboratory

Using the terms in the left box, draw and then label the blood vessels. Alternatively, you may paste pictures and then label the blood vessels. If you need more space use separate sheets of paper.

Systemic Arteries (oxygen rich blood) (note: arteries are listed separately from veins)

Aortic arch
• Brachiocephalic artery
  ○ Right common carotid artery
  ○ Right subclavian artery
• Left common carotid artery
• Left subclavian artery	

Subclavian arteries (Right and Left)
• Vertebral artery (Right and Left)
• Axillary artery (Right and Left)
• Brachial artery (Right and Left)
  ○ Radial artery (Right and Left)
  ○ Ulnar artery (Right and Left)	

Carotid arteries • External carotid artery (Right and Left) • Internal carotid artery (Right and Left) • Carotid sinus	

Circle of Willis
 	
• Vertebral artery (Right and Left)
• Basilar artery
  ○ Posterior cerebral artery (Right and Left)
  ▪ Posterior communicating artery (Right and Left)
 	
• Internal carotid artery (Right and Left)
  ○ Middle cerebral artery (Right and Left)
  ○ Anterior cerebral artery (Right and Left)
  ▪ Anterior communicating artery	

Descending Aorta
 	
• Inferior phrenic artery (Right and Left)
• Celiac trunk
  ○ Gastric artery
  ○ Hepatic artery
  ○ Splenic artery
• Superior mesenteric artery
• Renal artery (Right and Left)
• Adrenal artery (Right and Left)
• Gonadal artery (Right and Left)
• Inferior mesenteric artery
• Common iliac artery (Right and Left	

Common iliac artery (Right and Left)
 	
• Internal iliac artery (Right and Left)
• External iliac artery (Right and Left)
  ○ Deep femoral artery (Right and Left)
  ○ Femoral artery (Right and Left)
  ▪ Popliteal artery (Right and Left)
  ▪ Anterior tibal artery (Right and Left)
  ▪ Posterior tibial artery (Right and Left)
  ▪ Fibularis artery (Right and Left)	

Deep Systemic Veins

Superior vena cava
 	
• Brachiocephalic vein (Right and Left)
  ○ Internal jugular vein (Right and Left)
  ○ Vertebral vein (Right and Left)
  ○ External jugular vein (Right and Left)
  ○ Subclavian vein (Right and Left)	

Subclavian vein (Right and Left)
 	
• Axillary vein (Right and Left)
  ○ Brachial vein (Right and Left)
  ▪ Radial vein (Right and Left)
  ▪ Ulnar vein (Right and Left)	

Inferior vena cava • Phrenic vein (Right and Left) • Hepatic vein (Right and Left) • Renal vein (Right and Left) • Adrenal vein (Right and Left) • Gonadal vein (Right and Left) • Common iliac vein (Right and Left)	

Common iliac vein (Right and Left)
 	
• Internal iliac vein (Right and Left)
• External iliac vein (Right and Left)
  ○ Femoral vein (Right and Left)
  ○ Popliteal vein (Right and Left)
  ▪ Anterior tibial vein (Right and Left)
  ▪ Posterior tibial vein (Right and Left)
  ▪ Fibularis vein (Right and Left)	

Hepatic Portal System Inferior vena cava • Hepatic veins • liver • Hepatic portal vein • Gastric vein • Splenic vein ○ Inferior Mesenteric vein • Superior Mesenteric vein	

Superficial Veins

Superficial Branches of Subclavian vein • Cephalic vein (Right and Left) • Basilic vein (Right and Left)	
Superficial Branches of Femoral vein • Great saphenous vein (Right and Left)	

Lymphatic vessels

• Thoracic duct • Right lymphatic duct	

Histology of Arteries and Veins

Tunica Interna • endothelium • internal elastic lamina Tunica Media • smooth muscle Tunica Externa • external elastic lamina	
Smooth Muscle • Smooth muscle cells • Endomysium	

Blood Pressure, Blood Flow, and Vascular Resistance

Just like we saw for the pumping of blood through the heart, the flow of blood through the blood vessels can be viewed simply as the movement of blood from an area of higher pressure to an area of lower pressure.

- Blood flows from an area of higher pressure to an area of lower pressure.
- Blood flows most through the path of least resistance.

Although the flow of blood out of the ventricles is intermittent, movement through the blood vessel is relatively continuous. This is largely due to the fact that the aorta and arteries distend during ventricular contraction (systole) and the elastic tissue recoils during ventricular relaxation (diastole). There is relatively little frictional resistance in the aorta and its arterial branches and blood moves rapidly through with little drop in pressure.

However, in the small arteries and arterioles, resistance to blood flow is large and the drop in pressure as blood moves through these vessels is also large. Blood will flow preferentially to the tissues and organs with the least resistance. The smooth muscle in the arterioles plays a critical role in controlling tissue blood flow and in controlling arterial pressure. The arteriolar smooth muscle just prior to a group of capillaries is sometimes referred to as a pre-capillary sphincter.

Blood Pressure

As just noted there is little drop in pressure as blood moves through the aorta and its arterial branches. However, as the blood moves through the small arteries and arterioles there is a large drop in pressure. The mean arterial pressure (MAP) in the aorta is about 100 mmHg and the central venous pressure (CVP) in the vena cava is about 5 mmHg. The capillary pressure (CP) starts at about 32 mmHg and ends at about 12 mmHg. Although not shown, the mean pulmonary arterial pressure is about 15 mmHg and the pulmonary venous pressure is about 5 mmHg.

Because the flow of blood out of the heart is intermittent, the pressure in the aorta and large arteries is pulsatile. As a result, there is a systolic pressure that corresponds to ventricular contraction (systole), and a diastolic pressure that corresponds to ventricular relaxation (diastole). As the blood moves into the smaller arteries and arterioles, the pressure becomes progressively less pulsatile as the blood vessels absorb the systolic energy. At this point only single pressures are evident. The pressure in the veins is not pulsatile.

The pulsatile pressure in the aorta and large arteries can be reduced to a single pressure by averaging the pressures over time. This is called the mean arterial pressure (MAP). When monitoring arterial pressure directly, mean arterial pressure is usually determined electronically by integration. When measuring arterial pressure indirectly (using a blood pressure cuff), mean arterial pressure is usually estimated from the systolic and diastolic readings. We need to

examine a pressure tracing again to understand the procedure involved. As shown previously, only about 1/3 of each cardiac cycle corresponds to systole and the remaining 2/3 corresponds to diastole. Accordingly, mean arterial pressure is estimated as:

$$MAP = \frac{SYSTOLIC + 2 \cdot DIASTOLIC}{3}$$

In an average person the systolic pressure will be about 120 mmHg and the diastolic pressure will be about 80 mmHg. From these values an estimate of MAP can be calculated.

$$MAP = \frac{120 + 2 \cdot 80}{3}$$

$$MAP = 93 \text{ mmHg}$$

Mean arterial pressure is a good measure of the pressure that drives the blood through the blood vessels, and of the stress that the pressure exerts on the cardiovascular system.

Blood Flow

Blood flow (F) is usually expressed as mL/min or L/min. Blood flow through a blood vessel is dependent on the pressure driving the blood and the resistance of the vessel (R). The pressure driving the blood (ΔP) is the difference between the higher pressure at one end of the vessel and the lower pressure at the other end of the vessel. Formally, blood flow (F) equals the pressure driving the blood (ΔP) divided by the resistance of the blood vessel (R).

$$F = \frac{\Delta P}{R}$$

Vascular resistance

The general equation for the calculation of blood flow is easily rearranged to obtain a better appreciation of the concept of resistance.

$$F = \frac{\Delta P}{R} \quad ; \quad R = \frac{\Delta P}{F}$$

Resistance is simply measured as the change in pressure for a given change in flow. Pressure is usually measured in mmHg, and flow is usually measured in mL/min or L/min. Therefore, resistance is expressed as mmHg/ mL/min or mmHg/ L/min.

As we have indicated in our discussions of blood vessel anatomy, resistance increases as blood vessels decrease in size. Conversely, resistance decreases as blood vessels increase in size. Vascular resistance (R) is affected by the radius and the length of a blood vessel. Radius (r) is extremely important because of the following relationship:

$$R \sim \frac{1}{r^4}$$

Very small changes in the size of blood vessels can markedly change the vascular resistance. The radius of blood vessels, especially small arteries and arterioles, is affected by contraction or relaxation of the smooth muscle of the tunica media.

Cardiac output (blood flow out of the heart)

We can also apply the general equation for blood flow to the calculation of cardiac output. Cardiac output is defined as the amount of blood pumped out of the heart each minute. The amount of blood pumped out each minute is the flow; therefore cardiac output is the flow of blood out of the heart. Accordingly, cardiac output can be expressed as the driving pressure between the aorta (MAP) and the vena cava (CVP) divided by the resistance of the systemic blood vessels. The expression total peripheral resistance (TPR) is often used to describe the resistance of the systemic blood vessels.

$$CO = \frac{MAP - CVP}{TPR}$$

In an average 70 kg person the CO will be about 4.9 L / min, MAP will be about 100 mmHg and CVP will be about 5 mmHg. From these data TPR can be calculated and expressed in units of mmHg/L/min.

$$4.9 \text{ L / min} = \frac{100 \text{ mmHg} - 5 \text{ mmHg}}{\text{TPR}}$$

$$\text{TPR} = \frac{100 \text{ mmHg} - 5 \text{ mmHg}}{4.9 \text{ L / min}} = \frac{95 \text{ mmHg}}{4.9 \text{ L / min}} = 19.4 \text{ mmHg / L / min}$$

Blood Pressure Revisited

The importance of our general equation for blood flow becomes more apparent when we rearrange it and find that mean arterial pressure is equal to cardiac output multiplied by total peripheral resistance. This shows us that increases in either cardiac output or total peripheral resistance will increase arterial pressure.

$$CO = \frac{MAP - CVP}{TPR} \quad ; \quad MAP = (CO \times TPR) - CVP$$

We saw in chapter 16 that increases in heart rate and/or stroke volume can increase cardiac output. Such increases can increase mean arterial pressure. This is one of the major reasons why drugs that decrease heart rate and the force of cardiac contraction decrease arterial pressure.

We now see that vasoconstriction or vascular obstruction can increase total peripheral resistance. Such increases can increase mean arterial pressure. This is one of the major reasons why drugs that decrease vasoconstriction decrease arterial pressure.

Vascular Compliance and Blood Volume

Blood pressure is also affected by blood volume. In a way this is rather obvious, because without blood there would be no blood pressure. At any given degree of vascular compliance (C), as blood volume (BV) increases, mean arterial pressure increases. Compliance is a description of the flexibility of the blood vessels measured as the change in volume for a given change in pressure. Compliance is usually expressed as mL/mmHg or L/mmHg.

$$MAP = \frac{BV}{C} \quad ; \quad C = \frac{BV}{MAP}$$

About 80% of the blood volume is held in the veins. Contraction of the smooth muscle of the blood vessels, especially the veins, decreases the compliance. As the compliance decreases, mean arterial pressure will increase unless the blood volume is reduced.

We now see another reason why vasoconstriction can increase mean arterial pressure. Furthermore, we can see how drugs that cause diuresis and lower blood volume decrease arterial pressure.

Local, Neural, and Hormonal Control of Blood Vessels

Local factors

- Decreased oxygen and increased carbon dioxide and, H^+ leads locally to vasodilation.
- Increases in many paracrines such as adenosine, nitric oxide, eicosanoids, bradykinin and histamine lead locally to vasodilation.
- Vessel stretch or damage cause increased Ca^{2+} entry or release of endothelin-1 causing vasoconstriction.

Neural and hormonal factors

Postganglionic neurons of the sympathetic nervous system secrete norepinephrine and the adrenal medulla secretes epinephrine which acts on blood vessels to cause either vasoconstriction or vasodilation.

- Stimulation of alpha-1 receptors leads to vasoconstriction especially in blood vessels in abdominal organs, kidney, skin and genitals.
- Stimulation of beta-2 receptors leads to vasodilation especially in blood vessels in skeletal muscle.

The renin-angiotensin system produces angiotensin II which acts on blood vessels to cause either cause either vasoconstriction or vasodilation.

- Angiotensin II acts on AT-1 receptors (most common) to cause vasoconstriction of arterioles and pre-capillary sphincters.
- Angiotensin II acts on AT-2 receptors to cause vasodilation.

The posterior pituitary produces vasopressin which acts on blood vessels to cause vasoconstriction.

- Vasopressin acts on V1a receptors to cause vasoconstriction of arterioles and pre-capillary sphincters.

Reflex Vascular Regulation

The cardiovascular system contains sensory receptors that monitor blood pressures in the neck, trunk, and heart. Signals from these sensory receptor travel to the brainstem where they are compared to reference values. When necessary, cardiovascular responses are generated to normalize the pressures.

- Carotid sinus baroreceptors respond to pressure changes in the carotid arteries going to the head.
- Aortic arch baroreceptors respond to pressure changes in the aorta.
- Cardiac atrial stretch receptors respond to pressure changes in the cardiac atria.

Baroreceptor control of vasoconstriction is mediated in part by the sympathetic nervous system, as shown below ( ). Decreases in carotid artery pressure "de-stimulate" the carotid sinus baroreceptors. The glossopharyngeal nerve carries the baroreceptor signal into the medulla of the brainstem and by way of interneurons stimulates the sympathetic nervous system which secretes norepinephrine, activates alpha-1 receptors and causes vasoconstriction.

Baroreceptor control of vasoconstriction is mediated in part by the posterior pituitary. Decreases in carotid artery pressure "de-stimulate" the carotid sinus baroreceptors. The glossopharyngeal nerve carries the baroreceptor signal into the medulla of the brainstem and by way of interneurons stimulates the hypothalamus and pituitary which secretes vasopressin, activates V1a receptors and causes vasoconstriction.

Low arterial pressure and/or decreased atrial filling reflexively cause:

- Increased sympathetic stimulation and release of adrenal catecholamines.
    - Increases heart rate.
    - Increases force of ventricular contraction.
    - Leads to vasoconstriction of arteries in organs least in need of blood.
    - Increases fluid and electrolyte conservation.
    - Increases fluid movement into circulation.
- Increased release of pituitary and adrenal hormones.
    - Increases fluid and electrolyte conservation.
    - Increases fluid movement into circulation.

High arterial pressure and/or increased atrial filling reflexively causes:

- Decreased sympathetic stimulation and release of adrenal catecholamines.
    - Decreases heart rate.
    - Leads to vasoconstriction of arteries in organs least in need of blood.
    - Decreases fluid and electrolyte conservation.
    - Decreases fluid movement into circulation.
- Decreased release of pituitary and adrenal hormones.
    - Decreases fluid and electrolyte conservation.
    - Decreases fluid movement into circulation.

Blood

Functions of blood

- Transports gases, nutrients and metabolic wastes.
- Delivers enzymes and hormones.
- Regulates pH and electrolyte composition of interstitial fluids.
- Restricts fluid losses by way of the clotting reaction.
- Defends the body against toxins and pathogens.
- Helps regulate body temperature.

Composition of blood

Plasma – 55% (53% to 58%)

- Water – 90% to 92% of plasma.
- Electrolytes, nutrients, organic wastes.
- Proteins.
    - Albumins – Major contributor of osmolarity, transport lipids.
    - Globulins – Transport ions, hormones, lipids.
    - Fibrinogen – Converted to fibrin in clotting reaction.

Formed elements (blood cells) – 45% (42% to 47%)

- Red blood cells (Erythrocytes).
- White blood cells (Leukocytes).
- Platelets (Thrombocytes).
- hematocrit – Percentage of whole that is composed of red blood cells.

Blood cells

Erythrocytes (Red blood cells)

- Cytoplasm contains hemoglobin.
- Flattened, no nucleus, mitochondria or ribosomes.
- Transport oxygen and carbon dioxide.

Leukocytes (White blood cells)

Neutrophils (57%)

- Engulf pathogens and debris.
- Release cytotoxins.

Eosinophils (2.4%)

- Engulf antibody bound pathogens.
- Attack parasites with cytotoxins.

Basophils (0.6%)

- Release histamine.
- Complement histamine release by Mast cells.

Monocytes (6.5%)

- Capture or engulf pathogens.
- Enter tissues to become Macrophages.

Lymphocytes – small (28%)

- B-lymphocytes form antibodies.
- T-lymphocytes attack viruses and invaded cells.

Lymphocytes – large (3%)

- NK-lymphocytes attack damaged or foreign cells.

Thrombocytes (Platelets)

- Clump together, activate coagulation.

Hemostasis

Vascular phase

- Contraction of smooth muscle cells in vessel wall.

Platelet phase

- Membranes of the endotheial cells become sticky.
- Platelets attach to the exposed endothelium.
- Platelets stick to one another.

Coagulation phase

- Conversion of fibrinogen to fibrin.
- Requires clotting factors (procoagulants or proenzymes).

Extrinsic pathway

- Release of tissue factors from damaged endothelium.
- Tissue factors combine with calcium and a clotting factor to form Tissue Thomboplastin.

Intrinsic pathway

- Activation of a proenzyme exposed to collagen fibers.
- Platelet thromboplastic factor from aggregating platelets.
- Combine with calcium and clotting factors to form Platelet Thromboplastin.

Common pathway

- Thromboplastin activates a clotting factor that converts Prothrombin into Thrombin.
- Thrombin converts Fibrinogen into Fibrin.
- Platelets and blood cells stick to the Fibrin strands and the platelets contract

Fibrinolysis

- Activation of Plasminogen by Tissue Plasminogen Activator.
- Plasminogen produces Plasmin which digests the Fibrin.

Blood types

- Blood type is determined by the presence or absence of specific proteins (agglutinogens) in the cell membrane of the erythrocytes.
- Your blood plasma contains antibodies (agglutinens) that attack foreign agglutinogens as shown below.

Blood Type	*Frequency*	*Agglutinogen (Antigen)*	*Agglutinen (Antibody)*
A	40%	A	anti-B
B	10%	B	anti-A
AB	4%	AB	none
O	46%	none	anti-A and anti-B
Rh+	85%	Rh	none
Rh-	15%	none	none (anti-Rh if exposed to Rh blood)

Blood – Laboratory

Using the terms in the left box, draw and then label the blood cells. Alternatively, you may paste pictures and then label the blood cells. If you need more space use separate sheets of paper.

Histology of Blood

Erythrocytes flattened, no nucleus	
Neutrophils pale granules in cytoplasm, multi-lobed beaded nucleus	
Lymphocytes, small very little cytoplasm, round nucleus	
Lymphocytes, large relatively little cytoplasm, rounded bean nucleus	

Monocytes large cell, pale cytoplasm, lima bean shaped nucleus	
Eosinophils reddish granules in cytoplasm, bi-lobed nucleus	
Basophils dark bluish granules in cytoplasm, bi-lobed nucleus	
Platelets cytoplasmic fragments, no nucleus	

Formed elements – prepared slide

Identify erythrocytes, each of the white cells, and platelets. Perform a differential white count by examining 100 white cells and tallying the number of each type.

White Blood Cells	Tally
neutrophils	
lymphocytes	
monocytes	
eosinophils	
basophils	

Table 1. Differental white count.

Analysis of Your Own Blood

For the procedures below you will need to clean one of your own fingers with alcohol, prick it and collect blood.

Formed elements – smear of your own blood.

1. Place a drop of blood on a clean slide.
2. Smear the drop of blood across the slide using a second slide.
3. Place several drops of Wright's stain on the slide and rock gently for 2 min. (Do not permit the slide to dry.)
4. Place several drops of distilled water on the slide and wait 5 min.
5. Wash the stain off the slide with distilled water and drain.
6. Identify each of the white cells.

Blood types – determining your own blood type.

1. Place a drop of anti–Rh serum on one slide
2. Place a drop of anti-A serum on the left half and a drop of anti-B serum on the right half of a second slide.
3. Add a drop of blood to the first slide and mix with a toothpick.
4. Add a drop of blood to each antisera on the second slide and mix each with clean toothpicks.
5. Place the first slide on a slide warmer for 2 min.
6. Rock the second slide for 2 min.
7. Examine each slide for agglutination and determine your blood type.

Hematocrit – determining your own hematocrit.

1. Fill a heparinized capillary tube to the red band with blood.
2. Plug the banded end of the tube with clay capillary sealant.
3. Place into a numbered slot in a microhematocrit centrifuge.
4. Centrifuge for at least 3 min.
5. Determine the hemotocrit with the hematocrit reader provided.

Immunity

Nonspecific defenses

Microphages

- Tissue located neutrophils and eosinophils.
- Neutrophils – phagocytize cellular debris, pathogens and antibody bound pathogens.
- Eosinophils – phagocytize parasites and antibody coated pathogens.

Macrophages

- Tissue phagocytes derived from monocytes.
- Capture or phagocytize cellualr debris, pathogens and antibody bound pathogens.

Specific defenses (Immunity)

Lymphocytes

- Cytoxic T-cells – attack foreign cells or body cells infected by viruses.
- B-cells – differentiate into plasma cells which produce antibodies.
- Natural Killer (NK) cells – attack foreign cells, normal cells infected with viruses, or cancer cells appearing in normal tissue.

Cellular immunity

- Direct attack by cytotoxic T-cells.
- Antigen is captured and presented on membranes of macrophages.
- T-cells sensitive to the antigen bind to the antigen.
- T-cells differentiate into cytoxic T-cells and memory cells.
- Cytotoxic T-cells track down and attack cells containing antigen.

Humoral immunity

- Attack by circulating antibodies.
- Antigen is captured and presented on membranes of macrophages.
- Helper T-cells sensitive to antigen bind to the antigen.
- Antigen is presented by Helper T-cells to antigen sensitive B-cell or antigen exposed B-cell is activated by Helper T-cell lymphokines.
- The B-cells differentiate into plasma cells and memory cells.
- Plasma cells divide and produce antibodies to the antigen.
- Antibodies bind to antigen and:

- Neutralize active sites.
- Prevent pathogen attachment.
- Precipitate immune complexes.
- Attract phagocytes.
- Enhance phagocytosis.

Functions of the lymphatic system

There is a continual movement of fluid from the capillaries, into the interstitial spaces between tissue cells, and back to the circulation via the lymphatic vessels. The lymphatic system serves two major purposes:

- To return plasma lost from the capillaries back to the systemic veins.
- To collect, capture and destroy pathogens in the body.

Lymphatic tissues and organs are composed mainly of connective tissues dominated by lymphocytes and include:

- Lymph nodes – contain macrophages and lymphocytes acting on lymph.
- Thymus – site for maturation of T-cells.
- Spleen – contains macrophages and lymphocytes acting on blood.

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Practice Questions – Cardiovascular System

Choices may be used more than once or not at all.

1-5. Matching

A)	Left atrium	receives blood from the pulmonary veins	1) _____
B)	Right atrium	discharges blood into pulmonary arteries	2) _____
C)	Left ventricle	receives blood from the coronary sinus	3) _____
D)	Right ventricle	discharges blood into systemic arteries	4) _____
E)	None of the above	receives blood from the system veins	5) _____

6-10. Matching

A)	Epicardium	composed of simple squamous epithelium	6) _____
B)	Myocardium	also called the visceral pericardium	7) _____
C)	Endocardium	covers the outside of the heart	8) _____
D)	A and C	covers the inside of the heart	9) _____
E)	None of the above	composed of cardiac muscle	10) _____

11-15. Trace the flow of a drop of blood through the heart.

A)	Vena cava	11) _____
B)	Mitral valve	12) _____
C)	Tricuspid valve	13) _____
D)	Aortic semilunar valve	14) _____
E)	Pulmonary semilunar valve	15) _____

16-20. Matching

A)	Contains oxygen rich blood	Vena Cava	16) _____
B)	Contains oxygen poor blood	Left atrium	17) _____
		Right atrium	18) _____
		Left ventricle	19) _____
		Right ventricle	20) _____

21-25. Matching

A)	Ventricular contraction	opens semilunar valves	21) _____
B)	Ventricular relaxation	pulls blood out of atria	22) _____
		sucks blood into ventricles	23) _____
		pushes blood out of ventricles	24) _____
		opens mitral and tricuspid valves	25) _____

26-30. Matching

A)	Ventricular contraction	opens semilunar valves	26) _____
B)	Ventricular relaxation	sucks blood into ventricles	27) _____
C)	None of the above	pulls blood out of vena cava	28) _____
		opens atrioventricular valves	29) _____
		closes atrioventricular valves	30) _____

31-35. Matching

A)	End Diastolic Volume	affected by heart rate	31) _____
B)	End Systolic Volume	affected by filling time	32) _____
C)	None of the above	affected by blood flow in vena cava	33) _____
		greatly affected by force of contraction	34) _____
		immediately affected by norepinephrine	35) _____

36-40. Matching

A)	Right coronary artery	is connected to right atrium	36) _____
B)	Left coronary artery	is connected to ascending aorta	37) _____
C)	Coronary sinus	branches to form the marginal arteries	38) _____
D)	A and B	branches to form the circumflex artery	39) _____
		branches to form the anterior descending artery	40) _____

41-45. Trace a drop of blood thru the coronary circulation.

A)	Aorta	41) _____
B)	Coronary sinus	42) _____
C)	Marginal branches	43) _____
D)	Right coronary artery	44) _____
E)	Posterior descending artery	45) _____

46-50. Matching

A)	SA node	located near the vena cava	46) _____
B)	AV node	conducts thru the bundle of His	47) _____
		located near the tricuspid valve	48) _____
		intrinsic rate about 40-60 per minute	49) _____
		intrinsic rate about 80-100 per minute	50) _____

51-55. Place in the order that signals pass through the cardiac conduction system.

A)	Atrial conduction fibers (internodal pathway)	51) _____
B)	Bundle branches	52) _____
C)	Bundle of His	53) _____
D)	SA node	54) _____
E)	AV node	55) _____

56-60. Matching

A)	About 0.17 sec	typical PR interval	56) _____
B)	About 0.35 sec	typical QT interval	57) _____
C)	About 0.60 sec	RR interval with a HR of 50	58) _____
D)	About 0.86 sec	RR interval with a HR of 70	59) _____
E)	None of the above	RR interval with a HR of 100	60) _____

61-65. Matching

A)	P wave	usually contains the largest of the waves	61) _____
B)	T wave	disappears with damage to the SA node	62) _____
C)	QRS complex	depolarization of the ventricles	63) _____
		repolarization of the ventricles	64) _____
		depolarization of the atria	65) _____

66-70. Matching

A)	Acetylcholine	increases sarcoplasmic storage of calcium	66) _____
B)	Norepinephrine	acts on myocardium via Beta 1 receptors	67) _____
C)	None of the above	acts on nodes via muscarinic receptors	68) _____
		hyperpolarizes nodal membrane	69) _____
		depolarizes nodal membrane	70) _____

71-75. Matching

A)	Stimulation of muscarinic receptors	increases heart rate	71) _____
B)	Stimulation of alpha-1 receptors	decreases heart rate	72) _____
C)	Stimulation of beta-1 receptors	increases stroke volume	73) _____
D)	Stimulation of beta-2 receptors	increases force of contraction	74) _____
E)	None of the above	decreases force of contraction	75) _____

76-80. Place in the order that blood travels to the <u>right arm</u>, starting at the aortic arch.

A)	Radial artery	76) _____
B)	Axillary artery	77) _____
C)	Brachial artery	78) _____
D)	Subclavian artery	79) _____
E)	Brachiocephalic artery	80) _____

81-85. Place in the order that blood may reach the <u>right brain</u>, starting at the <u>lungs</u>.

A)	Left ventricle	81) _____
B)	Pulmonary veins	82) _____
C)	Brachiocephalic artery	83) _____
D)	Internal carotid artery	84) _____
E)	Common carotid artery	85) _____

86-90. Place in the order that blood may reach the <u>left leg</u>, starting at the <u>aorta</u>.

A)	Descending aorta	86) _____
B)	Common iliac artery	87) _____
C)	External iliac artery	88) _____
D)	Femoral artery	89) _____
E)	Tibial arteries	90) _____

91-95. Matching

A)	Blood drains into hepatic portal vein	renal veins	91) _____
B)	Blood drains directly into vena cava	splenic vein	92) _____
		gastric veins	93) _____
		adrenal veins	94) _____
		mesenteric veins	95) _____

96-100. Matching

A)	Compliance (C)	equals BV / C	96) _____
B)	Blood Pressure (BP)	equals SV x HR	97) _____
C)	Cardiac Output (CO)	equals CO x VR	98) _____
D)	None of the above	equals ΔBV / ΔBP	99) _____
		equals (EDV-ESV) x HR	100) _____

101-105. Matching

A)	Vascular Resistance (VR)	equals BP / VR	101) _____
B)	Blood Flow (BF)	equals BP / BF	102) _____
C)	None of the above	equals BF / BP	103) _____
		increases as vessel size increases	104) _____
		decreases as vessel size increases	105) _____

106-110. Matching

A)	Skeletal muscle	cells are long	106) _____
B)	Cardiac muscle	cells are short	107) _____
C)	Smooth muscle	cells are found in the tunica media	108) _____
D)	B and C	cells are connected by intercalated discs	109) _____
		contraction depends on calcium from extracellular fluid	110) _____

111-115. Matching

A)	Post-capillary constriction	increases arterial pressure	111) _____
B)	Pre-capillary constriction	increases capillary pressure	112) _____
C)	A and B	decreases capillary pressure	113) _____
D)	None of the above	increases peripheral resistance	114) _____
		increases fluid uptake by blood	115) _____

116-120. Matching

A)	Cortisol	stimulates aldosterone secretion	116) _____
B)	Glucagon	facilitates fluid movement out of cells	117) _____
C)	Vasopressin	stimulates water reabsorption by kidney	118) _____
D)	Angiotensin	increases glucose concentration in blood	119) _____
E)	Norepinephrine	leads to vasoconstriction via alpha receptors	120) _____

121-125. Matching

A)	Atrial receptors	respond to changes in venous return	121) _____
B)	Carotid sinus	generally lead to reflex changes in volume	122) _____
C)	Aortic arch	generally lead to reflex changes in pressure	123) _____
D)	B and C	respond to changes in blood pressure to head	124) _____
		respond to changes in blood pressure in chest	125) _____

121-130. Given: HR = 70; Blood Pressure = 120/ 80; Cardiac Output = 4.9 L; determine

A)	0.86	R-R interval (sec)	126) _____
B)	70	Stroke Volume (mL)	127) _____
C)	80	Mean arterial pressure (mmHg)	128) _____
D)	93.3	Systolic arterial pressure (mmHg)	129) _____
E)	120	Diastolic arterial pressure (mmHg)	130) _____

131-135. Matching

A)	Basophils	responsible for producing antibodies	131) _____
B)	Neutrophils	engulf and destroy parasites	132) _____
C)	Eosinophils	attack and destroy viruses	133) _____
D)	B-lymphocytes	produce histamine	134) _____
E)	T-lymphocytes	engulf debris	135) _____

136-140. Matching

A)	Blood type A	has antibodies to the Rh protein	136) _____
B)	Blood type B	has antibodies to the A protein only	137) _____
C)	Blood type AB	has antibodies to the B protein only	138) _____
D)	Blood type O	has antibodies to both the A and B protein	139) _____
E)	do not know	has antibodies to neither the A or B protein	140) _____

141-145. Matching

A)	Coagulation phase	involves plasmin	141) _____
B)	Retraction phase	involves vasoconstriction	142) _____
C)	Vascular phase	involves production of fibrin	143) _____
D)	Platelet phase	involves clumping of thrombocytes	144) _____
		enhanced by tissue plasminogen activator	145) _____

146-150. Matching

A)	Platelet Thromboplastin	digests Fibrin	146) _____
B)	Tissue Thromboplastin	production involves Thrombin	147) _____
C)	Thrombin	produced by damaged endothelium	148) _____
D)	Plasmin	production involves Thromboplastin	119) _____
E)	Fibrin	produced by platelets exposed to collagen	150) _____

151-155. Matching

A)	Albumins	are a major contributor of blood osmolality	151) _____
B)	Globulins	are found dissolved in blood plasma	152) _____
C)	Fibrinogen	act as carrier proteins for hormones	153) _____
D)	All of the above	transformed by thrombin	154) _____
E)	None of the above	contain hemoglobin	155) _____

Short Essays

1. Describe the mechanical events that are responsible for pumping blood through the heart. Include a description of the changes in pressure and the opening and closing of valves that are associated with the contraction and relaxation of the cardiac chambers.

2. Describe the organization of the cardiac conduction system and its role in coordinating the pumping action of the heart.

3. Describe the inter-relations among cardiac output, stroke volume, and heart rate. Include a description of how neural and hormonal signals influence stroke volume and heart rate.

4. Describe the inter-relations among blood flow, blood pressure, and vascular resistance. Include a description of how neural and hormonal signals influence vascular resistance.

5. Describe three mechanisms that play central roles in controlling blood volume.

6. Describe the major mechanisms responsible for the formation of a blood clot following damage to the endothelium.

Section 6 – Respiratory, Digestive, and Urinary Systems

Respiratory Airways and Lungs

The respiratory system in humans includes the nasal and oral cavities, the respiratory airways leading to the lungs, the lungs and pleural cavities, and the muscles of the chest and abdomen responsible for moving air into and out of the lungs during breathing. The primary purpose of the respiratory system is to obtain oxygen from the air and transfer it to the blood, and to transfer carbon dioxide from the blood and move it to the air. Additionally, the amount of carbon dioxide in the blood affects pH and the respiratory system plays a critical role in controlling acid-base balance.

Organization of the Respiratory System

The lungs are located within the pleural cavities of the chest. The diaphragm is located below the pleural cavities, and forms a partition between the thoracic cavity and the abdominal cavity.

The respiratory airways carry air into and out of the alveoli which make up the major portion of the lungs. The alveoli are spherical structures made largely of simple squamous epithelium that are clustered together to form alveolar sacs. The alveolar sacs in turn connect to bronchioles that in turn connect to intrapulmonary bronchi (segmental bronchi). The epithelium of the alveoli is surrounded by elastic connective tissue and by the pulmonary capillaries. The elastic connective tissue places a constant pressure on the alveoli and causes then to recoil after being stretched. Elastic connective tissue is also found under the visceral pleura of the lungs. The pulmonary capillaries provide for the exchange of gasses between the blood and the air in the alveoli. Pulmonary arterioles and venules connect the capillaries to the pulmonary arteries and veins.

Pleural membranes and pleural fluid

The pleural membranes are composed of simple squamous epithelia and are located in the pleural cavities of the chest. The parietal pleura line each of the pleural cavities. The visceral pleura cover each of the lungs. Pleural fluid is secreted by the pleural membranes and fills the spaces between the pleural membranes. The pleural fluid creates a fluid bond (and an associated negative intrapleural pressure) that pulls the pleural membranes against each other. Without this fluid bond, expansion of the chest does not cause the lungs to expand and inhalation does not occur. This is seen following chest trauma that causes a pneumothorax.

Upper respiratory tract

Nose – lined with an epithelial barrier composed of pseudostratified ciliated columnar epithelium

External nares – nostrils.

Nasal cavity (right and left)

Nasal septum – partitions the nasal cavity into right and left cavities; composed of the:

- Perpendicular Plate of the ethmoid bone
- Vomer bone
- Nasal Cartilage

Hard palate – Floor of the nose composed of maxillary and palatine bone.

Soft palate – Soft tissue posterior to the hard palate.

Internal nares – Connection between nasal cavity and nasopharynx.

Nasal conchae – Projections from the ethmoid and maxillary bones around the nasal cavity.

Superior, Middle and Inferior Nasal Conchae

Nasal meatus(i) – Spaces between adjacent conchae for air passage.

Superior, Middle and Inferior Nasal Meati

Pharynx

Auditory tube (Eustachian tube) – Connects nasopharynx to middle ear.

Nasopharynx – Behind internal nares.

Oropharynx – Behind tongue.

Laryngopharynx – Behind larynx.

Larynx

Glottis – Opening of larynx.

Epiglottis – Surrounds the glottis.

Thyroid cartilage – Major anterior structure of the larynx.

Cricoid cartilage – Major posterior structure of the larynx.

Ventricular folds – Narrowing of the glottis superior to the vocal cords.

Vocal folds – Narrowing of the glottis inferior to the vocal cords.

Vocal cords – Fibrous connective tissue "strings" between the ventricular and vocal folds.

Trachea – Lined with an epithelial barrier composed of pseudostratified ciliated columnar epithelium.

Tracheal cartilage – Structural corrugations of the trachea.

Primary bronchi – Lined with an epithelial barrier composed of pseudostratified ciliated columnar epithelium.

Right primary bronchus – Right branch of trachea
Left primary bronchus – Left branch of trachea.

Secondary bronchi – Lined with an epithelial barrier composed of pseudostratified ciliated columnar epithelium.

Right secondary bronchi – 3 or 4 branches of right primary bronchus.

Left secondary bronchi – 2 branches of left primary bronchus.

Lower respiratory tract

Lungs

Cardiac notch – Depression in left lung for pericardium.

Lobes

Right lung – Superior, middle and inferior lobes.
Left lung – Superior and inferior lobes.

Pleural cavities

Mediastinum – *Aka*: pericardial sac; separates the left and right pleural cavities.

Pleural cavity – Space on either side of the pericardial cavity for the lungs.

Parietal pleura – Simple squamous epithelium that lines pleural cavities and covers the mediastinum.

Visceral pleura – Simple squamous epithelium that covers the lungs.

Pleural space – Space between parietal and visceral pleura.

Pulmonary circulation

Right and left pulmonary arteries.
Right and left pulmonary veins.

Intrapulmonary (Segmental) bronchi – tertiary and smaller bronchi – Lined with an epithelial barrier composed of pseudostratified ciliated columnar epithelium.

Terminal bronchioles – Branches of the smallest segmental bronchi; lined with an epithelial barrier composed of simple cuboidal epithelium.

Respiratory bronchioles – Branches of the terminal bronchiole; lined with an epithelial barrier composed of simple squamous epithelium.

Alveolar ducts – Branches of the respiratory bronchiole.

Alveolar Sacs – Clusters of alveoli that form around the alveolar ducts.

Alveoli – The site of gas exchange with the blood; lined with an epithelial barrier composed of simple squamous epithelium.

Histology of Bronchi, Bronchioles, and Alveoli

Intrapulmonary (Segmental) Bronchi

Mucosa

- PCCE

Submucosa

- smooth muscle layer
- cartilage plates
- mucus glands (periodically)

Terminal bronchioles

Mucosa

- Simple Cuboidal-like Epithelium with less cilia.
- PCCE begins to disappear.

Submucosa

- smooth muscle layer begins to disappear.
- No cartilage plates.

Respiratory bronchioles

Mucosa

- Simple Squamous Epithelium
- No PCCE.

Submucosa

- No smooth muscle.
- No cartilage plates.

Alveolar ducts and Alveoli

Mucosa

- Simple Squamous Epithelium
- Surfactant cells are interspersed.

Respiratory Airways and Lungs – Laboratory

Using the terms in the left box, draw and then label the structures. Alternatively, you may paste pictures and then label the structures. If you need more space use separate sheets of paper.

Models of Upper respiratory tract

Nose
 	
• External Nares
• Nasal Cavity
• Nasal Septum
  ○ Perpendicular Plate of Ethmoid Bone
  ○ Vomer Bone
  ○ Nasal Cartilage
• Hard Palate
• Soft Palate
• Uvula
• Internal Nares
• Nasal Conchae(Superior, Middle and Inferior)
• Nasal Meatus(i) (Superior, Middle and Inferior)	

Pharynx • Nasopharynx ○ Auditory Tube • Oropharynx • Laryngopharynx	

Larynx • Glottis • Epiglottis • Thyroid cartilage • Cricoid cartilage • Vestibular folds (false vocal cords) • Vocal folds (true vocal cords) • Vocal cords	
Trachea • Tracheal Cartilage	
Primary bronchi • Right Primary Bronchus • Left Primary Bronchus Secondary Bronchi	

Histology of Trachea

Mucosa • PCCE • Lamina propria Submucosa • Fibrous Connective Tissue • Tracheal cartilage • Trachealis muscle	

Models of Lower respiratory tract

Right lung • Superior, Middle and Inferior Lobes Left lung • Superior and Inferior Lobes • Cardiac notch	
Lungs Intrapulmonary Bronchi (aka Segmental Bronchi) Pulmonary Circulation • Right and Left Pulmonary Arteries • Right and Left Pulmonary Veins	
Pleural Cavities • Mediastinum • Parietal Pleura • Visceral Pleura • Pleural Space	

Lung Lobule • Visceral Pleura • Elastic Connective Tissue • Intrapulmonary Bronchus • Pulmonary Venule • Terminal Bronchiole • Pulmonary Arteriole • Respiratory Bronchiole • Alveolar Sacs • Alveolar Ducts • Alveoli • Pulmonary (Alveolar) Capillaries	
Alveoli • Pulmonary (Alveolar) Capillaries • Alveolar Membrane ○ Simple Squamous Epithelium • Elastic Connective Tissue • Alveolar Ducts	

Histology of Lung

Intrapulmonary Bronchi Mucosa • PCCE Submucosa • smooth muscle layer • cartilage plates	
Terminal Bronchioles Mucosa • Cuboidal Epithelium Submucosa • no cartilage plates	
Respiratory Bronchioles Mucosa • Simple Squamous Epithelium Submucosa • no cartilage plates	

Alveolar Ducts and Alveoli Alveolar Ducts Alveoli • Simple Squamous Epithelium • Pulmonary (Alveolar) Capillaries	

Pulmonary Ventilation and Lung Mechanics

Pulmonary ventilation involves moving air between the atmosphere and the alveoli of the lungs. Movement of air depends on changing the size of the lungs and on the elastic connective tissue of the lungs, the pleural membranes and pleural fluid, and the muscles of the chest and abdomen.

Respiratory pressures

Atmospheric pressure at sea level is 760 mmHg. Alveolar pressure (P_{alv}) ranges from slightly higher than this during exhalation to slightly less than this during inhalation. The difference between alveolar pressure (P_{alv}) and atmospheric pressure (P_{atm}) is called respiratory system pressure (P_{rs}) and is a major determinant of air flow into and out of the lungs.

- Atmospheric pressure (P_{atm}) (absolute measurement).
    - ~ 760 mmHg.
- Alveolar pressure (P_{alv}) (absolute measurement).
    - During quiet inspiration ≈ 757 mmHg.
    - During quiet expiration ≈ 763 mmHg.
- Respiratory system pressure (P_{rs}) is the difference between alveolar pressure (P_{alv}) and atmospheric pressure (P_{atm}) and is a major determinant of air flow.
    - during quiet inspiration ≈ –3 mmHg.
    - during quiet expiration ≈ +3 mmHg.

Intrapleural pressure (P_{ip}) is almost always negative and ranges from slightly less than atmospheric pressure (P_{atm}) during exhalation to much less than atmospheric pressure (P_{atm}) during inhalation. The difference between alveolar pressure (P_{alv}) and intrapleural pressure (P_{ip}) is called transpulmonary pressure (P_{tp}) and is a major determinant of lung volume.

- Intrapleural pressure (P_{ip}) (absolute measurement).
    - During quiet inspiration ≈ 754 mmHg.
    - During quiet expiration ≈ 757 mmHg.
- Transpulmonary pressure (P_{tp}) is the difference between alveolar pressure (P_{alv}) and intrapleural pressure (P_{ip}) and is a major determinant of air flow.
    - during quiet inspiration ≈ +3 mmHg.
    - during quiet expiration ≈ +6 mmHg.

Boyle's Law

Boyle's law establishes the relationship between the pressure (P) and the volume (V) of gasses.

$$P = \frac{1}{V}$$

As the volume of the lungs increases the pressure decreases; as the volume of the lungs decreases the pressure increases.

Exhalation and Inhalation

During quiet exhalation, the diaphragm and external intercostal muscles relax and:

1. The elastic connective tissue of the lungs recoils.
2. The lungs shrink, and at about the same time:
3. The visceral pleura of the lungs pull on the parietal pleura of the diaphragm and chest.
4. The diaphragm ascends, and the ribcage contracts.
5. Pressure increases in the lungs and air is expelled.

During forced exhalation contraction of the internal intercostal muscles, the rectus abdominus and the oblique muscles assist in decreasing the size of the thoracic cavity by compressing the ribcage and compressing the abdominal contents.

During quiet inhalation, the diaphragm and external intercostal muscles contract, and:

1. The diaphragm descends and the ribcage expands.
2. The parietal pleura of the diaphragm and chest pull on the visceral pleura of the lungs, and at about the same time:
3. The lungs expand.
4. The elastic connective tissue of the lungs stretches.
5. Pressure decreases in the lungs and air is drawn in.

During forced inhalation contraction of the external intercostal muscles, the serratus anterior and posterior muscles, and the sternocleidomastoid and scalene muscles, increase the size of the thoracic cavity by expanding the ribcage.

Airway flow

The basis for airway flow is the same as for blood flow. Airway flow (F_{air}) is usually expressed as mL/min or L/min. Air flow through the airways is dependent on the pressure driving the air and the resistance of the airways (R_{aw}). The pressure driving the air (ΔP) is the difference between the higher pressure at one end of the airways and the lower pressure at the other end of the airways. In the respiratory system, the pressure driving the air is called respiratory system pressure (P_{rs}) and is the difference between the alveolar pressure (P_{alv}) and the atmospheric pressure (P_{atm}). Formally, air flow (F_{air}) equals the pressure driving the air (P_{rs}) divided by the resistance of the airways (R_{aw}).

$$F = \frac{\Delta P}{R} \quad ; \quad F_{air} = \frac{P_{alv} - P_{atm}}{R_{aw}} = \frac{P_{rs}}{R_{aw}}$$

Airway resistance

Like we have seen before, the equation for the calculation of air flow is easily rearranged to show the concept of airway resistance.

$$F_{air} = \frac{P_{rs}}{R_{aw}} \quad ; \quad R_{aw} = \frac{P_{rs}}{F_{air}}$$

Airway resistance (R_{aw}) is simply measured as the change in respiratory system pressure (P_{rs}) for a given change in air flow (F_{air}). Pressure is usually measured in mmHg, and flow is usually measured in mL/min or L/min. Therefore, airway resistance is expressed as mmHg/ mL/min or mmHg/ L/min.

As airway resistance (R_{aw}) increases, a greater change in respiratory system pressure (P_{rs}) is needed to produce the same change in air flow (F_{air}). Airway resistance (R_{aw}) is commonly affected by mechanical manipulation, and by contraction of the smooth muscle of the airways. **Obstructive pulmonary diseases** are caused by increases in airway resistance. Common obstructive pulmonary diseases include:

- COPD caused by chronic bronchitis and emphysema.
- Emphysema caused y fracturing or bursting of the alveoli.
- Asthma caused by airway constriction.
- Bronchiectasis caused by mucus buildup in the airways.

An example of normal mechanical manipulation is seen during inhalation when there is a pulling on the airways that tends to decrease the resistance. Conversely, during exhalation there is a pushing on the airways that tends to increase the resistance.

Changes in smooth muscle contraction are a major factor affecting airway resistance.

- Asthma increases resistance by causing spastic contraction of the smooth muscle of the airways, increasing mucus secretion, and increasing inflammation.
- Histamine release increases airway resistance by stimulating bronchoconstriction and increasing mucus secretion.
- CO_2 decreases resistance by stimulating bronchodilation.
- Acetylcholine increases airway resistance by stimulating bronchoconstriction via activation of M3 receptors.
- Epinephrine decreases resistance by stimulating bronchodilation via activation of β2 receptors.

Lung compliance

Lung compliance (C_{lung}) is a description of the flexibility of the lungs measured as the change in lung volume (V_{lung}) for a given change in transpulmonary pressure (P_{tp}). Lung compliance is usually expressed as mL/mmHg or L/mmHg.

$$P_{tp} = \frac{V_{lung}}{C_{lung}} \quad ; \quad C_{lung} = \frac{V_{lung}}{P_{tp}}$$

As lung compliance (C_{lung}) increases a smaller change in transpulmonary pressure (P_{tp}) is necessary for a given change in lung volume. Conversely, as lung compliance (C_{lung}) decreases a larger change in transpulmonary pressure (P_{tp}) is necessary for a given change in lung volume. Lung compliance depends on the elasticity of the lungs and the surface tension in the alveoli. **Restrictive pulmonary diseases** are caused by decreases in lung compliance. Common restrictive pulmonary diseases include:

- Pulmonary fibrosis caused by overgrowth of the connective tissues of the lungs
- Sarcoidosis caused by inflammation of tissues producing small nodules or granulomas.
- Lungs cancers caused by abnormal reproduction of cells.
- Pneumonia caused by inflammation of the lung caused by an infection.

Minute volume

Minute volume (V_{min}) is comparable to cardiac output, and is the volume of air moved by the lungs each minute and equals the respiratory rate (RR) times the volume per breath (TV).

$$V_{min} = RR \times TV$$

However, the airways form a dead space and only part of the tidal volume reaches the alveoli. Alveolar ventilation (V_{alv}) is the volume of air moved into the alveoli each minute and equals the respiratory rate (RR) times the difference between the volume per breath (TV) and the dead space (DS).

$$V_{min} = \quad RR \times (TV - DS)$$

The dead space (DS) in the airways is typically about 150 mL and tidal volume (TV) is about 500 mL. Therefore, for each breath only about 350 mL of fresh air reaches the alveoli.

Ventilatory volumes

Ventilatory volumes refer to the volumes of air that can be found in the lungs with different levels of breathing. Even after maximum exhalation, air remains in the lungs. This volume of air is called the residual volume (RV). Usually we do not exhale maximally with each exhalation, and the difference in lung volume between maximum inhalation and normal inhalation is called the expiratory reserve volume (ERV). The sum of the residual volume (RV) and the expiratory reserve volume (ERV) is called the functional residual volume (FRV) because it represents the volume of air that is commonly left in the lungs. The difference in lung volume between normal inhalation and exhalation is called the tidal volume (TV). Even after a normal inhalation, we can inhale considerably more, and the difference in lung volume between maximum inhalation and a normal inhalation is called the inspiratory reserve volume (IRV). Vital capacity (VC) is the maximum volume of air we can exhale from the lungs, and is the sum of ERV, TV and IRV.

$$VC = IRV + TV + ERV$$

- Vital Capacity (VC) = volume of air moved by the lungs between maximum inhalation and maximum exhalation.
- Inspiratory Reserve Volume (IRV) = volume of air that can be moved into the lungs between normal inhalation and maximum inhalation.
- Tidal Volume (TV) = volume of air moved by the lungs between normal inhalation and normal exhalation.
- Functional Residual Volume (FRV) = RV + ERV.
- Expiratory Reserve Volume (ERV) = volume of air that can be expelled from the lungs between normal expiration and maximum exhalation.
- Residual volume (RV) = volume of air remaining in the lungs after maximum exhalation.

Spirometry – Lab

Ventilatory Measurements

- Vital Capacity (VC) – volume of air moved by the lungs between maximum inspiration and maximum expiration.
- Tidal Volume (TV) – volume of air moved by the lungs between quiet inspiration and quiet expiration.
- Expiratory Reserve Volume (ERV) – volume of air that can be expelled from the lungs between quiet expiration and maximum expiration.
- Inspiratory Reserve Volume (IRV) – volume of air that can be moved into the lungs between quiet inspiration and maximum inspiration.
- Residual Volume (RV) – volume of air remaining in lungs after maximum expiration.

$$VC = IRV + TV + ERV$$

Students in each group will individually obtain measurements of:

Ventilatory measurement	***measured*** *(liters)*	***calculated*** (*liters*)
Tidal volume		
Expiratory reserve volume		
Vital capacity		
Inspiratory reserve volume		

Each student will answer the following questions.

1. Identify the following lung volumes and capacities.

A) maximum amount of air that can be expired after a maximum inspiration.

_____.

B) maximum amount of air that can be inspired after a normal inspiration.

_____.

C) maximum amount of air that can be inspired after a normal expiration

_____.

D) the amount of air left in the lungs after a maximum expiration

_____.

2. Pulmonary disorders in which the alveoli are normal but there is abnormally high resistance to airflow are categorized as

_____ disorders.

3. One pulmonary test for the above disorders is the
_____.

4. Does your chest expand because your lungs inflate? _____

Explain. _____

5. Describe three factors that are responsible for contraction of the lungs during expiration.

_____

_____

_____

Gas Exchange and Transport

Partial Pressures

Atmospheric air is composed of many gases and the most common are as shown below. The total pressure of air at sea level is 760mmHg (sometimes called Torr, T). The contribution to the total pressure by a given gas is called the partial pressure of that gas. The partial pressure of oxygen in the atmosphere is about 160 mmHg (usually expressed as $pO_2 = 160T$). The partial pressure of carbon dioxide is considerably less, about 0.24 (usually expressed as $pCO_2 = 0.24T$)

Composition of Atmospheric Air.

	percent of atmosphere	partial pressure (mmHg) (T)
All gases in Air	100	760
Nitrogen	78.08	593.4
Oxygen	20.95	159.2
Argon	0.93	7.1
Carbon Dioxide	~0.04	~0.3

In the alveoli of the lungs and in the systemic and pulmonary blood vessels the partial pressures of oxygen and carbon dioxide are quite different from what is seen in atmospheric air, as shown above. The partial pressure of oxygen is about 105T in the alveoli compared to 160T in the atmosphere. Most dramatically, the partial pressure of carbon dioxide is about 40T in the alveoli compared to about 0.3T in the atmosphere. This disparity occurs in large part because of the functional residual volume of the lungs and the dead space of the airways. The tidal volume, typically about 500 mL, brings in and removes a relatively small volume of air compared to the functional residual volume, typically about 2200 mL. As a result carbon dioxide accumulates in the alveoli.

Gas exchange

The partial pressures of oxygen and carbon dioxide in the alveoli, blood vessels and systemic tissues are summarized in following Table. Please refer to the cardiovascular system for a clarification of why the blood gases of the systemic venous blood and pulmonary arterial blood will be about the same, and why the blood gases of systemic arterial blood and pulmonary venous blood will be about the same.

Alveolar and Vascular Blood Gasses.

region	pO_2 *T*	pCO_2 *T*
Alveoli	~105	~40
Systemic venous blood and Pulmonary arterial blood	~40	~46
Systemic arterial blood and Pulmonary venous blood	~100	~40
Tissue Cytoplasm	~20	~50

Oxygen will diffuse from an area of higher partial pressure to an area of lower partial pressure. Similarly, carbon dioxide will diffuse from an area of higher partial pressure to an area of lower partial pressure.

In the lungs, O_2 in the alveoli diffuses into the pulmonary capillary blood, and CO_2 in the pulmonary blood diffuses into the alveoli. Blood that enters the pulmonary capillaries has a pO_2 of 40T and a pCO_2 of 46T. After leaving the pulmonary capillaries the pO_2 is about 100T and the pCO_2 is about 40T.

In the systemic organs, O_2 in the systemic capillary blood diffuses into systemic tissues, and CO_2 in the systemic tissues diffuse into the systemic capillary blood. Blood that enters the systemic capillaries has a pO_2 of about 100T and a pCO_2 of about 40T. After leaving the systemic capillaries the pO_2 is about 40T and the pCO_2 is about 46T.

Oxygen Transport

Only bout 1.5% of O_2 is transported in the blood dissolved in plasma, the remainder is transported bound to hemoglobin. Oxygen combines with hemoglobin in the blood in a reversible reaction. Hemoglobin has a very high affinity for oxygen. At a pO_2 of 40T hemoglobin is 80% saturated (80% of the binding sites for O_2 are occupied by O_2).

$$O_2 + HbH \longleftrightarrow Hb\text{-}O_2 + H^+$$

- as oxygen concentration in the blood increases, more oxygen combines with hemoglobin.
- as oxygen concentration in the blood decreases, less oxygen combines with hemoglobin.

- Both H^+ and CO_2 compete with O_2 for binding sites on hemoglobin, although with a lower affinity than O_2.

The competition for oxygen binding sites by H^+ is referred to as the Bohr effect, and the competition for oxygen binding sites by CO_2 is referred to as the carbamino effect. Increased H^+ and CO_2 as seen in metabolically active tissue will dislodge more O_2 from the hemoglobin, making more oxygen available for the tissues.

Oxygen gas transport is illustrated below. In the alveolar capillaries, where the oxygen concentration within the alveoli is greater than the oxygen concentration of the blood, oxygen moves into the blood and combines with hemoglobin.

$$O_2 + HbH \rightarrow Hb\text{-}O_2 + H^+$$

In the tissue capillaries, where the oxygen concentration of the tissues is less than the oxygen concentration of the blood, oxygen dissociates from hemoglobin and moves out of the blood.

$$Hb\text{-}O_2 + H^+ \rightarrow HbH + O_2$$

Carbon Dioxide Transport

Carbon dioxide combines only to a limited extent with hemoglobin in the blood in a reversible reaction. Although hemoglobin plays a small role in the transport of CO_2, the binding of O_2 to hemoglobin decreases the affinity of hemoglobin for CO_2 (Haldane effect) and further reduces the transport of CO2 by hemoglobin.

$$Hb + CO_2 \longleftrightarrow Hb\text{-}CO_2$$

Most carbon dioxide combines with water in the erythrocytes in a reversible reaction to form carbonic acid that in turn dissociates in a reversible reaction to form hydrogen ions and bicarbonate ions.

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow HCO_3^- + H^+$$

- as carbon dioxide concentration in the blood increases, more hydrogen ions and bicarbonate ions are formed.
- as carbon dioxide concentration in the blood decreases, fewer hydrogen ions and bicarbonate ions are formed.

Added bicarbonate ions (such as from sodium bicarbonate) will decrease the dissociation of the carbonic acid and thus, decrease the production of hydrogen ions and raise the pH (refer to 'Acid-Base Balance'). Bicarbonate ions (HCO_3^-) are transported out of the erythrocytes and into the plasma in exchange for Cl^- (chloride shift).

In the alveolar capillaries, where the carbon dioxide concentration within the alveoli is less than the carbon dioxide concentration of the blood, hydrogen ions combine with bicarbonate ions

to form carbonic acid. The carbonic acid dissociates into water and carbon dioxide, and the carbon dioxide moves out of the blood.

$$HCO_3^- + H^+ \rightarrow H_2CO_3 \rightarrow H_2O + CO_2$$

In the tissue capillaries, where the carbon dioxide concentration of the tissues is greater than the carbon dioxide concentration of the blood, carbon dioxide moves into the blood and combines with water to form carbonic acid. The carbonic acid dissociates into bicarbonate ions and hydrogen ions.

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$$

Respiratory Control and Acid-Base Balance

Brainstem control of respiration

The rhythm and depth of respiration is controlled by structures in the brainstem. A group of neurons in middle portion of the medulla oblongata act as the pacemaker for the basic rhythm of inhalation. These neurons appear to be in the pre-Boltzinger complex. Just posterior to these pacemaker neurons is another group of neurons that stimulate inhalation, and probably determine the basic depth of respiration. These inspiratory neurons form the rostral ventral respiratory group. More posterior in the posterior medulla oblongata are a group of neurons that stimulate exhalation, probably causing forced respiration. These expiratory neurons form the caudal ventral respiratory group. Much more anterior in the pons is a group of neurons that inhibit inhalation, probably causing an increase in the rate of respiration. These neurons form the pontine respiratory group.

- Pre-Boltzinger complex neurons act as a pacemaker and establish the basic rate of respiration.
- Rostral ventral respiratory group neurons stimulate inspiratory muscles and establish he basic depth of respiration.
- Caudal ventral respiratory group neurons stimulate expiratory muscles during forced breathing.
- Pontine respiratory group neurons inhibit rostral ventral respiratory group neurons and increases rate of respiration.

Mechanoreceptor reflexes

The lungs contain stretch receptors that monitor inflation and deflation of the lungs. Signals from these receptors travel to the brainstem where respiratory responses are generated. During inhalation, signals from stretch receptors prevent overinflation of the lungs by inhibiting inspiratory neurons. During exhalation, signals from stretch receptors prevent collapse of the lungs by inhibiting expiratory and stimulating inspiratory neurons.

Chemoreceptor reflexes

The cardiovascular system and brainstem contains sensory receptors that monitor the partial pressure of oxygen (pO_2), carbon dioxide (pCO_2) and the concentration of hydrogen ions ($[H^+]$) in the blood. Signals from these sensory receptor travel into the brainstem where they are compared to reference values. Respiratory responses are generated to normalize the blood gases and pH.

- Carotid body chemoreceptors respond to increased blood pCO_2 (and/or increased $[H^+]$) or decreased pO_2.
- Aortic body chemoreceptors respond similarly to carotid body chemoreceptors.
- Medullary chemoreceptors near the ventral respiratory group respond preferentially to increased $[H^+]$.

Decreases in pO_2 or increases in $[H^+]$ in the carotid artery stimulate the carotid body chemoreceptors. The glossopharyngeal nerve carries the chemoreceptor signal into the medulla of the brainstem. By way of interneurons, inspiratory neurons in or near the rostral ventral respiratory group are stimulated and respiratory rate and depth are increased.

Conversely, increases in pO2 or decreases in $[H^+]$ "destimulate" the carotid body chemoreceptors. Inspiratory neurons in or near the rostral ventral respiratory group are less stimulated and respiratory rate and depth are decreased.

Control of acid – base balance

As we just saw the transport of carbon dioxide in blood is through carbonic acid, and bicarbonate and hydrogen ion formation.

$$CO_2 + H2O \longleftrightarrow H_2CO_3 \longleftrightarrow HCO_3^- + H^+$$

- Excess carbon dioxide in the blood will increase the hydrogen ion concentration and lower the pH.

By way of the chemoreceptor reflexes, excess CO_2 (and excess H^+) will stimulate increases in rate and depth of respiration. The excess H^+ in the blood combines with HCO_3- to form H_2CO_3. The H_2CO_3 will produce H_2O and CO_2 in the blood of the lungs. Removal of the CO_2 by the lungs will thus decrease the H^+ concentration and raise the pH.

$$HCO_3\text{-} + H^+ \rightarrow H_2CO_3 \rightarrow H_2O + CO_2$$

$$CO_2 \rightarrow \text{into alveoli of lungs}$$

Furthermore, excess H^+ (from any source) can combine with HCO_3- to produce H_2CO_3 and thus H_2O and CO_2 that can be removed by the lungs. The critical role of CO_2 and HCO_3- in determining pH is seen by the following relationship.

$$pH = 6.1 + \log \frac{[HCO_3^-]}{[CO_2]}$$

Acidosis and Alkalosis

pH can be low (acidosis) or high (alkalosis) due to ventilatory or metabolic causes, as shown in the following Table.

- Inadequate removal of carbon dioxide by the lungs leads to respiratory acidosis.
- Excess removal of carbon dioxide leads to respiratory alkalosis.
- High levels of hydrogen ions from metabolic activity lead to metabolic acidosis.
- Low levels of hydrogen ions lead to metabolic alkalosis.

Acidosis and Alkalosis

pH status	*pCO_2*	*HCO_3*	*cause*
Respiratory Acidosis	high	high	hypoventilation
Respiratory alkalosis	low	low	hyperventilation
Metabolic Acidosis	normal	low	increased lactic acid, ketone bodies, diarrhea
Metabolic Alkalosis	normal	high	vomiting, hypokalemia, excess steroids

Gastrointestinal Tract, Pancreas and Liver

The digestive system includes the gastrointestinal tract, the mouth, pharynx, esophagus, stomach, small intestines, and large intestines; and the accessory organs, the salivary glands, liver, gallbladder, and pancreas. The primary purpose of the digestive system is to convert food into molecular forms that can be transferred along with water and minerals into the blood and used by cells of the body. Accordingly, the digestive system is concerned with digestion, the process of breaking down food; absorption, the process of moving molecules across the epithelial cells of the gastrointestinal tract; and motility, the process of moving food through the gastrointestinal tract by smooth muscle contraction. The gastrointestinal system is under the control of an enteric nervous and endocrine system and by the central nervous system.

Digestive Tract

Oral cavity

Parotid gland – Largest of the salivary glands.

Tongue

Hard ands soft palate

Uvula – Between oral cavity and oropharynx; contains sensory receptors for swallowing.

Teeth

Central and Lateral Incisors – For clipping or cutting; single root.

Cuspids – For tearing or slashing; single root.

First and Second Premolars – For crushing, mashing and grinding; one or two roots.

First, Second, and Third Molars) – For crushing and grinding; three or more roots.

Superior Alveolar nerves – Innervate the upper teeth; branches of Maxillary nerve.

Inferior Alveolar nerves– Innervate the lower teeth; branches of Mandibular nerve.

Pharynx

Oropharynx – Posterior to tongue; contains sensory receptors initiating swallowing.

Laryngopharynx – Posterior to larynx, connects to esophagus.

Esophagus

Upper esophageal sphincter – Prevents regurgitation into pharynx.

Lower esophageal sphincter (cardiac sphincter)

- Controls movement of food into stomach; prevents regurgitation into esophagus.

Stomach

Fundus, body, pyloris

Rugae – Infoldings of the stomach.

Pyloric sphincter – Controls movement of chyme into duodenum.

Small intestine

Duodenum

- First part of small intestine.
- Site for mixing chyme with secretions from the pancreas and liver/gallbladder.

Plicae circularis – Circular infolding of small intestine.

Common Bile duct – Connects to duodenum from liver/gallbladder.

Pancreatic duct – Connects to duodenum from pancreas.

Jejunum and ileum

- Second and third parts of small intestine.
- Sites for most nutrient absorption.

Mesentery – Holds small intestines in place.

Colon (Large Intestine)

- Cecum – First part of colon.
- Ileocecal valve – Controls movement of chyme into colon.
- Appendix – Functions as a lymphatic organ.
- Ascending, transverse, descending colon – Region for fluid reabsorption and vitamin B synthesis.
- Sigmoid colon – "S" shaped portion between the descending colon and the rectum.
- Taenia Coli – Separated enlargements of longitudinal muscle.
- Haustrae – Pouches formed by longitudinal muscle contraction.
- Mesentery (Mesocolon) – Holds large intestines in place.

Rectum – Final storage site for feces.

- Internal and external anal sphincters

Liver and Pancreas

Liver

- Gallbladder – Stores bile.
- Cystic Duct – Connects gallbladder to common bile duct.
- Hepatic Ducts – Collects bile from liver and connects to common bile duct.
- Common Bile Duct – Connects to duodenum after joining cystic and hepatic ducts.

Pancreas

- Pancreatic Ducts

Histology of GI Tract

Teeth

Crown – The visible portion of the tooth that projects above the Gingiva.

Neck – The boundary between the Root and the Crown.

Root – The base(s) of the teeth.

Pulp Cavity – In the center of the tooth and similar to the marrow cavity.

Root Canal – Channel through which nerves and blood vessels reach the pulp.

Enamel – Covers the Dentin of the Crown; densely packed calcium phosphate.

Dentin – Forms the bulk of the tooth and is similar to bone, no Osteocytes.

Tooth Pulp – In the center of the tooth and similar to bone marrow.

Cementum – Covers the Dentin of the Root and anchors the Periodontal Ligament; similar to but harder than Dentin.

Periodontal Ligament – Fibrous connective tissue that anchors the Dentin to the Alveolar bone; similar to periosteum / ligaments.

Gingiva – Attaches to the tooth above the Neck; an epithelial barrier.

Esophagus (exemplary for most of GI tract except as noted).

Mucosa

- Stratified squamous epithelium

Submucosa

- Fibrous connective tissue

Muscularis externa

- Inner circular layer – Circular layer of smooth muscle; for peristalsis.
- Myentreric plexus – Autonomic ganglia and neurons.
- Outer longitudinal layer – Longitudinal layer of smooth muscle; for peristalsis.

Stomach

Mucosa

- Simple Columnar Epithelium
- Gastric Glands – Deep in lamina propria – Produce mucous.
- Mucus Neck Cells – Clear – Produce mucus.
- Parietal Cells – Pinkish – Produce hydrochloric acid.
- Chief Cells – Bluish – Produce pepsinogen.

Submucosa – Fibrous connective tissue, no glands.

Muscularis externa

- Inner circular layer
- Outer longitudinal layer

Duodenum

Mucosa

- Intestinal Villi
- Simple Columnar Epithelium
- Goblet Cells – Interspersed among columnar epithelia.
- Intestinal Glands
- Lacteals – Terminal lymphatics inside of the villi.

Submucosa

- Duodenal Glands
- Lymphatic Nodules

Muscularis Externa

- Inner Circular Layer
- Myenteric Plexus – Autonomic ganglia and neurons.
- Outer Longitudinal Layer

Gastrointestinal Tract, Pancreas and Liver – Laboratory

Using the terms in the left box, draw and then label the structures. Alternatively, you may paste pictures and then label the structures. If you need more space use separate sheets of paper.

Models of the Digestive Tract

Oral cavity • Parotid Gland • Hard Palate • Soft Palate • Uvula	
Teeth / Jaw • Central Incisor • Lateral Incisor • Cuspid (Canine) • 1st Premolar • 2nd Premolar • 1st Molar • 2nd Molar • 3rd Molar • Superior Alveolar nerve • Inferior Alveolar nerve	

Tooth • Dentin • Pulp Cavity • Root Canal • Periodontal Ligament • Cementum • Root • Crown • Neck • Gingiva • Enamel	
Esophagus • Upper Esophageal Sphincter • Lower Esophageal Sphincter (Cardiac Sphincter)	
Pharynx • Oropharynx • Laryngopharynx	
Stomach • Fundus • Body • Pyloris • Rugae • Pyloric Sphincter	

Small intestine
 	
• Duodenum
  ○ Plicae Circularis
  ○ Common Bile Duct
  ○ Pancreatic Duct
• Jejunum
• Ileum
• Mesentary	

Small Intestine Wall Mucosa • Intestinal Villi • Simple Columnar Epithelium • Goblet Cells • Intestinal Capillaries • Lacteals • Intestinal Glands • Lymphatic Vessels • Muscularis Mucosae Submucosa • Duodenal Glands • Lymphatic Nodules Muscularis Externa • Inner Circular Layer • Myenteric Plexus • Outer Longitudinal Layer Serosa	

Colon • Cecum • Ileocecal Valve • Appendix • Ascending Colon • Transverse Colon • Descending Colon • Sigmoid Colon • Taenia Coli • Haustrae	
Rectum • Internal Anal Sphincters • External Anal Sphincters	

Models of the Liver and Pancreas

Liver • Gallbladder • Cystic Duct • Hepatic Duct • Common Bile Duct • Hepatic Veins • Hepatic Arteries • Hepatic Portal Vein	
Pancreas • Pancreatic Ducts	

Histology of GI Tract, Liver and Pancreas

Esophagus
 	
• Mucosa
  ○ Stratified Squamous Epithelium
  ○ Muscularis Mucosae
• Submucosa
  ○ Mucous and Serous Glands
• Muscularis externa
  ○ Inner Circular Layer
  ○ Myentreric Plexus
  ○ Outer Longitudinal Layer
• Adventitia	

Stomach
 	
• Mucosa
  ○ Simple Columnar Epithelium
  ○ Gastric Pits
  ○ Gastric Glands
  ▪ Mucus Neck Cells
  ▪ Parietal Cells
  ▪ Chief Cells
  ○ Muscularis Mucosae
• Submucosa
• Muscularis Externa
  ○ Inner Circular Layer
  ○ Outer Longitudinal Layer
• Serosa	

Duodenum
 	
• Mucosa
  ○ Intestinal Villi
  ○ Simple Columnar Epithelium
  ○ Goblet Cells
  ○ Intestinal Glands
  ○ Intestinal Capillaries
  ○ Lacteals
  ○ Muscularis Mucosae
• Submucosa
  ○ Duodenal Glands
  ○ Lymphatic Nodules
• Muscularis Externa
  ○ Inner Circular Layer
  ○ Myenteric Plexus
  ○ Outer Longitudinal Layer
• Serosa	

Liver
 	
• Liver Lobules
• Hepatocytes
• Central Vein
• Portal Areas
  ○ Hepatic Portal Vein and Hepatic Artery
  ○ Bile Ductule
• Liver sinusoids	

Pancreas • Pancreatic Lobules • Pancreatic Acini (Acinar Glands) • Pancreatic Ductules	

Digestion and Absorption

Digestion

Mouth

Carbohydrate digestion

- Salivary amylase – Breaks down carbohydrates to simpler sugars (disaccharides and trisaccharides).

Stomach

Protein digestion

- Pepsin – Breaks down proteins to polypeptides.
- (Pepsinogen is secreted and converted to pepsin by HCl).
- HCl – Disrupts cell membranes in food, activates pepsin.

Small intestine

Carbohydrate digestion

- Pancreatic amylase (from pancreas) – Breaks down carbohydrates to simpler sugars (disaccharides and trisaccharides).
- Disaccharides are broken down into monosaccharides by intestinal enzymes.
    - Maltase (from small intestine) – Breaks down maltose (a disaccharide) to two glucose molecules.
    - Sucrase (from small intestine) – Breaks down sucrose (adisaccharide) to glucose and fructose.
    - Lactase (from small intestine) – Breakdown lactose (a disaccharide) to glucose and galactose.

Protein digestion

- Pancreatic proteinases (from pancreas: chymotrypsin, trypsin, carboxypeptidase, elastase) – Break down proteins and polypeptides to short chain peptides.
- Dipeptides and tripeptides are broken down into amino acids by peptidase (from pancreas and small intestine).

Fat digestion

- Bile (from liver) – Emulsifies fats.
- Pancreatic lipase (from pancreas) – breaks down triglycerides to fatty acids and monoglycerides.

Absorption

- Simple sugars are absorbed through intestinal epithelium into blood capillaries by facilitated diffusion and cotransport.
- Amino acids are absorbed through the intestinal epithelium into blood capillaries by facilitated diffusion and cotransport.
- Large fatty acids (greater than 10 carbons) and monoglycerides enter the intestinal lacteals and lymphatics through a three stage process.

    1) Fatty acids and monoglycerides bind to bile salts to form micelles.
    2) The micelles diffuse into the intestinal epithelium where they are rejoined as triglycerides and coated with protein to form chylomicrons.
    3) The chylomicrons enter the intestinal lacteals and lymphatics.

Urinary System

The urinary system includes the kidneys, ureters, bladder, and urethra. The primary purpose of the urinary system is to filter the blood plasma, to reabsorb needed fluids and electrolytes, and to excrete unneeded (or excess) substances. The urinary system plays a critical role in maintaining fluid and electrolyte balance and in the long-term regulation of acid-base balance, blood volume and blood pressure.

Organization of the Urinary System

The kidneys are located in the retroperitoneal cavity of the abdomen, as shown below. The ureters extend from the hilus of each kidney, travel along the psoas muscles and cross over the iliac arteries and veins on their way to the urinary bladder. The urinary bladder rests on the anterior floor of the pelvic cavity.

The internal structure of the kidney is shown in below. Each kidney is surrounded by the renal capsule. Internally, the outer region is the cortex and the inner region is the medulla. Blood enters the kidney by way of the renal artery which branches into several segmental arteries (not labeled). The segmental arteries branch into interlobar arteries which pass into the medulla and around the renal pyramids. The interlobar arteries become the arcuate arteries and follow the junction between the medulla and the cortex where interlobular arteries branch off into the cortex. The process of blood filtration occurs in the cortex. Reabsorption begins in the cortex and continues into the pyramids of the medulla. Urine is collected from each pyramid by a minor calyx and transported to the renal pelvis and ureter.

Blood travels from the interlobular arteries to afferent arterioles that enter renal corpuscles where filtration occurs. Filtrate from the blood passes into the proximal convoluted tubules and the blood continues into the efferent arterioles and to the peritubular capillaries. Blood is collected from the peritubular capillaries by the interlobular veins. The filtrate continues through the proximal convoluted tubules, the descending and ascending nephron loops, the distal convoluted tubules, the collecting tubules and ducts where reabsorption occurs. The collecting ducts merge to form papillary ducts which empty into the minor calyx. Cortical nephrons are located predominantly in the cortex. Juxtamedullary nephrons are located closer to the medulla and their nephron loops extend deep into the medulla.

Kidney

Renal capsule – Layer of collagen fibers covering the kidney.

Renal Hilus – Indentation.

Renal artery – Carries blood to kidney.

Renal vein – Drains blood from kidney.

Ureter – Drains urine from kidney.

Renal Cortex – Outer region.

Renal Medulla – Intermediate region.

Renal Pyramids – Distinct units within the medulla.

Renal Lobe – Pyramid, each adjacent ½ Renal Column, and corresponding cortex.

Renal columns – Extensions of the cortex between pyramids.

Renal Papillae – Extensions of the pyramids that empty into the minor calyces.

Renal pelvis – Expansion of ureter at renal sinus.

Major calyces – Branchings of renal pelvis.

Minor calyces – Branchings of major calyces that surround the papilla.

Blood supply to the Nephron

Renal artery

Interlobar arteries – Radiate between lobes (pyramids).

Arcuate arteries – Arch along boundary of medulla and cortex.

Interlobular arteries – Branchings within the cortex of a lobe.

Afferent arteriole – Carries blood to glomerulus.

Glomerulus – Enclosed capillary network.

Efferent arteriole – Carries blood away from glomerulus to peritubular capillaries.

Peritubular capillaries – Surround proximal and distal convoluted tubules.

Vasa recta – Vascular network extending into the renal medulla, parallels the loop of Henle.

Interlobular veins

Arcuate veins

Interlobar veins

Renal vein

Nephron

Nephron – The functional unit of the kidney that consists of:

Renal corpuscle (Bowman's capsule) – slide

Renal tubules

Collecting system

Renal corpuscle (Bowman's capsule)

Parietal Epithelium (Capsular Epithelium) – Simple squamous epithelium forming outer wall.

Visceral Epithelium (Glomerular Epithelium) – Simple squamous epithelium that covers the capillary network (Glomerulus / Glomerular Capillaries).

- Podocytes – Cells of the glomerular epithelium that filter the blood plasma.

Capsular space – Space between capsular and glomerular epithelium.

Glomerulus – Enclosed capillary network.

- Capillaries – Fenestrated; incomplete simple squamous epithelium.

Juxtaglomerular cells – Specialized smooth muscle cells in the adjacent afferent arteriole (produce Renin).

Proximal Convoluted tubule (PCT)

- Tubing whose lumen is continuous with the capsular space.
- Lined with simple cuboidal epithelium (with microvilli).

Nephron Loop (of Henle)

- Tubing whose lumen is continuous with proximal convoluted tubule.
  Thick Descending limb – Lined with simple cuboidal cells (some microvilli).
  Thin Descending limb – Lined with simple squamous cells.
  Thin Ascending limb – Lined with simple squamous cells.
  Thick Ascending limb – Lined with simple cuboidal cells.

Distal Convoluted tubule (DCT)

- Tubing whose lumen is continuous with the thick ascending limb of the nephron loop.
- Lined with simple cuboidal epithelium.

Macula Densa – Taller cells of DCT near the glomerulus that sense Sodium.

Collecting system

Collecting tubules – Lined with simple cuboidal epithelium.

Collecting ducts – Lined with simple cuboidal epithelium (proximally).

Papillary ducts – Lined with simple columnar epithelium.

Urinary System – Laboratory

Using the terms in the left box, draw and then label the structures. Alternatively, you may paste pictures and then label the structures. If you need more space use separate sheets of paper.

Models of Kidney

Urinary Tract • Kidney • Ureter • Bladder • Urethra	
Kidney • Renal capsule • Hilus • Renal artery • Renal vein • Ureter • Cortex • Medulla • Pyramids • Lobe • Renal columns • Papillae • Renal pelvis • Major calyces • Minor calyces	

Renal Vessels • Renal artery • Interlobar arteries • Arcuate arteries • Interlobular arteries • Afferent arteriole • Glomerulus • Efferent arteriole • Peritubular capillaries • Vasa recta • Interlobular veins • Arcuate veins • Interlobar veins • Renal vein	
Nephron • Renal corpuscle (Bowman's capsule) • Renal tubules • Collecting system	

Renal corpuscle
 	
• Parietal Epithelium (Capsular Epithelium)
• Visceral Epithelium (Glomerular Epithelium)
  • Podocytes
• Capsular space
• Glomerulus
  • Capillaries
• Afferent arteriole
• Efferent arteriole	

Renal Tubules Proximal Convoluted tubule (PCT) Nephron Loop (of Henle) • Thick Descending limb • Thin Descending limb • Thin Ascending limb • Thick Ascending limb Distal Convoluted tubule (DCT) • Macula Densa • Juxtaglomerular cells	
Collecting system • Collecting tubules • Collecting ducts • Papillary ducts • Calyces • Renal pelvis • Ureter • Bladder • Urethra	

Histology of Kidney

Kidney • Proximal convoluted tubules • Distal convoluted tubules • Macula densa • Renal corpuscle • Glomerulus / Glomerular Capillaries • Juxtaglomerular cells • Capsular Space • Parietal Epithelium	
Ureter • Lumen • Transitional Epithelium • Smooth Muscle	

Filtrate and Urine Formation

The kidney acts on the blood to filter plasma, to reabsorb needed fluids and electrolytes, and to excrete unneeded substances. Plasma is filtered out of the blood by Glomerular Filtration, as shown below. Substances are reabsorbed from the Renal Tubules into the peritubular capillaries.

Filtrate formation

Glomerular filtration

- Blood travels through the afferent arteriole to the glomerular capillaries.
- Water and solute molecules pass through the wall of glomerular capillaries, through glomerular epithelium and into capsular space.
- The rate of filtrate formation (glomerular filtration rate) is about ~ 125 ml/min.

Urine formation

Tubular reabsorption and the proximal tubule

About 60% of filtered water and 65% of filtered solutes are reabsorbed in this region.

- Reabsorption of glucose, amino acids, and other nutrients via facilitated transport and cotransport.
- Reabsorption of sodium, potassium, calcium, magnesium, phosphate and sulfate ions via active transport.
- Reabsorption of bicarbonate ions (and secretion of hydrogen ions) via active transport.
- Reabsorption of water via diffusion.
- Reabsorption of urea via diffusion.

Osmotic gradient and the nephron loop

About 20% of filtered water and 25% of filtered solutes are reabsorbed in this region..

- Reabsorption of water from Descending Limb via diffusion (The membrane of the thin descending limb contains open water channels.)
- Reabsorption of sodium and chloride from Ascending Limb via active transport (The membrane of the thick ascending limb contains transport pumps and few water channels).
- Increases osmotic pressure in peritubular fluid (countercurrent multiplication) responsible for water reabsorption from descending limb.

Tubular secretion (and reabsorption) and the distal tubule (early segment)

About 5% of filtered sodium is reabsorbed in this region.

- Secretion of potassium (and reabsorption of sodium) via active transport under control of aldosterone (The tubular membrane contains sodium / potassium pumps controlled by aldosterone.)

Tubular reabsorption and the distal tubule (late segment), collecting tubules and ducts

About 5% of filtered sodium and about 10% to 20% of filtered water is reabsorbed in this region.

- Secretion of potassium (and reabsorption of sodium) via active transport under control of aldosterone (The tubular membrane contains sodium / potassium pumps controlled by aldosterone.)
- Reabsorption of water via diffusion under control of vasopressin (The tubular membrane contains water channels controlled by vasopressin).
- Secretion of hydrogen ions (and reabsorption of bicarbonate ions) via active transport.

Renal Handling of Salt and Water – Lab

One or more students in each group will void their urine at the beginning of the laboratory session, and according to their group drink water and/or eat pretzels as follows.

Group I – drink 500 ml of tap water.

Group II – drink 500 ml of tap water and eat 3 oz of pretzels.

Group III – eat 3 oz of pretzels.

Group IV – neither drinks nor eats.

These students will void their urine at 30 min intervals for 2 hours.

Time	Group I		Group II		Group III		Group IV	
Min.	Vol.	Osmol.	Vol.	Osmol.	Vol.	Osmol.	Vol.	Osmol.
0								
30								
60								
90								
120								

Table 1. Urine Volume and Osmolarity.

Each student will answer the following questions.

1. Explain the differences in urine volume (if any) between group I and group II.

_____

_____

2. Explain the differences in osmolarity (if any) between group I and group II.

_____

_____

3. Explain the difference in urine volume (if any) between group I and group III.

_____

_____

4. Explain the differences in osmolarity (if any) between group I and group III.

_____

_____

5. Name the hormone that stimulates reabsorption of water.

_____

6. Name the hormone that stimulates reabsorption of sodium.

_____

Fluid Balance

Reflex Fluid Regulation

Blood volume and blood osmolarity are maintained at a level consistent with supplying the needs of the body.

The cardiovascular, renal and endocrine systems are able to maintain appropriate levels of blood volume and blood osmolarity by relying, in part, on information about:

- Atrial filling.
- Blood osmolarity.
- Renal arterial pressure.
- Renal tubular sodium concentration.

Cardiovascular and Renal Reflexes

Receptors

- Stretch receptors of the cardiac atria – respond to changes in atrial filling (venous return).
- Osmoreceptors of the hypothalamus and liver – respond to osmolarity of blood.
- The juxtaglomerular cells of the renal afferent arterioles – respond to changes in renal arterial pressure and flow.
- The macula densa cells of the renal tubules, and specialized cells of the central nervous system – respond to sodium concentration.
- Specialized cells of the adrenal cortex – respond to potassium concentration.

Reflexes

Decreased blood volume (decreased atrial filling) reflexively causes:

- fluid and electrolyte conservation and fluid movement into circulation via:
    - Sympathetic stimulation.
    - Stimulation of vasopressin.
    - Stimulation of renin - angiotensin - aldosterone.
    - Stimulation of cortisol and glucagon.

Increased blood volume (increased atrial filling) reflexively cause:

- fluid and electrolyte excretion and fluid movement out of circulation via:
    - Stimulation of atrial natriuretic hormone.

Decreased osmolarity of blood reflexively causes:

- water excretion, sodium conservation and sodium appetite via:
    - Stimulation of renin - angiotensin - aldosterone.

Decreased sodium concentration of blood reflexively causes:

- sodium conservation and sodium appetite via:
    - Stimulation of renin - angiotensin - aldosterone.

Increased potassium concentration of blood reflexively causes:

- potassium excretion via:
    - Stimulation of aldosterone.

Control of Fluid Balance

Local factors

- Capillary pressure – Increased capillary pressure will lead to movement of fluid out of the vascular space.
- Interstitial fluid pressures – Increased interstitial fluid pressure will lead to movement into the vascular space.

Neural and hormonal factors

- Sympathetic stimulation – Leads to vasoconstriction of pre-capillary sphincters, lowering of capillary pressure, and movement of fluid into the vascular space.
- Cortisol – Leads to movement of fluid out of cells, into the interstitial space, and thus into the vascular space(probably by increasing osmotic pressure).
- Glucagon – Enhances fluid movement into the vascular space.
- Renin – Responsible for conversion of Angiotensinogen to Angiotensin I.
- Converting Enzyme – Responsible for changing Angiotensin I to Angiotensin II.
- Angiotensin II – Stimulates production of Aldosterone; stimulates thirst.
- Aldosterone – Leads to renal conservation of sodium; leads to renal excretion of potassium.
- Vasopressin – Leads to renal conservation of water; stimulates thirst.
- Atrial Natriuretic Hormone – Leads to renal excretion of sodium and water.

Practice Questions – Respiratory, Digestive, Urinary

Choices may be used more than once or not at all.

1-5. Matching

A)	Visceral pleura	covers the lungs	1) _____
B)	Parietal pleura	lines the pleural cavities	2) _____
C)	A and B	covers the pericardial sac	3) _____
D)	None of the above	produces the pleural fluid	4) _____
		composed of simple squamous epithelium	5) _____

6-10. Matching

A)	Inspiration	visceral pleura pulls in on parietal pleura	6) _____
B)	Expiration	parietal pleura pulls out on visceral pleura	7) _____
		occurs with a lowered intrapulmonary pressure	8) _____
		occurs with an elevated intrapulmonary pressure	9) _____
		is associated with a decrease in intrapleural pressure	10) _____

11-15. Matching

A)	Forced inspiration	caused by contraction of diaphragm	11) _____
B)	Forced expiration	caused by recoil of elastic fibers	12) _____
C)	Quiet inspiration	assisted by contraction of the scalenes	13) _____
D)	Quiet expiration	assisted by contraction of abdominal muscles	14) _____
		assisted by contraction of internal intercostals	15) _____

16-20. Matching

A)	C =	1 / IPV	16) _____
B)	Vmin =	$\Delta V / \Delta P$	17) _____
C)	AF =	IPP / AR	18) _____
D)	IPP =	Vbr x RR	19) _____
		is markedly affected by lung flexibility	20) _____

21-25. Matching

A)	VC =	IRV + TV + ERV	21) _____
B)	IRV =	IRV + ERV	22) _____
C)	TV =	VC - IRV	23) _____
D)	RV =	IRV + TV	24) _____
E)	none of the above	VC – (TV + IRV)	25) _____

26-30. Matching

A)	Obstructive pulmonary disease	An example is asthma	26) _____
B)	Restrictive pulmonary disease	An example is emphysema	27) _____
		Related to decreased lung compliance	28) _____
		Related to increased airway resistance	29) _____
		The lungs and alveoli do not easily expand	30) _____

31-35. Matching

A)	Pulmonary capillaries	fluid leaks out of the blood	31) _____
B)	Systemic capillaries	oxygen moves from the blood into cells	32) _____
C)	A and B	oxygen moves from alveoli into the blood	33) _____
D)	None of the above	carbon dioxide moves from cells into the blood	34) _____
		carbon dioxide moves from the blood into the alveoli	35) _____

36-40. Matching

A)	pO_2 = ~100 mmHg; pCO_2 = ~40 mmHg	alveoli	36) _____
B)	pO_2 = ~20 mmHg; pCO_2 = ~50 mmHg	tissues	37) _____
C)	pO_2 = ~150 mmHg; pCO_2 = ~<1 mmHg	atmosphere	38) _____
D)	pO_2 = ~40 mmHg; pCO_2 = ~45 mmHg	systemic venous blood	39) _____
		systemic arterial blood	40) _____

41-45. Matching

A)	$O_2 + H_bH \rightarrow H_bO_2 + H^+$	seen when blood H^+ is high	41) _____
B)	$O_2 + H_bH \leftarrow H_bO_2 + H^+$	seen when blood pO_2 is high	42) _____
C)	None of the above	increases in the presence of lactic acid	43) _____
		occurs in blood in systemic capillaries	44) _____
		occurs in blood in pulmonary capillaries	45) _____

46-50. Matching

A)	$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$	seen in systemic tissues	46) _____
B)	$CO_2 + H_2O \leftarrow H_2CO_3 \leftarrow H^+ + HCO_3^-$	seen in pulmonary tissues	47) _____
C)	HCO_3^-	secreted into renal tubules	48) _____
D)	H^+	reabsorbed out of renal tubules	49) _____
		occurs in cytoplasm of renal tubular cells	50) _____

51-55. Matching

A)	High blood CO_2	lowers pH	51) _____
B)	Low blood CO_2	increases arterial pressure	52) _____
		makes blood more alkaline	53) _____
		increases rate and depth of respiration	54) _____
		effects can be partially offset with bicarbonate	55) _____

56-60. Matching

A)	$1.0x10^{-2}$ M $[H^+]$	neutral pH	56) _____
B)	$1.0x10^{-6}$ M $[H^+]$	weakly acidic	57) _____
C)	$1.0x10^{-7}$ M $[H^+]$	strongly acidic	58) _____
D)	$1.4x10^{-7}$ M $[H^+]$	normal blood pH	59) _____
		found in the stomach	60) _____

61-65. Matching

A)	Respiratory Acidosis	normal pCO_2, low HCO_3^-	61) _____
B)	Respiratory alkalosis	low pCO_2, low HCO_3^-	62) _____
C)	Metabolic Acidosis	high pCO_2, high HCO_3^-	63) _____
D)	Metabolic Alkalosis	normal pCO_2, high HCO_3^-	64) _____
		seen with vomiting	65) _____

66-70. Matching Place the following in the order that food passes.

A) Jejunum 66) _____
B) Ileocecal valve 67) _____
C) Transverse colon 68) _____
D) Pyloric sphincter 69) _____
E) Cardiac sphincter 70) _____

71-75. Matching

A) Carbohydrate digestion — occurs in mouth 71) _____
P protein digestion — occurs in stomach 72) _____
C) Fat digestion — occurs in esophagus 73) _____
D) All of the above — occurs in large intestine 74) _____
E) None of the above — occurs in small intestine 75) _____

76-80 Matching

A) Lliver — the major site for detoxification of absorbed substances 76) _____
B) Pancreas — the major source of digestive enzymes 77) _____
C) Stomach — the major site for nutrient absorption 78) _____
D) Small intestine — the major site for fluid reabsorption 79) _____
E) Large intestine — the source of bile 80) _____

81-85. Matching

A) Peptidase — emulsifies fats 81) _____
B) Amylase — breaks down fats in intestine 82) _____
C) Pepsin — breaks down protein in stomach 83) _____
D) Lipase — breaks down small proteins to amino acids 84) _____
E) Bile — breaks down carbohydrates in mouth and intestine 85) _____

86-90. Matching

A) Produced in liver — amylase 86) _____
B) Produced in stomach — elastase 87) _____
C) Produced in pancreas — sucrase 88) _____
D) Produced in small intestine — pepsin 89) _____
bile 90) _____

91-95. Matching

A) Absorbed into intestinal lymphatics — fats 91) _____
B) Absorbed into intestinal capillaries — proteins 92) _____
C) Not absorbed through intestines — fatty acids 93) _____
amino acids 94) _____
carbohydrates 95) _____

96-100. Matching

A) Found in renal medulla — ureter 96) _____
B) Found in renal cortex — renal artery 97) _____
C) Found in renal hilus — renal pyramids 98) _____
afferent arterioles 99) _____
Bowman's Capsules (renal corpuscles) 100) _____

101-105. Matching

A)	125 mL/min	normal reabsorption of tubular fluids by the kidney	101) _____
B)	124 mL/min	urine formation by the kidney without vasopressin	102) _____
C)	25 mL/min	normal filtrate formation by the kidney	103) _____
D)	1 mL/min	normal urine formation by the kidney	104) _____
E)	None of the above	normal cardiac output	105) _____

106-110. Matching

A)	60 mmHg	net glomerular filtration pressure	106) _____
B)	30 mmHg	glomerular capillary osmotic pressure	107) _____
C)	20 mmHg	systemic capillary hydrostatic pressure	108) _____
D)	10 mmHg	renal intracapsular hydrostatic pressure	109) _____
		glomerular capillary hydrostatic pressure	110) _____

111-115. Matching

A)	Filtration	proximal convoluted tubules	111) _____
B)	Reabsorption	collecting tubules and ducts	112) _____
C)	None of the above	distal convoluted tubules	113) _____
		renal corpuscles	114) _____
		loop of Henle	115) _____

116-120. Place in order the structures through which urinary filtrate passes.

A)	Loop of Henle	116) _____
B)	Capsular space	117) _____
C)	Distal convoluted tubule	118) _____
D)	Collecting tubules and ducts	119) _____
E)	Proximal convoluted tubule	120) _____

121-125. Matching

A)	Contains ciliated columnar epithelium (PCCE)	mucosa of alveoli	121) _____
B)	Contains stratified squamous epithelium	mucosa of trachea	122) _____
C)	Contains simple columnar epithelium	mucosa of duodenum	123) _____
D)	Contains simple cuboidal epithelium	mucosa of esophagus	124) _____
E)	None of the above	convoluted tubules of kidney	125) _____

126-130. Matching

A)	Reabsorption of sodium via active transport	distal C. T.	126) _____
B)	Reabsorption of water via diffusion	proximal C. T.	127) _____
C)	A and B	ascending nephron loop	128) _____
D)	None of the above	descending nephron loop	129) _____
		collecting tubules/ducts	130) _____

131-135. Matching

A)	Reabsorption of bicarbonate ions	proximal and distal C. T.	131) _____
B)	Secretion of potassium	20% complete in nephron loop	132) _____
C)	Reabsorption of water	60% complete in proximal C. T.	133) _____
		controlled by aldosterone in distal C. T.	134) _____
		controlled by vasopressin in collecting tubules/ducts	135) _____

136-140. Matching

A)	Atrial stretch receptors	respond to osmolality of blood	136) _____
B)	Juxtaglomerular cells	respond to sodium concentration	137) _____
C)	Adrenal cortex	respond to potassium concentration	138) _____
D)	Osmoreceptors	respond to changes in venous return	139) _____
E)	Macula densa	respond to changes in renal pressure and flow	140) _____

141-145. Matching

A)	Post-capillary constriction	increases arterial pressure	141) _____
B)	Pre-capillary constriction	increases capillary pressure	142) _____
C)	A and B	decreases capillary pressure	143) _____
D)	None of the above	increases peripheral resistance	144) _____
		increases fluid uptake by blood	145) _____

146-150. Matching

A)	Cortisol	stimulates aldosterone secretion	146) _____
B)	Glucagon	facilitates fluid movement out of cells	147) _____
C)	Vasopressin	stimulates water reabsorption by kidney	148) _____
D)	Angiotensin II	increases glucose concentration in blood	149) _____
E)	Norepinephrine	leads to vasoconstriction via alpha receptors	150) _____

151-155. Matching

A)	Hyperosmolality	will lead to loss of fluid	151) _____
B)	Hypervolemia	elevated solute concentration	152) _____
		will lead to accumulation of water	153) _____
		will often increase arterial pressure	154) _____
		is another term for elevated blood volume	155) _____

Short Essays

1. Describe the major mechanisms responsible for ventilation. Include the major factors responsible for inhalation and for exhalation.

2. Describe the exchange of oxygen and carbon dioxide in the lungs and in the systemic organs. Include the numerical values for the partial pressures of oxygen and carbon dioxide.

3. Describe the mechanisms responsible for the transport of carbon dioxide through the blood. Describe how the transport of carbon dioxide affects blood pH.

4. Describe the process of filtrate formation in the kidney.

5. Describe the process of sodium and water reabsorption in the distal convoluted tubules and in the collecting system.

6. Compare and contrast digestion in the mouth, stomach and small intestines.

Section 7 – Autonomic, Endocrine, and Reproductive Systems

Autonomic Nervous System

General Neural Organization

Two motor neurons are involved in the connection between the central nervous system and peripheral target organs.

Preganglionic neurons

- The first motor neuron in line.
- Cell bodies are located within the central nervous system.
- Axons leave the CNS to reach ganglionic neurons in the peripheral nervous system.

Ganglionic (Postganglionic) neurons

- The second motor neuron in line.
- Cell bodies are located in autonomic ganglia in the peripheral nervous system.
- Axons leave the autonomic ganglia to reach target cells in the peripheral organs.

Parasympathetic Division

Brainstem and Sacral Spinal organization

Nuclei of Medulla Oblongata (or Lateral Horns of Sacral Spinal Cord) – Contain cell bodies of parasympathetic preganglionic neurons (the first motor neurons in line).

Cranial Nerves (or Sacral Anterior Roots) – Carry axons of parasympathetic preganglionic neurons out of brainstem or sacral spinal cord.

Parasympathetic ganglia – Contain cell bodies of parasympathetic ganglionic neurons (the second motor neurons in line) with which axons of preganglionic neurons synapse, mostly in the target organs.

Parasympathetic Ganglia

Ciliary, Sphenopalatine, Submandibular and Otic Ganglia:

- Axons of preganglionic neurons travel through the III, VII, and IX cranial nerves and synapse on ganglion neurons.
- Axons of the postganglionic neurons control target organs in the:
    - Head – Pupil constriction, salivary secretion.

Thoracic Intramural Ganglia:

- Axons of preganglionic neurons travel through the X cranial nerve and synapse on ganglion neurons.
- Axons of the postganglionic neurons control organs in the:
    - Thoracic cavity – Bronchoconstriction, bradycardia.
    - Abdominal cavity – Gastrointestinal secretion, peristalsis.

Pelvic Intramural Ganglia:

- Axons of preganglionic neurons travel from the sacral spinal cord through the pelvic nerve and synapse on ganglion neurons.
- Axons of the postganglionic neurons control organs in the:
    - Pelvic cavity – Defecation, urination, erection.

Neurotransmitters

- Preganglionic neurons release acetylcholine which acts on receptors on the ganglionic neurons.
- Postganglionic neurons release acetylcholine which acts on receptors of the target organs.

Sympathetic Division

Lateral Horns of Thoracic Spinal Cord – contain cell bodies of sympathetic preganglionic neurons (the first motor neurons in line).

Anterior Roots – carry axons of sympathetic preganglionic neurons out of spinal cord.

Sympathetic Ganglia – contain cell bodies of sympathetic ganglionic neurons (the second motor neurons in line) with which axons of preganglionic neurons synapse, in one of three major groups of ganglia.

Sympathetic Ganglia

Sympathetic Chain Ganglia and Cervical Sympathetic Ganglia:

- Axons of preganglionic neurons travel through the White Rami and synapse on ganglionic neurons in the sympathetic chain ganglia.
- Axons of the ganglionic neurons travel through the Gray Rami and into spinal nerves to control target organs in the:
    - Head – Pupil dilation.
    - Thoracic cavity – Bronchodilation, cardioacceleration, increased force.
    - Skin and blood vessels in muscle – Piloerection, sweating, vasodilation.

Celiac and Mesenteric Ganglia:

- Axons of preganglionic neurons travel through the White Rami and pass through the sympathetic chain ganglia without synapsing,
- Travel through splanchnic nerves, and synapse in the Celiac and Mesenteric Ganglia.
- Axons of the ganglionic neurons travel through the splanchnic nerves to control target organs in the:
    - Abdominopelvic cavity – Vasoconstriction, intestinal relaxation.

Adrenal Medulla:

- Axons of preganglionic neurons travel through the White Rami and pass through the sympathetic chain ganglia and the Celiac Ganglia without synapsing.
- The axons of preganglionic neurons synapse in the adrenal medulla on ganglionic neurons that in turn release catecholamines into the blood circulation.

Neurotransmitters

- Preganglionic neurons release acetylcholine which acts on receptors on the ganglionic neurons.
- Postganglionic neurons release norepinephrine which acts on receptors of the target organs.

Autonomic Nervous System – Laboratory

Using the terms in the left box, draw and then label the cells and structures. Alternatively, you may paste pictures and then label the cells and structures. If you need more space use separate sheets of paper.

Parasympathetic

Brainstem
 	
• Medulla Oblongata
• Preganglionic Neurons
  ○ Acetylcholine
• Parasympathetic Ganglia
  ○ Ciliary, Sphenopalatine, Submandibular, and Otic Ganglia
  ○ Thoracic Intramural Ganglia
  ○ Abdominal Intramural Ganglia
• Ganglionic Neurons
  ○ Acetylcholine
• Target Organ / Tissue	

Sacral Spinal Cord
 	
• Sacral Spinal Cord
• Preganglionic Neurons
  ○ Acetylcholine
• Parasympathetic Ganglia
  ○ Sacral Intramural Ganglia
• Ganglionic Neurons
  ○ Acetylcholine
• Target Organ / Tissue	

Sympathetic

Chain Ganglia
 	
• Thoracic Spinal Cord
• Preganglionic Neurons
  ○ Secrete Acetylcholine
• White Rami
• Sympathetic Chain Ganglia
  ○ Cervical Ganglia
  ○ Thoracic Ganglia
  ○ Lumbar Ganglia
  ○ Sacral Ganglia
  ○ Rami Communicans
• Ganglionic Neurons
  ○ Secrete Norepinephrine
• Gray Rami
• Target Organ / Tissue	

Celiac and Mesenteric Ganglia
 	
• Thoracic Spinal Cord
• Preganglionic Neurons
  ○ Secrete Acetylcholine
• White Rami
• Splanchnic Nerves
• Sympathetic Celiac and Mesenteric Ganglia
• Ganglionic Neurons
  ○ Secrete Norepinephrine
• Target Organ / Tissue	

Adrenal Medulla
 	
• Thoracic Spinal Cord
• Preganglionic Neurons
  ○ Secrete Acetylcholine
• White Rami
• Splanchnic Nerves
• Adrenal Medulla
• Ganglionic Neurons
  ○ Secrete Norepinephrine
• Blood	

Neural Endocrine Organization

General Neural Organization

Chemical signals originate from neurons and are sent directly to other neurons or muscle cells

- Neural signals are transmitted along an axon to the synaptic bulb of the neuron.
- From the synaptic bulb chemical messengers are released into the synaptic cleft.
- The chemical messenger travels across the synaptic cleft to act on another neuron or muscle cell.
- By definition the chemical messenger is called a neurotransmitter.
- The neurotransmitter exerts its influence by attaching to receptors in the postsynaptic membrane of the target cells.

General Endocrine Organization

Chemical signals originate from neurons *or* from glandular epithelial cells and are sent through the blood to reach other cells.

Neurons

- Neural signals are transmitted along an axon to the synaptic bulb of the neuron.
- From the synaptic bulb chemical messengers are released into surrounding interstitial space.
- The chemical messenger is transported into the blood to act on other cells.
- By definition the chemical messenger is called a hormone.
- The hormone exerts its influence by attaching to receptors in the membrane of the target cells.

Glandular Epithelial Cells

- Chemical signals traveling through the blood attach to receptors in the membrane of glandular epithelial cells.
- The glandular epithelial cells in turn release a chemical messenger into the surrounding interstitial space.
- The chemical messenger is transported into the blood to act on other cells.
- By definition the chemical messenger is called a hormone.
- The hormone exerts its influence by attaching to receptors in the membrane of the target cells.

Overview of Endocrine glands

- Hypothalamus – Vasopressin, oxytocin, hypothalamic regulatory hormones.
- Pituitary gland
    - Anterior – TSH, ACTH, FSH, LH, PRL, GH
    - Posterior – Vasopressin, oxytocin.
- Thyroid gland – Thyroxine, triiodothyronin, calcitonin.
- Parathyroid gland – Parathormone.
- Heart – Atrial natriuretic peptide.
- Pancreas – Insulin, glucagon.
- Adrenal gland
    - Medulla – Epinephrine, norepinephrimne.
    - Cortex – Aldosterone, cortisol, testosterone.
- Kidney – Renin, erythropoetin.
- Digestive tract – Gastrin, secretin, cholecystokinin, others.
- Gonads
    - Ovaries – Estrogen, progesterone, relaxin, inhibin.
    - Testes – Testosterone, inhibin.

Endocrine Glands – Laboratory

Using the terms in the left box, draw and then label the cells and structures. Alternatively, you may paste pictures and then label the cells and structures. If you need more space use separate sheets of paper.

Models and Specimens

Head and Neck • Hypothalamus • Pituitary • Thyroid • Parathyroid	
Thoracic region • Heart	
Abdominal region • Pancreas • Adrenal • Kidney • GI Tract	
Pelvic region • Ovaries • Testes	

Histology of Pancreas, Thyroid, Adrenal and Pituitary

Pancreas
• Pancreatic islets
  ○ Alpha cells
  ○ Beta cells	

Parathyroid gland • Chief cells	
Thyroid gland • Interfollicular cells (C cells) • Thyroid follicles • Follicular cells • Colloid	

Adrenal gland
 	
• Adrenal medulla
  ○ Chromaffin cells
 	
• Adrenal cortex
  ○ Zona Glomerulosa
  ○ Zona Fascicularis
  ○ Zona Reticularis	

Pituitary gland, *l.s.*
 	
• Infundibulum
• Median eminence
• Posterior Pituitary
  ○ axons
• Anterior Pituitary
  ○ glandular epithelial cells	

Adrenal Medullary Hormones

The adrenal medulla contains neurons of the sympathetic nervous system (Chromaffin cells) that produce epinephrine and norepinephrine.

Adrenal Medulla and Actions of Adrenal Medullary Hormones

Stimulus	*Source /*	*Hormone*	*Action of Adrenal Medullary Hormones*
Physical activity, physical stress, emotional stress	Chromaffin Cells (ganglionic neurons)	Epinephrine (water soluble) Norepinephrine (water soluble)	Varies depending on adrenergic receptors – **α_1** , **α_2** , **β_1** , **β_2** , **β_3** (see below)

Actions of Alpha (α) and Beta (β) Adrenergic Receptor Activation

Hormone	*Receptor*	*Action of Adrenal Medullary Hormones*
Norepinephrine Epinephrine	**α_1** receptors or **α_2** postsynaptic receptors	act through G-protein coupled receptors. constrict blood vessels in abdominal organs, kidney, skin and genitals. increase breakdown of glycogen to glucose (Glycogenolysis) in liver and skeletal muscle via **α_1** stimulate glucagon secretion by pancreas via **α_1**
Norepinephrine Epinephrine	**α_2** presynaptic and some **α_2** non–synaptic receptors	act through G-protein coupled receptors. decrease neurotransmitter release via presynaptic **α_2**. inhibit insulin secretion by pancreas via non-synaptic **α_2**
Epinephrine Norepinephrine	**β_1** receptors	act through G-protein coupled receptors. increase heart rate and force of cardiac contraction. stimulate glucagon secretion by pancreas stimulate renin secretion by kidney
Epinephrine Norepinephrine	**β_2** receptors	act through G-protein coupled receptors. dilate airways and dilate blood vessels in skeletal muscle. increase breakdown of glycogen to glucose (Glycogenolysis) in liver and skeletal muscle increase production of glucose from fatty acids and amino acids (Gluconeogenesis) in liver
Epinephrine Norepinephrine	**β_3** receptors	act through G-protein coupled receptors. increase breakdown of lipids (lipolysis) and release of fatty acids in adipose tissue

Pancreas, Thyroid, and Kidney

Pancreas and Actions of Pancreatic Hormones

Stimulus	*Source*	*Hormone*	*Action of Pancreatic Hormone*
stimulated by low blood glucose and by epinephrine; inhibited by high blood glucose and Beta cell activity	pancreatic Alpha cells	Glucagon (water soluble)	act through G-protein coupled receptors. increase breakdown of glycogen to glucose (Glycogenolysis) in Liver. increase production of glucose (Gluconeogenesis) from amino acids in Liver. increase production of ketones (ketogenesis) from fatty acids in Liver
stimulated by high blood glucose; inhibited by epinephrine	pancreatic Beta cells	Insulin (water soluble)	act through a membrane tyrosine kinase stimulates transport of glucose into cells in Muscle and Adipose tissue and in Liver. stimulates glycogen formation from glucose (Glycogenesis) in Muscle and Liver. facilitates fat storage by stimulating transport of fatty acid into and inhibiting transport of fatty acids out of Adipose cells. facilitates protein storage by stimulating transport of amino acid into and inhibiting transport of amino acids out of Muscle cells

Thyroid Gland and Actions of Thyroid Hormones

Stimulus	*Source*	*Hormone*	*Action*
stimulated by Thyrotropin (TSH)	Thyroid follicles	Tetraiodothyronin (Thyroxin or T4) (lipid soluble) Triiodothyronin (T3) (lipid soluble)	act through cytoplasmic and nuclear receptors. increases Na^+/K^+-ATPase, mitochondrial, and respiratory enzymes. stimulates oxygen and food consumption, carbohydrate absorption, and substrate use. enhances response to epinephrine and norepinephrine (thermogenesis, lipolysis, glycogenolysis and gluconeogenesis). increases cardiac output, heart rate, direct or indirect?
stimulated by an increase in Extracellular Ca^{++}	Thyroid Parafollicular ("C") cells	Calcitonin (water soluble)	act through G-protein coupled receptors.. inhibits osteoclasts and inhibits resorption of calcium from bone into plasma

Parathyroid Gland and Actions of Parathyroid Hormones

Stimulus	*Source*	*Hormone*	*Action*
stimulated by a fall in Extracellular Ca^{++}	Parathyroid Chief cells	Parathyroid hormone (water soluble)	act through G-protein coupled receptors. stimulates osteoclasts and the resorption of calcium and phosphate from bone into plasma. stimulates reabsorption of calcium by the kidney into plasma. increases excretion of phosphate by the kidney into the urine. stimulates production of Calcitriol by kidney, liver, and intestine

Kidney and Actions of Renal Hormones

Stimulus	*Cells / Source*	*Hormone*	*Action*
stimulated by norepinephrine (NE) via β-1	JG cells	renin (water soluble)	enzymatically converts converts angiotensinogen to angiotensin I
stimulated by a fall in erythrocytes	kidney	Erythropoietin (water soluble)	act through protein tyrosine kinases. accelerates the differentiation of stem cells of the bone marrow into erythrocytes
stimulated by Parathyroid hormone (stimulated by a fall in extracellular Ca^{2+} or P_i)	kidney	Calcitriol (lipid soluble)	act through cytoplasmic and nuclear receptors. stimulates calcium and phosphate absorption from the intestinal tract. stimulates resorption of calcium and phosphate from bone into plasma. may decrease excretion of calcium and phosphate by the kidney into the urine

Hypothalamus and Pituitary Gland

Hypothalamus

- Contains cell bodies of hypothalamic neurons that send axons to the posterior pituitary and/or to the median eminence.

Posterior Pituitary

- Site of secretion of vasopressin and oxytocin from the synaptic bulbs of hypothalamic neurons.

Median eminence

- Site of secretion of hypothalamic regulatory hormones from the synaptic bulbs of hypothalamic neurons.

Anterior Pituitary and Intermediate Lobe

- Contain glandular epithelial cells that produce pituitary hormones in response to hypothalamic regulatory hormones.

Hypophyseal Portal System (Pituitary Portal Vessels)

- Connects the capillaries of the median eminence to the capillaries of the anterior pituitary.

Posterior Pituitary

Contains axons of hypothalamic neurons

Posterior Pituitary and Actions of Posterior Pituitary hormones

Stimulus	*Source*	*Hormone*	*Action*
physical stress (dehydration, hyperosmolarity, blood loss)	Hypothalamic axons in Posterior Pituitary	Vasopressin (water soluble)	V1a receptors act through G-protein receptors. constricts blood vessels. V1b receptors act through G-protein coupled receptors. stimulates corticotropin secretion from the anterior pituitary. V2 receptors act through G-protein coupled receptors. causes the insertion of aquaporin-2 channels into the luminal membrane of the cells lining the collecting duct of the kidney and thus increases reabsorption of water by kidney
childbirth, suckling, sexual activity	Hypothalamic axons in Posterior Pituitary	Oxytocin (water soluble	act through G-protein coupled receptors. facilitates milk ejection from mammary glands. stimulates uterine contraction. alters sodium excretion by the kidney. facilitates bonding and trust

Anterior Pituitary

Contain endocrine cells that produce pituitary hormones in response to hypothalamic hormones.

Anterior Pituitary and Actions of Anterior Pituitary hormones

Stimulus	*Source*	*Hormone*	*Action of Anterior Pituitary Hormone*
Thyrotropin Releasing Hormone (TRH)	Anterior Pituitary Thyrotrophs	Thyroid Stimulating Hormone (TSH) (Thyrotropin) (water soluble)	act through G-protein coupled receptors. stimulates T3 and T4 production by thyroid follicles
Corticotropin Releasing Hormone (CRH)	Anterior Pituitary Corticotrophs	Adrenocorticotropic Hormone (ACTH) (Corticotropin) (water soluble)	act through G-protein coupled receptors. stimulates cortisol production by adrenal cortex
Somatotropin Releasing Hormone (GHRH) and Inhibiting Hormone (GHIH) (Somatostatin)	Anterior Pituitary Somatotrophs	Growth Hormone (GH) (Somatotropin) (water soluble)	act through receptor coupled receptors. stimulates breakdown of fats to fatty acids (Lipolysis) in Adipose tissue. stimulates Insulin Like Growth Factor (IGF-1) production by liver. acts directly on cells to stimulate protein synthesis in muscle. enhance lipolysis. depress the action of insulin on glucose uptake. stimulate gluconeogenesis

Gonadotropin Releasing Hormone (GnRH)	Anterior Pituitary Gonadotrophs	Follicle Stimulating Hormone (FSH) (Follitropin) (water soluble)	act through G-protein coupled receptors. stimulates follicle development and estrogen production by ovary in female. stimulates spermatogenesis by testes in male
Gonadotropin Releasing Hormone (GnRH)	Anterior Pituitary Gonadotrophs	Luteinizing Hormone (LH) (Lutropin) (water soluble)	act through G-protein coupled receptors. stimulates ovulation and progesterone production by ovary in female. stimulates testosterone production by testes in male
Prolactin Releasing Hormone (PRH) and Inhibiting Hormone (PIH)(Dopamine)	Anterior Pituitary Prolactotrophs	Prolactin (PRL) (water soluble)	act through receptor coupled receptors. stimulates milk production by mammary glands. stimulates reabsorption of electrolytes by kidney

Male Reproductive System and Spermatogenesis

Scrotum, Testes, and Penis

Scrotum

Dartos – Layer of smooth muscle within dermis of scrotum which wrinkles the scrotum to decrease heat loss.

Cremaster muscle – Layer of skeletal muscle underneath dermis which raises the scrotum to decrease heat loss.

Testes

Lobules – Regions containing seminiferous tubules.

Seminiferous tubules – Coils of tubing in the lobules that produce sperm.

Straight tubule – Transports sperm from seminiferous tubules.

Rete testis – Mixes sperm.

Efferent ducts – Transports sperm to epididymis.

Epididymis – Site for maturation of sperm.

Spermatic Cord – Includes Vas deferens, testicular blood vessels and nerves.

Ductus Deferens (Vas deferens) – Transports sperm.

Ampulla – Enlarged region of Ductus Deferens; site for storage of sperm.

Seminal Vesicle – Produces seminal fluid that dilutes the sperm and provides nutrients.

Ejaculatory Duct – Connection between ampulla and prostatic urethra.

Prostate Gland – Produces prostatic fluid (fluid and enzymes).

Urethra and associated structures.

Prostatic Urethra – Passes thru prostate.

Bulbourethral Glands – Produces a lubricating and antibacterial fluid.

Penile Urethra – Passes thru penis.

External Urethral Meatus – Opening of urethra.

Penis

Corpus Spongiosum – Surrounds the penile urethra and becomes engorged with blood.

Corpora Cavernosa – Dorsal to the corpus spongiosum and becomes engorged with blood.

Glans Penis – End of penis surrounding Corpus Spongiosum.

Seminiferous Tubules

Interstitial Cells – Between tubules; produce testosterone.

Sertoli Cells

- Attached to inner surface of tubules; maintain a blood-testis barrier, secrete inhibin, and secrete androgen binding globulin which collects testosterone necessary for spermatogenesis.

Spermatogonia – Sem cells for production of sperm.

Primary Spermatocytes – From mitosis of spermatogonia.

Secondary Spermatocytes – From meiosis I of spermatocytes.

Spermatids – From meiosis II of spermatocytes.

Spermatozoan – From maturing of spermatids.

Male Reproductive System – Laboratory

Using the terms in the left box, draw and then label the structures. Alternatively, you may paste pictures and then label the structures. If you need more space use separate sheets of paper.

Models of Scrotum, Testes, and Penis

Scrotum • Cremaster muscle	
Testes • Lobules • Seminiferous tubules • Straight tubule • Rete testis • Efferent ducts Epididymis	
Spermatic Cord • Ductus Deferens • Testicular Artery	

Ductus Deferens (Vas deferens) • Ampulla • Seminal Vesicle • Ejaculatory Duct • Prostate Gland	
Urethra • Prostatic Urethra • Bulbourethral Glands • Penile Urethra • External Urethral Meatus	
Penis • Corpus Spongiosum • Corpora Cavernosa • Glans Penis	

Histology of Seminiferous Tubules and Penis

Seminiferous Tubules • Sertoli Cells • Spermatogonia • Primary Spermatocytes • Secondary Spermatocytes • Spermatids • Sperm • Interstitial Cells	
Penis • Penile Urethra • Corpus Spongiosum • Corpora Cavernosa	

Hormones and Male Reproduction

- FSH stimulates Sertoli cells to produce Androgen Binding Globulin, Estradiol, and Inhibin.
- LH stimulates Interstitial cells to produce Testosterone.

Testes and Actions of Testicular Hormones

Stimulus	*Cells / Source*	*Hormone*	*Action*
stimulated by follicle stimulating hormone (FSH)	Sertoli cells within the Seminiferous tubules	Estradiol (lipid soluble)	FSH stimulates production of androgen binding globulin which maintains high concentration of testosterone
stimulated by follicle stimulating hormone (FSH)	Sertoli cells	Inhibin (water soluble)	Inhibits FSH gonadotrophs in pituitary
stimulated by luteinizing hormone (LH)	Leydig cells between the Seminiferous tubules	Testosterone (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression and the transcription of mRNAs. Essential in high local concentration for spermatogenesis. Inhibits GnRH secretion by hypothalamic neurons. required for pubertal masculinization to occur. increases muscle mass and body growth. close Epiphyseal growth plate

Female Reproductive System

Ovaries, Uterus, and Vagina

Ovaries

Uterine Tubes (Fallopian tubes)

- Fimbrae – Catches ovulated 'egg'.
- Ampulla – Expansion of tubes.
- Isthmus – Narrowing of tubes.

Broad Ligament and associated ligaments

- Mesovarium – Extension of broad ligament between ovary and uterine tube.
- Ovarian Ligament – Supports ovary; extends toward uterus.
- Suspensory Ligament – Supports ovary; extends laterally toward pelvic wall.
- Uterosacral Ligaments – Supports uterus; extend posteriorly.
- Round Ligaments – Supports uterus; extend anteriorly.

Uterus

- Fundus, Body, Isthmus, and Cervix
- External Orifice (Cervial Os)

Vagina and external genitalia

- Vaginal Entrance and Canal
- Urethral Opening
- Labia Minora and Majora
- Clitoris – Erectile tissue.

Pubic Symphysis – The joint between the two pubis bones.

Mons Pubis – Adipose tissue overlying the pubic symphysis.

Ovary

Oocytes (are primary oocytes).

Growing follicle

- Follicular cells undergo mitosis, follicle enlarges and fills with Follicular fluid.

Mature follicle

- The oocyte projects into an expanded central chamber the primary oocyte completes miosis I and becomes a secondary oocyte.

Zona pellucida – Glycoprotein that attaches the oocyte to follicular (granulosa) cells.

Corpus luteum

- The follicular cells of the empty follicle differentiate into luteal cells.

Corpus albicans

- The corpus luteum is replaced by fibrous connective tissue.

Uterus

Endometrium

Functional zone – Sloughs off during menstruation.

Basilar zone – Source for re-growth of Functional zone.

Myometrium – Muscular layer.

Perimetrium – Connective tissue surrounding Uterus

Female Reproductive System – Laboratory

Using the terms in the left box, draw and then label the structures. Alternatively, you may paste pictures and then label the structures. If you need more space use separate sheets of paper.

Models of Ovaries, Uterus, and Vagina

Ovaries (sectioned) • Primary Oocytes • Developing Follicle • Mature Follicle • Developing Corpus Luteum • Corpus Luteum • Corpus Albicans	
Ovary and Uterine (Fallopian) Tubes • Fimbrae • Ampulla • Isthmus	
Broad Ligament and ligaments • Broad Ligament • Mesovarium • Ovarian Ligament • Suspensory Ligament • Uterosacral Ligaments • Round Ligaments	

Uterus • Fundus • Body • Isthmus • Cervix • External Orifice (Cervical Os)	
Vagina and external genitalia • Vaginal Entrance • Vaginal Canal • Urethral Opening • Labia Minora and Majora • Clitoris	
Pubic Symphysis • Pubic Symphysis • Mons Pubis	

Histology of Ovary and Uterus

Ovary
• Oocytes
• Growing follicle
• Mature follicle
  ○ Antrum
  ○ Zona pellucida
• Corpus luteum
• Corpus albicans	

Uterus
• Endometrium
  ○ Functional zone
  ○ Basilar zone
• Myometrium
• Perimetrium	

Hormones and Female Reproduction

- FSH stimulates Ovarian Follicle development.
- Ovarian Follicles (Granulosa cells) produce Estrogen.
- LH stimulates Ovulation and formation of the Corpus Luteum.
- Corpus Luteum (Luteal cells) produces Progesterone and Relaxin.

Ovary and Actions of Ovarian Hormones

Stimulus	*Cells / Source*	*Hormone*	*Action*
stimulated by follicle stimulating hormone (FSH)	Granulosa cells surrounding the oocyte	Estradiol (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression and the transcription of mRNAs. increases the endometrial thickness (3 to 5 fold). triggers the ovulatory surge of LH and FSH. inhibits the GnRH neurons of the hypothalamus and stimulates the LH gonadotrophs of the pituitary. increase receptors for Estradiol, LH and FSH
stimulated by luteinizing hormone (LH)	Theca cells of developing follicle	Androstenedione and Testosterone (lipid soluble)	serve as precursors for synthesis of Estradiol
stimulated by LH and FSH	Luteal cells of the corpus luteum	Progesterone and Estradiol (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression. Progesterone inhibits the rapid endometrial growth and stimulates growth of glands and elongation of arteries. Progesterone inhibits the GnRH neurons in the hypothalamus
stimulated by LH and FSH	Luteal cells of the corpus luteum	Relaxin (water soluble)	act through G-protein coupled activation of adenyl cyclase and cyclic-AMP (at least in part). relaxes the cervix and softens cartilage and fibrous connective tissue. stimulates VEGF in endometrium

Gametogenesis and Chromosome Distribution

Chromosomes

Human Somatic cells contain 23 pairs of chromosomes (for a total of 46 chromosomes – the diploid number).

- throughout most of the life of a cell each chromosome consists of a single chromatid.
- prior to cell division each chromatid duplicates so that each chromosome consists of two chromatids.

Human Gametes contain 23 single chromosomes (the haploid number) with one chromatid each.

Spermatogenesis and chromosome distribution

Spermatogonium

- Contains 23 pairs of chromosomes.
- Undergoes mitosis through out adult life.
- Produces a primary spermatocyte and a daughter spermatogonium.

Primary Spermatocyte

- Contains 23 pairs of chromosomes with 2 chromatids each.
- Undergoes meiosis I(1) in the seminiferous tubules.
- Produces two secondary spermatocytes.

Secondary Spermatocyte

- Contains 23 single chromosomes with 2 chromatids each.
- Undergoes meiosis II(2) in the seminiferous tubules.
- Produces two spermatids.

Spermatid

- Contains 23 chromosomes with one chromatid each.

Oogenesis and chromosome distribution

Oogonium

- Contains 23 pairs of chromosomes.
- Undergoes mitosis only before birth.
- Produces primary oocytes.

Primary Oocyte

- Contains 23 pairs of chromosomes with 2 chromatids each.
- Undergoes meiosis I(1) in the ovary (in mature ovarian follicle).
- Produces one secondary oocyte and one polar body.

Secondary Oocyte

- Contains 23 single chromosomes with 2 chromatids each.
- Undergoes meiosis II(2) after penetration by the sperm.
- Produces one ovum and one polar body.

Ovum

- Contains 23 chromosomes with one chromatid each.

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Practice Questions – Autonomic, Endocrine, Reproductive

Choices may be used more than once or not at all.

1-5. Matching

A) Parasympathetic
B) Sympathetic
C) None of the above

ganglia are typically close to the CNS 1) _____
postganglionic axons typically are short 2) _____
ganglia are typically in the target organs 3) _____
preganglionic neurons originate in spinal cord 4) _____
preganglionic neurons originate in medulla oblongata 5) _____

6-10. Matching

A) Norepinephrine
B) Acetylcholine
C) None of the above

released from the adrenal medulla 6) _____
released by sympathetic preganglionic axons 7) _____
released by sympathetic (post)ganglionic axons 8) _____
released by parasympathetic preganglionic axon 9) _____
released by parasympathetic (post)ganglionic axons 10) _____

11-15. Matching

A) Celiac and mesenteric ganglia
B) Sympathetic chain ganglia
C) None of the above

found anterior to the aorta 11) _____
directly influence bronchial tree 12) _____
directly influence thoracic organs 13) _____
directly influence abdominal visceral organs 14) _____
directly influence skeletal muscle blood vessels 15) _____

16-20. Matching

A) Parasympathetic
B) Sympathetic
C) None of the above

dilates pupils 16) _____
constricts pupils 17) _____
constricts bronchi 18) _____
increases gastrointestinal motility 19) _____
increases force of heart contraction 20) _____

21-25. Matching

A) Acetylcholine
B) Norepinephrine
C) None of the above

decreases heart rate 21) _____
causes bronchial dilation 22) _____
increases cellular glucose usage 23) _____
decreases gastrointestinal motility 24) _____
lead to increased force of cardiac contraction 25) _____

26-30. Matching : Binding of Epinephrine to

A) Beta-1 receptors
B) Beta-2 receptors

lead to vasoconstriction 26) _____
lead to bronchial dilation 27) _____
lead to potent vasodilation 28) _____
lead to relaxation of smooth muscle 29) _____
lead to increased cardiac contractility 30) _____

31-35. Matching

A)	Beta-2 agonists	lead to decreased force of cardiac contraction	31) _____
B)	Alpha-1 agonists	lead to increased vasoconstriction	32) _____
C)	Beta-2 antagonists	lead to contraction of bladder	33) _____
D)	None of the above	lead to increases in heart rate	34) _____
		lead to bronchial dilation	35) _____

36-40. Matching (Captopril is a converting enzyme inhibitor)

A)	Renin	inhibits conversion of angiotensin I into angiotensin II	36) _____
B)	Captopril	cleaves angiotensinogen into angiotensin I	37) _____
C)	Angiotensin II	stimulates secretion of aldosterone	38) _____
D)	Angiotensinogen	is precursor for angiotensin I	39) _____
		causes vasoconstriction	40) _____

41-45. Matching

A)	Insulin	produced by the adrenal zona fasciculatis	41) _____
B)	Cortisol	produced by the adrenal zona glomerulosa	42) _____
C)	Glucagon	produced by alpha cells of pancreas	43) _____
D)	Aldosterone	produced by beta cells of pancreas	44) _____
		responds to high blood glucose	45) _____

46-50 Matching

A)	Adrenocorticotropic hormone	stimulates milk production	46) _____
B)	Thyroid stimulating hormone	stimulates thyroid follicles	47) _____
C)	Growth hormone	suppresses the immune system	48) _____
D)	Prolactin	stimulates adrenal secretion of cortisol	49) _____
		stimulates growth; increases metabolism	50) _____

51-55. Matching

A)	Insulin	produced by alpha cells of pancreas	51) _____
B)	Glucagon	increases cellular uptake of glucose	52) _____
C)	None of the above	produced by beta cells of pancreas	53) _____
		responds to high blood glucose	54) _____
		responds to low blood glucose	55) _____

56-60. Matching

A)	Insulin	increases in response to high blood calcium	56) _____
B)	Glucagon	increases in response to low blood calcium	57) _____
C)	Glycogen	increases cellular breakdown of glucose	58) _____
D)	Calcitonin	increases cellular uptake of glucose	59) _____
E)	Parathyroid hormone	is a branched chain of glucose	60) _____

61-65. Matching

A)	Thyroxine and growth hormone	inhibits osteoclast activity	61) _____
B)	Parathyroid hormone	stimulates osteoclast activity	62) _____
C)	Calcitonin	responds to low blood calcium	63) _____
		responds to high blood calcium	64) _____
		necessary for normal bone growth	65) _____

66-70. Matching

A) Adrenal medulla
B) Adrenal cortex
C) None of the above

secretes cortisol 66) _____
secretes aldosterone 67) _____
secretes testosterone 68) _____
secretes epinephrine 69) _____
secretes norepinephrine 70) _____

71-75. Matching

A) Corticotropin (ACTH)
B) Thyrotropin (TSH)
C) Growth hormone (GH)
D) None of the above

stimulates adrenal secretion of cortisol 71) _____
stimulates adrenal secretion of testosterone 72) _____
stimulates liver production of somatomedins 73) _____
stimulates thyroid production of thyroxin (T4) 74) _____
stimulates thyroid production of Triiodothyronin (T3) 75) _____

76-80. Matching

A) Posterior pituitary
B) Anterior pituitary

secretes oxytocin 76) _____
produces prolactin 77) _____
produces thyrotropin 78) _____
secretes vasopressin 79) _____
produces corticotropin 80) _____

81-85. Matching

A) Anterior pituitary
B) Posterior pituitary

produces growth hormone (GH) 81) _____
produces Luteinizing hormone (LH) 82) _____
produces follicle stimulating hormone (FSH) 83) _____
produces thyroid stimulating hormone (TSH) 84) _____
produces adrenocorticotrophic hormone (ACTH) 85) _____

86-90. Matching

A) Controlled by releasing hormones
B) Controlled by inhibiting hormone
C) A and B
D) None of the above

prolactin 86) _____
vasopressin 87) _____
growth hormone 88) _____
Thyroid stimulating hormone 89) _____
Adrenocorticotropic hormone 90) _____

91-95. Matching

A) Gonadotropin releasing hormone (GnRH)
B) Corticotropin releasing hormone (CRH)
C) Thyrotropin releasing hormone (TRH)
D) None of the above

stimulates LH 91) _____
stimulates GH 92) _____
stimulates FSH 93) _____
stimulates TSH 94) _____
stimulates ACTH 95) _____

96-100. Place the following in the order that lead to release of anterior pituitary hormones.

A) Stimulation of anterior pituitary by hypothalamic regulatory hormones 96) _____
B) Release of hypothalamic regulatory hormones into pituitary portal vessels 97) _____
C) Transport of hypothalamic regulatory hormones into anterior pituitary 98) _____
D) Release of anterior pituitary hormone into the anterior pituitary veins 99) _____
E) Stimulation of hypothalamic neurons 100) _____

101-105. Matching

A)	Hepatocytes of liver	produce progesterone	101) _____
B)	Luteal cells of ovary	produce testosterone	102) _____
C)	Alpha cells of pancreas	produce glucagon	103) _____
D)	Follicular cells of ovary	produce estrogen	104) _____
E)	Interstitial cells of testes	produce bile	105) _____

106-110. Matching

A)	Increases breakdown of glycogen	insulin	106) _____
B)	Increases formation of glycogen	cortisol	107) _____
C)	None of the above	glucagon	108) _____
		aldosterone	109) _____
		epinephrine	110) _____

111-115. Matching

A)	Follicle stimulating hormone	stimulates ovulation	111) _____
B)	Luteinizing hormone	stimulates spermatogenesis	112) _____
		stimulates follicle development	113) _____
		stimulates production of estrogen	114) _____
		stimulates production of testosterone	115) _____

116-120. Matching

A)	Gonadotropin releasing hormone	stimulates luteal cells	116) _____
B)	Human chorionic gonadotropin	luteinizing hormone is a ____	117) _____
C)	Gonadotropin	stimulates luteinizing hormone	118) _____
D	A and B	follicle stimulating hormone is a ____	119) _____
		stimulates follicle stimulating hormone	120) _____

121-125. Place in order the structures thru which sperm pass.

A)	Vas deferens	121) _____
B)	Prostatic urethra	122) _____
C)	Ejaculatory duct	123) _____
D)	Head of epididymis	124) _____
E)	Seminiferous tubules	125) _____

126-130. Place in order the structures thru which the 'egg' pass.

A)	Fimbrae	126) _____
B)	Ampulla	127) _____
C)	Body of uterus	128) _____
D)	Isthmus of uterine tube	129) _____
E)	Graffian (mature) follicle	130) _____

131-135. Matching

A)	Ampulla	provides enzymes that activate sperm	131) _____
B)	Epididymis	provides for nutrients for the sperm	132) _____
C)	Prostate gland	site for maturation of sperm	133) _____
D)	Seminal vesicle	produces a lubricating fluid	134) _____
E)	Bulbourethral gland	site for storage of sperm	135) _____

136-140. Matching

A)	Proliferative phase	reflects regrowth of the basilar zone	136) _____
B)	Secretory phase	reflects the loss of the functional zone	137) _____
C)	Menses	reflects regrowth of the functional zone	138) _____
D)	None	reflects marked increase in uterine glands	139) _____
		stimulated by lack of progesterone and estrogen	140) _____

141-145. Matching

A)	Contain 23 pairs of chromosomes	spermatids	141) _____
B)	Contain 23 single chromosomes	primary oocytes	142) _____
C)	Contain 23 chromatids	secondary oocytes	143) _____
		primary spermatocytes	144) _____
		secondary spermatocytes	145) _____

146-150.

A)	Ova	are analogous to sperm	146) _____
B)	Oogonia	are analogous to spermatids	147) _____
C)	Primary oocytes	are analogous to spermatogonia	148) _____
D)	Secondary oocytes	are analogous to primary spermatocytes	149) _____
		are analogous to secondary spermatocytes	150) _____

Short Essays

1. Compare and contrast the sympathetic and parasympathetic divisions of the autonomic nervous system with regard to the neurotransmitters of the preganglionic and postganglionic neurons.

2. Compare and contrast the functions of the sympathetic and parasympathetic nervous systems.

3. Compare and contrast the anatomical organization of the adrenal medulla and of the adrenal cortex.

4. Describe the neurohumoral mechanisms responsible for control of release of the anterior pituitary hormones.

5. Describe the control of thyroxin by the hypothalamus, pituitary and thyroid.

6. Describe the neurohumoral events that are involved in control of the menstrual cycle.