

AP 150

# Integrative Anatomy and Physiology

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**Integrative Anatomy and Physiology  
with Laboratory Exercises**

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# **Section 1 – Cells and Tissues**

# Cellular Anatomy

## Plasma membrane

- composed of a phospholipid bilayer and various proteins
- act to enclose cell and regulate passage of substances
- membrane permeability depends on integral and carrier proteins, lipid solubility, molecular size and ionic charge

## Cilia

- extensions of cytoplasm containing microtubules
- secrete mucous and move

## Microvilli

- plasma membrane specializations that increase surface area

## Membranous Organelles

All of the material inside of the cell except for the **nucleus** is called the **cytoplasm**. The membranous organelles include the mitochondria, nucleus, endoplasmic reticulum, Golgi complex, lysosomes, and peroxisomes. The **cytosol** is the cytoplasm minus the **membranous organelles**.

### Cytoplasm

- All of the material inside of the cell except for the nucleus; includes 80% to 90% water plus various electrolytes

### Mitochondria

- composed of double phospholipid bilayers forming an outer membrane and an inner membrane
- Much of the inner membrane forms deep folds called **cristae**)
- site for cellular energy production

### Nucleus

- bounded by a double walled membrane with pores
- contain Chromatin - protein and DNA
- contains the Nucleolus - protein and RNA

### Endoplasmic reticulum (ER)

- consists of interconnected membranes, and tubules between the membranes, that connect to the nucleus
- 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
- acts in cellular secretion thru production of Vesicles, synthesize carbohydrate compounds

### 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 of course the molecular clusters in the cell that are not bounded by phospholipid bilayers. These include the ribosomes, the cytoskeleton, and other structures such as the centrioles.

### Ribosomes

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

### Fibrils and Microtubules

- act as a cytoskeleton
- Fibrils are specialized in muscle for contraction (Myofibrils)
- Microtubules transport macromolecules

### Centrioles

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

# Cellular Anatomy - Laboratory

## Model of Cell

<p>Plasma membrane</p> <ul style="list-style-type: none"><li>• Cytoplasm</li><li>• Lipid Bilayer</li><li>• Cilia</li><li>• Microvilli</li></ul>	
<p>Membranous Organelles</p> <ul style="list-style-type: none"><li>• Cytoplasm</li><li>• Mitochondria</li><li>• Nucleus</li><li>• Endoplasmic reticulum (ER)</li><li>• Golgi apparatus</li><li>• Vesicles</li><li>• Lysosomes</li><li>• Peroxisomes</li></ul>	
<p>Non-membranous Organelles</p> <ul style="list-style-type: none"><li>• Ribosomes</li><li>• Fibrils and Microtubules</li><li>• Centrioles</li></ul>	

# 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 <b>barrier</b> and produce <b>secretions</b>
Connective	small cells widely separated and surrounded by secreted substances	blood vessels intermingle with cells	provide <b>structure</b> , <b>support</b> and protection
Muscle	vary from long and spaghetti shaped to short and spindle shaped	blood vessels intermingle with cells	<b>contract</b> and provide <b>movement</b>
Nervous	vary from long, stringy and branched to short and compact	blood vessels are isolated from neurons	<b>process</b> and <b>transmit</b> signals

# Epithelial Tissues

## General Function and Anatomical Features

- act as a barrier
- produce secretions (function as glands)
- line body cavities, tubes; cover organs
- contain Germinative cells (cells that undergo mitosis)
- connected to underlying tissue by a Basement Membrane
- are Avascular (do not contain blood vessels)
- cells are tightly bonded together by Glycoprotein deposits, Desmosomes, Tight Junctions

## Classification of Epithelial Tissues and Cells

- single layered (Simple and Pseudostratified)
- multilayered (Stratified, Transitional)
- flat (Squamous), cube-like (Cuboidal), tall (Columnar), oval (seen in Transitional Epithelium)

## Simple Epithelia

### Simple Squamous

- cover visceral organs, line body cavities
- permit diffusion and filtration (easiest to pass through)

### Simple Cuboidal

- line exocrine glands, ducts, renal tubules, cover ovaries
- permit secretion\*, excretion, or absorption

### Simple Columnar

- line digestive tract
- provide protection, permit absorption and secretion\*

## Non-Simple Epithelia

### Pseudostratified Ciliated Columnar

- line respiratory airways
- provide protection, permit secretion\*, ciliary movement (sweep away debris)

### Stratified Squamous

- epidermis of skin (keratinized), ends of GI tract (non-keratinized)
- provide protection

### Transitional

- line ureter and bladder
- permit distension

## Glandular Epithelia

Unicellular Glands - single columnar cells - Goblet cells

Multicellular Glands - comprised of simple cuboidal epithelia

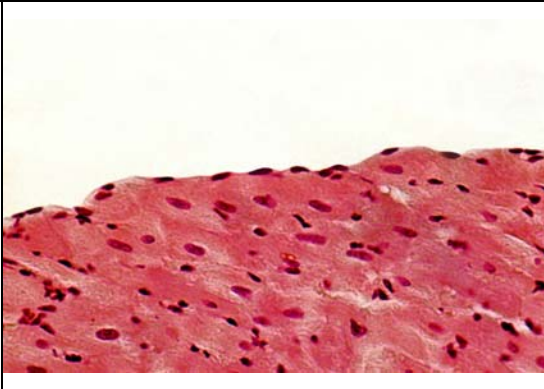
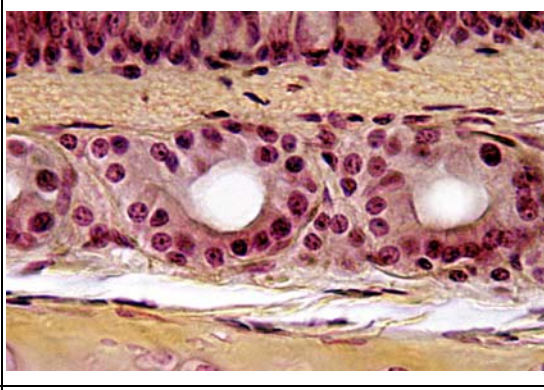

- Tubular glands - secretory portion tubular
- Acinar glands - secretory portion enlarged (bulb-like)
- Simple - ducts do not branch (intestine, stomach, skin)
- Compound - ducts branch (mammary, salivary, pancreas)

### Glandular Secretion

- Holocrine – whole cell discharged (sebaceous glands of skin)
- Apocrine - membrane pinches off (mammary glands and apocrine sweat glands)
- Merocrine - transmembrane secretion (salivary glands, pancreatic glands, and merocrine sweat glands)

# Epithelial Tissues - Laboratory

## Histology of Simple Epithelial Tissues

Simple Squamous Epithelium	 A light micrograph showing a single layer of simple squamous epithelium. The cells are flat and squamous, with their nuclei positioned near the base. The tissue is stained pink and purple, showing a thin, delicate appearance.
Simple Cuboidal Epithelium	 A light micrograph showing a single layer of simple cuboidal epithelium. The cells are cube-shaped with prominent, centrally located nuclei. The tissue is stained pink and purple, and appears to be lining a structure with a lumen.
Simple Columnar Epithelium	 A light micrograph showing a single layer of simple columnar epithelium. The cells are tall and narrow, with nuclei located near the base. The tissue is stained pink and purple, and appears to be lining a structure with a lumen.

## Histology of Non-Simple Epithelial Tissues

Pseudostratified Ciliated Columnar Epithelium	
Stratified Squamous Epithelium	
Transitional Epithelium	

## Histology of Glandular Epithelial Tissues

Unicellular glands <ul style="list-style-type: none"><li>Goblet cells</li></ul>		
Multicellular Glands <ul style="list-style-type: none"><li>Merocrine sweat gland</li><li>Sebaceous gland</li></ul>		

# Cellular Control and Transport

## Plasma Membrane

Lipid bilayer - two layers of Phospholipids

- Surface facing the outside of the cell - phosphate based – Hydrophilic
- Surface facing the inside of the cell - phosphate based – Hydrophilic
- Interior of plasma membrane -lipid and cholesterol based – Hydrophobic; water soluble ions and molecules cannot enter this region

Glycocalyx - carbohydrate complexes (glycoproteins and glycolipids) bound to the surface of the plasma membrane facing the outside of the cell

- act to protect the cell membrane and anchor the cell in place
- serve as **receptors** that permit extracellular substances to control activity of cells
- provides a genetically determined fingerprint that is recognized by the immune system as ‘self’ rather than ‘foreign’

Peripheral proteins - proteins bound to the surface of the plasma membrane facing the inside of the cell

- act in communication between cell membrane and interior of cell

Integral proteins - proteins embedded in cell membrane *redefine*

- permit passageways through the cell membrane
- Channels - passageways for water and water soluble substances formed by integral proteins
- Passive Channels – channels that are always open
- Gated Channels - channels that can open or close to control the passage of ions and molecules
- Facilitative Transporters
- Co-transporters and Counter-transporters
- Active Transport Pumps

## Membrane permeability: Passive processes

### Diffusion

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

- Concentration gradient - difference between the high and low concentrations
- Permeability - extent that substances can enter or leave a cell
  - Impermeable - nothing can cross the membrane
  - Freely Permeable - any substance can cross the membrane
  - Selectively permeable - only certain substances can cross

### Diffusion across cell membranes

lipid soluble substances can diffuse through the cell membrane

- water soluble substances can pass through channels if;
  - the substances are smaller than the channels
  - the charge of the channel permits passage of the substance

### Facilitated diffusion

some substances that are not lipid soluble or are too large to pass through the membrane channels, can diffuse through the cell membrane using a Carrier Protein that binds to the substance (diffusion is limited by the number of carrier proteins available)

### Osmosis

diffusion of water across a cell membrane

- Osmotic pressure - the force for water movement that is dependent on the concentration gradient of the water
- Osmolality - concentration of dissolved substances (solutes); determines the concentration gradient of the water
  - Isotonic - same osmolality as the cellular cytoplasm
  - Hypotonic - lower osmolality than the cytoplasm
  - Hypertonic - higher osmolality than the cytoplasm

### Filtration

movement of water across a cell membrane due to hydrostatic pressure

## **Membrane permeability: Active processes**

### **Active transport**

movement of substances across a cell membrane using a Carrier Protein and added energy

- occurs regardless of the concentration gradient
- Ion pumps - active transport of a single ion
- Exchange pumps - active transport of one ion in one direction and another ion in the opposite direction
  - Sodium-potassium exchange pump - an exchange pump where three sodium ions are exchanged with two potassium ions
- Endocytosis - packaging of extracellular material in a vesicle and the active transport into a cell

### **Transmembrane potential**

difference in charge between the inside and the outside of a cell (about -70 mV), due to the sodium-potassium exchange pump and the more rapid diffusion of potassium out of the cell than diffusion of sodium into the cell

- extracellular fluid contains large numbers of sodium and chloride ions
- intracellular fluid contains large numbers of potassium ions and negatively charged proteins

# Connective Tissues

## General Function and Anatomical Features

- provide structure, support and protection
- serve in transport
- consist of specialized secretory cells and of substances secreted from these cells (the Matrix)
- contain fibers composed mainly of Protein
- contain a gelatin like substance (Ground Substance)

## Fibrous Connective Tissues

Matrix produced by Fibroblasts

### Areolar Connective Tissue

- fine collagen fibers
- Mast cells
- around nerves and vessels
- between muscles, in skin, binds organs, holds tissues
- permit diffusion

### Dense Regular Connective Tissues

- thick collagen fibers
- in tendons, ligaments
- provides strong support in longitudinal direction

### Dense Irregular Connective Tissues

- thick collagen fibers
- in skin, fibrous capsules of organs and joints
- provides strong support in all directions

## Cartilage Tissues

matrix produced by Chondrocytes

### Hyaline Cartilage

- thick gelatin matrix
- in joint surfaces of bones, nose, respiratory airways
- provides flexible support
- is a precursor to bone

## **Osseous Tissues**

Matrix produced by Osteoblasts - Osteocytes

### **Bone**

- calcium phosphate deposits and collagen fibers
- in skeleton
- provides rigid support
- mineral metabolism

## **Adipose Tissue**

Composed of Adipocytes that accumulate lipids

- store fat droplets
- under skin, around heart, kidneys, eyeballs, joints
- provides protection, stores fat, insulates

# Connective Tissues - Laboratory

## Histology of Connective tissues

<p>Areolar Connective Tissue</p> <ul style="list-style-type: none"> <li>• Fibroblasts</li> <li>• fine Collagen fibers</li> <li>• Elastic fibers</li> <li>• Mast cells</li> </ul>	
<p>Dense Irregular Connective Tissue</p> <ul style="list-style-type: none"> <li>• Fibroblasts</li> <li>• thick Collagen fibers</li> </ul>	
<p>Dense Regular Connective Tissue</p> <ul style="list-style-type: none"> <li>• Fibroblasts</li> <li>• thick Collagen fibers</li> </ul>	

<p>Elastic Connective Tissue</p> <ul style="list-style-type: none"><li>• Fibroblasts</li><li>• Elastic Fibers</li></ul>	
<p>Hyaline Cartilage</p> <ul style="list-style-type: none"><li>• Chondrocytes</li><li>• Chondroitin Sulfate</li></ul>	
<p>Osseous Tissue</p> <ul style="list-style-type: none"><li>• Osteocytes</li><li>• Calcium Phosphate</li><li>• Collagen fibers</li></ul>	
<p>Adipose Tissue</p> <ul style="list-style-type: none"><li>• Adipocytes</li><li>• Lipids</li></ul>	

# 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 connected by a Basement-Membrane
- functions to control skin-permeability, provide a barrier to pathogens, and to synthesize vitamin-D.

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

### Dermis

- functions to nourish epidermis, restrict and destroy pathogens, store lipids, attach skin to underlying tissue, provide for sensory-detection, assist in thermoregulation by way of blood vessels.

#### Papillary-Layer

- composed of Areolar-Connective-Tissue
- contain many Blood-Capillaries and Lymphatic-vessel
- contain Meissner's-Corpuscles for detecting light-touch

#### Reticular-Layer

- composed of Dense-Irregular-Connective-Tissue
- contain Blood-Vessels, Lymph-Nodes and Lymphatic-Vessel
- contain Pacinian-Corpuscles for detecting deep-pressure

### Hypodermis (Subcutaneous-Layer)

- composed of Adipose-Tissue and Areolar connective tissue
- functions to provide cushioning and storage of fat.

## Skin Thickness

### Thick-skin

- stratum lucidum - *distinct*
- stratum corneum - *thick*
- papillary layer - *thin*

### Thin-skin

- stratum lucidum - *absent*
- stratum corneum - *thin*
- papillary layer - *distinct*

## Epidermal-Derivatives (Accessory Structures)

### Hair-Follicles

- are formed by invagination from the epidermis
- function to protect skull and to assist in sensory detection.

Papilla - connective tissue

Matrix - epithelial cells that are mitotically active and similar to stratum germinativum

- functions to provide growth of Hair

Hair-Shaft and Root - exposed and deep portions of hair

### Arrector-Pili-Muscles

- Smooth-Muscle connecting to hair follicle
- Function to 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

- 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

- 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

## Model of Skin

<p>Epidermis</p> <ul style="list-style-type: none"> <li>• Stratum Corneum</li> <li>• Stratum Lucidum</li> <li>• Stratum Granulosum</li> <li>• Stratum Spinosum</li> <li>• Stratum Germinativum</li> </ul>	
<p>Dermis</p> <ul style="list-style-type: none"> <li>• Papillary Layer</li> <li>• Reticular Layer</li> <li>• Tactile (Meissner's) Corpuscle</li> <li>• Sebaceous glands</li> <li>• Merocrine sweat glands</li> </ul>	
<p>Hypodermis</p> <ul style="list-style-type: none"> <li>• Lamellated (Pacinian) corpuscle</li> </ul>	

<p>Hair Follicles</p> <ul style="list-style-type: none"><li>• Papilla</li><li>• Matrix</li><li>• Hair</li><li>• Arrector Pili muscle</li></ul>	
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## Histology of Skin

### Thick Skin

<p>Epidermis</p> <ul style="list-style-type: none"><li>• Stratum Corneum</li><li>• Stratum Lucidum</li><li>• Stratum Granulosum</li><li>• Stratum Spinosum</li><li>• Stratum Germinativum</li></ul>	
<p>Dermis</p> <ul style="list-style-type: none"><li>• Reticular Layer</li><li>• Merocrine sweat glands</li></ul>	

Hypodermis	
------------	--

**Thin Skin / Scalp**

Epidermis <ul style="list-style-type: none"><li>• Stratum Corneum</li><li>• Stratum Granulosum</li><li>• Stratum Germinativum</li></ul>	
Dermis <ul style="list-style-type: none"><li>• Papillary Layer</li><li>• Reticular Layer</li><li>• Sebaceous glands</li><li>• Merocrine sweat glands</li></ul>	

Hypodermis	
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Hair Follicles <ul style="list-style-type: none"><li>• Papilla</li><li>• Matrix</li><li>• Hair</li></ul>	
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# **Skeletal Organization, Bone, and Bone Markings**

## **Organization of skeleton**

### Axial Skeleton

Skull

Hyoid bone

Vertebrae

Ribs and Sternum

### Appendicular Skeleton

#### Upper Appendicular

Shoulder girdle - clavicle and scapula

Arms - humerus, ulna, radius

Hands and Fingers - carpals, metacarpals, phalanges

#### Lower Appendicular

Pelvic girdle - coxa

Thighs - femur

Legs - tibia and fibula

Feet and Toes - tarsals, metatarsals, phalanges

## Shapes of bones

Flat bone - flat, 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 - long, such as bones of the limbs

Short bone - boxy, 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 groove

openings

Foramen - rounded passageway

Fissure - cleft

Meatus - canal

Sinus – chamber

# Osseous Tissue and Bone

## General organization of bone

### Diaphysis

- the shaft of a bone
- composed mainly of dense bone

### Epiphysis

- the heads of a bone
- composed mainly of spongy bone

### Articular Cartilage

- covering at end of the epiphysis
- composed of: Hyaline cartilage

### 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

### 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 (Haversian System)

- basic unit of organization with a **Central Canal** (Haversian Canal) for passage of blood vessels

Lamellae - circularly arranged layers of bone matrix

Interstitial Lamellae - bone matrix between the lamellae

Lacunae - the spaces in the bone matrix for the osteocytes

Osteocytes - the bone cells in the lacunae

Canaliculi - the channels in the bone matrix

### 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

- basic unit of organization, somewhat like an osteon

Lacunae

Osteocytes

Endosteum

- lining inside a bone ( marrow cavity)
- composed of: an epithelial cellular layer with:

Simple Squamous Epithelial cells - act as a barrier

Osteoblasts - cells responsible for producing new bone matrix

Osteoclasts - cells responsible for destroying old bone matrix

# Bone and Osseous Tissue - Laboratory

## Bone Sectioned

<p>Long Bone</p> <ul style="list-style-type: none"><li>• Diaphysis</li><li>• Epiphysis</li><li>• Epiphyseal line</li><li>• Marrow cavity</li><li>• Periosteum</li><li>• Endosteum</li></ul>	
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## Model of Bone

<p>Compact Bone</p> <ul style="list-style-type: none"><li>• Volkmann's canals (perforating canals)</li><li>• Osteons</li><li>• Haversian canals (central canals)</li><li>• Calcium phosphate matrix</li><li>• Lacunae</li><li>• Osteocytes</li><li>• Lamellae</li><li>• Canaliculi</li><li>• Interstitial lamellae</li><li>• Periosteal plates</li></ul>	
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	--

<p>Spongy Bone</p> <ul style="list-style-type: none"><li>• Trabeculae</li><li>• Lacunae</li><li>• Osteocytes</li><li>• Marrow Cavity</li><li>• Endosteum</li></ul>	
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## Histology of Bone and related structures

<p>Compact Bone</p> <ul style="list-style-type: none"><li>• Osteons</li><li>• central canals</li><li>• Calcium phosphate matrix</li><li>• Osteocytes in Lacunae</li><li>• Lamellae</li><li>• Canaliculi</li></ul>	
<p>Spongy Bone</p> <ul style="list-style-type: none"><li>• Trabeculae</li><li>• Osteocytes in Lacunae</li><li>• Marrow Cavity</li><li>• Endosteum</li><li>• Simple Squamous Epithelial cells</li><li>• Osteoblasts</li><li>• Osteoclasts</li><li>• Hyaline cartilage</li><li>• Epiphyseal plate</li></ul>	

# Bone growth and Metabolism

## Development and Growth

Ossification - replacing other tissue with bone

Calcification - deposition of calcium within a tissue

## Mineral metabolism

Parathormone

secreted in response to low blood levels of calcium

- stimulates osteoclast activity
- decreases rate of calcium excretion by kidney

Calcitriol

secreted in response to low blood levels of calcium

- increases rate of intestinal absorption of calcium

Calcitonin

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

# 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

<p>Occipital bone</p> <ul style="list-style-type: none"><li>• Occipital Condyles</li><li>• Foramen Magnum</li><li>• Jugular Foramen</li></ul>	
<p>Parietal bones</p> <ul style="list-style-type: none"><li>• Lambdoidal Suture</li><li>• Sagittal Suture</li><li>• Coronal Suture</li></ul>	
<p>Frontal bone</p> <ul style="list-style-type: none"><li>• Orbit</li><li>• Frontal Sinuses</li></ul>	
<p>Nasal bones</p>	

<p>Maxillary bones (Maxilla)</p> <ul style="list-style-type: none"><li>• Maxillary Sinus</li></ul>	
<p>Lacrimal bones</p>	
<p>Ethmoid bone</p> <ul style="list-style-type: none"><li>• Crista Galli</li><li>• Cribriform Plate</li><li>• Superior and Middle Nasal Conchae</li><li>• Perpendicular Plate</li></ul>	
<p>Inferior nasal conchae</p>	

<p>Vomer bone</p> <ul style="list-style-type: none"><li>• Nasal Septum (formed by the vomer bone, the perpendicular plate of the ethmoid bone, and cartilage)</li></ul>	
<p>Palatine bones</p>	
<p>Sphenoid bone</p> <ul style="list-style-type: none"><li>• Sella Turcica</li><li>• Optic Foramen (Canal)</li><li>• Superior Orbital Fissure</li><li>• Foramen Rotundum</li><li>• Foramen Ovale</li><li>• Foramen Spinosum</li><li>• Sphenoid Sinus</li></ul>	

<p>Zygomatic bones</p> <ul style="list-style-type: none"> <li>• Zygomatic Arch</li> <li>• Temporal Process (of Zygomatic Bone)</li> </ul>	
<p>Temporal bones</p> <ul style="list-style-type: none"> <li>• Zygomatic Process of Temporal Bone</li> <li>• Squamous Suture</li> <li>• External Acoustic Meatus (External Auditory Canal)</li> <li>• Internal Acoustic Meatus (Internal Auditory Canal)</li> <li>• Mastoid Process</li> <li>• Styloid Process</li> <li>• Mandibular Fossa</li> <li>• Carotid Foramen (Canal)</li> <li>• Foramen Lacerum</li> </ul>	
<p>Mandible</p> <ul style="list-style-type: none"> <li>• Ramus</li> <li>• Coronoid Process</li> <li>• Condylar Processes (Mandibular Condyles)</li> </ul>	

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# Practice Questions – Cells, Tissues, Skin, and Skull

For matching questions, choices may be used more than once or not at all.

## 1-5. Matching

- |                                       |                                            |          |
|---------------------------------------|--------------------------------------------|----------|
| A) Simple Squamous                    | line exocrine glands, ducts, renal tubules | 1) _____ |
| B) Simple Cuboidal                    | line body cavities and blood vessels       | 2) _____ |
| C) Simple Columnar                    | line respiratory airways                   | 3) _____ |
| D) Transitional                       | line ureter and bladder                    | 4) _____ |
| E) Pseudostratified Ciliated Columnar | line digestive tract                       | 5) _____ |

## 6-10. Matching

- |                 |                          |           |
|-----------------|--------------------------|-----------|
| A) chondrocytes | found in areolar CT      | 6) _____  |
| B) osteoblasts  | found in 'fatty' tissue  | 7) _____  |
| C) adipocytes   | produce bone matrix      | 8) _____  |
| D) fibroblasts  | produce collagen fibers  | 9) _____  |
|                 | produce cartilage matrix | 10) _____ |

## 11-15. Matching

- |                       |                                       |           |
|-----------------------|---------------------------------------|-----------|
| A) dense irregular CT | accumulates lipids                    | 11) _____ |
| B) hyaline cartilage  | often found under loose CT            | 12) _____ |
| C) osseous tissue     | found under most epithelium           | 13) _____ |
| D) adipose tissue     | found at end of joints and in trachea | 14) _____ |
| E) loose CT           | matrix composed of calcium phosphate  | 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) exterior of cell membrane | is hydrophilic            | 21) _____ |
| B) interior of cell membrane | contains lipids           | 22) _____ |
| C) none of the above         | is hydrophobic            | 23) _____ |
|                              | contains receptors        | 24) _____ |
|                              | contains phosphate groups | 25) _____ |

## 26-30. Matching

- |                        |                                           |           |
|------------------------|-------------------------------------------|-----------|
| A) peripheral proteins | may be channels                           | 26) _____ |
| B) integral proteins   | act as intracellular receptors            | 27) _____ |
| C) glycocalyx          | imbedded within the lipid bilayer         | 28) _____ |
|                        | provides for intracellular communication  | 29) _____ |
|                        | composed of glycolipids and glycoproteins | 30) _____ |

31-35. Matching

- |                          |                                                |           |
|--------------------------|------------------------------------------------|-----------|
| A) osmosis               | movement of water along concentration gradient | 31) _____ |
| B) diffusion             | movement along a concentration gradient        | 32) _____ |
| C) filtration            | movement of water due to pressure              | 33) _____ |
| D) active transport      | diffusion using a carrier protein              | 34) _____ |
| E) facilitated diffusion | transport using added energy                   | 35) _____ |

36-40. Matching

- |               |                             |           |
|---------------|-----------------------------|-----------|
| A) osmolality | osmolality high             | 36) _____ |
| B) hypertonic | concentration of solutes    | 37) _____ |
| C) hypotonic  | solute concentration low    | 38) _____ |
| D) isotonic   | solute concentration high   | 39) _____ |
|               | solute concentration normal | 40) _____ |

41-45. Matching

- |                          |                                                     |           |
|--------------------------|-----------------------------------------------------|-----------|
| A) endoplasmic reticulum | contains channels                                   | 41) _____ |
| B) cell membrane         | site for synthesis of channels                      | 42) _____ |
| C) nucleus               | contains genetic code for proteins                  | 43) _____ |
|                          | contains genetic code for channels                  | 44) _____ |
|                          | site for synthesis of proteins and other substances | 45) _____ |

46-50. Matching

- |               |                                              |           |
|---------------|----------------------------------------------|-----------|
| A) hypodermis | does not contain blood vessels               | 46) _____ |
| B) epidermis  | composed mainly of adipose tissue            | 47) _____ |
| C) dermis     | major location of light touch receptors      | 48) _____ |
|               | composed of stratified squamous epithelium   | 49) _____ |
|               | composed mainly of fibrous connective tissue | 50) _____ |

51-55. Matching

- |                              |                                               |           |
|------------------------------|-----------------------------------------------|-----------|
| A) papillary layer of dermis | contain Lymph Nodes                           | 51) _____ |
| B) reticular layer of dermis | contain Meissner's Corpuscles                 | 52) _____ |
| C) hypodermis                | contain many Blood Capillaries                | 53) _____ |
|                              | composed of Loose Connective Tissue           | 54) _____ |
|                              | composed of Dense Irregular Connective Tissue | 55) _____ |

56-60. Matching

- |                         |                                          |           |
|-------------------------|------------------------------------------|-----------|
| A) Stratum Lucidum      | cells attached by spine like projections | 56) _____ |
| B) Stratum Corneum      | nuclei and organelles disappear          | 57) _____ |
| C) Stratum Spinosum     | dead cells filled with Keratin           | 58) _____ |
| D) Stratum Granulosum   | keratohyalin formed here                 | 59) _____ |
| E) Stratum Germinativum | mitotically active                       | 60) _____ |

61-65. Matching

- |                           |                                               |           |
|---------------------------|-----------------------------------------------|-----------|
| A) merocrine sweat glands | secrete into hair follicles                   | 61) _____ |
| B) sebaceous glands       | invagination of epidermis into dermis         | 62) _____ |
| C) hair follicles         | secrete sweat onto surface of epidermis       | 63) _____ |
| D) A and B                | anatomically are simple coiled tubular glands | 64) _____ |
| E) none of the above      | common in axillary and pubic region           | 65) _____ |

66-70. Matching

- |                                 |                                               |           |
|---------------------------------|-----------------------------------------------|-----------|
| A) fluid from capillary leakage | sensible perspiration                         | 66) _____ |
| B) fluid from sweat glands      | insensible perspiration                       | 67) _____ |
| C) A and B                      | increases with elevated body temperature      | 68) _____ |
|                                 | increases with increased skin blood pressure  | 69) _____ |
|                                 | increases with increased skin blood flow rate | 70) _____ |

71-75. Matching

- |                            |                                         |           |
|----------------------------|-----------------------------------------|-----------|
| A) neurons                 | cells have semipermeable membranes      | 71) _____ |
| B) muscle cells            | cells are specializd to conduct signals | 72) _____ |
| C) epithelial cells        | cells are tightly connected together    | 73) _____ |
| D) connective tissue cells | cells are specialized to shorten        | 74) _____ |
| E) all of the above        | cells secrete a matrix material         | 75) _____ |

76-80. Matching

- |                  |                                         |           |
|------------------|-----------------------------------------|-----------|
| A) Diaphysis     | composed of Osteoblasts and Osteoclasts | 76) _____ |
| B) Epiphysis     | adipose tissue and hemopoietic tissue   | 77) _____ |
| C) Endosteum     | lined by the endosteum                  | 78) _____ |
| D) Bone Marrow   | the heads of a bone                     | 79) _____ |
| E) Marrow Cavity | the shaft of a bone                     | 80) _____ |

81-85. Matching

- |                        |                                               |           |
|------------------------|-----------------------------------------------|-----------|
| A) Articular Cartilage | connects bone to bone                         | 81) _____ |
| B) Joint Capsule       | composed of Hyaline cartilage                 | 82) _____ |
| C) Periosteum          | covering at end of the epiphysis              | 83) _____ |
| D) Ligaments           | covering around the outside of a bone         | 84) _____ |
| E) Tendons             | continuation of the periosteum around a joint | 85) _____ |

86-90. Matching

- |                  |                                                |           |
|------------------|------------------------------------------------|-----------|
| A) Lacunae       | channels in the bone for nourishing bone cells | 86) _____ |
| B) Canaliculi    | covering around the outside of a bone          | 87) _____ |
| C) Periosteum    | spaces within the cartilage matrix             | 88) _____ |
| D) Perichondrium | spaces within the bone matrix                  | 89) _____ |
|                  | covering around cartilage                      | 90) _____ |

91-95. Matching

- |                 |                                                  |           |
|-----------------|--------------------------------------------------|-----------|
| A) Trabeculae   | cells responsible for destroying old bone matrix | 91) _____ |
| B) Osteocytes   | cells responsible for producing new bone matrix  | 92) _____ |
| C) Osteoblasts  | the cartilage producing cells in the lacunae     | 93) _____ |
| D) Osteoclasts  | the bone cells in the lacunae                    | 94) _____ |
| E) Chondrocytes | basic unit of spongy bone                        | 95) _____ |

96-100. Matching

- |                   |                                             |            |
|-------------------|---------------------------------------------|------------|
| A) temporal bones | contains sella turcica                      | 96) _____  |
| B) sphenoid bone  | articulates with the atlas                  | 97) _____  |
| C) occipital bone | contains the mandibular fossa               | 98) _____  |
| D) ethmoid bone   | contains superior and middle concha         | 99) _____  |
| E) maxilla        | forms a major part of the roof of the mouth | 100) _____ |

101-105. Matching

- |                             |                             |            |
|-----------------------------|-----------------------------|------------|
| A) foramen ovale            | for nerves for eye movement | 101) _____ |
| B) optic foramen            | for trigeminal nerve        | 102) _____ |
| C) jugular foramen          | for jugular veins           | 103) _____ |
| D) foramen magnum           | for optic nerve             | 104) _____ |
| E) superior orbital fissure | for spinal cord             | 105) _____ |

106-110. Matching

- |                      |                                       |            |
|----------------------|---------------------------------------|------------|
| A) sodium channel    | may be passive or gated               | 106) _____ |
| B) water channel     | allow diffusion of sodium ions        | 107) _____ |
| C) sodium pump       | involve proteins in the cell membrane | 108) _____ |
| D) all of the above  | allow diffusion of water molecules    | 109) _____ |
| E) none of the above | allow diffusion of potassium ions     | 110) _____ |

111-115. Matching

- |                          |                                                      |            |
|--------------------------|------------------------------------------------------|------------|
| A) Nucleus               | transport synthesized substances throughout the cell | 111) _____ |
| B) Ribosomes             | package synthesized substances for secretion         | 112) _____ |
| C) Mitochondria          | produce ATP from glucose and fatty acids             | 113) _____ |
| D) Golgi Apparatus       | site for protein synthesis in the cytoplasm          | 114) _____ |
| E) Endoplasmic Reticulum | contains the genetic DNA code                        | 115) _____ |

116-120. Matching

- |               |                                              |            |
|---------------|----------------------------------------------|------------|
| A) dermis     | composed mainly of fibrous connective tissue | 116) _____ |
| B) epidermis  | composed of stratified squamous epithelium   | 117) _____ |
| C) hypodermis | composed mainly of adipose tissue            | 118) _____ |
|               | does not contain blood vessels               | 119) _____ |
|               | contains collagen fibers                     | 120) _____ |

121-125. Matching

- |                                                  |                                                     |            |
|--------------------------------------------------|-----------------------------------------------------|------------|
| A) Pseudostratified Ciliated Columnar Epithelium | sweep away debris                                   | 121) _____ |
| B) Simple Squamous Epithelium                    | provide(s) a barrier                                | 122) _____ |
| C) Simple Columnar Epithelium                    | most easily allows diffusion                        | 123) _____ |
| D) Simple Cuboidal Epithelium                    | often involved in nutrient absorption               | 124) _____ |
| E) All of the above                              | often involved in secretion of glandular substances | 125) _____ |

126-130. Matching

- |                                    |                                         |            |
|------------------------------------|-----------------------------------------|------------|
| A) dense regular connective tissue | contains lipids                         | 126) _____ |
| B) loose connective tissue         | contains Mast cells                     | 127) _____ |
| C) hyaline cartilage               | contains chondroitin                    | 128) _____ |
| D) adipose tissue                  | contains calcium phosphate              | 129) _____ |
| E) none of the above               | contains large parallel collagen fibers | 130) _____ |

131-135. Matching

- |                                    |                                       |            |
|------------------------------------|---------------------------------------|------------|
| A) dense regular connective tissue | often called "fat"                    | 131) _____ |
| B) loose connective tissue         | often found in tendons                | 132) _____ |
| C) hyaline cartilage               | found under most epithelium           | 133) _____ |
| D) adipose tissue                  | found in papillary layer of dermis    | 134) _____ |
| E) none of the above               | found at end of joints and in trachea | 135) _____ |

136-140. Matching

- |                      |                                                 |            |
|----------------------|-------------------------------------------------|------------|
| A) Ligaments         | continuation of the "periosteum" around a joint | 136) _____ |
| B) Endosteum         | covering around the outside of a bone           | 137) _____ |
| C) Periosteum        | contains osteoblasts and osteoclasts            | 138) _____ |
| D) Articular capsule | separates bone marrow from bone                 | 139) _____ |
| E) none of the above | connect(s) bone to bone                         | 140) _____ |

141-145. Matching

- |                          |               |            |
|--------------------------|---------------|------------|
| A) found in compact bone | lacunae       | 141) _____ |
| B) found in spongy bone  | canaliculi    | 142) _____ |
| C) A and B               | osteocytes    | 143) _____ |
| D) none of the above     | central canal | 144) _____ |
|                          | bone marrow   | 145) _____ |

146-150. Matching

- |                                           |                                     |            |
|-------------------------------------------|-------------------------------------|------------|
| A) forms part of the orbits (eye sockets) | vomer bone                          | 146) _____ |
| B) forms part of nasal septum             | frontal bone                        | 147) _____ |
| C) none of the above                      | sphenoid bone                       | 148) _____ |
|                                           | maxillary bones                     | 149) _____ |
|                                           | perpendicular plate of Ethmoid bone | 150) _____ |

151-155. Matching

- |                      |                                                |            |
|----------------------|------------------------------------------------|------------|
| A) calcitonin        | produced in response to elevated blood calcium | 151) _____ |
| B) parathormone      | produced by parathyroid 'chief' cells          | 152) _____ |
| C) none of the above | produced by thyroid 'C' cells                  | 153) _____ |
|                      | stimulate osteoclasts                          | 154) _____ |
|                      | inhibit osteoblasts                            | 155) _____ |

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.
6. Describe the mechanisms responsible for the maintenance of relatively constant levels of calcium in the blood. Include the role of hormones, osteoblasts and osteoclasts

# **Section 2 – Skeletal and Muscular Systems**

# 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, T1-T10 – for joints with tubercle of ribs
- Facets / Demifacets on body, 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

## Specimens

<p>General Features</p> <ul style="list-style-type: none"> <li>• Body</li> <li>• Vertebral foramen</li> <li>• Spinal process</li> <li>• Transverse processes</li> <li>• Superior and Inferior Articular processes</li> <li>• Intervertebral foramen</li> <li>• Intervertebral discs</li> </ul>	
<p>Cervical vertebrae (C1-C7)</p> <ul style="list-style-type: none"> <li>• Transverse foramen</li> <li>• C1 (Atlas)</li> <li>• C2 (Axis) <ul style="list-style-type: none"> <li>◦ Odontoid process (Dens)</li> </ul> </li> </ul>	
<p>Thoracic vertebrae (T1-T12)</p> <ul style="list-style-type: none"> <li>• Facets (on transverse processes, T1-T10) [for tubercle of rib]</li> <li>• Facets / Demifacets (on body, T1-T12 ) [for head of rib]</li> </ul>	

<p>Ribs</p> <ul style="list-style-type: none"><li>• Fixed ribs (1-10)</li><li>• Floating ribs (11-12)</li><li>• Tuberculum (Tubercle) (ribs 1-10)</li><li>• Capitulum (Head) (ribs 1-12)</li></ul>	
<p>Sternum</p> <ul style="list-style-type: none"><li>• Manubrium</li><li>• Body</li><li>• Xiphoid process</li></ul>	
<p>Lumbar vertebrae (L1-L5)</p>	
<p>Sacrum and Coccyx</p> <ul style="list-style-type: none"><li>• Sacral canal</li><li>• Sacral foramen</li></ul>	

# 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** - depression 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

## Pectoral girdle

<p>Clavicle</p> <ul style="list-style-type: none"><li>• Sternal end</li><li>• Acromial end</li></ul>	
<p>Scapula</p> <ul style="list-style-type: none"><li>• Superior border</li><li>• Glenoid fossa (cavity)</li><li>• Coracoid process</li><li>• Acromial process</li><li>• Scapular spine</li></ul>	

## Arm

<p>Humerus</p> <ul style="list-style-type: none"> <li>• Head</li> <li>• Deltoid tuberosity</li> <li>• Trochlea</li> <li>• Capitulum</li> <li>• Coronoid fossa</li> <li>• Olecranon fossa</li> </ul>	
<p>Ulna</p> <ul style="list-style-type: none"> <li>• Trochlear notch</li> <li>• Olecranon</li> <li>• Coronoid process</li> <li>• Head of ulna</li> <li>• Styloid process of ulna</li> </ul>	
<p>Radius</p> <ul style="list-style-type: none"> <li>• Head of radius</li> <li>• Radial tuberosity</li> <li>• Styloid process of radius</li> </ul>	

## Wrist and Hand

<p>Carpus</p> <ul style="list-style-type: none"><li>• Lunate</li><li>• Scaphoid</li></ul>	
<p>Hand</p> <ul style="list-style-type: none"><li>• Metacarpals - 1 thru 5</li><li>• Phalanges - 1 thru 5</li><li>• fingers - Digits<ul style="list-style-type: none"><li>○ Proximal, Middle, and Distal Phalanges</li></ul></li><li>• thumb - Pollex<ul style="list-style-type: none"><li>○ Proximal and Distal Phalanges</li></ul></li></ul>	

# Lower Appendicular Skeleton - Laboratory

## Coxa

Ilium <ul style="list-style-type: none"><li>• Anterior inferior iliac spine</li><li>• Anterior superior iliac spine</li><li>• Iliac crest</li><li>• Posterior superior iliac spine</li><li>• Posterior inferior iliac spine</li><li>• Greater sciatic notch</li></ul>	
Ischium <ul style="list-style-type: none"><li>• Ischial spine</li><li>• Lesser sciatic notch</li><li>• Ischial tuberosity</li><li>• Ischial ramus</li></ul>	
Pubis <ul style="list-style-type: none"><li>• Inferior ramus</li><li>• Pubic body</li><li>• Pubic Symphysis</li><li>• Superior ramus</li></ul>	

<p>Coxa</p> <ul style="list-style-type: none"><li>• Acetabulum</li><li>• Obturator foramen</li><li>• Sacroiliac joint</li></ul>	
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## Leg

<p>Femur</p> <ul style="list-style-type: none"><li>• Head</li><li>• Greater trochanter</li><li>• Lesser trochanter</li><li>• Gluteal tuberosity (tubercle)</li><li>• Linea aspera</li><li>• Lateral condyle</li><li>• Medial condyle</li><li>• Intercondylar fossa</li></ul>	
<p>Patella</p>	
<p>Tibia</p> <ul style="list-style-type: none"><li>• Lateral condyle</li><li>• Medial condyle</li><li>• Intercondylar eminence</li><li>• Tibial tuberosity</li><li>• Anterior crest</li><li>• Medial malleolus</li></ul>	

<p>Fibula</p> <ul style="list-style-type: none"><li>• Head of fibula</li><li>• Lateral malleolus</li></ul>	
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## **Ankle and Foot**

<p>Tarsus</p> <ul style="list-style-type: none"><li>• Talus</li><li>• Calcaneus</li></ul>	
<p>Foot</p> <ul style="list-style-type: none"><li>• Metatarsals - 1 thru 5</li><li>• Phalanges - 1 thru 5</li><li>• Little toes - Digits<ul style="list-style-type: none"><li>○ Proximal, Middle, and Distal Phalanges</li></ul></li><li>• big toe - Hallux<ul style="list-style-type: none"><li>○ Proximal and Distal Phalanges</li></ul></li></ul>	

# Muscle Tissues

## General Function and Anatomical Features

- cells are specialized to contract
- cells vary from ribbon to spindle shaped
- tissue is vascular
- connected between bones, in heart, in vessels, airways, intestines

## 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 single nuclei
- 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 single nuclei
- 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

## Organization of skeletal muscles

### Epimysium

- dense irregular (fibrous) connective tissue arising from Tendons that surrounds skeletal muscles

### Fascicles

- within the skeletal muscle the skeletal muscle cells are organized as bundles

### Perimysium

- the fascicles are surrounded by a dense irregular (fibrous) connective tissue

### Endomysium

- the individual skeletal muscle cells are surrounded by a dense irregular (fibrous) connective tissue
- Intrafusal Muscle Cells are attached in parallel to groups of one or more skeletal muscle cells by the endomysium

## Organization of individual muscle cells (muscle fibers)

Sarcolemma - a cell membrane surrounds the muscle cell

### Motor End Plate

- the sarcolemma contains specialized regions for receiving signals from neurons

Sarcoplasm - the cell contains cytoplasm

### Myofibrils

- much of the interior of a muscle cell is composed of bundles of protein fibers arranged in parallel
- each Myofibril is composed of bundles of many and alternating myofilaments
  - thin filaments (the protein Actin)
  - thick filaments (the protein Myosin)

### Sarcoplasmic reticulum

- a structure similar to the endoplasmic reticulum 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 form functional units for muscle shortening

## Organization of Sarcomeres (In a longitudinal view:)

A-band - the thick filaments (Myosin) are visible

I-band - the thin filaments (Actin) are visible

M-line - the junction between adjacent thick filaments (myosin)

Z-line - the junction between adjacent thin filaments (actin)

Zone of overlap - the region where thick filaments (myosin) and thin filaments (actin) overlap is visible

# Skeletal Muscle Tissue - Laboratory

## Model of Skeletal Muscle

<p>Cable</p> <ul style="list-style-type: none"><li>• Epimysium</li><li>• Fascicles</li><li>• Perimysium</li><li>• Endomysium</li></ul>	
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## Models of Skeletal Muscle Cell

<p>Muscle Cell in cross section</p> <ul style="list-style-type: none"><li>• Sarcolemma</li><li>• Motor End Plate</li><li>• Sarcoplasm</li></ul>	
<p>Myofibrils in longitudinal section</p> <ul style="list-style-type: none"><li>• thin filaments (the protein Actin)</li><li>• thick filaments (the protein Myosin)</li><li>• Sarcoplasmic reticulum</li><li>• Transverse Tubules</li><li>• Sarcomeres</li><li>• A-band</li><li>• I-band</li><li>• M-line</li><li>• Z-line</li><li>• Zone of overlap</li></ul>	

## Histology of Skeletal Muscle

<p>Skeletal Muscle in cross section</p> <ul style="list-style-type: none"><li>• Epimysium</li><li>• Fascicles</li><li>• Perimysium</li><li>• Endomysium</li></ul>	
<p>Skeletal Muscle in longitudinal section</p> <ul style="list-style-type: none"><li>• thin filaments (the protein Actin)</li><li>• thick filaments (the protein Myosin)</li></ul>	
<p>Neuromuscular Junction</p> <ul style="list-style-type: none"><li>• Motor End Plate</li><li>• Axon Terminals</li></ul>	

# Muscular Organization

## 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

<b>Muscles of Facial Expression</b>			
<i>Action</i>	<i>Muscle</i>	<i>Origin</i>	<i>Insertion</i>
<b><i>Scalp</i></b>			
Raise eyebrow	Frontalis	aponeurosis	eyebrow
Tense scalp	Occipitalis	occipital	aponeurosis
<b><i>Eye</i></b>			
Close eyes	Orbicularis oculi	medial orbit	eyelids
<b><i>Mouth</i></b>			
Compress 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
Mouth back, up	Zygomaticus	zygomatic	angle of mouth

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

<b>Muscles of the Spine and Trunk</b>			
<i>Action</i>	<i>Muscle</i>	<i>Origin</i>	<i>Insertion</i>
<i>Muscles of the Spine</i>			
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
<i>Oblique and Rectus Muscles</i>			
Elevate ribs, expand ribcage	Scalene	c vertebrae	1-2 ribs
	Ext. Intercostals	inferior ribs	superior ribs
Contract ribcage	Int. Intercostals	superior ribs	inferior ribs
Depress ribs, Flex waist	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

# Head and Trunk Muscles - Laboratory

## Muscles of Facial Expression

### Scalp and Eye

<p>Elevate Eyebrow</p> <ul style="list-style-type: none"> <li>• Frontalis</li> </ul> <p>Tense Scalp</p> <ul style="list-style-type: none"> <li>• Occipitalis</li> </ul> <p>Close Eye</p> <ul style="list-style-type: none"> <li>• Orbicularis oculi</li> </ul>	
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### Mouth

<p>Close Mouth</p> <ul style="list-style-type: none"> <li>• Orbicularis Oris</li> </ul> <p>Elevate Lips</p> <ul style="list-style-type: none"> <li>• Levator Labii</li> </ul> <p>Depress Lips</p> <ul style="list-style-type: none"> <li>• Depressor Labii</li> </ul> <p>Protrude Lips</p> <ul style="list-style-type: none"> <li>• Mentalis</li> </ul> <p>Compress Cheeks</p> <ul style="list-style-type: none"> <li>• Buccinator</li> </ul> <p>Smile</p> <ul style="list-style-type: none"> <li>• Zygomaticus</li> </ul>	
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## Muscles of Chewing and Swallowing

### Muscles of Mastication

Elevate Jaw <ul style="list-style-type: none"><li>• Temporalis</li><li>• Masseter</li></ul> Compress Cheek <ul style="list-style-type: none"><li>• Buccinator</li></ul>	
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### Muscles of the Tongue

Depress Tongue <ul style="list-style-type: none"><li>• Genioglossus</li></ul>	
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### Extrinsic Muscles of the Larynx

Elevate Larynx <ul style="list-style-type: none"><li>• Digastricus</li><li>• Stylohyoid</li></ul> Depress Larynx <ul style="list-style-type: none"><li>• Omohyoid</li></ul>	
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## Muscles of the Spine and Trunk

### Muscles of the Spine

<p>Flex Head/Neck</p> <ul style="list-style-type: none"> <li>• Sternocleidomastoid</li> </ul> <p>Extend Head/Neck</p> <ul style="list-style-type: none"> <li>• Semispinalis capitis</li> <li>• Splenius capitis</li> </ul> <p>Flex Back</p> <ul style="list-style-type: none"> <li>• Quadratus Lumborum</li> </ul> <p>Extend Back</p> <ul style="list-style-type: none"> <li>• Spinalis</li> <li>• Longissimus</li> <li>• Iliocostalis Lumborum</li> </ul>	
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### Oblique and Rectus Muscles

<p>Elevate Ribs</p> <ul style="list-style-type: none"> <li>• Scalene</li> </ul> <p>Compress Ribcage</p> <ul style="list-style-type: none"> <li>• Ext. Intercostals</li> </ul> <p>Expand Ribcage</p> <ul style="list-style-type: none"> <li>• Int. Intercostals</li> </ul> <p>Depress Ribs</p> <ul style="list-style-type: none"> <li>• Rectus Abdominus</li> </ul> <p>Compress Abdomen</p> <ul style="list-style-type: none"> <li>• External Oblique</li> <li>• Internal Oblique</li> <li>• Transverse Abdominus</li> </ul> <p>Depress Diaphragm</p> <ul style="list-style-type: none"> <li>• Diaphragm Muscle</li> </ul>	
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# Muscle Contraction

## Anatomy of Sliding Filament mechanism

### Actin Chain

- Composed of wound 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 tropomyosin 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 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 sarcomere 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 leads to a depolarization that sweeps across the cell (the action potential.)
- a neurotransmitter binds to receptors on the motor end-plate and leads to 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 leads to 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)

# Upper Body Muscles

<b>Muscles of the Shoulder and Upper Arm</b>			
<i>Action</i>	<i>Muscle</i>	<i>Origin</i>	<i>Insertion</i>
<i>Muscles that move the Shoulder Girdle</i>			
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
<i>Muscles that move the Upper Arm</i>			
Abductors	Deltoid	scapula, acromion	humerus deltoid
Adductors	Pectoralis Major	ribs stern clav	humerus greater
	Latissimus Dorsi	thoracic lumbar	humerus lesser
Flexors	Pectoralis Major	ribs stern clavicle	humerus greater
Extensors	Latissimus Dorsi	thoracic lumbar	humerus lesser
	Triceps (long)	scapula	ulna, olecranon

<b>Muscles of the Lower Arm and Wrist</b>			
<i>Action</i>	<i>Muscle</i>	<i>Origin</i>	<i>Insertion</i>
<i>Muscles that move the Lower Arm</i>			
Flexors	Biceps Brachii	scapula	radius, radial
	Brachioradialis	humerus	radius, styloid
Extensors	Triceps (lat/med)	humerus	ulna, olecranon
<i>Muscles that move the Wrist</i>			
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

<b>Muscles of the Fingers</b>			
<i>Action</i>	<i>Muscle</i>	<i>Origin</i>	<i>Insertion</i>
<i>Muscles that move the Fingers</i>			
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

## Muscles of the Shoulder and Upper Arm

### Muscles that move the Shoulder Girdle (Scapula)

<p>Elevate Scapula</p> <ul style="list-style-type: none"><li>• Levator Scapulae</li><li>• Trapezius</li></ul> <p>Depress Scapula</p> <ul style="list-style-type: none"><li>• Pectoralis Minor</li></ul> <p>Abduct Scapula</p> <ul style="list-style-type: none"><li>• Serratus Anterior</li></ul> <p>Adduct Scapula</p> <ul style="list-style-type: none"><li>• Rhomboideus Major</li></ul>	
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### Muscles that move the Upper Arm (Humerus)

<p>Abduct Humerus</p> <ul style="list-style-type: none"><li>• Deltoid</li></ul> <p>Adduct Humerus</p> <ul style="list-style-type: none"><li>• Pectoralis Major</li><li>• Latissimus Dorsi</li></ul> <p>Flex Humerus</p> <ul style="list-style-type: none"><li>• Pectoralis Major</li></ul> <p>Extend Humerus</p> <ul style="list-style-type: none"><li>• Latissimus Dorsi</li><li>• Triceps (long)</li></ul>	
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## Muscles of the Lower Arm and Wrist

### Muscles that move the Lower Arm (Radius / Ulna)

<p>Flexor Radius / Ulna</p> <ul style="list-style-type: none"> <li>• Biceps Brachii</li> <li>• Brachioradialis</li> </ul> <p>Extend Radius / Ulna</p> <ul style="list-style-type: none"> <li>• Triceps (lat/med)</li> </ul>	
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### Muscles that move the wrist (Carpus)

<p>Flex Carpus</p> <ul style="list-style-type: none"> <li>• Palmaris Longus</li> <li>• Flexor Carpi Radialis</li> <li>• Flexor Carpi Ulnaris</li> </ul> <p>Extend Carpus</p> <ul style="list-style-type: none"> <li>• Extensor Carpi Radialis Longus</li> <li>• Extensor Carpi Ulnaris</li> </ul>	
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## Muscles of the Fingers and Thumb

### Muscles that move the Fingers (Digits)

<p>Flex Digits</p> <ul style="list-style-type: none"><li>• Flexor Digitorum Profundus</li><li>• Flexor Digitorum Superficialis</li></ul> <p>Extend Digits</p> <ul style="list-style-type: none"><li>• Extensor Digitorum</li></ul>	
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## Lower Body Muscles

<b>Muscles of the Hip and Thigh</b>			
<i>Action</i>	<i>Muscle</i>	<i>Origin</i>	<i>Insertion</i>
<i>Muscles that Move the Thigh</i>			
Flexors	Iliopsoas	ilium	femur
Extensors	Gluteus Maximus	ilium, crest	femur, gluteal
Abductors	Gluteus Medius	ilium, crest	femur, greater
	Tensor Fasciae Latae	ilium, crest	iliotibial
Adductors	Adductor Magnus	pubis, inferior	femur, linea
	Adductor Longus	pubis, inferior	femur, linea

<b>Muscles of the Leg and Ankle</b>			
<i>Action</i>	<i>Muscle</i>	<i>Origin</i>	<i>Insertion</i>
<i>Muscles that Move the Leg</i>			
Flexors (Hamstrings)	Biceps Femoris	ischium femur	fibula tibia
	Semitendinosus	ischium, tuber.	tibia, post.
	Semimembranosus	ischium, tuber.	tibia, post
	Gracilis	pubis ischium	tibia, med
	Sartorius	ilium, ant. inf.	tibia, med
Extensors (Quadriceps)	Rectus Femoris	ilium, ant. inf.	tibia, tuber.
	Vastus Intermedius	femur, linea dist.	tibia, tuber.
	Vastus Lateralis	femur, linea prox.	tibia, tuber.
	Vastus Medialis	femur, linea	tibia, tuber.
<i>Muscles that Move the Ankle</i>			
Dorsiflexors	Tibialis anterior	tibia, lateral	1st metatarsal
Plantar flexors	Gastrocnemius	femur	calcaneus
	Soleus	fibula tibia	calcaneus

<b>Muscles of the Toes</b>			
<i>Action</i>	<i>Muscle</i>	<i>Origin</i>	<i>Insertion</i>
<i>Muscles that Move the Little Toes</i>			
Flexors	Flexor Digitorum Longus	tibia, post. med.	2-5 phalanges
Extensors	Extensor Digitorum Longus	tibia fibula, ant.	2-5 phalanges

# Lower Body Muscles - Laboratory

## Muscles of the Hip and Thigh

### Muscle that move the Thigh (Femur)

<p>Flex Femur</p> <ul style="list-style-type: none"><li>• Iliopsoas</li></ul> <p>Extend Femur</p> <ul style="list-style-type: none"><li>• Gluteus Maximus</li></ul> <p>Abduct Femur</p> <ul style="list-style-type: none"><li>• Gluteus Medius</li><li>• Tensor Fasciae Latae</li></ul> <p>Adduct Femur</p> <ul style="list-style-type: none"><li>• Adductor Magnus</li><li>• Adductor Longus</li></ul>	
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**Muscle that move the Leg (Tibia / Fibula)**

<p>Flex Tibia / Fibula</p> <ul style="list-style-type: none"><li>• Biceps Femoris</li><li>• Semitendinosus</li><li>• Semimembranosus</li><li>• Gracilis</li><li>• Sartorius</li></ul> <p>Extend Tibia / Fibula</p> <ul style="list-style-type: none"><li>• Rectus Femoris</li><li>• Vastus Intermedius</li><li>• Vastus Lateralis</li><li>• Vastus Medialis</li></ul>	
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**Muscles that move the Ankle (Tarsus)**

<p>Dorsiflex Tarsus</p> <ul style="list-style-type: none"><li>• Tibialis anterior</li></ul> <p>Plantar Flex Tarsus</p> <ul style="list-style-type: none"><li>• Gastrocnemius</li><li>• Soleus</li></ul>	
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## Muscles of the Toes

### Muscles that move the Little Toes (Digits)

<p>Flex Digits</p> <ul style="list-style-type: none"><li>• Flexor Digitorum Longus</li></ul> <p>Extend Digits</p> <ul style="list-style-type: none"><li>• Extensor Digitorum Longus</li></ul>	
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# 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:

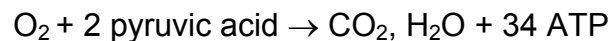


#### moderate activity in muscle

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



#### mitochondrial breakdown of pyruvic acid:



### Anaerobic metabolism

#### peak activity in muscle

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



- conversion of pyruvic acid to lactic acid (to provide NAD necessary for the breakdown of glucose to pyruvic acid)

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# Practice Questions – Skeletal and Muscular Systems

For matching questions, choices may be used more than once or not at all.

## 1-5. Matching

- |                           |                                                     |          |
|---------------------------|-----------------------------------------------------|----------|
| A) Sarcomere              | neurotransmitter sensitive portion of cell membrane | 1) _____ |
| B) Sarcolemma             | unit of Actin-Myosin-Myosin-Actin                   | 2) _____ |
| C) Sarcoplasm             | cytoplasm of muscle cell                            | 3) _____ |
| D) Motor End Plate        | muscle cell membrane                                | 4) _____ |
| E) Sarcoplasmic reticulum | stores calcium                                      | 5) _____ |

## 6-10. Matching

- |               |                                           |           |
|---------------|-------------------------------------------|-----------|
| A) Epimysium  | continues as tendons                      | 6) _____  |
| B) Fascicles  | bundles of muscle cells                   | 7) _____  |
| C) Perimysium | surrounds skeletal muscles                | 8) _____  |
| D) Endomysium | surrounds muscle fascicles                | 9) _____  |
|               | connects individual skeletal muscle cells | 10) _____ |

## 11-15. Matching

- |                      |                                  |           |
|----------------------|----------------------------------|-----------|
| A) Non-floating ribs | ribs 1- 7                        | 11) _____ |
| B) Floating ribs     | ribs 8-10                        | 12) _____ |
|                      | ribs 11-12                       | 13) _____ |
|                      | contain capitulum only           | 14) _____ |
|                      | contain capitulum and tuberculum | 15) _____ |

## 16-20. Matching

- |                       |                                                |           |
|-----------------------|------------------------------------------------|-----------|
| A) cervical vertebrae | contain transverse foramen                     | 16) _____ |
| B) thoracic vertebrae | contain articular processes                    | 17) _____ |
| C) lumbar vertebrae   | contain transverse processes                   | 18) _____ |
| D) all of the above   | contain facets or demifacets on bodies         | 19) _____ |
|                       | have large bodies with stout spinous processes | 20) _____ |

## 21-25. Matching

- |                                      |                                        |           |
|--------------------------------------|----------------------------------------|-----------|
| A) facet of lateral condyle of tibia | articulates with tibia                 | 21) _____ |
| B) lateral and medial malleolus      | articulates with fibula                | 22) _____ |
| C) condyles of femur                 | articulates with talus bone            | 23) _____ |
| D) glenoid fossa                     | articulates with head of humerus       | 24) _____ |
| E) acetabulum                        | articulates with the head of the femur | 25) _____ |

## 26-30. Matching

- |                      |                                    |           |
|----------------------|------------------------------------|-----------|
| A) radius            | articulates with the scaphoid bone | 26) _____ |
| B) ulna              | articulates with the lunate bone   | 27) _____ |
| C) none of the above | articulates with the capitulum     | 28) _____ |
|                      | articulates with the trochlea      | 29) _____ |
|                      | contains the radial notch          | 30) _____ |

31-35. Matching

- A) depress ribs
- B) elevate ribs
- C) compress abdomen
- D) none of these

- External Intercostals 31) \_\_\_\_\_
- Internal Intercostals 32) \_\_\_\_\_
- Internal Oblique 33) \_\_\_\_\_
- Splenius Capitis 34) \_\_\_\_\_
- Scalene 35) \_\_\_\_\_

36-40. Matching

- A) flex head
- B) flex waist
- C) elevate jaw
- D) extend head
- E) none of these

- sternocleidomastoid 36) \_\_\_\_\_
- semispinalis capitis 37) \_\_\_\_\_
- rectus abdominus 38) \_\_\_\_\_
- masseter 39) \_\_\_\_\_
- splenius 40) \_\_\_\_\_

41-45. Matching

- A) abduct shoulder (scapula)
- B) adduct shoulder (scapula)
- C) depress shoulder (scapula)
- D) elevate shoulder (scapula)
- E) none of these (scapula)

- Levator Scapulae 41) \_\_\_\_\_
- Latissimus dorsi 42) \_\_\_\_\_
- Pectoralis Minor 43) \_\_\_\_\_
- Rhomboideus Major 44) \_\_\_\_\_
- Serratus Anterior 45) \_\_\_\_\_

46-50. Matching

- A) extend wrist
- B) flex wrist
- C) extend lower arm
- D) flex lower arm
- E) none of these

- Extensor Carpi Radialis Longus 46) \_\_\_\_\_
- Extensor Digitorum Ulnaris 47) \_\_\_\_\_
- Flexor Carpi Ulnaris 48) \_\_\_\_\_
- Palmaris Longus 49) \_\_\_\_\_
- Brachioradialis 50) \_\_\_\_\_

51-55. 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 51) \_\_\_\_\_
- Pectoralis Major 52) \_\_\_\_\_
- Biceps Femoris 53) \_\_\_\_\_
- Rectus Femoris 54) \_\_\_\_\_
- Deltoid 55) \_\_\_\_\_

56-60. Matching

- A) plantar flex foot
- B) dorsiflex foot
- C) none of these

- Soleus 56) \_\_\_\_\_
- Gastrocnemius 57) \_\_\_\_\_
- Rectus Femoris 58) \_\_\_\_\_
- Tibialis Anterior 59) \_\_\_\_\_
- Extensor Digitorum Longus 60) \_\_\_\_\_

61-65. Matching

- A) extend thigh
- B) flex thigh
- C) abduct thigh
- D) adduct thigh

- Tensor Facia Latae 61) \_\_\_\_\_
- Gluteus Maximus 62) \_\_\_\_\_
- Gluteus Medius 63) \_\_\_\_\_
- Iliopsoas 64) \_\_\_\_\_
- Gracilis 65) \_\_\_\_\_

66-70. Matching

- |                      |                                        |           |
|----------------------|----------------------------------------|-----------|
| A) cervical vertebra | contain facets for ribs                | 66) _____ |
| B) thoracic vertebra | contain vertebral foramen              | 67) _____ |
| C) lumbar vertebra   | contain spinous processes              | 68) _____ |
| D) all of these      | contain transverse foramen             | 69) _____ |
|                      | contain intervertebral foramen (notch) | 70) _____ |

71-75. Matching

- |                      |                                                             |           |
|----------------------|-------------------------------------------------------------|-----------|
| A) ribs 1-10         | are called the floating ribs                                | 71) _____ |
| B) ribs 11 and 12    | contain head <u>and</u> tubercle                            | 72) _____ |
| C) none of the above | contain head and <u>no</u> tubercle                         | 73) _____ |
|                      | connect to the vertebrae only at the bodies                 | 74) _____ |
|                      | connect to vertebrae at the bodies and transverse processes | 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) obturator foramen | connects with the sacrum               | 90) _____ |

91-95. Matching

- |                                          |                                   |           |
|------------------------------------------|-----------------------------------|-----------|
| A) underside of lateral condyle 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) _____ |

96-100. Matching

- |                                   |                       |            |
|-----------------------------------|-----------------------|------------|
| A) elevate larynx                 | External Intercostals | 96) _____  |
| B) depress larynx                 | Internal Intercostals | 97) _____  |
| C) elevate ribs / expand ribcage  | Stylohyoid            | 98) _____  |
| D) depress ribs /contract ribcage | Omohyoid              | 99) _____  |
|                                   | Scalenes              | 100) _____ |

101-105. Matching

- |                     |                  |      |       |
|---------------------|------------------|------|-------|
| A) elevate mandible | Masseter         | 101) | _____ |
| B) compress cheeks  | Buccinator       | 102) | _____ |
| C) depress tongue   | Temporalis       | 103) | _____ |
| D) compress lips    | Genioglossus     | 104) | _____ |
| E) none of these    | Orbicularis Oris | 105) | _____ |

106-110. Matching

- |                               |                                      |      |       |
|-------------------------------|--------------------------------------|------|-------|
| A) abduct upper arm (humerus) | Deltoid                              | 106) | _____ |
| B) adduct upper arm (humerus) | Gluteus Medius                       | 107) | _____ |
| C) abduct thigh (femur)       | Adductor Magnus                      | 108) | _____ |
| D) adduct thigh (femur)       | Tensor Facia Latae                   | 109) | _____ |
| E) none of the above          | Lattissimus Dorsi / Pectoralis Major | 110) | _____ |

111-115. Matching

- |                             |                 |      |       |
|-----------------------------|-----------------|------|-------|
| A) flex thigh (femur)       | Gluteus Maximus | 111) | _____ |
| B) extend thigh (femur)     | Semitendinosus  | 112) | _____ |
| C) flex lower leg (tibia)   | Rectus Femoris  | 113) | _____ |
| D) extend lower leg (tibia) | Biceps Femoris  | 114) | _____ |
| E) none of the above        | Iliopsoas       | 115) | _____ |

116-120. Matching

- |                      |                                                    |      |       |
|----------------------|----------------------------------------------------|------|-------|
| A) origin            | a muscle that opposes the action of another muscle | 116) | _____ |
| B) agonist           | a muscle primarily responsible for a movement      | 117) | _____ |
| C) insertion         | the end of a muscle that acts as the anchor        | 118) | _____ |
| D) antagonist        | the end of the muscle that usually moves           | 119) | _____ |
| E) none of the above | the humerus is the _____ for the deltoid           | 120) | _____ |

121-125. Matching

- |                         |                                                 |      |       |
|-------------------------|-------------------------------------------------|------|-------|
| A) actin                | contains binding sites that act break apart ATP | 121) | _____ |
| B) myosin               | contains binding sites for myosin               | 122) | _____ |
| C) troponin-tropomyosin | is short in contracted muscle                   | 123) | _____ |
| D) none of the above    | covers binding sites on actin                   | 124) | _____ |
|                         | is long in relaxed muscle                       | 125) | _____ |

126-130. Matching

- |                           |                                    |      |       |
|---------------------------|------------------------------------|------|-------|
| A) Sarcoplasmic reticulum | stores calcium                     | 126) | _____ |
| B) Sarcolemma             | muscle cell membrane               | 127) | _____ |
| C) Sarcoplasm             | cytoplasm of muscle cell           | 128) | _____ |
| D) Sarcomere              | extends from Z-line to Z-line      | 129) | _____ |
| E) A and B                | connects to the transverse tubules | 130) | _____ |

131-135. Matching

- |                    |                              |      |       |
|--------------------|------------------------------|------|-------|
| A) Z-line          | composed of myosin and actin | 131) | _____ |
| B) I-band          | composed mainly of actin     | 132) | _____ |
| C) M-line          | site for joining of myosin   | 133) | _____ |
| D) A-band          | site for joining of actin    | 134) | _____ |
| E) zone of overlap | contains much myosin         | 135) | _____ |

Short Essays

1. Describe the role of bone and hormones in the control of calcium metabolism.
2. 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.
3. Describe the mechanism allowing calcium to initiate muscle contraction. Describe how actin and myosin interact to cause contraction of muscle cells.
4. Describe the major muscles that are involved in standing up from a sitting position. Include a description of the agonists and antagonists involved.

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# **Section 3 – 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

## 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

## **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

## **Multipolar (Motor or Interneuron) Neuron structure**

### 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 away from the cell body / axon hillock
- contain neurotubules that facilitate transport within axons

Axon Collaterals - major branches of the axon

Synaptic Bulbs (knobs, boutons) - release neurotransmitters

### Dendrites

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

## **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

## 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 - insulating lipid material in the plasma membrane of Schwann cells and Oligodendrocytes

### 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

# Neurons, Glial Cells, and Nerves - Laboratory

## Models

<p>Unipolar Neuron</p> <ul style="list-style-type: none"><li>• Cell Body<ul style="list-style-type: none"><li>○ Nucleus</li><li>○ Nucleolus</li></ul></li><li>• Peripheral Axons</li><li>• Central Axons</li></ul>	
<p>Multipolar Neuron</p> <ul style="list-style-type: none"><li>• Cell Body<ul style="list-style-type: none"><li>○ Nucleus</li><li>○ Nucleolus</li></ul></li><li>• Dendrites</li><li>• Axons Hillock</li><li>• Axons</li><li>• Schwann Cells</li><li>• Myelin Sheath</li><li>• Nodes of Ranvier</li></ul>	
<p>Peripheral Nerve</p> <ul style="list-style-type: none"><li>• Perineurium</li><li>• Nerve Fascicle</li><li>• Epineurium</li><li>• Endoneurium</li><li>• Schwann Cell</li><li>• Axon</li></ul>	

# Spinal Cord and Spinal Nerves

## 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

## Spinal Cord

Cervical Region – gives rise to the Cervical Plexus

Cervical Enlargement - expanded region giving rise to Brachial Plexus

Thoracic Region - gives rise to Thoracic Spinal Nerves

Lumbar Enlargement - expanded region giving rise to Lumbar Plexus

- located inside of lower thoracic vertebrae

Sacral Region - expanded region giving rise to Sacral 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

## **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

### **Efferent (motor)**

#### Somatic

Anterior (Ventral) Horns - contain cell bodies of somatic motor neurons

Anterior (Ventral) Root - axons of somatic motor neurons

#### Autonomic

Lateral horns - contain cell bodies of autonomic motor neurons

Anterior (Ventral) Root - axons of autonomic preganglionic motor neurons

## **Ganglia and Nuclei**

Ganglia – groups of neuron cell bodies in the Peripheral Nervous System

Nuclei – groups of neuron cell bodies in the Central Nervous System

# Spinal Cord, Spinal Neurons – Laboratory

## Models and Specimens

<p>Spinal Cord (longitudinal)</p> <ul style="list-style-type: none"><li>• Cervical Enlargement</li><li>• Thoracic Region</li><li>• Lumbar Enlargement</li><li>• Sacral Region</li><li>• Conus Medullaris</li><li>• Filum Terminale</li><li>• Cauda Equina</li><li>• Anterior Median Fissure</li></ul>	
<p>Spinal Nerve Plexi and Nerves</p> <ul style="list-style-type: none"><li>• Cervical Plexus (C1-C5)<ul style="list-style-type: none"><li>◦ Phrenic Nerve</li></ul></li><li>• Brachial Plexus (C5-T1)</li><li>• Thoracic Spinal Nerves (T1-T12)</li><li>• Lumbar Plexus (T12-L4)<ul style="list-style-type: none"><li>◦ Femoral Nerve</li></ul></li><li>• Sacral Plexus (L4-S4)<ul style="list-style-type: none"><li>◦ Sciatic Nerve</li></ul></li></ul>	
<p>Spinal Cord and Meninges (cross)</p> <ul style="list-style-type: none"><li>• Dura Mater</li><li>• Epidural Space</li><li>• Subdural Space</li><li>• Arachnoid</li><li>• Pia Mater</li><li>• Denticulate Ligaments</li><li>• Central Canal</li></ul>	

<p>Spinal Cord</p> <ul style="list-style-type: none"> <li>• Spinal Commissure</li> <li>• Central Canal</li> <li>• Anterior Horns</li> <li>• Anterior Root</li> <li>• Posterior Horns</li> <li>• Posterior I Root</li> <li>• Posterior Root Ganglia</li> <li>• Anterior Columns</li> <li>• Lateral Columns</li> <li>• Posterior Columns (Axons)</li> </ul>	
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## Histology of the Spinal Cord

<p>Spinal Meninges</p> <ul style="list-style-type: none"> <li>• Anterior Median Fissure</li> <li>• Dura Mater</li> <li>• Subdural Space</li> <li>• Arachnoid</li> <li>• Subarachnoid Space (Interstitial Space)</li> <li>• Pia Mater</li> </ul>	
<p>Spinal Cord</p> <ul style="list-style-type: none"> <li>• Spinal Commissure</li> <li>• Central Canal</li> <li>• Anterior Horns</li> <li>• Anterior Root</li> <li>• Posterior Horns</li> <li>• Posterior I Root</li> <li>• Posterior Root Ganglia</li> <li>• Anterior Columns</li> <li>• Lateral Columns</li> <li>• Posterior Columns (Axons)</li> </ul>	

# 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 decrease 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

### Synaptic communication at the neuromuscular junction

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, arachnoid and pia mater

Dural Sinuses - act as veins

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

## Models and Specimens of Cranial Meninges and Ventricles

<p>Cranial meninges</p> <ul style="list-style-type: none"><li>• Dura Mater</li><li>• Dural Sinuses</li><li>• Falx Cerebri</li><li>• Tentorium Cerebelli</li></ul>	
<p>Ventricles</p> <ul style="list-style-type: none"><li>• Septum Pellucidum</li><li>• Lateral Ventricles</li><li>• Interventricular Foramen</li><li>• Third Ventricle</li><li>• Midbrain Aqueduct (Cerebral Aqueduct)</li><li>• Fourth Ventricle<ul style="list-style-type: none"><li>○ Choroid Plexus</li></ul></li></ul>	

## Models and Specimens of Cerebellar Cortex

<p>Cerebellar Cortex</p> <ul style="list-style-type: none"><li>• Anterior Lobe</li><li>• Posterior Lobe</li></ul>	
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## Models and Specimens of Cerebral Cortex

<p>Fissures and Sulci</p> <ul style="list-style-type: none"><li>• Longitudinal Fissure</li><li>• Central Sulcus</li><li>• Parieto-occipital Sulcus</li><li>• Lateral Sulcus</li></ul>	
<p>Frontal Lobe</p> <ul style="list-style-type: none"><li>• Precentral Gyrus (Primary Motor Cortex)</li><li>• Pre-Frontal Cortex</li></ul>	

<p>Parietal Lobe</p> <ul style="list-style-type: none"><li>• Postcentral Gyrus (Primary Somatosensory Cortex)</li><li>• Posterior Parietal Cortex</li><li>• Sensory Association Cortex</li></ul>	
<p>Occipital Lobe</p> <ul style="list-style-type: none"><li>• Visual Cortex</li></ul>	
<p>Temporal Lobe</p> <ul style="list-style-type: none"><li>• Primary Auditory Cortex</li><li>• Insular Cortex</li><li>• Parahippocampal Gyrus</li></ul>	

# 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, Brainstem and Subcortical Structures - Laboratory

## Models and Specimens of Cranial Nerves

<p>Cranial Nerves I through VI</p> <ul style="list-style-type: none"> <li>• Olfactory nerve (I)</li> <li>• Optic nerve (II)</li> <li>• Oculomotor nerve (III)</li> <li>• Trochlear nerve (IV)</li> <li>• Trigeminal nerve (V)</li> <li>• Abducens nerve (VI)</li> </ul>	
<p>Cranial Nerves VII through XII</p> <ul style="list-style-type: none"> <li>• Facial nerve (VII)</li> <li>• Vestibulocochlear nerve (VIII)</li> <li>• Glossopharyngeal nerve (IX)</li> <li>• Vagus nerve (X)</li> <li>• Spinal Accessory nerve (XI)</li> <li>• Hypoglossal nerve (XII)</li> </ul>	

## Models and Specimens of Brainstem

<p>Medulla Oblongata</p> <ul style="list-style-type: none"> <li>• Medullary Pyramid</li> </ul>	
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Pons	
Midbrain (Mesencephalon) <ul style="list-style-type: none"><li>• Cerebral Peduncles</li><li>• Colliculi</li></ul>	
Hypothalamus <ul style="list-style-type: none"><li>• Optic Chiasm</li><li>• Pituitary Gland</li></ul>	
Thalamus <ul style="list-style-type: none"><li>• Pineal Gland</li><li>• Thalamus</li></ul>	

## Models and Specimens of Subcortical and Limbic Structures

<p>Subcortical</p> <ul style="list-style-type: none"><li>• Corpus Callosum</li><li>• Basal Nuclei (ganglia)</li></ul>	
<p>Limbic</p> <ul style="list-style-type: none"><li>• Hippocampus</li><li>• Amygdala</li></ul>	

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# Practice Questions – Nervous System

For matching questions, choices may be used more than once or not at all.

## 1-5. Matching

- |                      |                                    |          |
|----------------------|------------------------------------|----------|
| A) motor neurons     | found in sympathetic chain ganglia | 1) _____ |
| B) sensory neurons   | commonly are multipolar neurons    | 2) _____ |
| C) none of the above | commonly are unipolar neurons      | 3) _____ |
|                      | found in dorsal root ganglia       | 4) _____ |
|                      | found in anterior horn             | 5) _____ |

## 6-10. Matching (motor neurons)

- |              |                                             |           |
|--------------|---------------------------------------------|-----------|
| A) axons     | conduct signals toward cell body            | 6) _____  |
| B) dendrites | conduct signals away from cell body         | 7) _____  |
|              | usually do not support action potentials    | 8) _____  |
|              | usually contain chemically gated channels   | 9) _____  |
|              | usually contain electrically gated channels | 10) _____ |

## 11-15. Matching

- |                                 |                                     |           |
|---------------------------------|-------------------------------------|-----------|
| A) excitatory neurotransmitters | usually open sodium channels        | 11) _____ |
| B) inhibitory neurotransmitters | make cytoplasm more positive        | 12) _____ |
|                                 | often open potassium channels       | 13) _____ |
|                                 | depolarize postsynaptic membrane    | 14) _____ |
|                                 | hyperpolarize postsynaptic membrane | 15) _____ |

## 16-20. Matching

- |                                |                                       |           |
|--------------------------------|---------------------------------------|-----------|
| A) mechanically gated channels | found in axon hillock                 | 16) _____ |
| B) chemically gated channels   | found in postsynaptic membranes       | 17) _____ |
| C) electrically gated channels | found in muscle spindle receptors     | 18) _____ |
|                                | found in taste and smell receptors    | 19) _____ |
|                                | found in dendrites of sensory neurons | 20) _____ |

## 21-25. Matching

- |                             |                         |           |
|-----------------------------|-------------------------|-----------|
| A) acetylcholine            | opens chloride channels | 21) _____ |
| B) acetylcholinesterase     | excites skeletal muscle | 22) _____ |
| C) gamma amino butyric acid | destroys acetylcholine  | 23) _____ |
| D) none of the above        | often excites neurons   | 24) _____ |
|                             | inhibits neurons        | 25) _____ |

## 26-30. Matching (during the resting period)

- |                                         |                 |           |
|-----------------------------------------|-----------------|-----------|
| A) higher inside than outside of neuron | sodium ions     | 26) _____ |
| B) higher outside than inside of neuron | calcium ions    | 27) _____ |
|                                         | chloride ions   | 28) _____ |
|                                         | potassium ions  | 29) _____ |
|                                         | positive charge | 30) _____ |

31-35. Matching

- |                              |                                     |
|------------------------------|-------------------------------------|
| A) peripheral nervous system | brain stem 31) _____                |
| B) central nervous system    | spinal cord 32) _____               |
|                              | sacral plexus 33) _____             |
|                              | dorsal root ganglion 34) _____      |
|                              | sympathetic chain ganglia 35) _____ |

36-40. Matching

- |               |                                                        |
|---------------|--------------------------------------------------------|
| A) somatic    | refers to integumentary and muscular systems 36) _____ |
| B) efferent   | refers to outside of the dorsal body cavity 37) _____  |
| C) afferent   | refers to visceral (internal) organ systems 38) _____  |
| D) peripheral | refers to incoming or sensory signals 39) _____        |
| E) autonomic  | refers to outgoing or motor signals 40) _____          |

41-45. Matching

- |                            |                                                   |
|----------------------------|---------------------------------------------------|
| A) anterior horn           | contains cell bodies of sensory neurons 41) _____ |
| B) anterior root           | contains cell bodies of motor neurons 42) _____   |
| C) posterior horn          | contains axons of sensory neurons 43) _____       |
| D) posterior root          | dorsal gray matter of spinal cord 44) _____       |
| E) posterior root ganglion | contains axons of motor neurons 45) _____         |

46-50. Matching

- |                    |                                                        |
|--------------------|--------------------------------------------------------|
| A) thalamus        | integrate sensory and motor cortical signals 46) _____ |
| B) cerebellum      | connection between right and left cerebrum 47) _____   |
| C) basal nuclei    | monitors and times contraction of muscles 48) _____    |
| D) choroid plexus  | produces cerebrospinal fluid 49) _____                 |
| E) corpus callosum | selects sensory information 50) _____                  |

51-55. Matching

- |                      |                                                      |
|----------------------|------------------------------------------------------|
| A) postcentral gyrus | location of the visual cortex 51) _____              |
| B) precentral gyrus  | involved in acting out of emotions 52) _____         |
| C) occipital cortex  | location of the primary motor cortex 53) _____       |
| D) parietal lobe     | location of the primary sensory cortex 54) _____     |
| E) frontal lobe      | location of the sensory association cortex 55) _____ |

56-60. Matching

- |                           |                                               |
|---------------------------|-----------------------------------------------|
| A) facial nerve           | branch passes through foramen ovale 56) _____ |
| B) trigeminal nerve       | sensory for posterior tongue 57) _____        |
| C) hypoglossal nerve      | sensory for anterior tongue 58) _____         |
| D) glossopharyngeal nerve | motor for chewing 59) _____                   |
|                           | motor for tongue 60) _____                    |

61-65. Matching

- |                            |                                                      |
|----------------------------|------------------------------------------------------|
| A) vagus                   | sensory and motor for many visceral organs 61) _____ |
| B) trochlear nerve         | motor to superior oblique eye muscles 62) _____      |
| C) oculomotor nerve        | motor to 3 of 4 rectus eye muscles 63) _____         |
| D) glossopharyngeal        | sensory from carotid arteries 64) _____              |
| E) vestibulocochlear nerve | sensory from inner ear 65) _____                     |

66-70. Matching

- |                              |                         |           |
|------------------------------|-------------------------|-----------|
| A) central nervous system    | posterior root ganglion | 66) _____ |
| B) peripheral nervous system | muscle receptor         | 67) _____ |
|                              | spinal nerves           | 68) _____ |
|                              | spinal cord             | 69) _____ |
|                              | brain                   | 70) _____ |

71-75. Matching

- |                 |                                                                                |           |
|-----------------|--------------------------------------------------------------------------------|-----------|
| A) axon         | region of neuron responsible for receiving incoming signals                    | 71) _____ |
| B) dendrite     | region of neuron responsible for conducting action potentials                  | 72) _____ |
| C) axon hillock | region of neuron responsible for integrating <u>incoming</u> signals           | 73) _____ |
|                 | extends from sensory receptor to synaptic bulb of the same neuron              | 74) _____ |
|                 | region of neuron responsible for initiating action potentials in motor neurons | 75) _____ |

76-80. Matching

- |                                            |                                    |           |
|--------------------------------------------|------------------------------------|-----------|
| A) voltage gated Na <sup>+</sup> channels  | found in axon                      | 76) _____ |
| B) chemical gated Na <sup>+</sup> channels | found in axon hillock              | 77) _____ |
| C) A and B                                 | found in motor end plates          | 78) _____ |
| D) none of the above                       | found in dendrites and cell bodies | 79) _____ |
|                                            | found in post-synaptic membranes   | 80) _____ |

81-85. Matching

- |                          |                               |           |
|--------------------------|-------------------------------|-----------|
| A) postsynaptic membrane | located on dendrites          | 81) _____ |
| B) presynaptic membrane  | located on cell bodies        | 82) _____ |
| C) none of the above     | located on synaptic bulbs     | 83) _____ |
|                          | releases neurotransmitters    | 84) _____ |
|                          | responds to neurotransmitters | 85) _____ |

86-90. Matching

- |                     |                                                          |           |
|---------------------|----------------------------------------------------------|-----------|
| A) peripheral axons | are often very long                                      | 86) _____ |
| B) central axons    | are often quite short                                    | 87) _____ |
| C) A and B          | extend from the ventral horn to skeletal muscles         | 88) _____ |
|                     | extend from the dorsal root ganglia into the spinal cord | 89) _____ |
|                     | extend from sensory receptors to the dorsal root ganglia | 90) _____ |

91-95. Place in the order that signals will pass into, through and out of the spinal cord.

- |                            |           |
|----------------------------|-----------|
| A) anterior root           | 91) _____ |
| B) anterior horn           | 92) _____ |
| C) posterior root          | 93) _____ |
| D) posterior horn          | 94) _____ |
| E) posterior root ganglion | 95) _____ |

96-100. Place in the order that signals will pass into, through and out of a motor neuron.

- |                   |            |
|-------------------|------------|
| A) axon           | 96) _____  |
| B) cell body      | 97) _____  |
| C) dendrites      | 98) _____  |
| D) axon hillock   | 99) _____  |
| E) synaptic bulbs | 100) _____ |

101-105. Matching

- |                      |                                                   |            |
|----------------------|---------------------------------------------------|------------|
| A) Myelin            | fibrous connective tissue around bundles of axons | 101) _____ |
| B) Epineurium        | fibrous connective tissue around Schwann cells    | 102) _____ |
| C) Perineurium       | fibrous connective tissue around a nerve          | 103) _____ |
| D) Endoneurium       | insulation around axons                           | 104) _____ |
| E) none of the above | bundles of axons                                  | 105) _____ |

106-110. Matching

- |                   |                                                            |            |
|-------------------|------------------------------------------------------------|------------|
| A) pia mater      | thick connective tissue covering the brain and spinal cord | 106) _____ |
| B) arachnoid      | attaches directly to brain and spinal cord                 | 107) _____ |
| C) dura mater     | supports numerous fine blood vessels                       | 108) _____ |
| D) epidural space | outside of spinal cord                                     | 109) _____ |
| E) subdural space | under dura mater                                           | 110) _____ |

111-115. Matching

- |                                        |                    |            |
|----------------------------------------|--------------------|------------|
| A) originates from the cervical plexus | sciatic nerve      | 111) _____ |
| B) originates from the brachial plexus | phrenic nerve      | 112) _____ |
| C) originates from the lumbar plexus   | femoral nerve      | 113) _____ |
| D) originates from the sacral plexus   | thoracic nerve     | 114) _____ |
| E) none of the above                   | nerves of the arms | 115) _____ |

116-120. Matching

- |                      |                  |            |
|----------------------|------------------|------------|
| A) cranial nerve I   | optic nerve      | 116) _____ |
| B) cranial nerve II  | trochlear nerve  | 117) _____ |
| C) cranial nerve III | olfactory nerve  | 118) _____ |
| D) cranial nerve IV  | trigeminal nerve | 119) _____ |
| E) cranial nerve V   | oculomotor nerve | 120) _____ |

121-125. Matching

- |                     |                                              |            |
|---------------------|----------------------------------------------|------------|
| A) vagus nerve      | motor, eye movement (superior oblique muscle | 121) _____ |
| B) optic nerve      | mixed sensory and motor; visceral organs     | 122) _____ |
| C) trochlear nerve  | special sensory, vision                      | 123) _____ |
| D) olfactory nerve  | special sensory, smell                       | 124) _____ |
| E) oculomotor nerve | motor, eye movement                          | 125) _____ |

126-130. Matching

- |                             |                                      |            |
|-----------------------------|--------------------------------------|------------|
| A) interventricular foramen | produces cerebrospinal fluid         | 126) _____ |
| B) spinal commissure        | connects right and left cerebrum     | 127) _____ |
| C) cerebral aqueduct        | connects third and fourth ventricle  | 128) _____ |
| D) corpus callosum          | connects third and lateral ventricle | 129) _____ |
| E) choroid plexus           | connects left and right spinal horns | 130) _____ |

131-135. Matching

- |                 |                                           |            |
|-----------------|-------------------------------------------|------------|
| A) pons         | monitors and times contraction of muscles | 131) _____ |
| B) thalamus     | carry signals to and from cerebellum      | 132) _____ |
| C) cerebellum   | critical for long term memory             | 133) _____ |
| D) hippocampus  | filters sensory information               | 134) _____ |
| E) hypothalamus | controls pituitary gland                  | 135) _____ |

136-140. Matching

- |                      |                                                |            |
|----------------------|------------------------------------------------|------------|
| A) medulla oblongata | connects to the pituitary                      | 136) _____ |
| B) hypothalamus      | is located below the 4 <sup>th</sup> ventricle | 137) _____ |
| C) midbrain          | critical for respiration and blood pressure    | 138) _____ |
| D) pons              | located between the midbrain and medulla       | 139) _____ |
| E) A and D           | is located just posterior to the hypothalamus  | 140) _____ |

141-145. Matching

- |                        |                                           |            |
|------------------------|-------------------------------------------|------------|
| A) cerebellum          | monitors and times contraction of muscles | 141) _____ |
| B) choroid plexus      | controls movement of the head             | 142) _____ |
| C) colliculi, superior | controls movement of the eyes             | 143) _____ |
| D) colliculi, inferior | produces cerebrospinal fluid              | 144) _____ |
| E) none of the above   | located in the ventricles                 | 145) _____ |

146-150. Matching

- |                   |                                                      |            |
|-------------------|------------------------------------------------------|------------|
| A) frontal lobe   | involved in making things happen (action / movement) | 146) _____ |
| B) parietal lobe  | involved in memory and emotion                       | 147) _____ |
| C) occipital lobe | contains primary visual cortex                       | 148) _____ |
| D) temporal lobe  | involved in decision making                          | 149) _____ |
| E) B and C        | receive sensory signals                              | 150) _____ |

Short Essays

1. Describe the mechanisms responsible for the conduction 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.

# **Section 4 – 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 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 Spinal organization

- Brainstem nuclei or Sacral Lateral Horns - 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
- Axons of preganglionic neurons in the brain stem or sacral spinal segments synapse on neurons in parasympathetic ganglia in the head or in visceral organs.

### 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 act on nicotinic receptors on the ganglionic neurons
- postganglionic neurons release acetylcholine which act on muscarinic receptors of the target organs

## Sympathetic Division

### Spinal organization

- Lateral Horns - contain cell bodies of sympathetic preganglionic neurons (the first motor neurons)
- Ventral Roots - carry axons of sympathetic preganglionic neurons out of spinal cord
- White rami - carry axons of sympathetic preganglionic neurons out of ventral roots and into the paravertebral ganglia
- Axons of preganglionic neurons from the thoracic and lumbar spinal segments synapse in three groups of ganglia located peripherally:

### 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, ionotropy
- 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 act on nicotinic receptors on the ganglionic neurons
- postganglionic fibers release norepinephrine which act on either alpha or beta receptors of the target organs

# Autonomic Nervous System - Laboratory

## Parasympathetic

<p>Brainstem</p> <ul style="list-style-type: none"><li>• Medulla Oblongata</li><li>• Preganglionic Neurons</li><li>• Parasympathetic Ganglia</li><li>• Ganglionic Neurons</li><li>• Acetylcholine</li></ul>	
<p>Sacral Spinal Cord</p> <ul style="list-style-type: none"><li>• Sacral Spinal Cord</li><li>• Preganglionic Neurons</li><li>• Parasympathetic Ganglia</li><li>• Ganglionic Neurons</li><li>• Acetylcholine</li></ul>	

## Sympathetic

<p>Chain Ganglia</p> <ul style="list-style-type: none"><li>• Thoracic Spinal Cord</li><li>• Preganglionic Neurons</li><li>• White Rami</li><li>• Sympathetic Chain Ganglia</li><li>• Ganglionic Neurons</li><li>• Gray Rami</li><li>• Target Organ</li><li>• Acetylcholine</li><li>• Norepinephrine</li></ul>	
<p>Celiac and Mesenteric Ganglia</p> <ul style="list-style-type: none"><li>• Thoracic Spinal Cord</li><li>• Preganglionic Neurons</li><li>• White Rami</li><li>• Splanchnic Nerves</li><li>• Sympathetic Celiac and Mesenteric Ganglia</li><li>• Ganglionic Neurons</li><li>• Acetylcholine</li><li>• Norepinephrine</li></ul>	
<p>Adrenal Medulla</p> <ul style="list-style-type: none"><li>• Thoracic Spinal Cord</li><li>• Preganglionic Neurons</li><li>• White Rami</li><li>• Splanchnic Nerves</li><li>• Adrenal Medulla</li><li>• Ganglionic Neurons</li><li>• Acetylcholine</li><li>• Norepinephrine</li></ul>	

# 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, norepinephrine
  - 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

## Models and Specimens

Head and Neck <ul style="list-style-type: none"><li>• Hypothalamus</li><li>• Pituitary</li> <li>• Thyroid</li><li>• Parathyroid</li></ul>	
Thoracic region <ul style="list-style-type: none"><li>• Heart</li></ul>	
Abdominal region <ul style="list-style-type: none"><li>• Pancreas</li><li>• Adrenal</li><li>• Kidney</li><li>• GI Tract</li></ul>	
Pelvic region <ul style="list-style-type: none"><li>• Ovaries</li><li>• Testes</li></ul>	

## Histology of Pancreas, Thyroid, Adrenal and Pituitary

<p>Pancreas</p> <ul style="list-style-type: none"><li>• Pancreatic islets<ul style="list-style-type: none"><li>○ Alpha cells</li><li>○ Beta cells</li></ul></li></ul>	
<p>Parathyroid gland</p> <ul style="list-style-type: none"><li>• Chief cells</li></ul>	
<p>Thyroid gland</p> <ul style="list-style-type: none"><li>• Interfollicular cells (C cells)</li><li>• Thyroid follicles</li><li>• Follicular cells</li><li>• Colloid</li></ul>	

<p>Adrenal gland</p> <ul style="list-style-type: none"><li>• Adrenal medulla<ul style="list-style-type: none"><li>○ Chromaffin cells</li></ul></li> <li>• Adrenal cortex<ul style="list-style-type: none"><li>○ Zona Glomerulosa</li><li>○ Zona Fascicularis</li><li>○ Zona Reticularis</li></ul></li></ul>	
<p>Pituitary gland, <i>l.s.</i></p> <ul style="list-style-type: none"><li>• Infundibulum</li><li>• Median eminence</li><li>• Posterior Pituitary<ul style="list-style-type: none"><li>○ axons</li></ul></li><li>• Anterior Pituitary<ul style="list-style-type: none"><li>○ glandular epithelial cells</li></ul></li></ul>	

# 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

<i>Stimulus</i>	<i>Source /</i>	<i>Hormone</i>	<i>Action of Adrenal Medullary Hormones</i>
Physical activity, physical stress, emotional stress	Chromaffin Cells (ganglionic neurons)	Epinephrine (water soluble) Norepinephrine (water soluble)	Varies depending on adrenergic receptors - $\alpha_1$ , $\alpha_2$ , $\beta_1$ , $\beta_2$ , $\beta_3$ (see below)

### Actions of Alpha ( $\alpha$ ) and Beta ( $\beta$ ) Adrenergic Receptor Activation

<i>Hormone</i>	<i>Receptor</i>	<i>Action of Adrenal Medullary Hormones</i>
Norepinephrine Epinephrine	$\alpha_1$ receptors or $\alpha_2$ postsynaptic receptors	act through G-protein coupled activation of phospholipase C and production of IP3 and DAG; release of Ca from the endoplasmic reticulum; activation of protein lipase C constrict blood vessels in abdominal organs, kidney, skin and genitals increase breakdown of glycogen to glucose (Glycogenolysis) in liver and skeletal muscle via $\alpha_1$ stimulate glucagon secretion by pancreas via $\alpha_1$
Norepinephrine Epinephrine	$\alpha_2$ presynaptic and some $\alpha_2$ non-synaptic receptors	act through G-protein coupled <i>inhibition</i> of adenylyl cyclase and cyclic-AMP; reduction of calcium decrease neurotransmitter release via presynaptic $\alpha_2$ inhibit insulin secretion by pancreas via non-synaptic $\alpha_2$
Epinephrine Norepinephrine	$\beta_1$ receptors	act through G-protein coupled activation of adenylyl cyclase, cyclic-AMP, and protein kinase A; increase of calcium increase heart rate and force of cardiac contraction stimulate glucagon secretion by pancreas stimulate renin secretion by kidney
Epinephrine Norepinephrine	$\beta_2$ receptors	act through G-protein coupled activation of adenylyl cyclase, cyclic-AMP, and protein kinase A; activate calcium pumps; modulate various enzymes 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	$\beta_3$ receptors	act through G-protein coupled activation of adenylyl cyclase, cyclic-AMP, and protein kinase A; modulate various enzymes increase breakdown of lipids (lipolysis) and release of fatty acids in adipose tissue

# Pancreas, Thyroid, and Kidney

## Pancreas and Actions of Pancreatic Hormones

<i>Stimulus</i>	<i>Source</i>	<i>Hormone</i>	<i>Action of Pancreatic Hormone</i>
stimulated by low blood glucose and by epinephrine; inhibited by high blood glucose and Beta cell activity	pancreatic Alpha cells	Glucagon (water soluble)	<p>act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP</p> <p>increase breakdown of glycogen to glucose (Glycogenolysis) in <u>Liver</u></p> <p>increase production of glucose (Gluconeogenesis) from amino acids in <u>Liver</u></p> <p>increase production of ketones (ketogenesis) from fatty acids in <u>Liver</u></p>
stimulated by high blood glucose; inhibited by epinephrine	pancreatic Beta cells	Insulin (water soluble)	<p>act through a membrane tyrosine kinase receptor that phosphorylates several proteins that act as insulin receptor substrates</p> <p>stimulates transport of glucose into cells in <u>Muscle</u> and <u>Adipose tissue</u> and in <u>Liver</u></p> <p>stimulates glycogen formation from glucose (Glycogenesis) in <u>Muscle</u> and <u>Liver</u></p> <p>facilitates fat storage by stimulating transport of fatty acid into and inhibiting transport of fatty acids out of <u>Adipose</u> cells</p> <p>facilitates protein storage by stimulating transport of amino acid into and inhibiting transport of amino acids out of <u>Muscle</u> cells</p>

**Thyroid Gland and Actions of Thyroid Hormones**

<i>Stimulus</i>	<i>Source</i>	<i>Hormone</i>	<i>Action</i>
stimulated by Thyrotropin (TSH)	Thyroid follicles	Tetraiodothyronin (Thyroxin or T4) (lipid soluble) Triiodothyronin (T3) (lipid soluble)	act through cytoplasmic and nuclear receptors and changes in gene expression and the transcription of mRNAs  increases Na <sup>+</sup> /K <sup>+</sup> -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 <sup>++</sup>	Thyroid Parafollicular ("C") cells	Calcitonin (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP  inhibits osteoclasts and inhibits resorption of calcium from <u>bone</u> into plasma

## Parathyroid Gland and Actions of Parathyroid Hormones

<i>Stimulus</i>	<i>Source</i>	<i>Hormone</i>	<i>Action</i>
stimulated by a fall in Extracellular $\text{Ca}^{++}$	Parathyroid Chief cells	Parathyroid hormone (water soluble)	<p>act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP</p> <p>stimulates osteoclasts and the resorption of calcium and phosphate from <u>bone</u> into plasma ?? via <del>calcitriol</del></p> <p>stimulates reabsorption of calcium by the <u>kidney</u> into plasma ?? via <del>calcitriol</del></p> <p>increases excretion of phosphate by the <u>kidney</u> into the urine ?? via <del>calcitriol</del></p> <p>stimulates production of Calcitriol by kidney, liver, and intestine</p>

## Kidney and Actions of Renal Hormones

<i>Stimulus</i>	<i>Cells / Source</i>	<i>Hormone</i>	<i>Action</i>
stimulated by norepinephrine (NE) via $\beta$ -1	JG cells	renin (water soluble)	enzymatically converts converts angiotensinogen to angiotensin I
stimulated by a fall in erythrocytes	kidney	Erythropoietin (water soluble)	<p>act through coupled "non-receptor protein tyrosine kinases."</p> <p>accelerates the differentiation of stem cells of the bone marrow into erythrocytes</p>
stimulated by Parathyroid hormone (stimulated by a fall in extracellular $\text{Ca}^{2+}$ or $\text{P}_i$ )	kidney	Calcitriol (lipid soluble)	<p>act through cytoplasmic and nuclear receptors and changes in gene expression and transcription of mRNAs</p> <p>stimulates calcium and phosphate absorption from the <u>intestinal tract</u></p> <p>stimulates resorption of calcium and phosphate from <u>bone</u> into plasma</p> <p>may decrease excretion of calcium and phosphate by the <u>kidney</u> into the urine</p>

# Pituitary Gland

## Hypothalamus and Pituitary

### Hypothalamus

- contains cell bodies of hypothalamic neurons that send axons to the posterior pituitary and/or to the median eminence

### Posterior Pituitary

- contains axons of hypothalamic neurons that produce vasopressin and oxytocin

### Median eminence

- region of hypothalamus that contains axons of hypothalamic neurons that produce hypothalamic regulatory hormones

### 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

<i>Stimulus</i>	<i>Source</i>	<i>Hormone</i>	<i>Action</i>
physical stress (dehydration, hyperosmolarity, blood loss)	Hypothalamic axons in Posterior Pituitary	Vasopressin (water soluble)	<p>V1a receptors act through G-protein coupled activation of phospholipase C and release of <math>\text{Ca}^{2+}</math> from the endoplasmic reticulum</p> <p>constricts blood vessels</p> <p>V1b receptors act through G-protein coupled activation of phospholipase C and subsequent release of <math>\text{Ca}^{2+}</math> from the endoplasmic reticulum</p> <p>stimulates corticotropin secretion from the anterior pituitary</p> <p>V2 receptors act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP</p> <p>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</p>
childbirth, suckling, sexual activity	Hypothalamic axons in Posterior Pituitary	Oxytocin (water soluble)	<p>act through G-protein coupled activation of phospholipase C and release of <math>\text{Ca}^{2+}</math> from the endoplasmic reticulum</p> <p>facilitates milk ejection from mammary glands</p> <p>stimulates uterine contraction</p> <p>alters sodium excretion by the kidney</p> <p>facilitates bonding and trust</p>

## Anterior Pituitary

Contain endocrine cells that produce pituitary hormones in response to hypothalamic hormones

### Anterior Pituitary and Actions of Anterior Pituitary hormones

<i>Stimulus</i>	<i>Source</i>	<i>Hormone</i>	<i>Action of Anterior Pituitary Hormone</i>
Thyrotropin Releasing Hormone (TRH)	Anterior Pituitary Thyrotrophs	Thyrotropin (Thyroid Stimulating Hormone) (TSH) (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP  stimulates T3 and T4 production by <u>thyroid</u> follicles
Corticotropin Releasing Hormone (CRH)	Anterior Pituitary Corticotrophs	Corticotropin (Adrenocorticotrophic Hormone) (ACTH) (water soluble)	act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP  stimulates cortisol production by <u>adrenal cortex</u>
Somatotropin Releasing Hormone (GHRH) and Inhibiting Hormone (GHIH) (Somatostatin)	Anterior Pituitary Somatotrophs	Somatotropin (Growth Hormone) (GH) (water soluble)	act through receptor coupled activation of tyrosine kinase  stimulates breakdown of fats to fatty acids (Lipolysis) in <u>Adipose tissue</u>  stimulates Insulin Like Growth Factor (IGF-1) production by <u>liver</u>  acts directly on cells to stimulate protein synthesis in muscle enhance lipolysis depress the action of insulin on glucose uptake stimulate gluconeogenesis

<p>Gonadotropin Releasing Hormone (GnRH)</p>	<p>Anterior Pituitary Gonadotrophs</p>	<p>Follicle Stimulating Hormone (FSH) (water soluble)</p>	<p>act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP</p> <p>stimulates follicle development and estrogen production by <u>ovary</u> in female;</p> <p>stimulates spermatogenesis by <u>testes</u> in male</p>
<p>Gonadotropin Releasing Hormone (GnRH)</p>	<p>Anterior Pituitary Gonadotrophs</p>	<p>Luteinizing Hormone (LH) (water soluble)</p>	<p>act through G-protein coupled activation of adenylyl cyclase and cyclic-AMP</p> <p>stimulates ovulation and progesterone production by <u>ovary</u> in female;</p> <p>stimulates testosterone production by <u>testes</u> in male</p>
<p>Prolactin Releasing Hormone (PRH) and Inhibiting Hormone (PIH)(Dopamine)</p>	<p>Anterior Pituitary Prolactotrophs</p>	<p>Prolactin (PRL) (water soluble)</p>	<p>act through receptor coupled activation of tyrosine kinase</p> <p>stimulates milk production by <u>mammary glands</u>;</p> <p>stimulates reabsorption of electrolytes by <u>kidney</u></p>

# Male Reproductive System

## 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 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 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 (Leydig Cells) - between tubules; produce testosterone

### Sertoli Cells

- attached to inner surface of tubules; maintain a blood-testis barrier, produce androgen binding globulin, secrete inhibin and estradiol

Spermatogonia - stem 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

## Models of Scrotum, Testes, and Penis

<p>Scrotum</p> <ul style="list-style-type: none"> <li>• Dartos</li> <li>• Cremaster muscle</li> </ul>	
<p>Testes</p> <ul style="list-style-type: none"> <li>• Lobules</li> <li>• Seminiferous tubules</li> <li>• Straight tubule</li> <li>• Rete testis</li> <li>• Efferent ducts</li> </ul> <p>Epididymis</p>	
<p>Spermatic Cord</p> <ul style="list-style-type: none"> <li>• Ductus Deferens</li> <li>• Testicular Artery</li> </ul>	

<p>Ductus Deferens (Vas deferens)</p> <ul style="list-style-type: none"><li>• Ampulla</li><li>• Seminal Vesicle</li><li>• Ejaculatory Duct</li><li>• Prostate Gland</li></ul>	
<p>Urethra</p> <ul style="list-style-type: none"><li>• Prostatic Urethra</li><li>• Bulbourethral Glands</li><li>• Penile Urethra</li><li>• External Urethral Meatus</li></ul>	
<p>Penis</p> <ul style="list-style-type: none"><li>• Corpus Spongiosum</li><li>• Corpora Caverosa</li><li>• Glans Penis</li></ul>	

## Histology of Seminiferous Tubules and Penis

<p>Seminiferous Tubules</p> <ul style="list-style-type: none"><li>• Interstitial Cells</li><li>• Sertoli Cells</li><li>• Spermatogonia</li><li>• Primary Spermatocytes</li><li>• Secondary Spermatocytes</li><li>• Spermatids</li><li>• Sperm</li></ul>	
<p>Penis</p> <ul style="list-style-type: none"><li>• Penile Urethra</li><li>• Corpus Spongiosum</li><li>• Corpora Cavernosa</li></ul>	

# 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

<i>Stimulus</i>	<i>Cells / Source</i>	<i>Hormone</i>	<i>Action</i>
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)	<p>act through cytoplasmic and nuclear receptors and changes in gene expression and the transcription of mRNAs</p> <p>Essential in high local concentration for spermatogenesis</p> <p>Inhibits GnRH secretion by hypothalamic neurons</p> <p>required for pubertal masculinization to occur</p> <p>increases muscle mass and body growth</p> <p>close Epiphyseal growth plate</p>

# Female Reproductive System

## Ovaries, Uterus, and Vagina

### Ovaries

#### Uterine Tubes (Fallopian tubes)

Fimbriae – 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 (Cervical Os)

#### Uterine wall

Endometrium – cuboidal epithelium intermingled with blood vessels; for implantation of the embryo

Myometrium – muscular layer

Perimetrium – fibrous connective tissue

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

## Histology of 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 meiosis 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

## Histology of 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

## Models of Ovaries, Uterus, and Vagina

Ovaries (sectioned) <ul style="list-style-type: none"><li>• Primary Oocytes</li><li>• Developing Follicle</li><li>• Mature Follicle</li><li>• Developing Corpus Luteum</li><li>• Corpus Luteum</li><li>• Corpus Albicans</li></ul>	
Ovary and Uterine (Fallopian) Tubes <ul style="list-style-type: none"><li>• Fimbriae</li><li>• Ampulla</li><li>• Isthmus</li></ul>	
Broad Ligament and ligaments <ul style="list-style-type: none"><li>• Broad Ligament</li><li>• Mesovarium</li><li>• Ovarian Ligament</li><li>• Suspensory Ligament</li><li>• Uterosacral Ligaments</li><li>• Round Ligaments</li></ul>	
Uterus <ul style="list-style-type: none"><li>• Fundus</li><li>• Body</li><li>• Isthmus</li><li>• Cervix</li><li>• External Orifice (Cervical Os)</li></ul>	

<p>Uterine wall</p> <ul style="list-style-type: none"><li>• Endometrium</li><li>• Myometrium</li><li>• Perimetrium</li></ul>	
<p>Vagina and external genitalia</p> <ul style="list-style-type: none"><li>• Vaginal Entrance</li><li>• Vaginal Canal</li><li>• Urethral Opening</li><li>• Labia Minora and Majora</li><li>• Clitoris</li></ul>	
<p>Pubic Symphysis</p> <ul style="list-style-type: none"><li>• Pubic Symphysis</li><li>• Mons Pubis</li></ul>	

## Histology of Ovary and Uterus

<p>Ovary</p> <ul style="list-style-type: none"><li>• Oocytes</li><li>• Growing follicle</li><li>• Mature follicle<ul style="list-style-type: none"><li>○ Antrum</li><li>○ Zona pellucida</li><li>○ Corona radiata</li></ul></li><li>• Corpus luteum</li><li>• Corpus albicans</li></ul>	
<p>Uterus</p> <ul style="list-style-type: none"><li>• Endometrium<ul style="list-style-type: none"><li>○ Functional zone</li><li>○ Basilar zone</li></ul></li><li>• Myometrium</li><li>• Perimetrium</li></ul>	

# 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

<i>Stimulus</i>	<i>Cells / Source</i>	<i>Hormone</i>	<i>Action</i>
stimulated by follicle stimulating hormone (FSH)	Granulosa cells surrounding the oocyte	Estradiol (lipid soluble)	<p>act through cytoplasmic and nuclear receptors and changes in gene expression and the transcription of mRNAs</p> <p>increases the endometrial thickness (3 to 5 fold)</p> <p>triggers the ovulatory surge of LH and FSH</p> <p>inhibits the GnRH neurons of the hypothalamus and stimulates the LH gonadotrophs of the pituitary</p> <p>increase receptors for Estradiol, LH and FSH</p>
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)	<p>act through cytoplasmic and nuclear receptors and changes in gene expression</p> <p>Progesterone inhibits the rapid endometrial growth and stimulates growth of glands and elongation of arteries</p> <p>Progesterone inhibits the GnRH neurons in the hypothalamus</p>
stimulated by LH and FSH	Luteal cells of the corpus luteum	Relaxin (water soluble)	<p>act through G-protein coupled activation of adeny cyclase and cyclic-AMP (at least in part)</p> <p>relaxes the cervix and softens cartilage and fibrous connective tissue</p> <p>stimulates VEGF in endometrium</p>

# 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 - Exam # 4

For matching questions, choices may be used more than once or not at all.

### 1-5. Matching

- |                      |                                      |          |
|----------------------|--------------------------------------|----------|
| A) parasympathetic   | dilates pupils                       | 1) _____ |
| B) sympathetic       | constricts pupils                    | 2) _____ |
| C) none of the above | constricts bronchi                   | 3) _____ |
|                      | increases gastrointestinal motility  | 4) _____ |
|                      | increases force of heart contraction | 5) _____ |

### 6-10. Matching

- |                      |                                                    |           |
|----------------------|----------------------------------------------------|-----------|
| A) norepinephrine    | released from the adrenal medulla                  | 6) _____  |
| B) acetylcholine     | released by sympathetic preganglionic axons        | 7) _____  |
| C) none of the above | released by sympathetic (post)ganglionic axons     | 8) _____  |
|                      | released by parasympathetic preganglionic axon     | 9) _____  |
|                      | released by parasympathetic (post)ganglionic axons | 10) _____ |

### 11-15. Matching

- |                      |                                         |           |
|----------------------|-----------------------------------------|-----------|
| A) alpha-1 receptors | lead to vasoconstriction                | 11) _____ |
| B) beta-1 receptors  | lead to bronchial dilation              | 12) _____ |
| C) beta-2 receptors  | lead to potent vasodilation             | 13) _____ |
| D) alpha cells       | lead to relaxation of smooth muscle     | 14) _____ |
|                      | lead to increased cardiac contractility | 15) _____ |

### 16-20. Matching

- |                      |                                   |           |
|----------------------|-----------------------------------|-----------|
| A) alpha-1 receptors | lead to bronchial dilation        | 16) _____ |
| B) beta-1 receptors  | lead to insulin production        | 17) _____ |
| C) beta-2 receptors  | lead to increased heart rate      | 18) _____ |
| D) alpha cells       | lead to increased cardiac force   | 19) _____ |
| E) beta cells        | lead to blood vessel constriction | 20) _____ |

### 21-25. Matching

- |                      |                                                |           |
|----------------------|------------------------------------------------|-----------|
| A) albuterol         | lead to decreased force of cardiac contraction | 21) _____ |
| B) propranolol       | lead to increased vasoconstriction             | 22) _____ |
| C) alpha-1 agonists  | lead to contraction of bladder                 | 23) _____ |
| D) none of the above | lead to increases in heart rate                | 24) _____ |
|                      | lead to bronchial dilation                     | 25) _____ |

### 26-30. Matching

- |                        |                        |           |
|------------------------|------------------------|-----------|
| A) posterior pituitary | secretes oxytocin      | 26) _____ |
| B) anterior pituitary  | produces prolactin     | 27) _____ |
|                        | produces thyrotropin   | 28) _____ |
|                        | secretes vasopressin   | 29) _____ |
|                        | produces corticotropin | 30) _____ |

31-35. Matching

- A) anterior pituitary produces growth hormone (GH) 31) \_\_\_\_\_  
B) posterior pituitary produces Luteinizing hormone (LH) 32) \_\_\_\_\_  
produces follicle stimulating hormone (FSH) 33) \_\_\_\_\_  
produces thyroid stimulating hormone (TSH) 34) \_\_\_\_\_  
produces adrenocorticotrophic hormone (ACTH) 35) \_\_\_\_\_

36-40. Matching

- A) controlled by releasing hormones prolactin 36) \_\_\_\_\_  
B) controlled by inhibiting hormone vasopressin 37) \_\_\_\_\_  
C) A and B growth hormone 38) \_\_\_\_\_  
D) none of the above Thyroid stimulating hormone 39) \_\_\_\_\_  
Adrenocorticotrophic hormone 40) \_\_\_\_\_

41-45. Matching

- A) gonadotropin releasing hormone (GnRH) stimulates LH 41) \_\_\_\_\_  
B) corticotropin releasing hormone (CRH) stimulates GH 42) \_\_\_\_\_  
C) thyrotropin releasing hormone (TRH) stimulates FSH 43) \_\_\_\_\_  
D) none of the above stimulates TSH 44) \_\_\_\_\_  
stimulates ACTH 45) \_\_\_\_\_

46-50. Place the following in the order that lead to release of anterior pituitary hormones.

- A) stimulation of anterior pituitary by hypothalamic regulatory hormones 46) \_\_\_\_\_  
B) release of hypothalamic regulatory hormones into pituitary portal vessels 47) \_\_\_\_\_  
C) transport of hypothalamic regulatory hormones into anterior pituitary 48) \_\_\_\_\_  
D) release of anterior pituitary hormone into the anterior pituitary veins 49) \_\_\_\_\_  
E) stimulation of hypothalamic neurons 50) \_\_\_\_\_

51-55. Matching

- A) hepatocytes of liver produce progesterone 51) \_\_\_\_\_  
B) luteal cells of ovary produce testosterone 52) \_\_\_\_\_  
C) alpha cells of pancreas produce glucagon 53) \_\_\_\_\_  
D) follicular cells of ovary produce estrogen 54) \_\_\_\_\_  
E) interstitial cells of testes produce bile 55) \_\_\_\_\_

56-60. Matching

- A) increases breakdown of glycogen insulin 56) \_\_\_\_\_  
B) increases formation of glycogen cortisol 57) \_\_\_\_\_  
C) none of the above glucagon 58) \_\_\_\_\_  
aldosterone 59) \_\_\_\_\_  
epinephrine 60) \_\_\_\_\_

61-65. Matching

- A) Follicle stimulating hormone stimulates ovulation 61) \_\_\_\_\_  
B) Luteinizing hormone stimulates spermatogenesis 62) \_\_\_\_\_  
stimulates follicle development 63) \_\_\_\_\_  
stimulates production of estrogen 64) \_\_\_\_\_  
stimulates production of testosterone 65) \_\_\_\_\_

66-70. Matching

- |                                   |                                         |           |
|-----------------------------------|-----------------------------------------|-----------|
| A) gonadotropin releasing hormone | luteinizing hormone                     | 66) _____ |
| B) human chorionic gonadotropin   | stimulates luteal cells                 | 67) _____ |
| C) are gonadotropins              | follicle stimulating hormone            | 68) _____ |
| D) A and B                        | stimulates luteinizing hormone          | 69) _____ |
|                                   | stimulates follicle stimulating hormone | 70) _____ |

71-75. Place in order the structures thru which sperm pass.

- |                         |           |
|-------------------------|-----------|
| A) vas deferens         | 71) _____ |
| B) prostatic urethra    | 72) _____ |
| C) ejaculatory duct     | 73) _____ |
| D) head of epididymis   | 74) _____ |
| E) seminiferous tubules | 75) _____ |

76-80. Place in order the structures thru which the 'egg' pass.

- |                               |           |
|-------------------------------|-----------|
| A) fimbrae                    | 76) _____ |
| B) ampulla                    | 77) _____ |
| C) body of uterus             | 78) _____ |
| D) isthmus of uterine tube    | 79) _____ |
| E) Graffian (mature) follicle | 80) _____ |

81-85. Matching

- |                        |                                      |           |
|------------------------|--------------------------------------|-----------|
| A) ampulla             | provides enzymes that activate sperm | 81) _____ |
| B) epididymis          | provides for nutrients for the sperm | 82) _____ |
| C) prostate gland      | site for maturation of sperm         | 83) _____ |
| D) seminal vesicle     | produces a lubricating fluid         | 84) _____ |
| E) bulbourethral gland | site for storage of sperm            | 85) _____ |

86-90. Matching

- |                        |                                                 |           |
|------------------------|-------------------------------------------------|-----------|
| A) proliferative phase | reflects regrowth of the basilar zone           | 86) _____ |
| B) secretory phase     | reflects the loss of the functional zone        | 87) _____ |
| C) menses              | reflects regrowth of the functional zone        | 88) _____ |
| D) none                | reflects marked increase in uterine glands      | 89) _____ |
|                        | stimulated by lack of progesterone and estrogen | 90) _____ |

91-95. Matching

- |                                    |                         |           |
|------------------------------------|-------------------------|-----------|
| A) contain 23 pairs of chromosomes | spermatids              | 91) _____ |
| B) contain 23 single chromosomes   | primary oocytes         | 92) _____ |
| C) contain 23 chromatids           | secondary oocytes       | 93) _____ |
|                                    | primary spermatocytes   | 94) _____ |
|                                    | secondary spermatocytes | 95) _____ |

96-100. Matching

- |                      |                                                      |            |
|----------------------|------------------------------------------------------|------------|
| A) parasympathetic   | ganglia are typically close to the CNS               | 96) _____  |
| B) sympathetic       | postganglionic axons typically are short             | 97) _____  |
| C) none of the above | ganglia are typically in the target organs           | 98) _____  |
|                      | preganglionic neurons originate in spinal cord       | 99) _____  |
|                      | preganglionic neurons originate in medulla oblongata | 100) _____ |

101-105. Matching

- |                                  |                                                  |            |
|----------------------------------|--------------------------------------------------|------------|
| A) celiac and mesenteric ganglia | found next to the aorta                          | 101) _____ |
| B) sympathetic chain ganglia     | directly influence bronchial tree                | 102) _____ |
| C) none of the above             | directly influence thoracic organs               | 103) _____ |
|                                  | directly influence abdominal visceral organs     | 104) _____ |
|                                  | directly influence skeletal muscle blood vessels | 105) _____ |

106-110. Matching

- |                      |                                                |            |
|----------------------|------------------------------------------------|------------|
| A) acetylcholine     | decreases heart rate                           | 106) _____ |
| B) norepinephrine    | causes bronchial dilation                      | 107) _____ |
| C) none of the above | increases cellular glucose usage               | 108) _____ |
|                      | decreases gastrointestinal motility            | 109) _____ |
|                      | lead to increased force of cardiac contraction | 110) _____ |

111-115. Matching

- |                |                                           |            |
|----------------|-------------------------------------------|------------|
| A) insulin     | produced by the adrenal zona fascicularis | 111) _____ |
| B) cortisol    | produced by the adrenal zona glomerulosa  | 112) _____ |
| C) glucagon    | produced by alpha cells of pancreas       | 113) _____ |
| D) aldosterone | produced by beta cells of pancreas        | 114) _____ |
|                | responds to high blood glucose            | 115) _____ |

116-120. Matching

- |                    |                                                          |            |
|--------------------|----------------------------------------------------------|------------|
| A) renin           | inhibits conversion of angiotensin I into angiotensin II | 116) _____ |
| B) Captopril       | converts angiotensinogen into angiotensin I              | 117) _____ |
| C) angiotensin II  | stimulates secretion of aldosterone                      | 118) _____ |
| D) angiotensinogen | precursor for angiotensin I                              | 119) _____ |
|                    | causes vasoconstriction                                  | 120) _____ |

121-125. Matching

- |                                 |                                          |            |
|---------------------------------|------------------------------------------|------------|
| A) Adrenocorticotrophic hormone | stimulates milk production               | 121) _____ |
| B) Thyroid stimulating hormone  | stimulates thyroid follicles             | 122) _____ |
| C) Growth hormone               | suppresses the immune system             | 123) _____ |
| D) Prolactin                    | stimulates adrenal secretion of cortisol | 124) _____ |
|                                 | stimulates growth; increases metabolism  | 125) _____ |

126-130. Matching

- |                 |                                             |            |
|-----------------|---------------------------------------------|------------|
| A) insulin      | increases in response to high blood calcium | 126) _____ |
| B) glucagon     | increases in response to low blood calcium  | 127) _____ |
| C) glycogen     | increases cellular breakdown of glucose     | 128) _____ |
| D) calcitonin   | increases cellular uptake of glucose        | 129) _____ |
| E) parathormone | chains of glucose                           | 130) _____ |

131-135. Matching

- |                      |                                      |            |
|----------------------|--------------------------------------|------------|
| A) insulin           | produced by alpha cells of pancreas  | 131) _____ |
| B) glucagon          | increases cellular uptake of glucose | 132) _____ |
| C) none of the above | produced by beta cells of pancreas   | 133) _____ |
|                      | responds to high blood glucose       | 134) _____ |
|                      | responds to low blood glucose        | 135) _____ |

136-140. Matching

- |                      |                         |      |       |
|----------------------|-------------------------|------|-------|
| A) adrenal medulla   | secretes cortisol       | 136) | _____ |
| B) adrenal cortex    | secretes aldosterone    | 137) | _____ |
| C) none of the above | secretes testosterone   | 138) | _____ |
|                      | secretes epinephrine    | 139) | _____ |
|                      | secretes norepinephrine | 140) | _____ |

141-145. Matching

- |                                 |                                  |      |       |
|---------------------------------|----------------------------------|------|-------|
| A) thyroxine and growth hormone | inhibits osteoclast activity     | 141) | _____ |
| B) parathormone                 | stimulates osteoclast activity   | 142) | _____ |
| C) calcitonin                   | responds to low blood calcium    | 143) | _____ |
|                                 | responds to high blood calcium   | 144) | _____ |
|                                 | necessary for normal bone growth | 145) | _____ |

146-150. Matching

- |                         |                                                       |      |       |
|-------------------------|-------------------------------------------------------|------|-------|
| A) Corticotropin (ACTH) | stimulates adrenal secretion of cortisol              | 146) | _____ |
| B) Thyrotropin (TSH)    | stimulates adrenal secretion of testosterone          | 147) | _____ |
| C) Growth hormone (GH)  | stimulates liver production of somatomedins           | 148) | _____ |
| D) none of the above    | stimulates thyroid production of thyroxin (T4)        | 149) | _____ |
|                         | stimulates thyroid production of Triiodothyronin (T3) | 150) | _____ |

151-155. Matching

- |                 |                                  |      |       |
|-----------------|----------------------------------|------|-------|
| A) progesterone | inhibits GnRH neurons            | 151) | _____ |
| B) testosterone | stimulates muscle growth         | 152) | _____ |
| C) estrogen     | enhances spermatogenesis         | 153) | _____ |
| D) A and B      | stimulates Luteinizing hormone   | 154) | _____ |
| E) A and C      | stimulates growth of endometrium | 155) | _____ |

156-160.

- |                      |                                          |      |       |
|----------------------|------------------------------------------|------|-------|
| A) ova               | are analogous to sperm                   | 156) | _____ |
| B) oogonia           | are analogous to spermatids              | 157) | _____ |
| C) primary oocytes   | are analogous to spermatogonia           | 158) | _____ |
| D) secondary oocytes | are analogous to primary spermatocytes   | 159) | _____ |
|                      | are analogous to secondary spermatocytes | 160) | _____ |

161-165. Matching

- |    |      |       |
|----|------|-------|
| A) | 161) | _____ |
| B) | 162) | _____ |
| C) | 163) | _____ |
| D) | 164) | _____ |
| E) | 165) | _____ |

166-170. Matching

- |    |      |       |
|----|------|-------|
| A) | 166) | _____ |
| B) | 167) | _____ |
| C) | 168) | _____ |
| D) | 169) | _____ |
| E) | 170) | _____ |

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.

# **Section 5 – Cardiovascular System**

# Cardiovascular Organization

The primary function of the cardiovascular system is to transport oxygen and nutrients to the tissues of the body, and to transport carbon dioxide and other metabolic byproducts away from these tissues. It is of course the responsibility of the respiratory system to obtain oxygen and remove carbon dioxide, the digestive system to initially obtain nutrients and metabolic substrates, and the digestive and urinary systems to remove excess metabolic byproducts.

## Circulatory Circuits

The cardiovascular system basically consists of the heart, the pulmonary circuit, the systemic circuit, and the lymphatic vessels, as shown on the next page (Overview of the Circulation).

### Pulmonary circuit

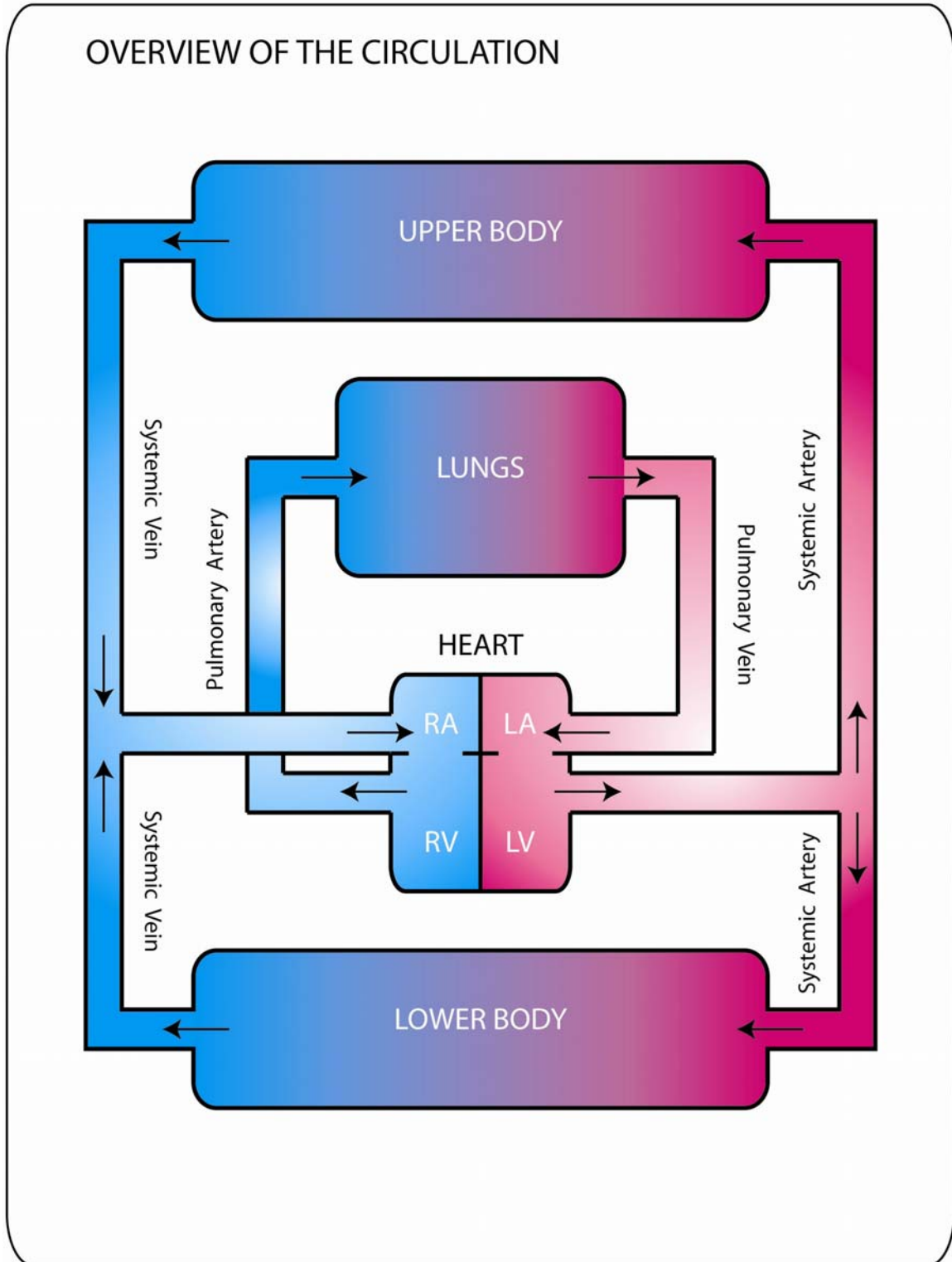
- Pulmonary circuit - carries blood to and from the lungs
- Pulmonary Arteries - carry blood away from the heart to the lungs
- Pulmonary Veins - carry blood from the lungs to the heart

### 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



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## **Relationship between the Heart and Blood Vessels**

### **Right side of the heart**

#### Right atrium

- receives blood from the systemic circuit 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 left 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

**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**

**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

## 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 Interventricular branch (Posterior Descending) - within the posterior interventricular sulcus

Left Coronary artery - follows coronary sulcus

Anterior Interventricular branch (Anterior Descending) - within the anterior interventricular sulcus

Circumflex branch - follows coronary sulcus; part fuses with right coronary artery; part extends along left border

**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

Middle cardiac vein - adjacent to posterior descending arteries

Great cardiac vein - adjacent to anterior descending arteries; empties into the coronary sinus

Posterior cardiac vein - adjacent to circumflex branch arteries

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

## Models and Specimens of Heart

### Superficial Anatomy

<p>Heart</p> <ul style="list-style-type: none"> <li>• Pericardial Cavity</li> <li>• Pericardial Sac</li> <li>• Parietal pericardium</li> <li>• Visceral pericardium (Epicardium)</li> <li>• Base</li> <li>• Apex</li> </ul>	
<p>Chambers</p> <ul style="list-style-type: none"> <li>• Right Atria and Auricle (Atrial Appendage)</li> <li>• Left Atria and Auricle (Atrial Appendage)</li> <li>• Right Ventricle</li> <li>• Left Ventricle</li> </ul>	
<p>Major Veins</p> <ul style="list-style-type: none"> <li>• Superior vena cava</li> <li>• Inferior vena cava</li> <li>• Pulmonary veins (right and left)</li> </ul>	
<p>Major arteries</p> <ul style="list-style-type: none"> <li>• Ascending aorta</li> <li>• Pulmonary trunk</li> <li>• Pulmonary arteries (right and left)</li> </ul>	

### Sectional Anatomy

<p>Right side</p> <ul style="list-style-type: none"><li>• Right Atrioventricular (AV) (tricuspid) valve</li><li>• Fossa ovale</li><li>• Chordae tendinae</li><li>• Papillary muscles</li><li>• Trabeculae carnae</li><li>• Pulmonary semilunar valve</li></ul>	
<p>Left side</p> <ul style="list-style-type: none"><li>• Left Atrioventricular (AV) (bicuspid valve, Mitra) valve</li><li>• Fossa ovale</li><li>• Chordae tendinae</li><li>• Papillary muscles</li><li>• Trabeculae carnae</li><li>• Aortic Semilunar valve</li></ul>	

### Coronary Circulation

<p>Coronary Arteries</p> <ul style="list-style-type: none"><li>• Right Coronary artery</li><li>• Marginal branch</li><li>• Posterior Descending</li><li>• Left Coronary artery</li><li>• Anterior Descending</li><li>• Circumflex branch</li></ul>	
<p>Coronary Veins</p> <ul style="list-style-type: none"><li>• Anterior cardiac veins</li><li>• Small cardiac Vein</li><li>• Middle cardiac vein</li><li>• Great cardiac vein</li><li>• Posterior cardiac vein</li><li>• Coronary Sinus</li></ul>	

### Fetal Heart

<ul style="list-style-type: none"><li>• Foramen ovale (becomes the fossa ovale after birth)</li><li>• Ductus arteriosus (becomes the ligamentum arteriosus after birth)</li></ul>	
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### Histology of the Heart

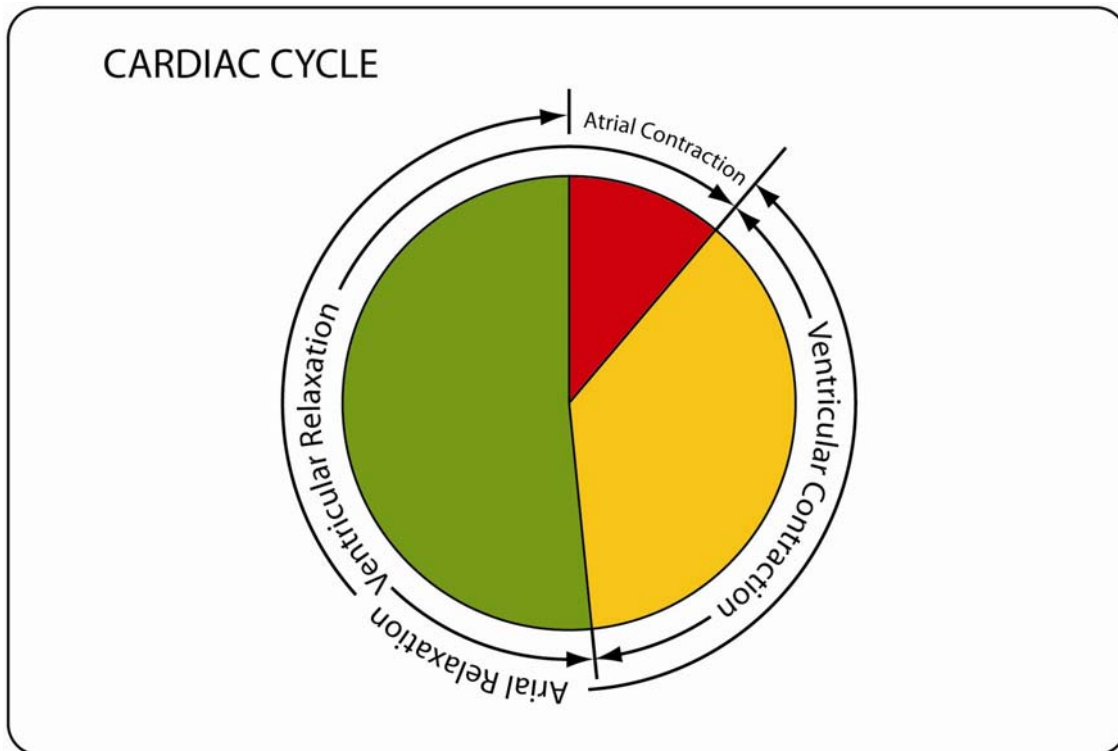
<p>Heart Wall</p> <ul style="list-style-type: none"><li>• Epicardium (visceral pericardium)</li><li>• Myocardium</li><li>• Endocardium</li></ul>	
<p>Cardiac Muscle</p> <ul style="list-style-type: none"><li>• Cardiac muscle cells</li><li>• Intercalated discs</li><li>• Endomysium</li></ul>	

# 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, as shown below (Cardiac Cycle) and on the following pages (Cardiac Pumping).

- 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.



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It is important to recognize that during most of the cardiac cycle the atria and/or the ventricles are relaxing. As the atria relax and the ventricles relax blood is drawn into the heart. Unless there is blood in the heart, contraction of the heart can not pump out blood. For this reason I am choosing to show the pumping actions of the heart starting with atrial relaxation. The pumping of blood through the heart can be viewed simply as the movement of blood from an area of higher pressure to an area of lower pressure.

- Blood moves from an area of higher pressure to an area of lower pressure

## **Pumping actions of the heart**

### Atrial Relaxation

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

### Ventricular Relaxation (Diastole)

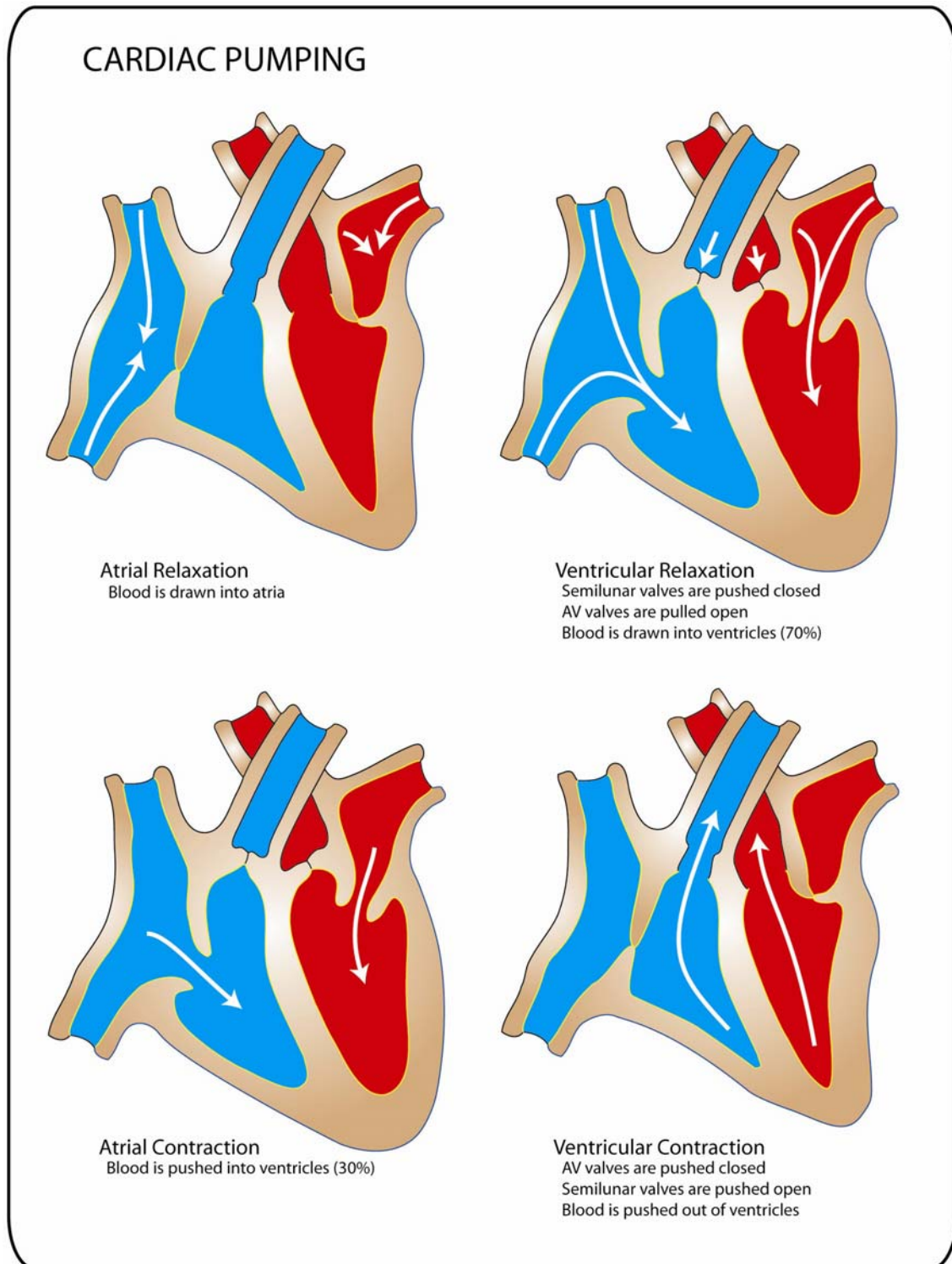
- Leads to a rapid decrease in ventricular pressure
- As the ventricular pressures become less than the arterial pressures, the semilunar valves close.
- As the ventricular pressures become less than the atrial pressures, the atrioventricular valves open and blood moves from the atria into the ventricles.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

### Atrial Contraction

- Leads to a rapid increase in atrial pressures.
- As the atrial pressures increase, more blood moves from the atria into the ventricles.
- The pressure differences between the atria and the ventricles leads to about 30% of ventricular filling.

### Ventricular Contraction (Systole)

- Leads to 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 into the arteries.



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# Coordination of Cardiac Muscle Contraction

We need to remember that there are no valves between the veins and the atria and that the semilunar valves and corresponding arteries are at the top of the heart (base). In order to optimize the movement of blood from the atria into the ventricles during atrial contraction, the atria must contract from the atrial appendages toward the AV valves. In order to optimize the movement of blood from the ventricles into the arteries the ventricles must contract from the bottom of the heart (apex) toward the semilunar valves.

## Cardiac conduction system

The coordination of the contraction of the cardiac muscle cells is mediated by the cardiac conduction system.

Some cardiac muscle cells are specialized to generate and conduct action potentials. These include cells of the:

- Sinoatrial (SA) node in the posterior wall of the right atrium
- Atrial conduction fibers in the right and left atria (which include atrial pacemaker foci)
- Atrioventricular (AV) node in the floor of the right atrium near the ventricle
- AV bundle (of His) in the interventricular septum
- Bundle branches in the interventricular septum
- Purkinje fibers (of the ventricles) in the right and left ventricles (which include ventricular pacemaker foci)

Pacemaker signals originate in the SA node and travel through atrial conduction fibers into both atria. The atrial conduction fibers are in direct contact with cardiac muscle cells. As signals pass through the conduction fibers, cardiac muscle cells in the atria are stimulated and sequentially contract toward the AV valves. In addition, the pacemaker signals that travel through the right atrial conduction fibers synchronize the activity of the AV node. The AV node in turn generates pacemaker signals that travel through the AV bundle and bundle branches in the interventricular septum to the apex of the heart. Both the AV bundle and the bundle branches are isolated from cardiac muscle cells. However, at the apex the bundle branches divide into fine Purkinje fibers that are in direct contact with cardiac muscle cells. As signals pass through the Purkinje fibers, cardiac muscle cells in the ventricles are stimulated and sequentially contract toward the semilunar valves.

## Pacemaker cells

Pacemaker cells are unique in that their cell membranes depolarize spontaneously and cyclically. The cells of the SA node and the AV node are normally the dominant

pacemakers. In addition, there are focal pacemaker cells in the atria and in the ventricles. Each of these has different intrinsic rates.

- The sinoatrial (SA) node intrinsically produces about 80-100 action potentials per minute.
- Atrial foci intrinsically produce about 60-80 action potentials per minute.
- The atrioventricular (AV) node intrinsically produces about 40-60 action potentials per minute.
- Ventricular foci intrinsically produce about 20-40 action potentials per minute.

As long as the SA node communicates with the AV node, the atrial foci, the AV node, and the ventricular foci will be synchronized at the same rate as the SA node. However, with damage to the SA node, the AV node will act as an independent pacemaker and generate action potentials at a lower rate. With damage to the SA node and atrial foci, the atria will not contract and “top-off” the filling of the ventricles. When the AV node operates at a lower rate the ventricles will stay relaxed longer and have more time to fill.

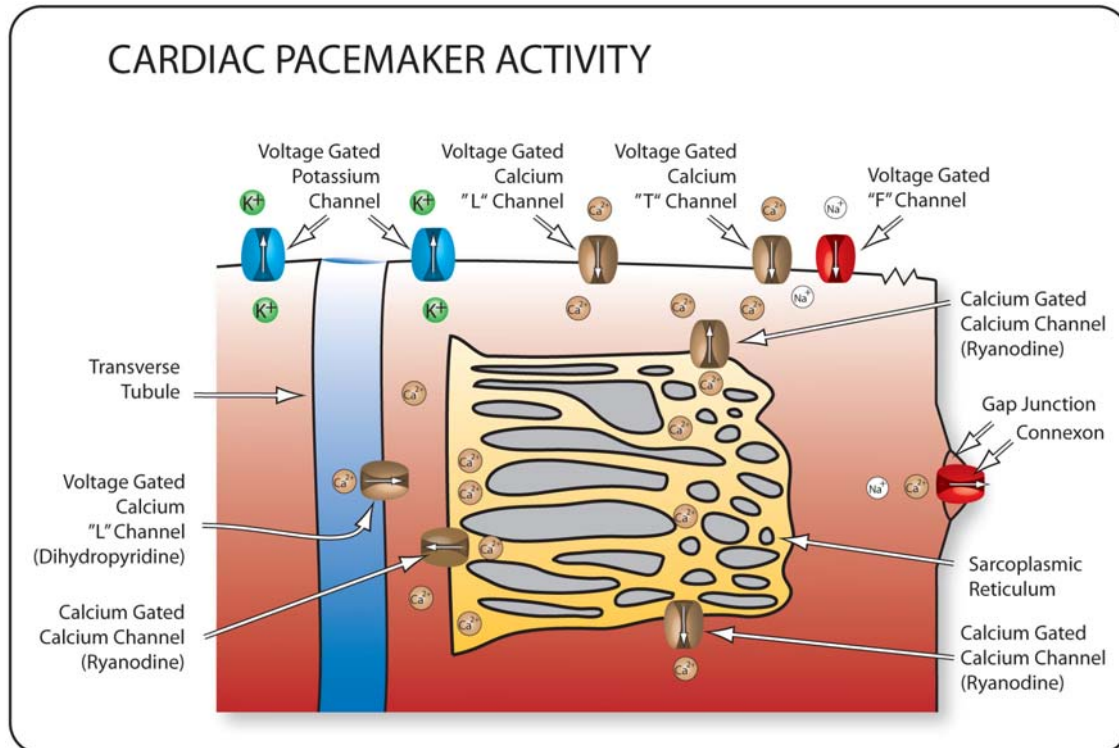
It is important to point out that the autonomic nervous system has considerable influence on the pacemakers. At rest the parasympathetic nervous system dominates and reduces the rate of the SA node to about 70 action potentials per minute. We will return to this issue toward the end of the chapter.

- Tachycardia refers to a heart rate greater than 100 beats / minute
- Bradycardia refers to a heart rate less than 60 beats / minute

### **Pacemaker potentials**

The cellular mechanisms responsible for the generation of cardiac pacemaker activity involve the cyclic depolarization of the cell membranes of pacemaker cells due to the opening and closing of several membrane channels, as shown on the following page (Cardiac Pacemaker Activity).

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



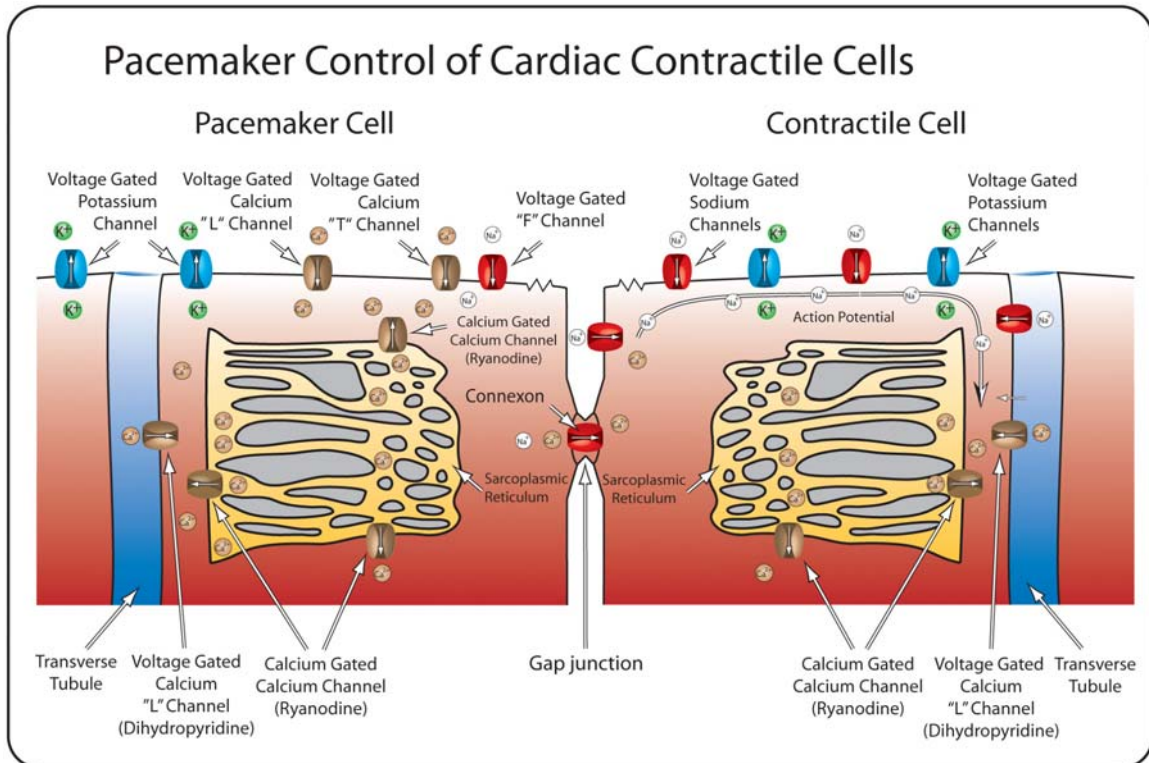
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### Pacemaker control of cardiac muscle contraction

Cardiac muscle cells are mainly activated by diffusion of cations through gap junctions in the intercalated discs, as shown on the following page (

- 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<sup>+</sup> channels in the sarcolemma of the contractile cell.
- The sequential opening and closing of Na<sup>+</sup> channels and K<sup>+</sup> 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<sup>++</sup> 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<sup>+</sup> channels open in response to the prolonged depolarization, and subsequently close.

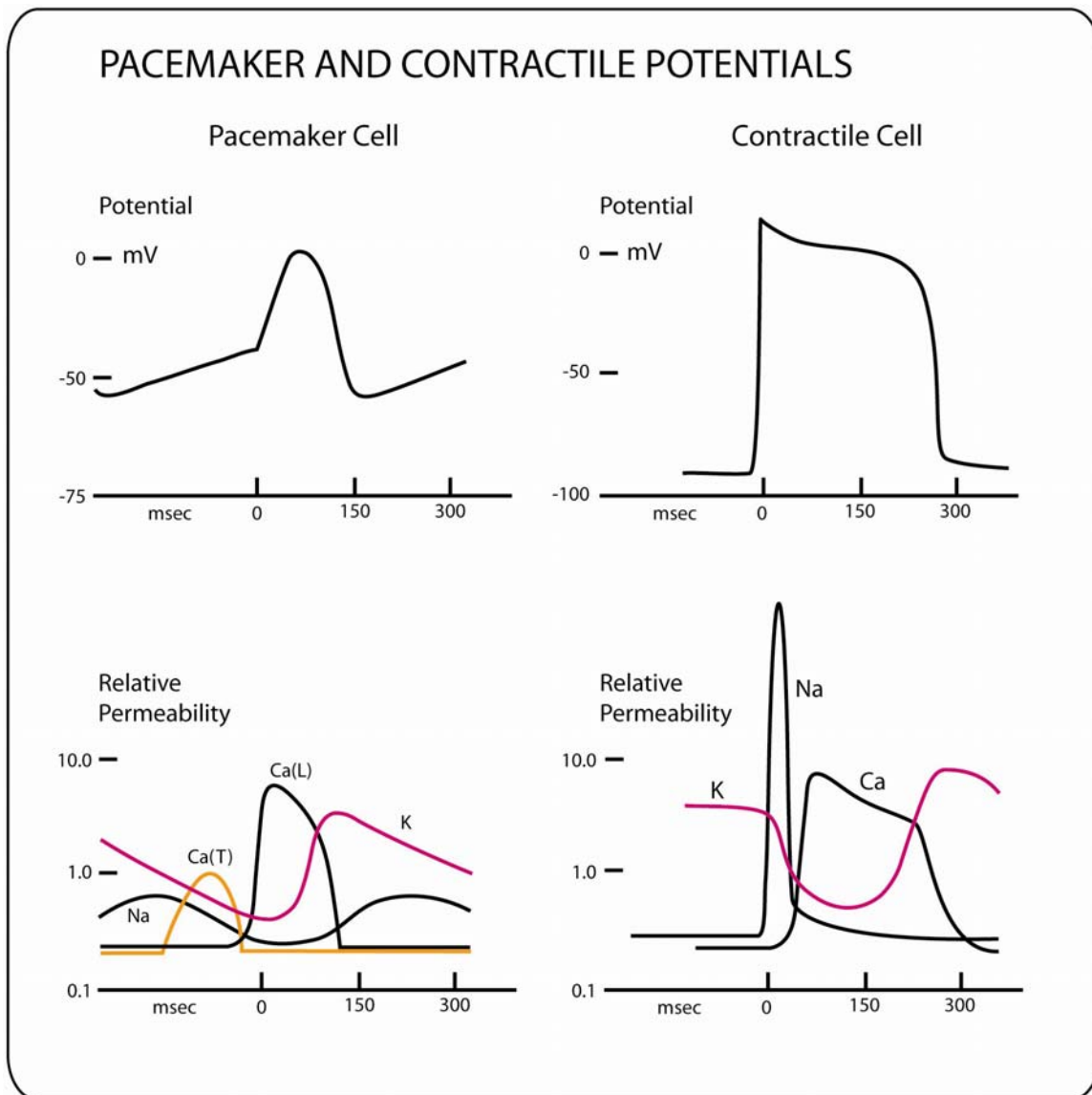
- The  $\text{Ca}^{++}$  that enters the sarcoplasm binds to troponin and moves tropomyosin away from the binding sites on actin, allows the myosin heads to bind to actin, and causes muscle contraction.



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# 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.



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## EKG waves

In the EKG tracing several waves are prominent. As shown above and on the following page ( ).

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

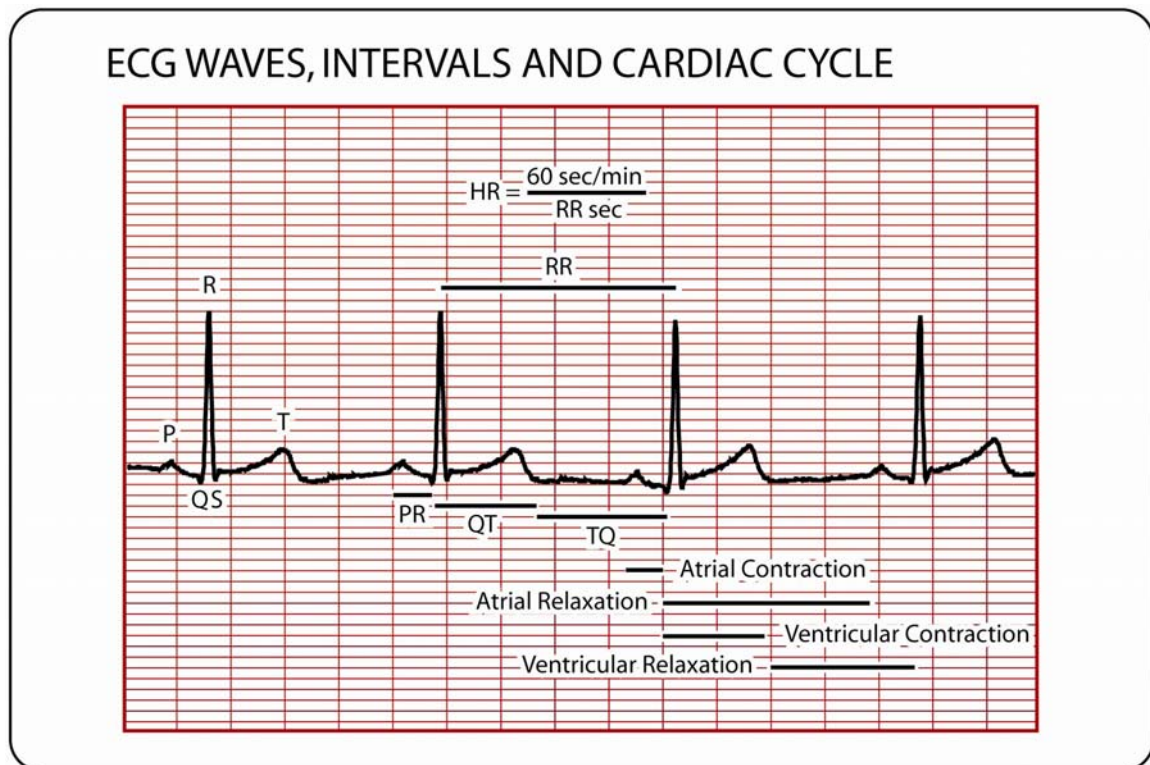
The timing of the intervals between the waves is of diagnostic importance. The most useful intervals are the RR interval, PR interval, QRS interval, and the QT interval.

- 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 cardiac pumping is of course to pump blood out of the heart, 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.

$$\text{Cardiac output (CO)} = \text{Stroke volume (SV)} \times \text{Heart rate (HR)}$$

- 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 see that the stroke volume would be 70 mL.

$$4900 \text{ mL / min} = 70 \text{ mL} \times 70 \text{ beats / min}$$

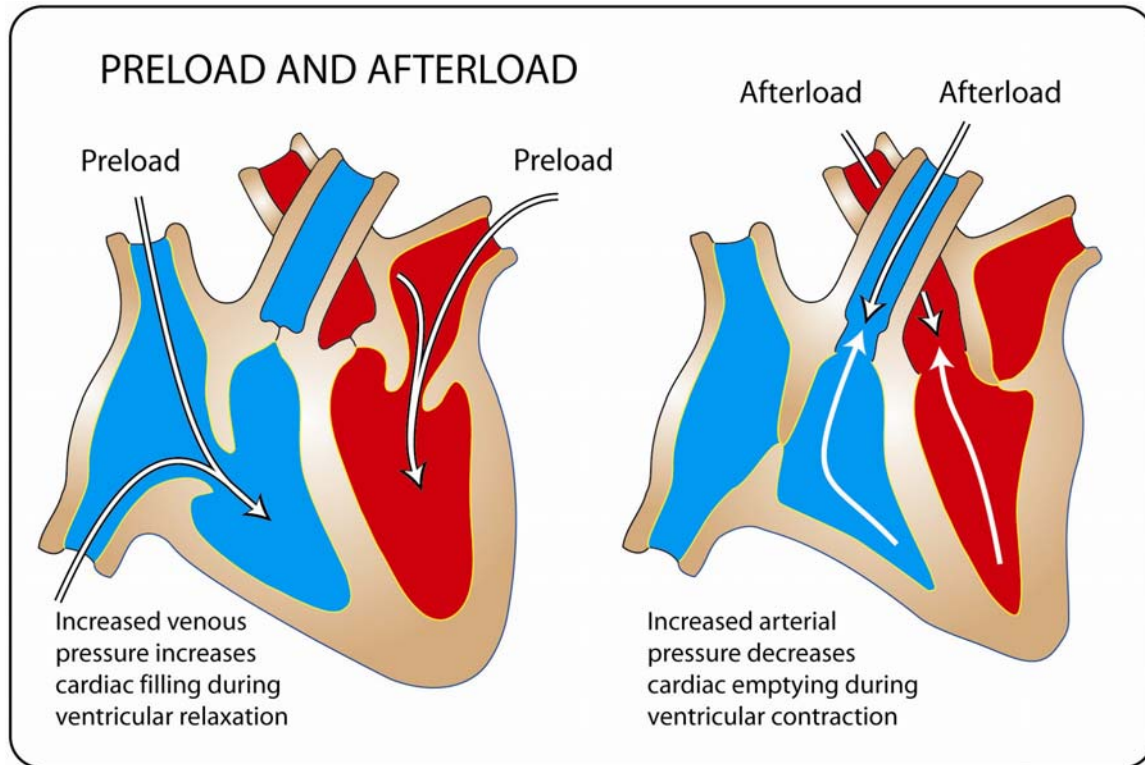
However, stroke volume is influenced by two major factors, the end diastolic volume and the end systolic volume.

$$\text{Stroke volume (SV)} = \text{End Diastolic Volume (EDV)} - \text{End Systolic Volume (ESV)}$$

- 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 shown on the following page (Preload and Afterload), 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,



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### 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. .

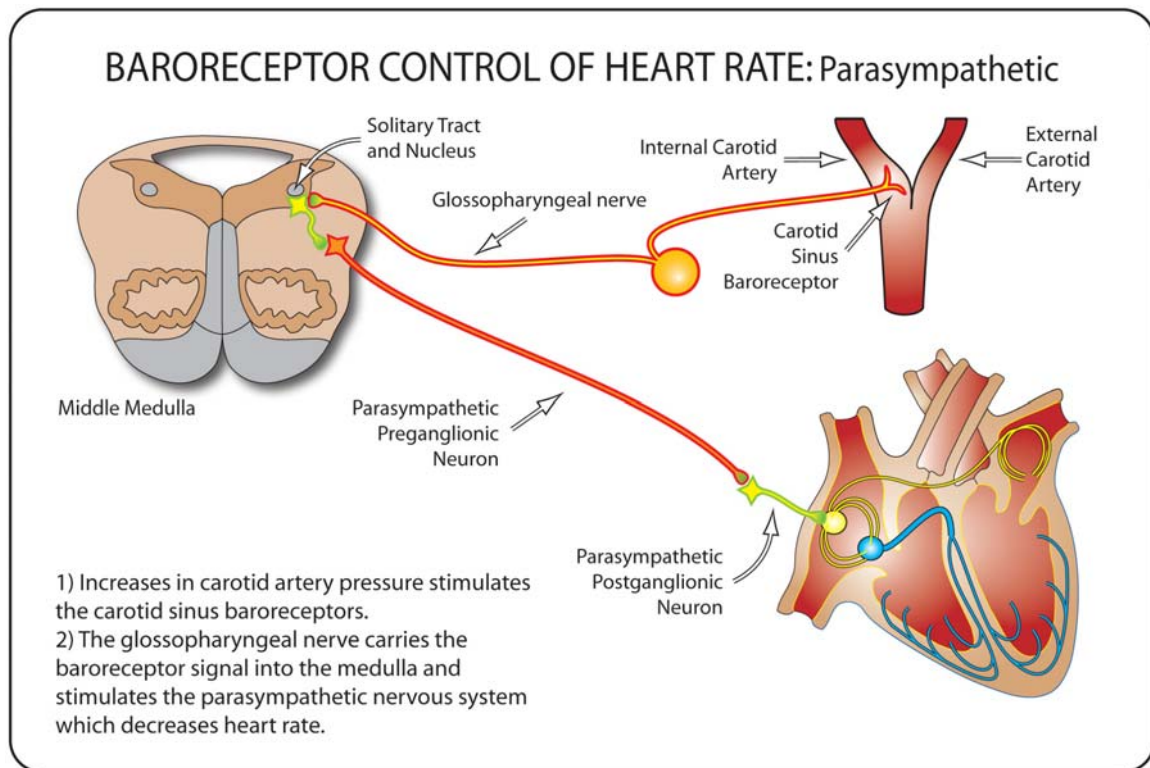
Cardiac muscle cells are not only controlled by the cardiac conduction system, they are modulated by the sympathetic nervous system and various hormones, for example by epinephrine. The sympathetic nervous system controls cardiac force.. Sympathetic postganglionic neurons secrete norepinephrine which 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, as shown on the following page (Baroreceptor Control of Heart Rate: Parasympathetic). 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. Although not shown, this same signal inhibits the sympathetic nervous system which also contributes to the decrease in heart rate. The effect of the increase in parasympathetic activity generally dominates the effect of decreases in sympathetic activity.



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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. The increase in heart rate will be dominated by the decrease in parasympathetic activity until the heart rate exceeds 100 beats / minute.

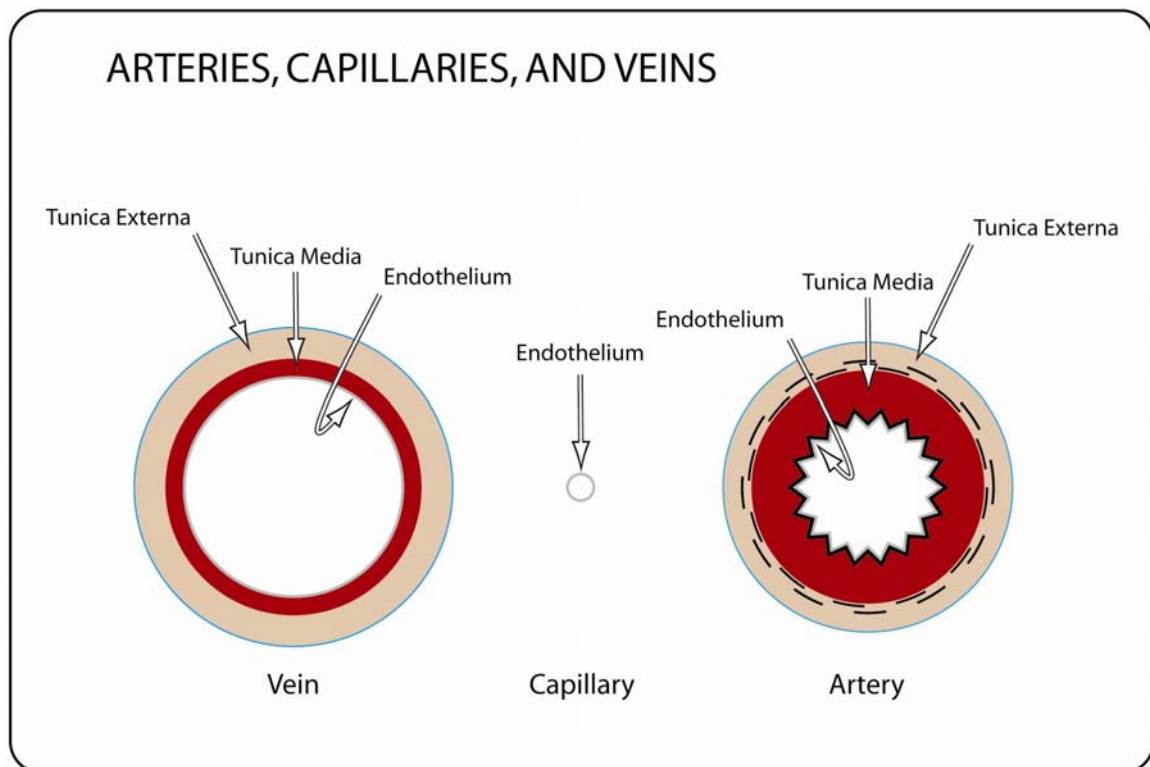
# Blood Vessels, Microcirculation and Lymphatic Vessels

## Blood Vessels

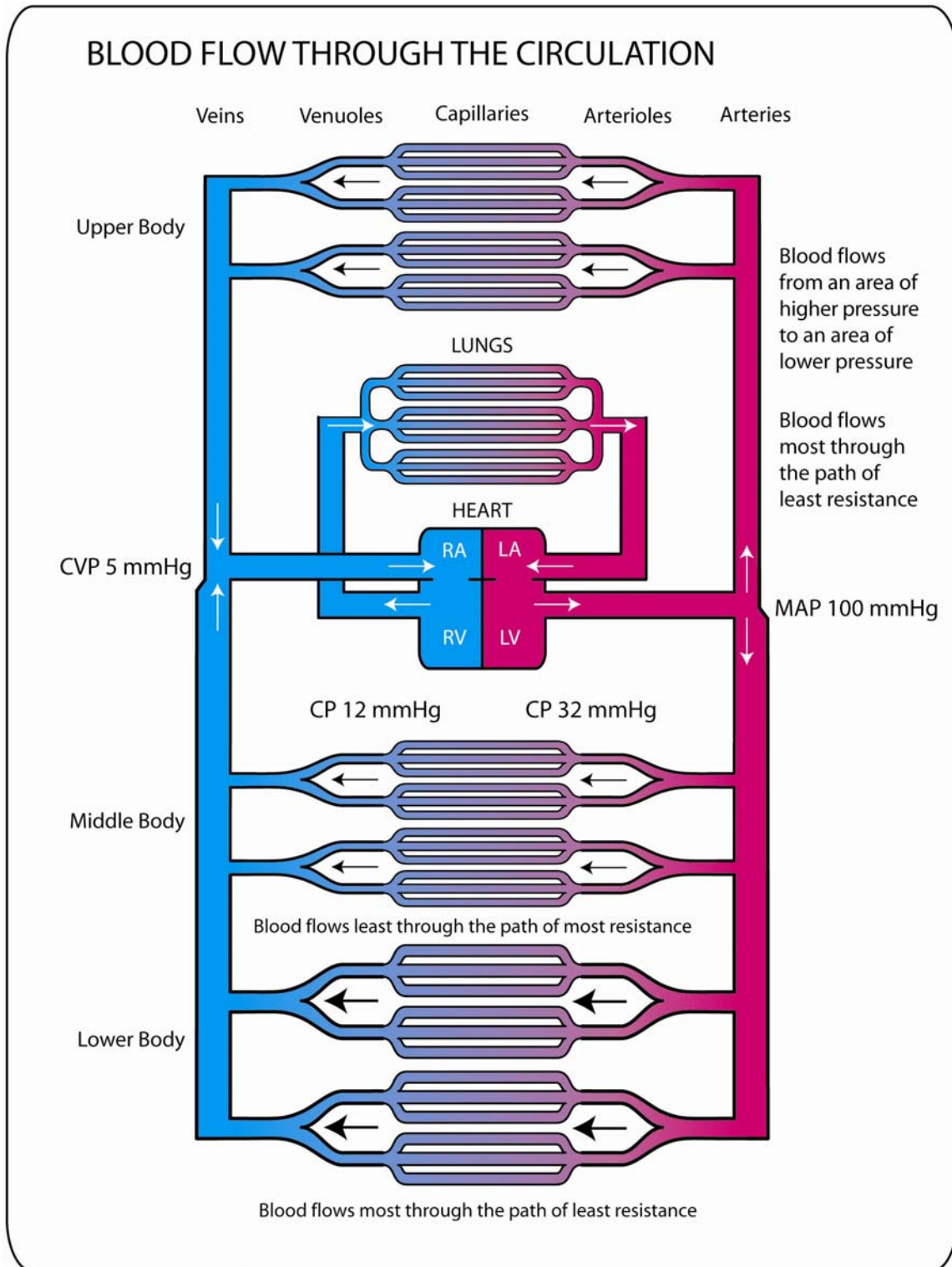
The flow of blood through the circulatory system is shown on the following page

- 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.

The general organization of an artery, capillary and vein is shown below. 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.



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## **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

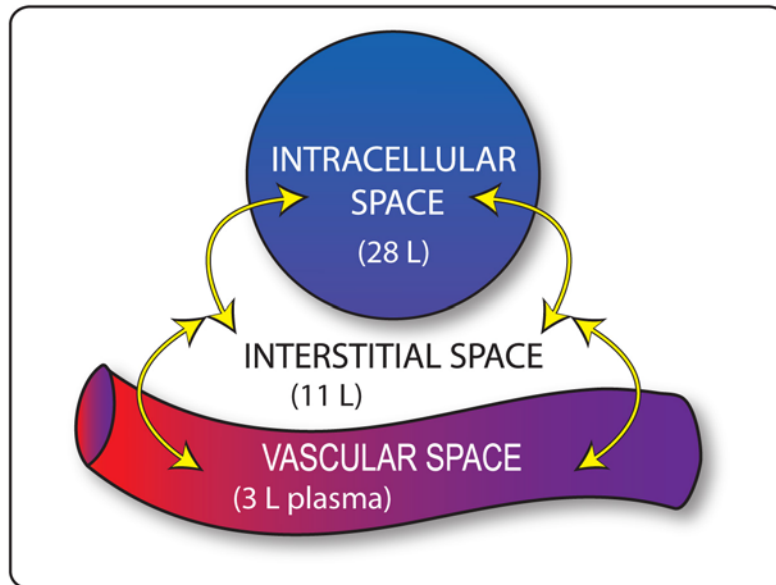
- Thin layer of smooth muscle

### 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), as shown on the following page.



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### 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. The microcirculation is shown on the following page (Microcirculation).

### Lymphatic capillaries

- recover interstitial fluid
- composed of endothelial cells with no basement membrane
- overlapping endothelial cells act as one way valves

### Lymphatic nodules

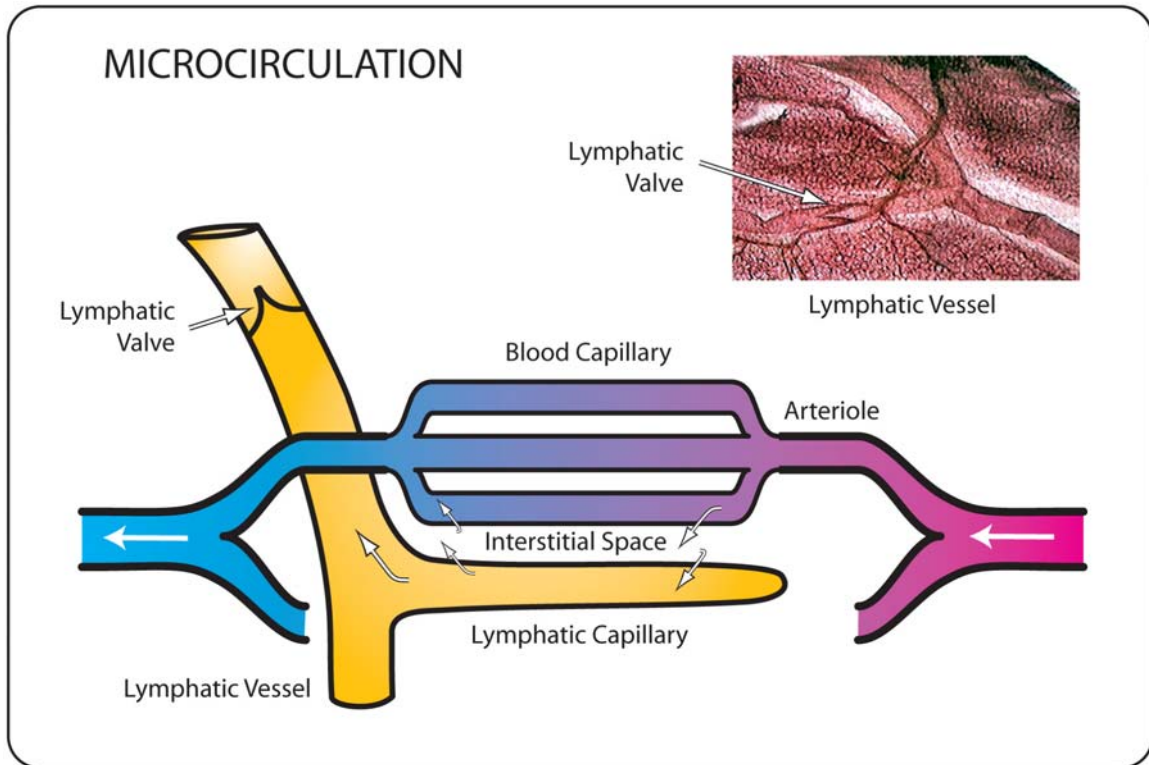
- filter and destroy pathogens in the lymphatic fluid
- composed of reticular tissue and lymphocytes
- interspersed along the lymphatic vessels

### 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



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# Blood Vessels - Laboratory

## Systemic Arteries

<p>Aortic arch</p> <ul style="list-style-type: none"><li>• Brachiocephalic artery<ul style="list-style-type: none"><li>◦ Right common carotid artery</li><li>◦ Right subclavian artery</li></ul></li><li>• Left common carotid artery</li><li>• Left subclavian artery</li></ul>	
<p>Subclavian arteries (Right and Left)</p> <ul style="list-style-type: none"><li>• Vertebral artery (Right and Left)</li><li>• Axillary artery (Right and Left)</li><li>• Brachial artery (Right and Left)<ul style="list-style-type: none"><li>◦ Radial artery (Right and Left)</li><li>◦ Ulnar artery (Right and Left)</li></ul></li></ul>	
<p>Carotid arteries</p> <ul style="list-style-type: none"><li>• External carotid artery (Right and Left)</li><li>• Internal carotid artery (Right and Left)</li><li>• Carotid sinus</li></ul>	

<p><b>Circle of Willis</b></p> <ul style="list-style-type: none"> <li>• Vertebral artery (Right and Left)</li> <li>• Basilar artery             <ul style="list-style-type: none"> <li>○ Posterior cerebral artery (Right and Left)                 <ul style="list-style-type: none"> <li>▪ Posterior communicating artery (Right and Left)</li> </ul> </li> </ul> </li> <li>• Internal carotid artery (Right and Left)             <ul style="list-style-type: none"> <li>○ Middle cerebral artery (Right and Left)</li> <li>○ Anterior cerebral artery (Right and Left)                 <ul style="list-style-type: none"> <li>▪ Anterior communicating artery</li> </ul> </li> </ul> </li> </ul>	
<p><b>Descending Aorta</b></p> <ul style="list-style-type: none"> <li>• Inferior phrenic artery (Right and Left)</li> <li>• Celiac trunk             <ul style="list-style-type: none"> <li>○ Gastric artery</li> <li>○ Hepatic artery</li> <li>○ Splenic artery</li> </ul> </li> <li>• Superior mesenteric artery</li> <li>• Renal artery (Right and Left)</li> <li>• Adrenal artery (Right and Left)</li> <li>• Gonadal artery (Right and Left)</li> <li>• Inferior mesenteric artery</li> <li>• Common iliac artery (Right and Left)</li> </ul>	

<p>Common iliac artery (Right and Left)</p> <ul style="list-style-type: none"><li>• Internal iliac artery (Right and Left)</li><li>• External iliac artery (Right and Left)<ul style="list-style-type: none"><li>○ Deep femoral artery (Right and Left)</li><li>○ Femoral artery (Right and Left)<ul style="list-style-type: none"><li>▪ Popliteal artery (Right and Left)<ul style="list-style-type: none"><li>▪ Anterior tibial artery (Right and Left)</li><li>▪ Posterior tibial artery (Right and Left)</li><li>▪ Fibularis artery (Right and Left)</li></ul></li></ul></li></ul></li></ul>	
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## Deep Systemic Veins

<p>Superior vena cava</p> <ul style="list-style-type: none"> <li>• Brachiocephalic vein (Right and Left) <ul style="list-style-type: none"> <li>○ Internal jugular vein (Right and Left)</li> <li>○ Vertebral vein (Right and Left)</li> <li>○ External jugular vein (Right and Left)</li> <li>○ Subclavian vein (Right and Left)</li> </ul> </li> </ul>	
<p>Subclavian vein (Right and Left)</p> <ul style="list-style-type: none"> <li>• Axillary vein (Right and Left) <ul style="list-style-type: none"> <li>○ Brachial vein (Right and Left) <ul style="list-style-type: none"> <li>▪ Radial vein (Right and Left)</li> <li>▪ Ulnar vein (Right and Left)</li> </ul> </li> </ul> </li> </ul>	
<p>Inferior vena cava</p> <ul style="list-style-type: none"> <li>• Phrenic vein (Right and Left)</li> <li>• Hepatic vein (Right and Left)</li> <li>• Renal vein (Right and Left)</li> <li>• Adrenal vein (Right and Left)</li> <li>• Gonadal vein (Right and Left)</li> <li>• Common iliac vein (Right and Left)</li> </ul>	

<p>Common iliac vein (Right and Left)</p> <ul style="list-style-type: none"><li>• Internal iliac vein (Right and Left)</li><li>• External iliac vein (Right and Left)<ul style="list-style-type: none"><li>○ Femoral vein (Right and Left)</li><li>○ Popliteal vein (Right and Left)<ul style="list-style-type: none"><li>▪ Anterior tibial vein (Right and Left)</li><li>▪ Posterior tibial vein (Right and Left)</li><li>▪ Fibularis vein (Right and Left)</li></ul></li></ul></li></ul>	
<p>Hepatic Portal System</p> <p>Inferior vena cava</p> <ul style="list-style-type: none"><li>• Hepatic veins</li><li>• liver</li><li>• Hepatic portal vein</li><li>• Gastric vein</li><li>• Splenic vein<ul style="list-style-type: none"><li>○ Inferior Mesenteric vein</li></ul></li><li>• Superior Mesenteric vein</li></ul>	

## Superficial Veins

<p>Superficial Branches of Subclavian vein</p> <ul style="list-style-type: none"> <li>• Cephalic vein (Right and Left)</li> <li>• Basilic vein (Right and Left)</li> </ul>	
<p>Superficial Branches of Femoral vein</p> <ul style="list-style-type: none"> <li>• Great saphenous vein (Right and Left)</li> </ul>	

## Lymphatic vessels

<ul style="list-style-type: none"> <li>• Thoracic duct</li> <li>• Right lymphatic duct</li> </ul>	
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## Histology of Arteries and Veins

<p>Tunica Interna</p> <ul style="list-style-type: none"><li>• endothelium</li><li>• internal elastic lamina</li></ul> <p>Tunica Media</p> <ul style="list-style-type: none"><li>• smooth muscle</li></ul> <p>Tunica Externa</p> <ul style="list-style-type: none"><li>• external elastic lamina</li></ul>	
<p>Smooth Muscle</p> <ul style="list-style-type: none"><li>• Smooth muscle cells</li><li>• Endomysium</li></ul>	

# 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 pressure of the blood as it moves from the aorta to the vena cava is illustrated on page 198 (Blood Flow through the Circulation). 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 flow of blood in relation to the ECG is shown on the next page.



## 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.

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:

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

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.

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

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

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 ( $\Delta P$ ) 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 ( $\Delta P$ ) divided by the resistance of the blood vessel (R).

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

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

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

## 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.

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

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.

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

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

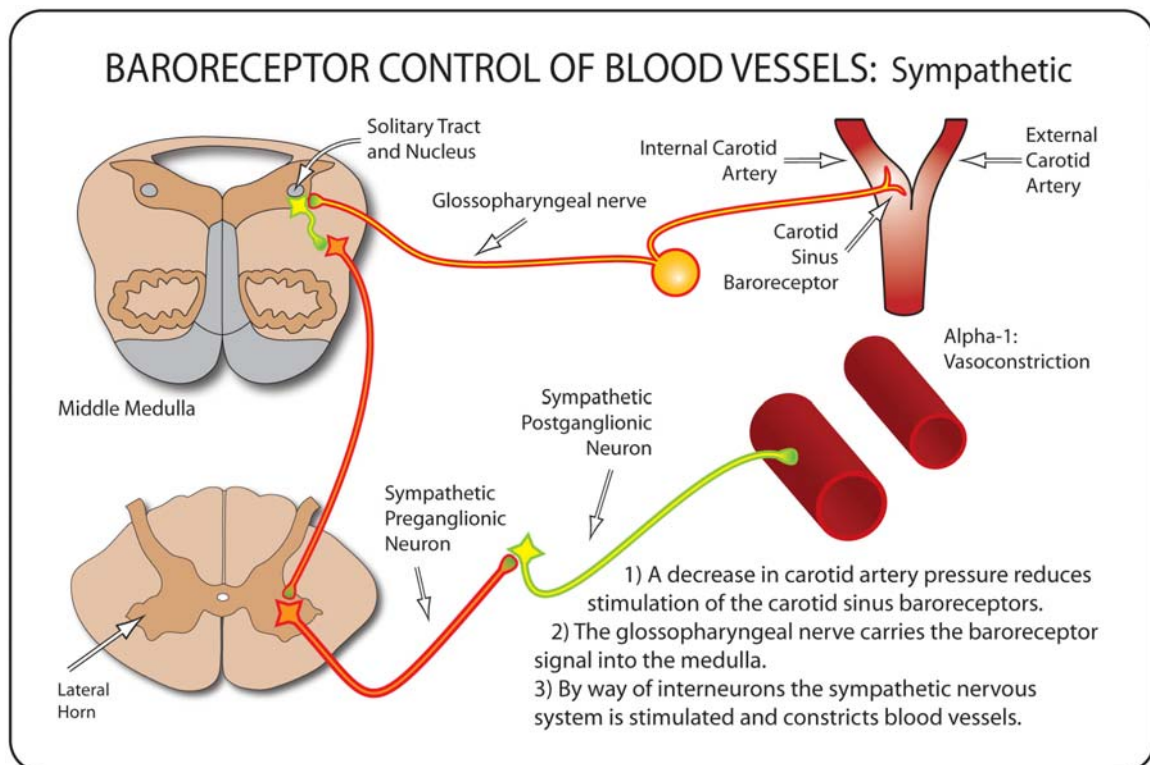
- Vasopressin acts on V1a receptors to cause vasoconstriction of arterioles and pre-capillary sphincters

## Reflex Vascular Regulation

The cardiovascular system contains sensory receptors that monitor blood pressures in the neck, trunk, and heart. Signals from these sensory receptors 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.



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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 Pressure - Laboratory

**Blood pressure** is defined as the pressure the blood exerts against any unit area of the blood vessel walls, and it is generally measured in the arteries. Because the heart alternately contracts and relaxes, the resulting rhythmic flow of blood into the arteries causes the blood pressure to rise and fall during each beat. Thus you must take two blood pressure readings: the **systolic pressure**, which is the pressure in the arteries at the peak of ventricular ejection, and the **diastolic pressure**, which reflects the pressure during ventricular relaxation. Blood pressures are reported in millimeters of mercury (mm Hg), with the systolic pressure appearing first; 120/80 translates to 120 over 80, or a systolic pressure of 120 mm Hg and a diastolic pressure of 80 mm Hg. Normal blood pressure varies considerably from one person to another.

In this procedure, you will measure arterial and venous pressures by indirect means and under various conditions. You will investigate and demonstrate factors affecting blood pressure, the rapidity of blood pressure changes, and the large differences between arterial and venous pressures.

## Indirect Measurement of Arterial Blood Pressure

The **sphygmomanometer** commonly called a *blood pressure cuff*; is an instrument used to obtain blood pressure readings by the auscultatory method. It consists of an inflatable cuff with an attached pressure gauge. The cuff is placed around the arm and inflated to a pressure higher than systolic pressure to occlude circulation to the forearm. As cuff pressure is gradually released, the examiner listens with a stethoscope for characteristic sounds called the **sounds of Korotkoff**, which indicate the resumption of blood flow into the forearm: The pressure at which the first soft tapping sounds can be detected is recorded as the systolic pressure. As the pressure is reduced further, blood flow becomes more turbulent, and the sounds become louder. As the pressure is reduced still further, below the diastolic pressure, the artery is no longer compressed; and blood flows freely and without turbulence. At this point, the sounds of Korotkoff can no longer be detected. The pressure at which the sounds disappear is recorded as the diastolic pressure.

## Methods and Results

1. Work in pairs to obtain radial artery blood pressure readings. Obtain a stethoscope, alcohol swabs, and a sphygmomanometer. Clean the earpieces of the stethoscope with the alcohol swabs, and check the cuff for the presence of trapped air by compressing it

against the laboratory table. (A partially inflated cuff will cause erroneous measurements.)

2. The subject should sit in a comfortable position with one arm resting on the laboratory table (approximately at heart level if possible). Wrap the cuff around the subject's arm, just above the elbow, with the inflatable area on the medial arm surface. The cuff may be marked with an arrow; if so, the arrow should be positioned over the brachial artery. Secure the cuff by tucking the distal end under the wrapped portion or by bringing the Velcro areas together.

3. Palpate the brachial pulse, and lightly mark its position with a felt pen. Don the stethoscope, and place its diaphragm over the pulse point.

The cuff should not be kept inflated for more than 1 minute. If you have any trouble obtaining a reading within this time, deflate the cuff, wait 1 or 2 minutes, and try again. (A prolonged interference with BP homeostasis can lead to fainting.)

4. Inflate the cuff to approximately 160 mm Hg pressure, and slowly release the pressure valve. Watch the pressure gauge as you listen carefully for the first soft thudding sounds of the blood spurting through the partially occluded artery. Mentally note this pressure (systolic pressure), and continue to release the cuff pressure. You will notice first an increase, then a muffling, of the sound. Note, as the diastolic pressure, the pressure at which the sound becomes muffled or disappears: Controversy exists over which of the two points should be recorded as the diastolic pressure; so in some cases you may see readings such as 120/80/78, which indicates the systolic pressure followed by the *first* and *second diastolic end points*. The first diastolic end point is the pressure at which the sound muffles; the second is the pressure at which the sound disappears. It makes little difference here which of the two diastolic pressures is recorded, but be consistent. Make two blood pressure determinations, and record your results below.

First trial:

systolic pressure \_\_\_\_\_ diastolic pressure \_\_\_\_\_

Second trial:

systolic pressure \_\_\_\_\_ diastolic pressure \_\_\_\_\_

5. Compute the **pulse pressure** for each trial. The pulse pressure is the difference between the systolic and diastolic pressures, and indicates the amount of blood forced from the heart during systole, or the actual "working" pressure.

Pulse pressure:

first trial \_\_\_\_\_ second trial \_\_\_\_\_

6. Compute the **mean arterial pressure (MAP)** for each trial using the following equation:

$MAP = (\text{diastolic pressure} + \text{diastolic pressure} + \text{systolic pressure}) / 3$

first trial \_\_\_\_\_ second trial \_\_\_\_\_

## Estimation of Venous Pressure

It is not possible to measure venous pressure with the sphygmomanometer. The methods available for measuring it produce estimates at best, because venous pressures are so much lower than arterial pressures. The difference in pressure becomes obvious when these vessels are cut. If a vein is cut, the blood flows evenly from the cut. A lacerated artery produces rapid spurts of blood.

## Methods and Results

1. Ask your lab partner to stand with his or her right side toward the blackboard, arms hanging freely at the sides. On the board, mark the approximate level of the right atrium. (This will be just slightly higher than the point at which you auscultated the apical pulse.)
2. Observe the superficial veins on the dorsum of the right hand as the subject alternately raises and lowers it. Notice the collapsing and filling of the veins as internal pressures change. Have the subject repeat this action until you can determine the point at which the veins have just collapsed. Then measure, in millimeters, the distance in the vertical plane from this point to the level of the right atrium (previously marked). Record this value.

Distance of right arm from right atrium at point of venous collapse: \_\_\_\_\_ mm

3. Compute the venous pressure (Pv), in millimeters of mercury, with the following formula:

$$P = 1.056 (\text{specific gravity of blood}) \times \text{mm (measured)} / 13.6 (\text{specific gravity of Hg})$$

Venous pressure computed: \_\_\_\_\_ mm Hg

Normal venous pressure varies from approximately 3 to 9 mm Hg. That of the hand ranges between 3 and 4 mm Hg. How does your computed value compare?

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4. Because venous walls are so thin, pressure within them is readily affected by external factors such as muscle activity, deep pressure, and pressure changes occurring in the thorax during breathing. The Valsalva maneuver, which increases intrathoracic pressure, is used to demonstrate the effect of thoracic pressure changes on venous pressure.

To perform this maneuver take a deep breath, and then mimic the motions of exhaling forcibly, but without actually exhaling. In reaction to this, the glottis will close; and intrathoracic pressure will increase. (Most of us have performed this maneuver unknowingly in acts of defecation in which there is "straining at stool.") Measure and record below the distance of the right arm from right atrium at the point of venous collapse while the subject is performing the Valsalva maneuver. Compute the venous pressure and record it below.

Venous pressure: \_\_\_\_\_ mm Hg

How does this value compare with the venous pressure measurement computed for the relaxed state?

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## Effect of Posture and Exercise

Arterial blood pressure is directly proportional to cardiac output (amount of blood pumped out of the left ventricle per unit time) and peripheral resistance to blood flow, that is

$$BP = CO \times PR$$

Peripheral resistance is increased by constriction of blood vessels (most importantly the arterioles), by an increase in blood viscosity or volume, and by a loss of elasticity of the

arteries (seen in arteriosclerosis). Any factor that increases either the cardiac output or the peripheral resistance causes an almost immediate reflex rise in blood pressure. A close examination of these relationships reveals that many factors--age, weight, time of day, exercise, body position, emotional state, and various drugs, for example--alter blood pressure. The influence of a few of these factors is investigated here.

The following tests are done most efficiently if one student acts as the subject; two are examiners (one taking the radial pulse and the other auscultating the brachial blood pressure); and a fourth student collects and records data. The sphygmomanometer cuff should be left on the subject's arm throughout the experiments (in a deflated state, of course) so that, at the proper times, the blood pressure can be taken quickly. In each case, take the measurements at least twice.

**Posture**

**Methods and Results**

To monitor circulatory adjustments to changes in position, take blood pressure and pulse measurements under the conditions noted in Chart I. Also record your results on that chart.

chart 1 Posture

	TRIAL 1		TRIAL 2	
Sitting quietly	BP	PULSE	BP	PULSE
Reclining for 3 min				
Immediately on standing				
After standing for 3 min				

**Exercise**

Blood pressure and pulse changes occurring during and after exercise provide a good yardstick for measuring one's overall cardiovascular fitness. Although there are more sophisticated and more accurate tests that evaluate fitness according to a specific point

system, the *Harvard step test* described here is a quick way to compare the relative fitness level of a group of people.

## Methods and Results

You will be working in groups of four, duties assigned as indicated above, except that student 4, in addition to recording the data, will act as the timer and call the cadence.

***Any student with a known heart problem should refuse to participate as the subject.***

All four students may participate as the subject in turn, if desired, but the bench stepping is to be performed *at least twice* in each group--once with a well-conditioned person acting as the subject, and once with a poorly conditioned subject.

Bench stepping is the following series of movements repeated sequentially:

1. Place one foot on the step.
2. Step up with the other foot so that both feet are on the platform. Straighten the legs and the back.
3. Step down with one foot.
4. Bring the other foot down.

The pace for the stepping will be set by the "timer" (student 4), who will repeat "Up-2-3-4, up-2-3-4" at such a pace that each "up-2-3-4" sequence takes 2 sec (i.e., 30 cycles/min).

1. Student 4 should obtain the step (20-in. height for male subject, or 16 in. for a female subject) while baseline measurements are being obtained on the subject.
2. Once the baseline pulse and blood pressure measurements have been recorded on Chart 2, the subject is to stand quietly at attention for 2 min to allow his or her blood pressure to stabilize before beginning to step.
3. The subject is to perform the bench stepping for as long as possible, up to a maximum of 5 min, according to the cadence called by the timer. The subject is to be watched for and warned against crouching (posture must remain erect). If he or she is unable to keep the pace for a span of 15 sec, the test is to be terminated.
4. When the subject is stopped by the pacer, stops voluntarily because he or she is unable to continue, or has completed 5 min of bench stepping, he or she is to sit down. The duration of exercise (in seconds) is to be recorded, and the blood pressure and pulse are to be measured immediately and thereafter at 1-min intervals for 4 min post-exercise.
5. The subject's *index of physical Fitness* is to be calculated using the formula given below:

duration of exercise in seconds x 100

Index = -----

2 X sum of the 3 pulse counts in recovery

Scores are interpreted according to the following scale:

below 55 poor physical condition

55 to 62 low average

63 to 71 average

72 to 79 high average

80 to 89 good

90 and over excellent

6. Record the test values on Chart 2, and repeat the testing and recording procedure with the second subject.

Chart 2 Exercise

Harvard Step Test			Interval Following Test							
Baseline			Immediately		1 min		2 min		3 min	
	BP	P	BP	P	BP	P	BP	P	BP	P
Well conditioned										
Poorly conditioned										

## Discussion

1. When did you notice a greater elevation of blood pressure and pulse? Explain.
2. Was there a sizeable difference between the after-exercise values for well-conditioned and poorly conditioned individuals? Explain.
3. Did the diastolic pressure also increase?

# 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%

- water - 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%

- Red blood cells, White blood cells, Platelets
- 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%)

- engulf or capture pathogens and debris
- 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

### Platelets

- clump together, activate coagulation

# Hemostasis

## Vascular phase

- contraction of smooth muscle cells in vessel wall

## Platelet phase

- membranes of the endothelial 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 (agglutinins) that attack foreign agglutinogens as shown below.

<i>Blood Type</i>	<i>Frequency</i>	<i>Agglutinogen (Antigen)</i>	<i>Agglutinen (Antibody)</i>
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, Blood Types and Hematocrit - Laboratory

## 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	

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

## 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. Differential white count.

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 cellular debris, pathogens and antibody bound pathogens

## Specific defenses (Immunity)

### Lymphocytes

- Cytotoxic 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 cytotoxic 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



# Practice Questions – Cardiovascular System

For matching questions, choices may be used more than once or not at all.

## 1-5. Matching

- |                  |                                      |          |
|------------------|--------------------------------------|----------|
| A) basophils     | responsible for producing antibodies | 1) _____ |
| B) neutrophils   | engulf and destroy parasites         | 2) _____ |
| C) eosinophils   | attack and destroy viruses           | 3) _____ |
| D) b-lymphocytes | produce histamine                    | 4) _____ |
| E) t-lymphocytes | engulf debris                        | 5) _____ |

## 6-10. Matching

- |                  |                                              |           |
|------------------|----------------------------------------------|-----------|
| A) Blood type A  | has antibodies to the Rh protein             | 6) _____  |
| B) Blood type B  | has antibodies to the A protein only         | 7) _____  |
| C) Blood type AB | has antibodies to the B protein only         | 8) _____  |
| D) Blood type O  | has antibodies to both the A and B protein   | 9) _____  |
| E) do not know   | has antibodies to neither the A or B protein | 10) _____ |

## 11-15. Matching

- |                      |                                          |           |
|----------------------|------------------------------------------|-----------|
| A) coagulation phase | involves plasmin                         | 11) _____ |
| B) retraction phase  | involves vasoconstriction                | 12) _____ |
| C) vascular phase    | involves production of fibrin            | 13) _____ |
| D) platelet phase    | involves clumping of thrombocytes        | 14) _____ |
|                      | enhanced by tissue plasminogen activator | 15) _____ |

## 16-20. Matching

- |                            |                                           |           |
|----------------------------|-------------------------------------------|-----------|
| A) Platelet Thromboplastin | digests Fibrin                            | 16) _____ |
| B) Tissue Thromboplastin   | production involves Thrombin              | 17) _____ |
| C) Thrombin                | produced by damaged endothelium           | 18) _____ |
| D) Plasmin                 | production involves Thromboplastin        | 19) _____ |
| E) Fibrin                  | produced by platelets exposed to collagen | 20) _____ |

## 21-25. Matching

- |                      |                                             |           |
|----------------------|---------------------------------------------|-----------|
| A) albumins          | are a major contributor of blood osmolality | 21) _____ |
| B) globulins         | are found dissolved in blood plasma         | 22) _____ |
| C) fibrinogen        | act as carrier proteins for hormones        | 23) _____ |
| D) all of the above  | transformed by thrombin                     | 24) _____ |
| E) none of the above | contain hemoglobin                          | 25) _____ |

## 26-30. Matching

- |                               |                 |           |
|-------------------------------|-----------------|-----------|
| A) contains oxygen rich blood | Vena Cava       | 26) _____ |
| B) contains oxygen poor blood | Left atrium     | 27) _____ |
|                               | Right atrium    | 28) _____ |
|                               | Left ventricle  | 29) _____ |
|                               | Right ventricle | 30) _____ |

31-35. Trace the flow of a drop of blood thru the heart.

- A) vena cava 31) \_\_\_\_\_
- B) mitral valve 32) \_\_\_\_\_
- C) tricuspid valve 33) \_\_\_\_\_
- D) aortic semilunar valve 34) \_\_\_\_\_
- E) pulmonary semilunar valve 35) \_\_\_\_\_

36-40. Matching

- A) Ventricular contraction opens semilunar valves 36) \_\_\_\_\_
- B) Ventricular relaxation pulls blood out of atria 37) \_\_\_\_\_  
sucks blood into ventricles 38) \_\_\_\_\_  
pushes blood out of ventricles 39) \_\_\_\_\_  
opens mitral and tricuspid valves 40) \_\_\_\_\_

41-45. Matching

- A) End Diastolic Volume affected by heart rate 41) \_\_\_\_\_
- B) End Systolic Volume affected by filling time 42) \_\_\_\_\_
- C) none of the above affected by blood flow in vena cava 43) \_\_\_\_\_  
greatly affected by force of contraction 44) \_\_\_\_\_  
immediately affected by norepinephrine 45) \_\_\_\_\_

46-50. Matching

- A) Skeletal muscle cells are long 46) \_\_\_\_\_
- B) Cardiac muscle cells are short 47) \_\_\_\_\_
- C) Smooth muscle cells are found in the tunica media 48) \_\_\_\_\_
- D) B and C cells are connected by intercalated discs 49) \_\_\_\_\_  
contraction depends on calcium from extracellular fluid 50) \_\_\_\_\_

51-55. Matching

- A) SA node located near the vena cava 51) \_\_\_\_\_
- B) AV node conducts thru the bundle of His 52) \_\_\_\_\_  
located near the tricuspid valve 53) \_\_\_\_\_  
intrinsic rate about 40-60 per minute 54) \_\_\_\_\_  
intrinsic rate about 70-80 per minute 55) \_\_\_\_\_

56-60. Matching

- A) Acetylcholine increases sarcoplasmic storage of calcium 56) \_\_\_\_\_
- B) Norepinephrine acts on myocardium via Beta 1 receptors 57) \_\_\_\_\_
- C) none of the above acts on nodes via muscarinic receptors 58) \_\_\_\_\_  
hyperpolarizes nodal membrane 59) \_\_\_\_\_  
depolarizes nodal membrane 60) \_\_\_\_\_

61-65. Trace a drop of blood thru the coronary circulation.

- A) aorta 61) \_\_\_\_\_
- B) coronary sinus 62) \_\_\_\_\_
- C) marginal branches 63) \_\_\_\_\_
- D) right coronary artery 64) \_\_\_\_\_
- E) posterior descending branch 65) \_\_\_\_\_

66-70. Matching

- A) Compliance (C) equals  $BV / C$  66) \_\_\_\_\_  
 B) Blood Pressure (BP) equals  $SV \times HR$  67) \_\_\_\_\_  
 C) Cardiac Output (CO) equals  $CO \times VR$  68) \_\_\_\_\_  
 D) none of the above equals  $\Delta BV / \Delta BP$  69) \_\_\_\_\_  
 equals  $(EDV-ESV) \times HR$  70) \_\_\_\_\_

71-75. Matching

- A) Vascular Resistance (VR) equals  $BP / VR$  71) \_\_\_\_\_  
 B) Blood Flow (BF) equals  $BP / BF$  72) \_\_\_\_\_  
 C) none of the above equals  $BF / BP$  73) \_\_\_\_\_  
 increases as a power function of vessel radius 74) \_\_\_\_\_  
 decreases as a power function of vessel radius 75) \_\_\_\_\_

76-80. Matching

- A) post-capillary constriction increases arterial pressure 76) \_\_\_\_\_  
 B) pre-capillary constriction increases capillary pressure 77) \_\_\_\_\_  
 C) A and B decreases capillary pressure 78) \_\_\_\_\_  
 D) none of the above increases peripheral resistance 79) \_\_\_\_\_  
 increases fluid uptake by blood 80) \_\_\_\_\_

81-85. Matching

- A) cortisol stimulates aldosterone secretion 81) \_\_\_\_\_  
 B) glucagon facilitates fluid movement out of cells 82) \_\_\_\_\_  
 C) vasopressin stimulates water reabsorption by kidney 83) \_\_\_\_\_  
 D) angiotensin increases glucose concentration in blood 84) \_\_\_\_\_  
 E) norepinephrine leads to vasoconstriction via alpha receptors 85) \_\_\_\_\_

86-90. Matching

- A) atrial receptors respond to changes in venous return 86) \_\_\_\_\_  
 B) carotid sinus generally lead to reflex changes in volume 87) \_\_\_\_\_  
 C) aortic arch generally lead to reflex changes in pressure 88) \_\_\_\_\_  
 D) B and C respond to changes in blood pressure to head 89) \_\_\_\_\_  
 respond to changes in blood pressure in chest 90) \_\_\_\_\_

91-95. Matching

- A) P wave usually contains the largest of the waves 91) \_\_\_\_\_  
 B) T wave disappears with damage to the SA node 92) \_\_\_\_\_  
 C) QRS complex depolarization of the ventricles 93) \_\_\_\_\_  
 repolarization of the ventricles 94) \_\_\_\_\_  
 depolarization of the atria 95) \_\_\_\_\_

96-100. Matching

- A) Left atrium receives blood from the pulmonary veins 96) \_\_\_\_\_  
 B) Right atrium discharges blood into pulmonary arteries 97) \_\_\_\_\_  
 C) Left ventricle receives blood from the coronary sinus 98) \_\_\_\_\_  
 D) Right ventricle discharges blood into systemic arteries 99) \_\_\_\_\_  
 E) none of the above receives blood from the system veins 100) \_\_\_\_\_

101-105. Matching

- |                            |                                |            |
|----------------------------|--------------------------------|------------|
| A) Ventricular contraction | opens semilunar valves         | 101) _____ |
| B) Ventricular relaxation  | sucks blood into ventricles    | 102) _____ |
| C) none of the above       | pulls blood out of vena cava   | 103) _____ |
|                            | opens atrioventricular valves  | 104) _____ |
|                            | closes atrioventricular valves | 105) _____ |

106-110. Matching

- |                      |                                        |            |
|----------------------|----------------------------------------|------------|
| A) epicardium        | composed of simple squamous epithelium | 106) _____ |
| B) myocardium        | also called the visceral pericardium   | 107) _____ |
| C) endocardium       | covers the outside of the heart        | 108) _____ |
| D) A and C           | covers the inside of the heart         | 109) _____ |
| E) none of the above | composed of cardiac muscle             | 110) _____ |

111-115. Place in the order that signals pass through the cardiac conduction system.

- |                                                  |            |
|--------------------------------------------------|------------|
| A) atrial conduction fibers (internodal pathway) | 111) _____ |
| B) bundle branches                               | 112) _____ |
| C) bundle of His                                 | 113) _____ |
| D) SA node                                       | 114) _____ |
| E) AV node                                       | 115) _____ |

116-120. Matching

- |                      |                              |            |
|----------------------|------------------------------|------------|
| A) about 0.17 sec    | typical PR interval          | 116) _____ |
| B) about 0.35 sec    | typical QT interval          | 117) _____ |
| C) about 0.60 sec    | RR interval with a HR of 50  | 118) _____ |
| D) about 0.86 sec    | RR interval with a HR of 70  | 119) _____ |
| E) none of the above | RR interval with a HR of 100 | 120) _____ |

121-125. Matching

- |                                        |                                |            |
|----------------------------------------|--------------------------------|------------|
| A) stimulation of muscarinic receptors | increases heart rate           | 121) _____ |
| B) stimulation of alpha-1 receptors    | decreases heart rate           | 122) _____ |
| C) stimulation of beta-1 receptors     | increases stroke volume        | 123) _____ |
| D) stimulation of beta-2 receptors     | increases force of contraction | 124) _____ |
| E) none of the above                   | decreases force of contraction | 125) _____ |

126-130. Matching

- |                          |                                                 |            |
|--------------------------|-------------------------------------------------|------------|
| A) right coronary artery | is connected to right atrium                    | 126) _____ |
| B) left coronary artery  | is connected to ascending aorta                 | 127) _____ |
| C) coronary sinus        | branches to form the marginal arteries          | 128) _____ |
| D) A and B               | branches to form the circumflex artery          | 129) _____ |
|                          | branches to form the anterior descending artery | 130) _____ |

131-135. Place in the order that blood travels to the right arm, starting at the aortic arch.

- |                           |            |
|---------------------------|------------|
| A) radial artery          | 131) _____ |
| B) axillary artery        | 132) _____ |
| C) brachial artery        | 133) _____ |
| D) subclavian artery      | 134) _____ |
| E) brachiocephalic artery | 135) _____ |

136-140. Place in the order that blood may reach the right brain, starting at the lungs.

- |                            |      |       |
|----------------------------|------|-------|
| A) left ventricle          | 136) | _____ |
| B) pulmonary veins         | 137) | _____ |
| C) brachiocephalic artery  | 138) | _____ |
| D) internal carotid artery | 139) | _____ |
| E) common carotid artery   | 140) | _____ |

141-145. Place in the order that blood may reach the left leg, starting at the aorta.

- |                          |      |       |
|--------------------------|------|-------|
| A) descending aorta      | 141) | _____ |
| B) common iliac artery   | 142) | _____ |
| C) external iliac artery | 143) | _____ |
| D) femoral artery        | 144) | _____ |
| E) tibial arteries       | 145) | _____ |

146-150. Matching

- |                                          |                  |      |       |
|------------------------------------------|------------------|------|-------|
| A) blood drains into hepatic portal vein | renal veins      | 146) | _____ |
| B) blood drains directly into vena cava  | splenic vein     | 147) | _____ |
|                                          | gastric veins    | 148) | _____ |
|                                          | adrenal veins    | 149) | _____ |
|                                          | mesenteric veins | 150) | _____ |

151-155. Given: HR = 70; Blood Pressure = 120/ 80; Cardiac Output = 4.9 L; determine

- |         |                                    |      |       |
|---------|------------------------------------|------|-------|
| A) 0.86 | R-R interval (sec)                 | 151) | _____ |
| B) 70   | Stroke Volume (mL)                 | 152) | _____ |
| C) 80   | Mean arterial pressure (mmHg)      | 153) | _____ |
| D) 93.3 | Systolic arterial pressure (mmHg)  | 154) | _____ |
| E) 120  | Diastolic arterial pressure (mmHg) | 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

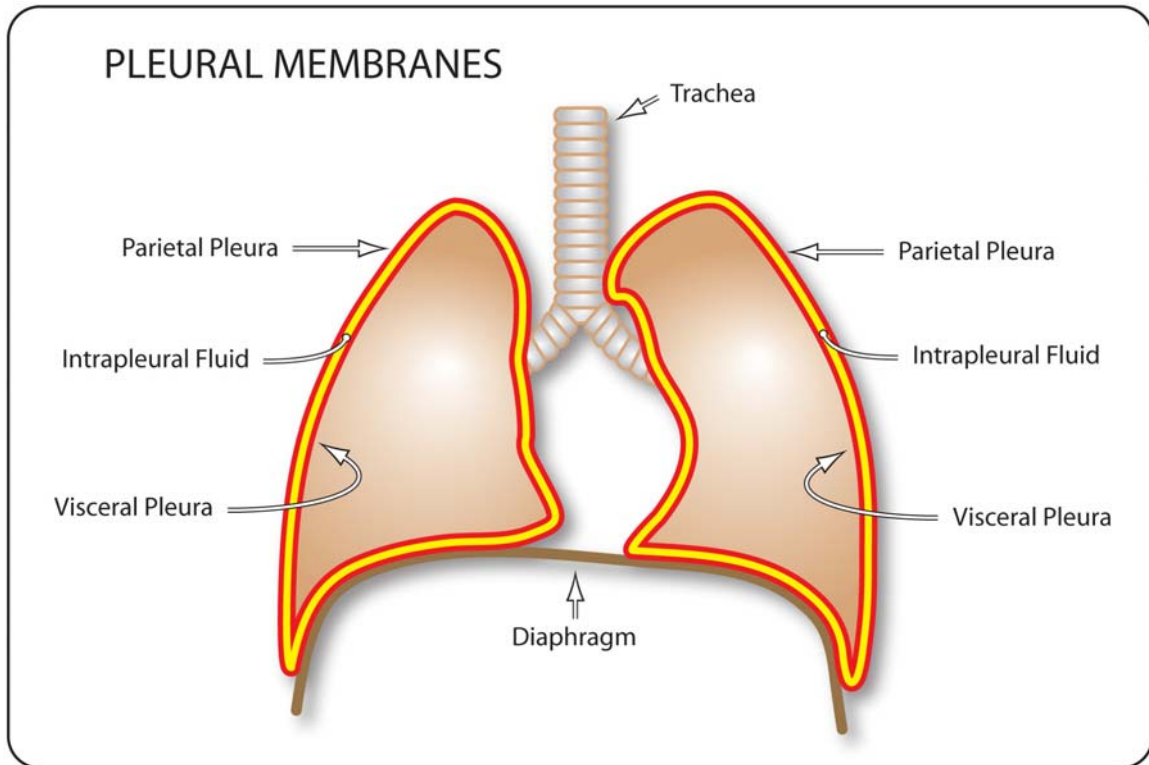
The lungs are located within the pleural cavities of the chest. The diaphragm is located below the pleural cavities, and forms a partition between the thoracic cavity and the abdominal cavity

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 them 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.

The pleural membranes are illustrated on the following page (Pleural Membranes).



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## Upper respiratory tract

### Nose

External nares – nostrils

Nasal cavity (ies)

Nasal septum – partition in the nasal cavity composed of the perpendicular plate of the ethmoid bone, the vomer bone, and nasal cartilage; produces a right and a left nasal cavity

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 lateral walls of nasal cavity

superior, middle and inferior

Nasal meatus(es) – spaces between adjacent conchae for air passage

superior, middle and inferior

### 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

Tracheal cartilage – structural corrugations of the trachea

## Primary bronchi

Right primary bronchus – right branch of trachea

Left primary bronchus – left branch of trachea

## Secondary bronchi

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

Left primary 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

Intrapulmonary (Segmental) bronchi – tertiary and smaller bronchi

Terminal bronchioles – branches of the smallest segmental bronchi

Respiratory bronchioles – branches of the terminal bronchiole

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

### Pulmonary circulation

right and left pulmonary arteries

right and left pulmonary veins

### Pleural cavities

Mediastinum – fibrous connective tissue that extends above and below the pericardial sac to separate 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

## Histology of Trachea and Lungs

### Trachea

#### Mucosa

- Pseudostratified ciliated columnar epithelium (PCCE)

#### Submucosa

- Tracheal cartilage
- Trachealis muscle – between open ends of tracheal cartilage

### Intrapulmonary (Segmental) bronchi

#### Mucosa

- PCCE

#### Submucosa

- smooth muscle layer
- cartilage plates

### Terminal bronchioles – branches of the smallest segmental bronchi

#### Mucosa

- Simple Cuboidal-like Epithelium with less cilia

#### Submucosa

- smooth muscle layer begins to disappear
- No cartilage plates

### Respiratory bronchioles – branches of the terminal bronchiole

#### Mucosa

- Simple Squamous Epithelium

#### Submucosa

- No smooth muscle
- No cartilage plates

**Alveolar ducts** – branches of the respiratory bronchiole

**Alveolar ducts and Alveoli**

Mucosa

- Simple Squamous Epithelium
- Surfactant cells are interspersed
- Elastic fibers are prominent
- Capillaries are prominent

**Alveolar Sacs** – clusters of alveoli that form around the alveolar ducts

# Respiratory Airways and Lungs - Laboratory

## Models of Upper respiratory tract

<p>Nose</p> <ul style="list-style-type: none"><li>• External Nares</li><li>• Nasal Cavity</li><li>• Nasal Septum</li><li>• Hard Palate</li><li>• Soft Palate</li><li>• Uvula</li><li>• Internal Nares</li><li>• Nasal Conchae</li><li>• Nasal Meatus(i) (superior, middle and inferior)</li></ul>	
<p>Pharynx</p> <ul style="list-style-type: none"><li>• Auditory tube</li><li>• Nasopharynx</li><li>• Oropharynx</li><li>• Laryngopharynx</li></ul>	
<p>Larynx</p> <ul style="list-style-type: none"><li>• Glottis</li><li>• Epiglottis</li><li>• Thyroid cartilage</li><li>• Cricoid cartilage</li><li>• Vestibular folds</li><li>• Vocal folds</li><li>• Vocal cords</li></ul>	

<p>Trachea</p> <ul style="list-style-type: none"><li>• Tracheal Cartilage</li></ul>	
<p>Primary bronchi</p> <ul style="list-style-type: none"><li>• Right Primary Bronchus</li><li>• Left Primary Bronchus</li></ul> <p>Secondary Bronchi</p> <ul style="list-style-type: none"><li>• Right Secondary Bronchi</li><li>• Left Secondary Bronchi</li></ul>	

## Models of Lower respiratory tract

<p>Right lung</p> <ul style="list-style-type: none"> <li>• Superior, Middle and Inferior Lobes</li> </ul> <p>Left lung</p> <ul style="list-style-type: none"> <li>• Superior and Inferior Lobes</li> <li>• Cardiac notch</li> </ul>	
<p>Intrapulmonary Bronchi (Segmental Bronchi)</p> <p>Pulmonary Circulation</p> <ul style="list-style-type: none"> <li>• Right and Left Pulmonary Arteries</li> <li>• Right and Left Pulmonary Veins</li> </ul>	
<p>Pleural Cavities</p> <ul style="list-style-type: none"> <li>• Mediastinum</li> <li>• Parietal Pleura</li> <li>• Visceral Pleura</li> <li>• Pleural Space</li> </ul>	

## Histology of Trachea

<p>Mucosa</p> <ul style="list-style-type: none"><li>• PCCE</li></ul> <p>Submucosa</p> <ul style="list-style-type: none"><li>• Tracheal cartilage</li><li>• Trachealis muscle</li><li>• Fibrous Connective Tissue</li></ul>	
----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------	--

## Histology of Lung

<p>Lung Lobule</p> <ul style="list-style-type: none"><li>• Visceral Pleura</li><li>• Elastic Connective Tissue</li><li>• Fibrous Connective Tissue</li></ul>	
<p>Intrapulmonary Bronchi</p> <p>Mucous</p> <ul style="list-style-type: none"><li>• PCCE</li></ul> <p>Submucosa</p> <ul style="list-style-type: none"><li>• smooth muscle layer</li><li>• cartilage plates</li></ul>	

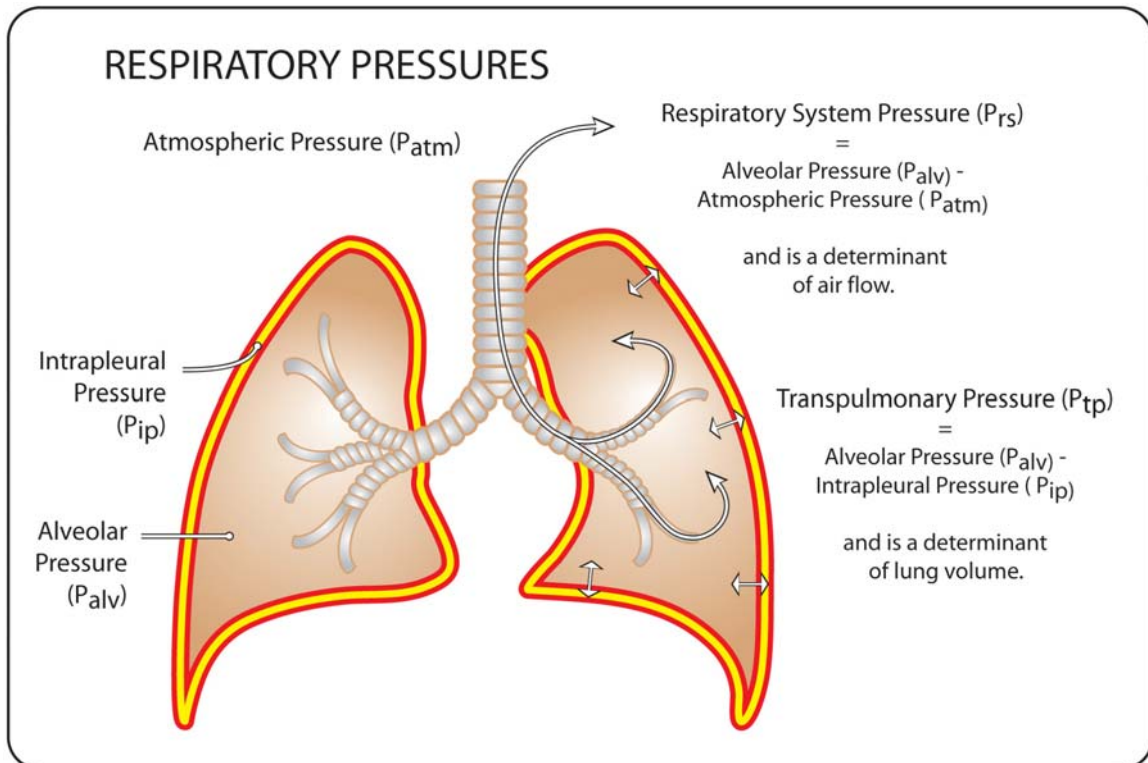
<p>Terminal Bronchioles</p> <p>Mucosa</p> <ul style="list-style-type: none"> <li>• Simple Cuboidal-like Epithelium</li> </ul> <p>Submucosa</p> <ul style="list-style-type: none"> <li>• no cartilage plates</li> </ul>	
<p>Respiratory Bronchioles</p> <p>Mucosa</p> <ul style="list-style-type: none"> <li>• Simple Squamous Epithelium</li> </ul> <p>Submucosa</p> <ul style="list-style-type: none"> <li>• no cartilage plates</li> </ul>	
<p>Alveolar ducts and Alveoli</p> <ul style="list-style-type: none"> <li>• Simple Squamous Epithelium</li> <li>• Elastic Connective Tissue</li> <li>• Pulmonary (Alveolar) Capillaries</li> </ul>	

# Pulmonary Ventilation and Lung Mechanics

Pulmonary ventilation is the process of moving air between the atmosphere and the alveoli of the lungs. Movement of air depends on changing the size of the lungs and is critically dependent on the elastic connective tissue of the lungs, the pleural membranes and pleural fluid, and the muscles of the chest and abdomen.

## Respiratory pressures

The role of atmospheric pressure ( $P_{atm}$ ), alveolar pressure and intrapleural pressure ( $P_{ip}$ ) in ventilation are illustrated below. 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.



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- Atmospheric pressure ( $P_{\text{atm}}$ ) (absolute measurement)
  - $\sim 760$  mmHg
- Alveolar pressure ( $P_{\text{alv}}$ ) (absolute measurement)
  - During quiet inspiration =  $\sim 757$  mmHg
  - During quiet expiration =  $\sim 763$  mmHg
- Respiratory system pressure ( $P_{\text{rs}}$ ) is the difference between alveolar pressure ( $P_{\text{alv}}$ ) and atmospheric pressure ( $P_{\text{atm}}$ ) and is a major determinant of air flow
  - during quiet inspiration =  $\sim -3$  mmHg
  - during quiet expiration =  $\sim +3$  mmHg

Intrapleural pressure ( $P_{\text{ip}}$ ) is almost always negative and ranges from slightly less than atmospheric pressure ( $P_{\text{atm}}$ ) during exhalation to much less than atmospheric pressure ( $P_{\text{atm}}$ ) during inhalation. The difference between alveolar pressure ( $P_{\text{alv}}$ ) and intrapleural pressure ( $P_{\text{ip}}$ ) is called transpulmonary pressure ( $P_{\text{tp}}$ ) and is a major determinant of lung volume.

- Intrapleural pressure ( $P_{\text{ip}}$ ) (absolute measurement)
  - During quiet inspiration =  $\sim 754$  mmHg
  - During quiet expiration =  $\sim 757$  mmHg
- Transpulmonary pressure ( $P_{\text{tp}}$ ) is the difference between alveolar pressure ( $P_{\text{alv}}$ ) and intrapleural pressure ( $P_{\text{ip}}$ ) and is a major determinant of air flow
  - during quiet inspiration =  $\sim +3$  mmHg
  - during quiet expiration =  $\sim +6$  mmHg

## Boyle's Law

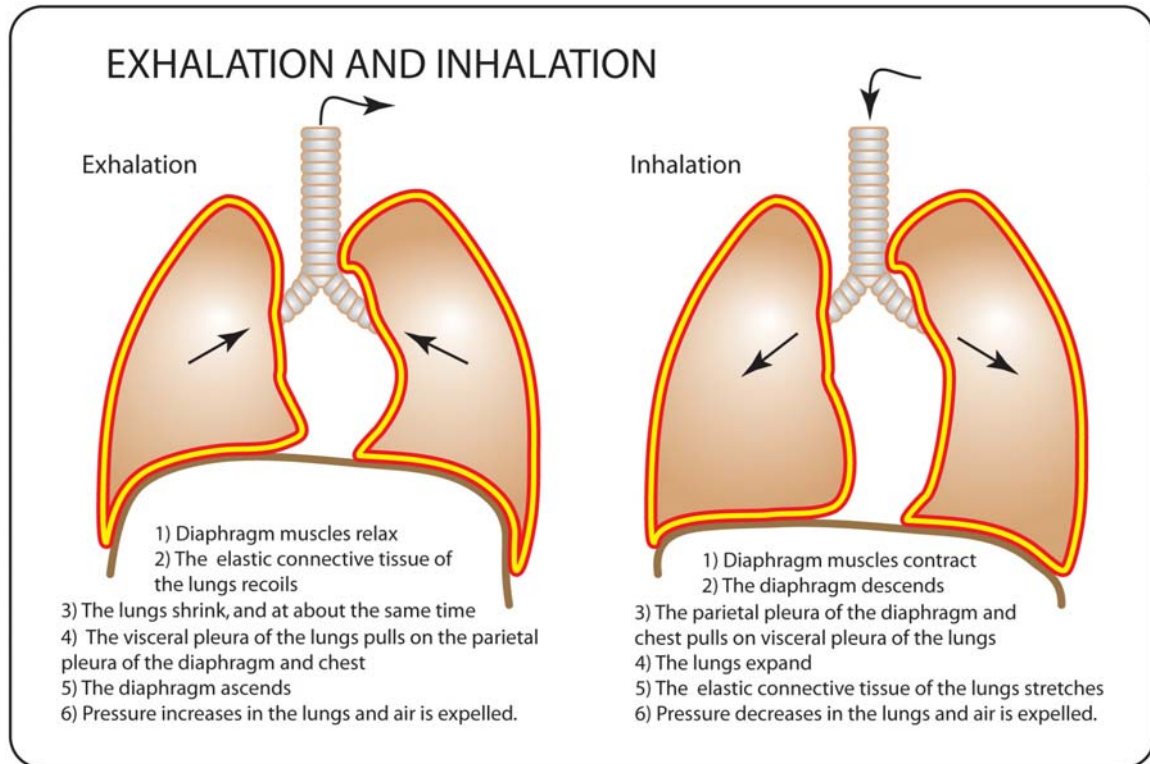
Boyle's law establishes the relationship between the pressure (P) and the volume (V) of gasses.

$$P = \frac{1}{V}$$

As the volume of the lungs increases the pressure decreases; as the volume of the lungs decreases the pressure increases.

## Exhalation and Inhalation

Exhalation and inhalation are illustrated below.



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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 ( $F_{\text{air}}$ ) 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 ( $R_{\text{aw}}$ ). The pressure driving the air ( $\Delta P$ ) 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 ( $P_{\text{rs}}$ ) and is the difference between the alveolar pressure ( $P_{\text{alv}}$ ) and the atmospheric pressure ( $P_{\text{atm}}$ ). Formally, air flow ( $F_{\text{air}}$ ) equals the pressure driving the air ( $P_{\text{rs}}$ ) divided by the resistance of the airways ( $R_{\text{aw}}$ ).

$$F = \frac{\Delta P}{R} \quad ; \quad F_{\text{air}} = \frac{P_{\text{alv}} - P_{\text{atm}}}{R_{\text{aw}}} = \frac{P_{\text{rs}}}{R_{\text{aw}}}$$

## 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.

$$F_{\text{air}} = \frac{P_{\text{rs}}}{R_{\text{aw}}} \quad ; \quad R_{\text{aw}} = \frac{P_{\text{rs}}}{F_{\text{air}}}$$

Airway resistance ( $R_{\text{aw}}$ ) is simply measured as the change in respiratory system pressure ( $P_{\text{rs}}$ ) for a given change in air flow ( $F_{\text{air}}$ ). 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 ( $R_{\text{aw}}$ ) increases, a greater change in respiratory system pressure ( $P_{\text{rs}}$ ) is needed to produce the same change in air flow ( $F_{\text{air}}$ ). Airway resistance ( $R_{\text{aw}}$ ) 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 by 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<sub>2</sub> 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 β<sub>2</sub> receptors.

## Lung compliance

Lung compliance ( $C_{\text{lung}}$ ) is a description of the flexibility of the lungs measured as the change in lung volume ( $V_{\text{lung}}$ ) for a given change in transpulmonary pressure ( $P_{\text{tp}}$ ). Lung compliance is usually expressed as mL/mmHg or L/mmHg.

$$P_{\text{tp}} = \frac{V_{\text{lung}}}{C_{\text{lung}}} \quad ; \quad C_{\text{lung}} = \frac{V_{\text{lung}}}{P_{\text{tp}}}$$

As lung compliance ( $C_{\text{lung}}$ ) increases a smaller change in transpulmonary pressure ( $P_{\text{tp}}$ ) is necessary for a given change in lung volume. Conversely, as lung compliance ( $C_{\text{lung}}$ ) decreases a larger change in transpulmonary pressure ( $P_{\text{tp}}$ ) 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).

$$V_{\min} = \text{RR} \times \text{TV}$$

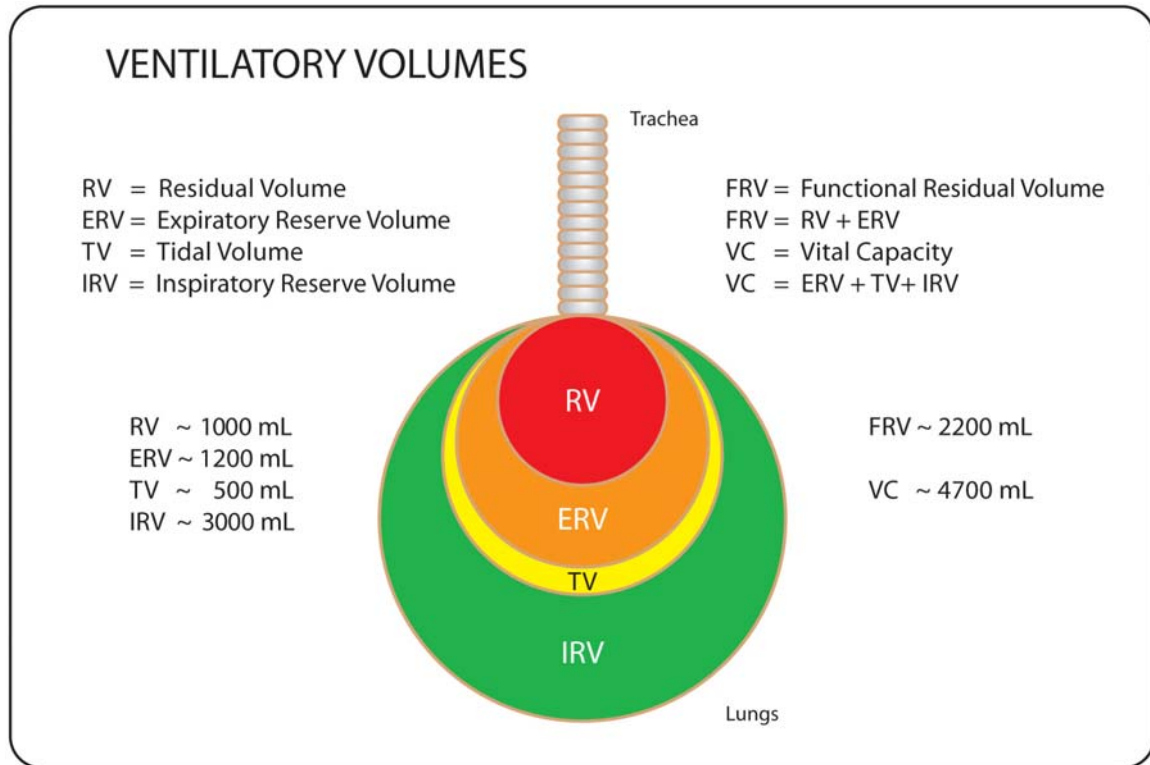
However, the airways form a dead space and only part of the tidal volume reaches the alveoli. Alveolar ventilation ( $V_{\text{alv}}$ ) is the volume of air moved into the alveoli each minute and equals the respiratory rate (RR) times the difference between the volume per breath (TV) and the dead space (DS).

$$V_{\min} = \text{RR} \times (\text{TV} - \text{DS})$$

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, as illustrated on the following page. 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.



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$$VC = IRV + TV + ERV$$

- 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:

<i>Ventilatory measurement</i>	<i>measured (liters)</i>	<i>calculated (liters)</i>
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

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_.

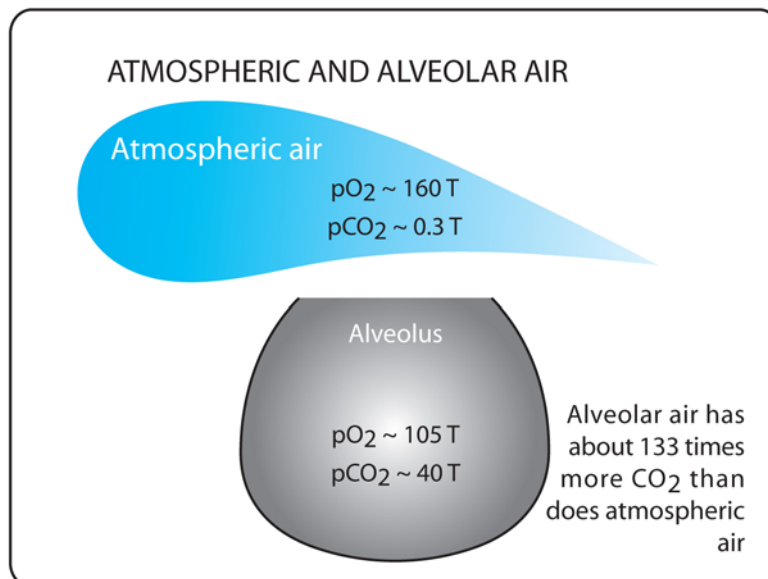
# Gas Exchange and Transport

## 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



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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.

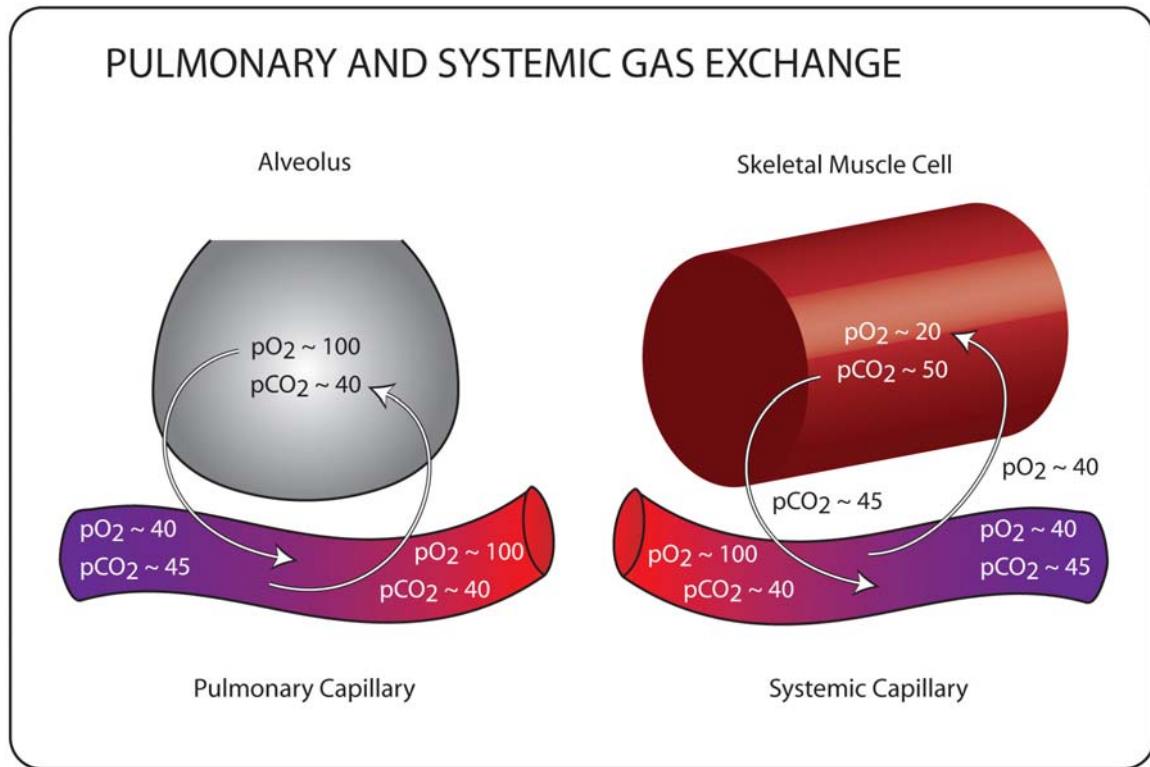
## Gas exchange

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.

<i>region</i>	$pO_2 T$	$pCO_2 T$
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. The figure on the following page illustrates the diffusion of gases in the lungs between the alveoli and pulmonary capillaries, and the diffusion of gases in muscle between muscle cells and systemic capillaries.



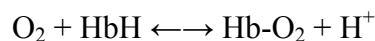
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In the lungs,  $O_2$  in the alveoli diffuses into the pulmonary capillary blood, and  $CO_2$  in the pulmonary blood diffuses into the alveoli. Blood that enters the pulmonary capillaries has a  $pO_2$  of 40T and a  $pCO_2$  of 46T. After leaving 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 about 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  $O_2$ ).

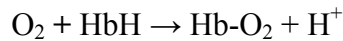


- as oxygen concentration in the blood increases, more oxygen combines with hemoglobin
- as oxygen concentration in the blood decreases, less oxygen combines with hemoglobin

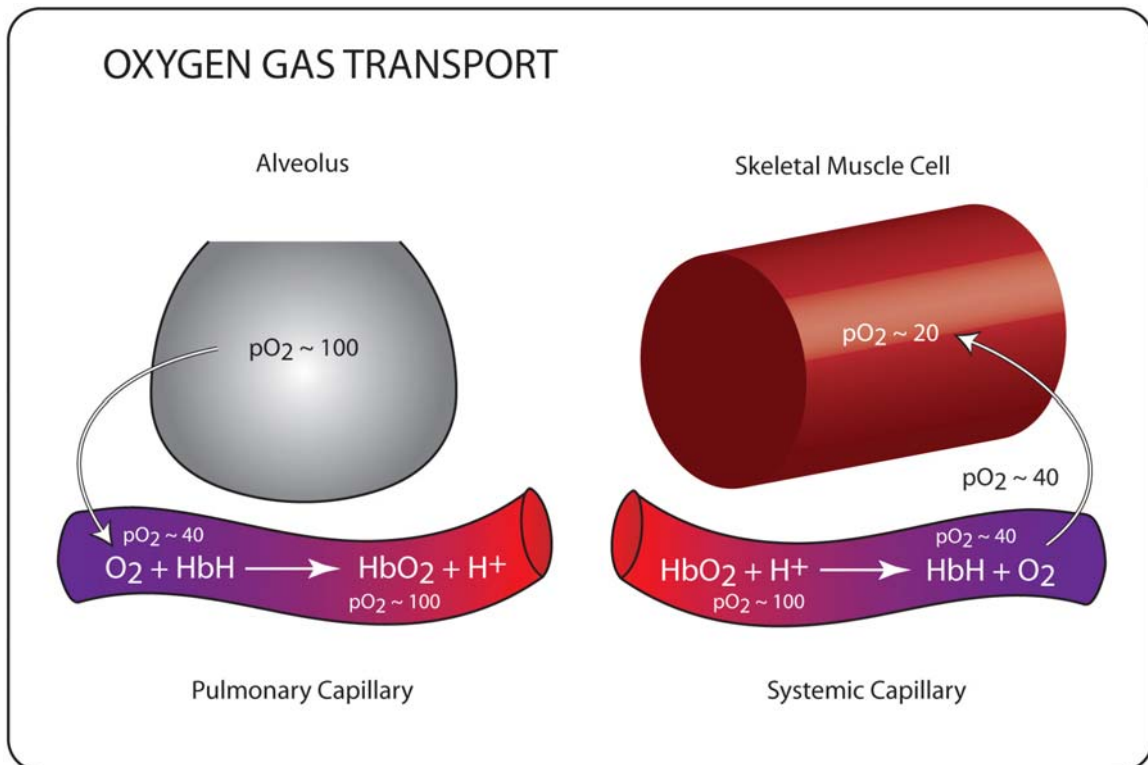
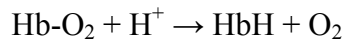
- Both  $H^+$  and  $CO_2$  compete with  $O_2$  for binding sites on hemoglobin, although with a lower affinity than  $O_2$ .

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.



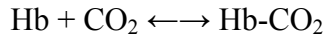
In the tissue capillaries, where the oxygen concentration of the tissues is less than the oxygen concentration of the blood, oxygen dissociates from hemoglobin and moves out of the blood.



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## 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<sub>2</sub>, the binding of O<sub>2</sub> to hemoglobin decreases the affinity of hemoglobin for CO<sub>2</sub> (Haldane effect) and further reduces the transport of CO<sub>2</sub> by hemoglobin.



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.



- 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

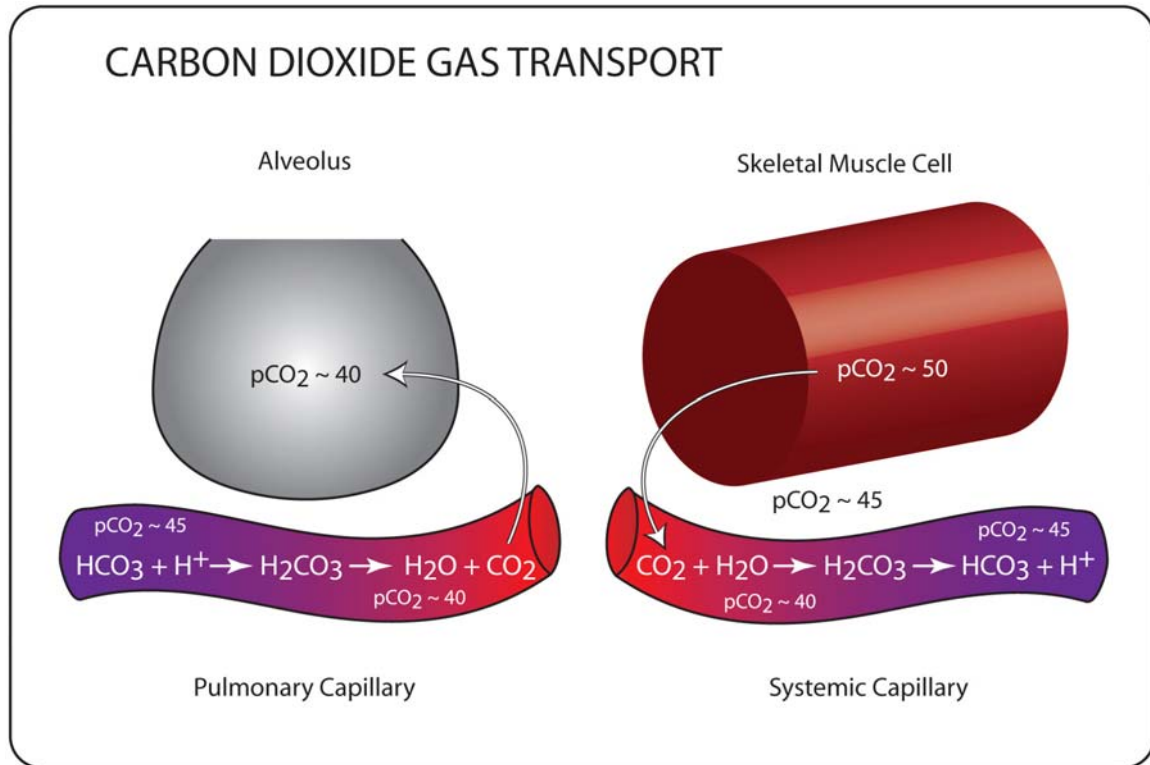
Added bicarbonate ions (such as from sodium bicarbonate) will decrease the dissociation of the carbonic acid and thus, decrease the production of hydrogen ions and raise the pH (refer to 'Acid-Base Balance'). Bicarbonate ions (HCO<sub>3</sub><sup>-</sup>) are transported out of the erythrocytes and into the plasma in exchange for Cl<sup>-</sup> (chloride shift).

Carbon dioxide transport is illustrated on the next page. 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.



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.





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## 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 the 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  $[H^+]$ .

Chemoreceptor control of respiration is shown on the next page. 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  $pO_2$  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**

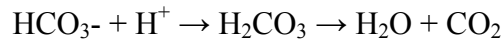
As we just saw the transport of carbon dioxide in blood is through carbonic acid, and bicarbonate and hydrogen ion formation.



- 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.

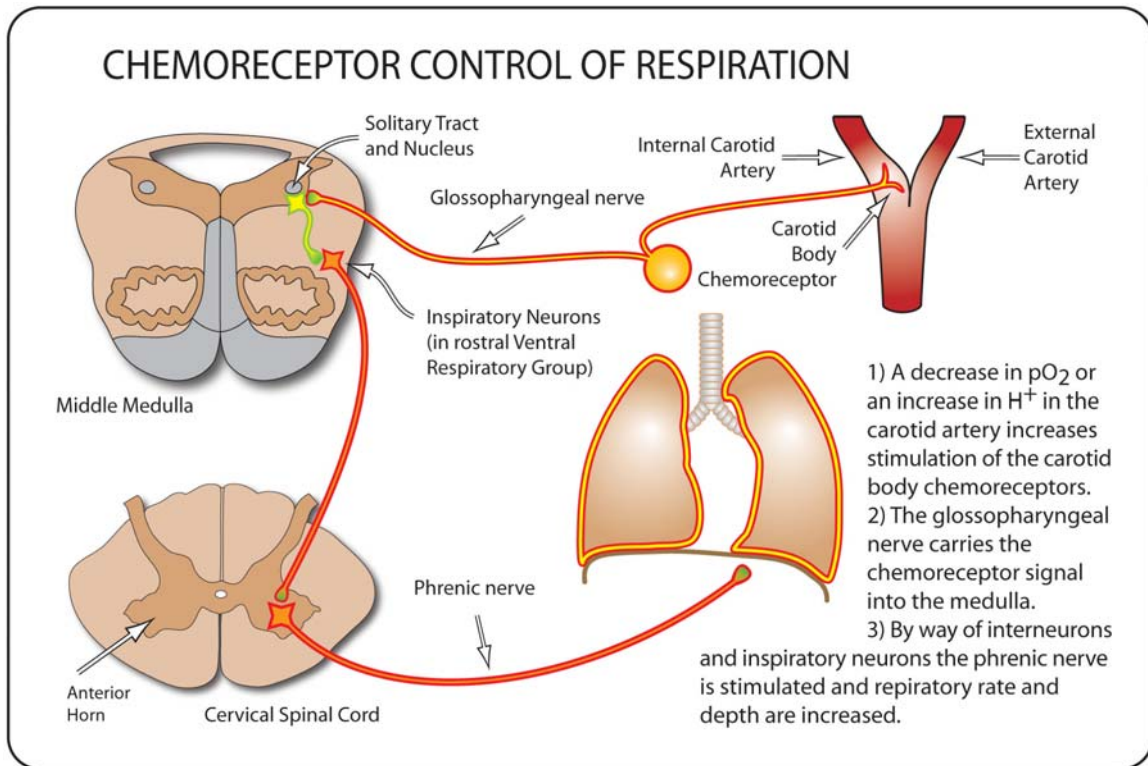
Removal of the  $\text{CO}_2$  by the lungs will thus decrease the  $\text{H}^+$  concentration and raise the pH.



$\text{CO}_2 \rightarrow$  into alveoli of lungs

Furthermore, excess  $\text{H}^+$  (from any source) can combine with  $\text{HCO}_3^-$  to produce  $\text{H}_2\text{CO}_3$  and thus  $\text{H}_2\text{O}$  and  $\text{CO}_2$  that can be removed by the lungs. The critical role of  $\text{CO}_2$  and  $\text{HCO}_3^-$  in determining pH is seen by the following relationship.

$$\text{pH} = 6.1 + \log \frac{[\text{HCO}_3^-]}{[\text{CO}_2]}$$



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### 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

<i>pH status</i>	<i>pCO<sub>2</sub></i>	<i>HCO<sub>3</sub></i>	<i>cause</i>
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 and soft palate

Uvula – between oral cavity and oropharynx; contains sensory receptors for swallowing

### Teeth

Incisors – for clipping or cutting; single root

Cuspids – for tearing or slashing; single root

Bicuspid (Premolars) – for crushing, mashing and grinding; one or two roots

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, pylorus

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 Gallbladder

### 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

Dentin – forms the bulk of the tooth and is similar to bone, no Osteocytes

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

Periodontal Ligament – fibrous connective tissue that anchors the Dentin to the Alveolar bone; similar to periosteum / ligaments

Cementum – covers the Dentin of the Root and anchors the Periodontal Ligament; similar to but harder than Dentin

Root – the base(s) of the teeth

Crown – the visible portion of the tooth that projects above the Gingiva

Neck – the boundary between the Root and the Crown

Gingiva – attaches to the tooth above the Neck; an epithelial barrier

Enamel – covers the Dentin of the Crown; densely packed calcium phosphate

### Esophagus (exemplary for most of GI tract except as noted) - slide of esophagus

#### Mucosa

- Stratified squamous epithelium

#### Submucosa

- Fibrous connective tissue

#### Muscularis externa

- Inner circular layer - circular layer of smooth muscle; for peristalsis
- Myenteric 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 – loose 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

## Models of the Digestive Tract

<p>Oral cavity</p> <ul style="list-style-type: none"> <li>• Parotid Gland</li> <li>• Hard Palate</li> <li>• Soft Palate</li> <li>• Uvula</li> </ul>	
<p>Teeth / Jaw</p> <ul style="list-style-type: none"> <li>• Central Incisor</li> <li>• Lateral Incisor</li> <li>• Cuspid (Canine)</li> <li>• 1<sup>st</sup> Premolar</li> <li>• 2<sup>nd</sup> Premolar</li> <li>• 1<sup>st</sup> Molar</li> <li>• 2<sup>nd</sup> Molar</li> <li>• 3<sup>rd</sup> Molar</li> </ul>	
<p>Tooth</p> <ul style="list-style-type: none"> <li>• Dentin</li> <li>• Pulp Cavity</li> <li>• Root Canal</li> <li>• Periodontal Ligament</li> <li>• Cementum</li> <li>• Root</li> <li>• Crown</li> <li>• Neck</li> <li>• Gingiva</li> <li>• Enamel</li> </ul>	

<p>Esophagus</p> <ul style="list-style-type: none"><li>• Upper Esophageal Sphincter</li><li>• Lower Esophageal Sphincter (Cardiac Sphincter)</li></ul>	
<p>Pharynx</p> <ul style="list-style-type: none"><li>• Oropharynx</li><li>• Laryngopharynx</li></ul>	
<p>Stomach</p> <ul style="list-style-type: none"><li>• Fundus</li><li>• Body</li><li>• Pylorus</li><li>• Rugae</li><li>• Pyloric Sphincter</li></ul>	
<p>Stomach Wall</p> <ul style="list-style-type: none"><li>• Mucosa<ul style="list-style-type: none"><li>○ Simple Columnar Epithelium</li><li>○ Gastric Pits</li><li>○ Gastric Glands</li><li>○ Muscularis Mucosae</li></ul></li><li>• Submucosa</li><li>• Muscularis Externa<ul style="list-style-type: none"><li>○ Inner Circular Layer</li><li>○ Outer Longitudinal Layer</li></ul></li><li>• Serosa</li></ul>	

<p>Small intestine</p> <ul style="list-style-type: none"> <li>• Duodenum             <ul style="list-style-type: none"> <li>○ Plicae Circularis</li> <li>○ Common Bile Duct</li> <li>○ Pancreatic Duct</li> </ul> </li> <li>• Jejunum</li> <li>• Ileum</li> <li>• Mesentary</li> </ul>	
<p>Small Intestine Wall</p> <ul style="list-style-type: none"> <li>• Intestinal Villi</li> <li>• Simple Columnar Epithelium</li> <li>• Goblet Cells</li> <li>• Intestinal Glands</li> <li>• Lacteals</li> <li>• Muscularis Mucosae</li> <li>• Duodenal Glands</li> <li>• Lymphatic Nodules</li> <li>• Inner Circular Layer</li> <li>• Myenteric Plexus</li> <li>• Outer Longitudinal Layer</li> </ul>	
<p>Colon</p> <ul style="list-style-type: none"> <li>• Cecum</li> <li>• Ileocecal Valve</li> <li>• Appendix</li> <li>• Ascending Colon</li> <li>• Transverse Colon</li> <li>• Descending Colon</li> <li>• Sigmoid Colon</li> <li>• Taenia Coli</li> <li>• Haustrae</li> <li>• Mesentary</li> </ul>	

<p>Rectum</p> <ul style="list-style-type: none"><li>• Internal Anal Sphincters</li><li>• External Anal Sphincters</li></ul>	
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## **Models of the Liver and Pancreas**

<p>Liver</p> <ul style="list-style-type: none"><li>• Gallbladder</li><li>• Cystic Duct</li><li>• Hepatic Duct</li><li>• Common Bile Duct</li><li>• Hepatic Veins</li><li>• Hepatic Arteries</li><li>• Hepatic Portal Vein</li></ul>	
<p>Pancreas</p> <ul style="list-style-type: none"><li>• Pancreatic Ducts</li></ul>	

## Histology of GI Tract

<p>Esophagus</p> <ul style="list-style-type: none"><li>• Mucosa<ul style="list-style-type: none"><li>○ Stratified Squamous Epithelium</li></ul></li><li>• Submucosa</li><li>• Muscularis externa<ul style="list-style-type: none"><li>○ Inner Circular Layer</li><li>○ Outer Longitudinal Layer</li></ul></li><li>• Adventitia</li></ul>	
<p>Stomach</p> <ul style="list-style-type: none"><li>• Mucosa<ul style="list-style-type: none"><li>○ Simple Columnar Epithelium</li><li>○ Gastric Pits</li><li>○ Gastric Glands<ul style="list-style-type: none"><li>▪ Mucus Neck Cells</li><li>▪ Parietal Cells</li><li>▪ Chief Cells</li></ul></li><li>○ Muscularis Mucosae</li></ul></li><li>• Submucosa</li><li>• Muscularis Externa<ul style="list-style-type: none"><li>○ Inner Circular Layer</li><li>○ Outer Longitudinal Layer</li></ul></li><li>• Serosa</li></ul>	

<p>Duodenum</p> <ul style="list-style-type: none"><li>• Mucosa<ul style="list-style-type: none"><li>○ Intestinal Villi</li><li>○ Simple Columnar Epithelium</li><li>○ Goblet Cells</li><li>○ Intestinal Glands</li><li>○ Lacteals</li><li>○ Lamina Propria</li><li>○ Muscularis Mucosae</li></ul></li><li>• Submucosa<ul style="list-style-type: none"><li>○ Duodenal Glands</li><li>○ Lymphatic Nodules</li></ul></li><li>• Muscularis Externa<ul style="list-style-type: none"><li>○ Inner Circular Layer</li><li>○ Myenteric Plexus</li><li>○ Outer Longitudinal Layer</li></ul></li><li>• Serosa</li></ul>	
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# 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 (a disaccharide) 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

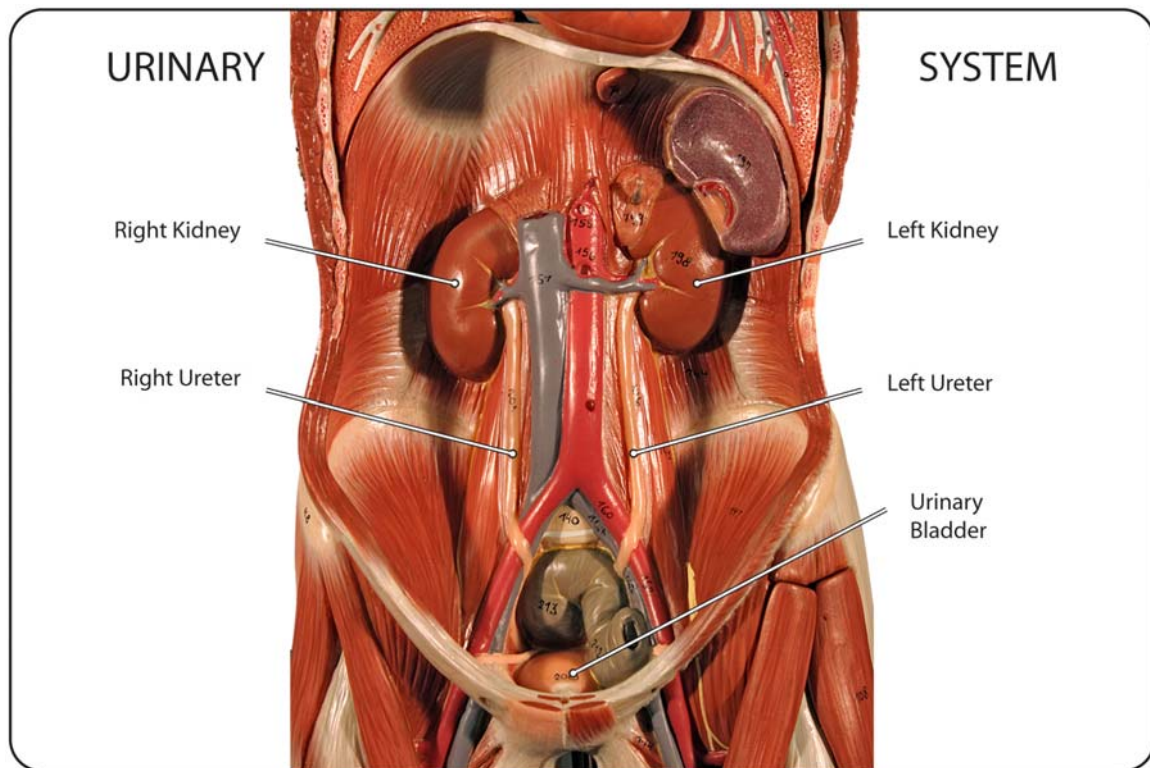
- simple sugars are absorbed through intestinal epithelium into blood capillaries by facilitated diffusion and cotransport
- amino acids are absorbed through the intestinal epithelium into blood capillaries by facilitated diffusion and cotransport
- large fatty acids (greater than 10 carbons) and monoglycerides 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

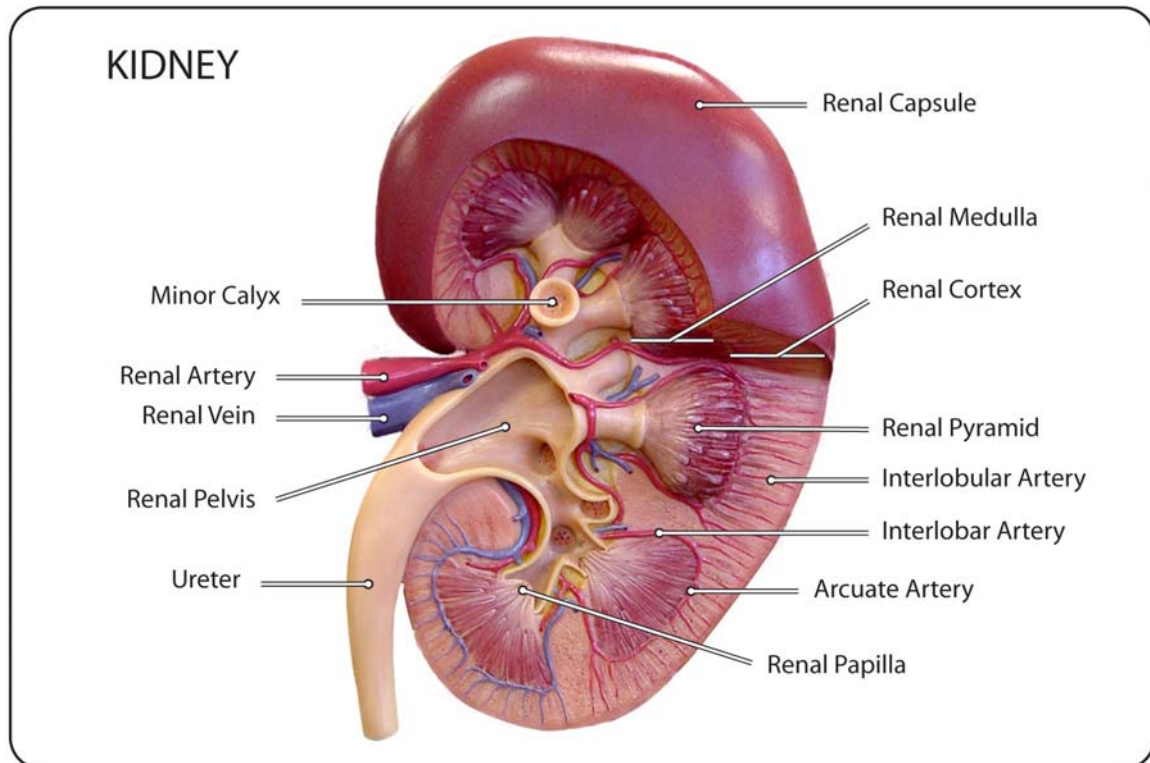
The kidneys are located in the retroperitoneal cavity of the abdomen, as shown below. The ureters extend from the hilus of each kidney, travel along the psoas muscles and cross over the iliac arteries and veins on their way to the urinary bladder. The urinary bladder rests on the anterior floor of the pelvic cavity.



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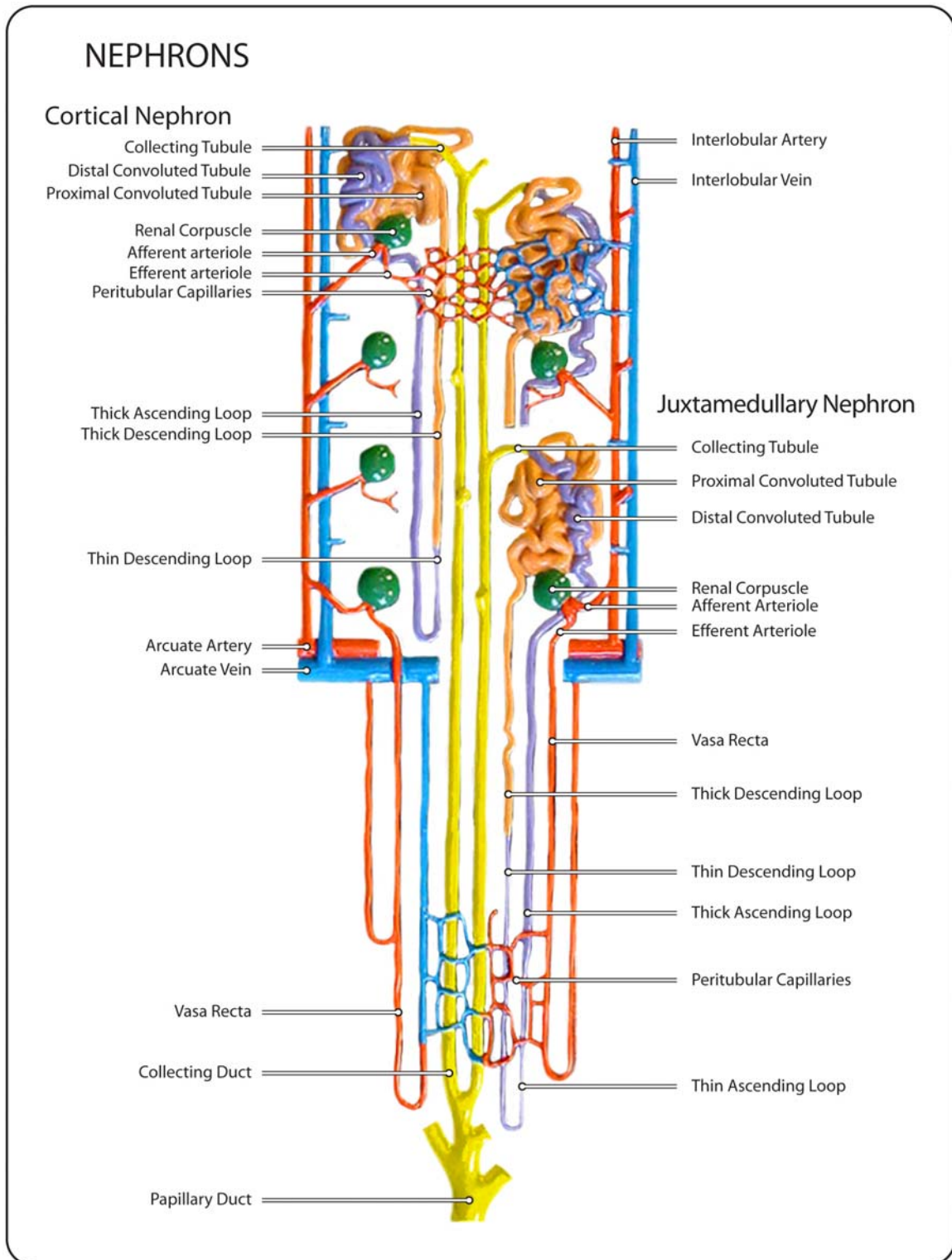
The internal structure of the kidney is shown in below. Each kidney is surrounded by the renal capsule. Internally, the outer region is the cortex and the inner region is the medulla. Blood enters the kidney by way of the renal artery which branches into several segmental arteries (not labeled). The 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.



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The processes of filtration and reabsorption occur in the nephrons which are shown on the next page. 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.



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## **Kidney**

Renal capsule - layer of collagen fibers covering the kidney

Adipose capsule - layer of adipose tissue covering the renal capsule

Hilus - indentation

Renal artery - carries blood to kidney

Renal vein - drains blood from kidney

Ureter - drains urine from kidney

Cortex - outer region

Medulla - intermediate region

Pyramids - distinct units within the medulla

Lobe – pyramid, each adjacent  $\frac{1}{2}$  Renal Column, and corresponding cortex

Renal columns - extensions of the cortex between pyramids

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 enclosed capillary network (**Glomerulus**)

- **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 loop of Henle
- lined with simple cuboidal epithelium

**Macula Densa** – taller cells of DCT near glomerulus (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

## Models of Kidney

<p>Kidney</p> <ul style="list-style-type: none"><li>• Renal capsule</li><li>• Hilus</li><li>• Renal artery</li><li>• Renal vein</li><li>• Ureter</li><li>• Cortex</li><li>• Medulla</li><li>• Pyramids</li><li>• Lobe</li><li>• Renal columns</li><li>• Papillae</li><li>• Renal pelvis</li><li>• Major calyces</li><li>• Minor calyces</li></ul>	
<p>Nephron</p> <ul style="list-style-type: none"><li>• Renal corpuscle (Bowman's capsule)</li><li>• Renal tubules</li><li>• Collecting system</li></ul>	

<p>Renal corpuscle</p> <ul style="list-style-type: none"> <li>• Parietal Epithelium (Capsular Epithelium)</li> <li>• Visceral Epithelium (Glomerular Epithelium)             <ul style="list-style-type: none"> <li>• Podocytes</li> </ul> </li> <li>• Capsular space</li> <li>• Glomerulus             <ul style="list-style-type: none"> <li>• Capillaries</li> </ul> </li> <li>• Afferent arteriole</li> <li>• Efferent arteriole</li> </ul>	
<p>Renal Tubules</p> <p>Proximal Convoluted tubule (PCT)</p> <p>Nephron Loop (of Henle)</p> <ul style="list-style-type: none"> <li>• Thick Descending limb</li> <li>• Thin Descending limb</li> <li>• Thin Ascending limb</li> <li>• Thick Ascending limb</li> </ul> <p>Distal Convoluted tubule (DCT)</p> <ul style="list-style-type: none"> <li>• Macula Densa</li> <li>• Juxtaglomerular cells</li> </ul>	

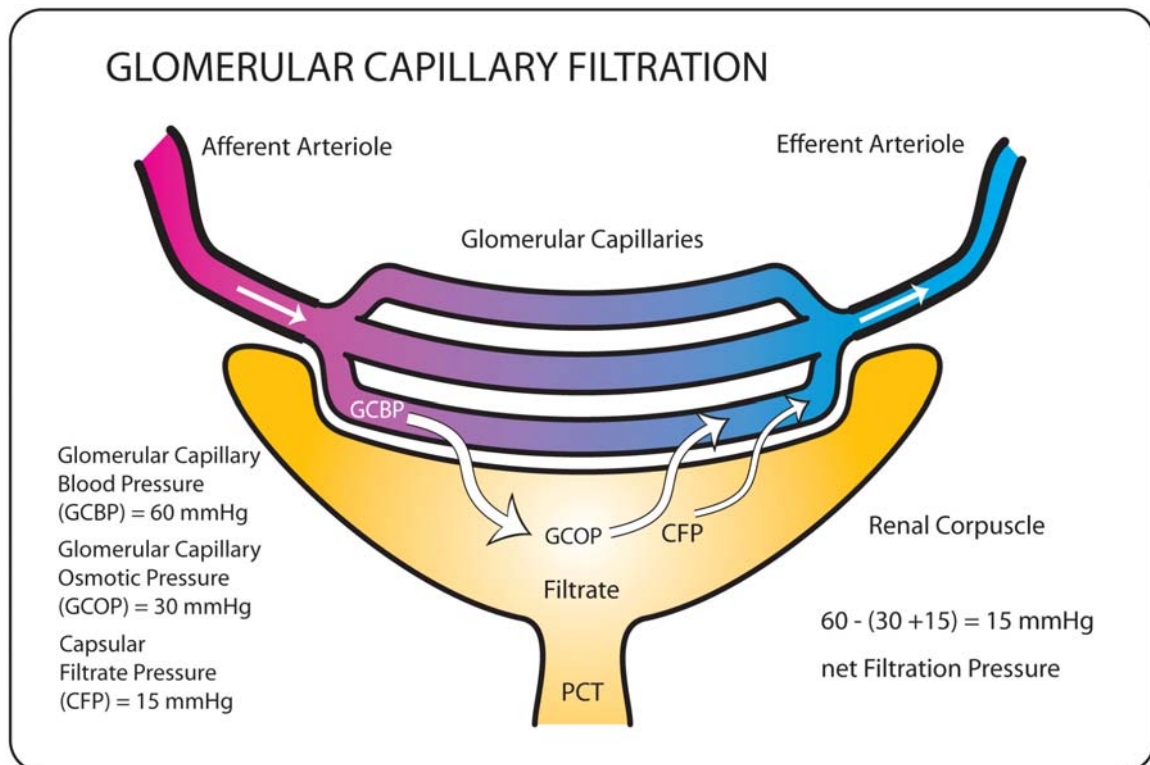
<p>Collecting system</p> <ul style="list-style-type: none"><li>• Collecting tubules</li><li>• Collecting ducts</li><li>• Papillary ducts</li><li>• Calyces</li><li>• Renal pelvis</li><li>• Ureter</li><li>• Bladder</li><li>• Urethra</li></ul>	
<p>Renal Vessels</p> <ul style="list-style-type: none"><li>• Renal artery</li><li>• Interlobar arteries</li><li>• Arcuate arteries</li><li>• Interlobular arteries</li><li>• Afferent arteriole</li><li>• Glomerulus</li><li>• Efferent arteriole</li><li>• Peritubular capillaries</li><li>• Vasa recta</li><li>• Interlobular veins</li><li>• Arcuate veins</li><li>• Interlobar veins</li><li>• Renal vein</li></ul>	

## **Histology of Kidney**

<p>Kidney</p> <ul style="list-style-type: none"><li>• Renal corpuscle</li><li>• Glomerulus</li><li>• Juxtaglomerular cells</li><li>• Proximal convoluted tubules</li><li>• Distal convoluted tubules</li><li>• Macula densa</li></ul>	
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# 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.



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## 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

Reabsorption from the renal tubules is summarized on the next page.

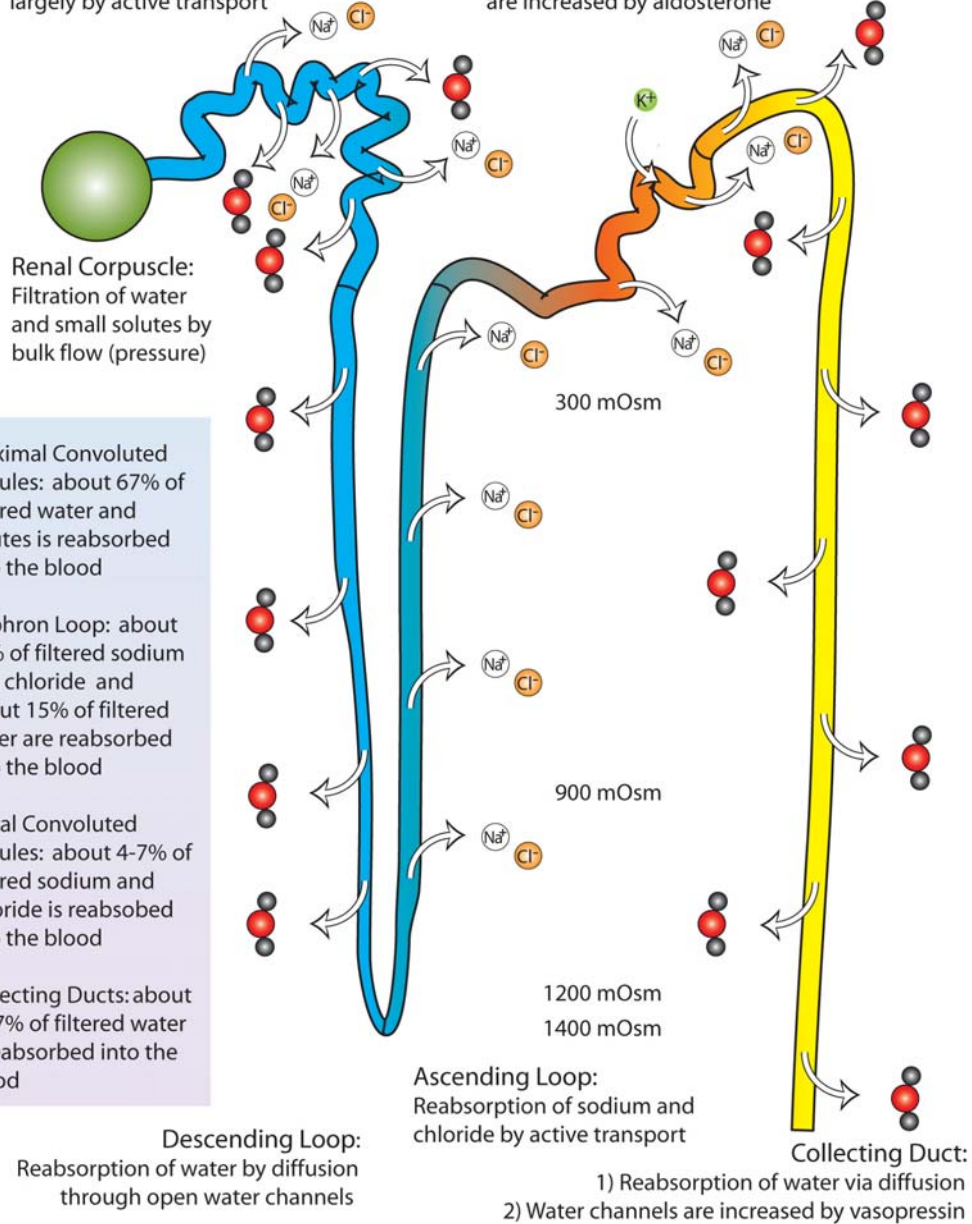
## REABSORPTION IN TUBULES AND DUCTS

### Proximal Convolved Tubule:

- 1) Reabsorption of water by diffusion through open water channels
- 2) Reabsorption of sodium and chloride largely by active transport

### Distal Convolved Tubule:

- 1) Reabsorption of sodium and chloride by active transport
- 2) Sodium / potassium pumps and channels are increased by aldosterone



# 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

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# Practice Questions - Exam # 6

For matching questions, choices may be used more than once or not at all.

## 1-5. Matching

- |                       |                                                  |          |
|-----------------------|--------------------------------------------------|----------|
| A) forced inspiration | caused by contraction of diaphragm               | 1) _____ |
| B) forced expiration  | caused by recoil of elastic fibers               | 2) _____ |
| C) quiet inspiration  | assisted by contraction of the scalenes          | 3) _____ |
| D) quiet expiration   | assisted by contraction of abdominal muscles     | 4) _____ |
|                       | assisted by contraction of internal intercostals | 5) _____ |

## 6-10. Matching

- |                |                                                        |           |
|----------------|--------------------------------------------------------|-----------|
| A) inspiration | parietal pleura pulls visceral pleura                  | 6) _____  |
| B) expiration  | visceral pleura pulls parietal 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) VC =              | IRV + TV + ERV  | 11) _____ |
| B) IRV =             | IRV + ERV       | 12) _____ |
| C) TV =              | VC - IRV        | 13) _____ |
| D) RV =              | IRV + TV        | 14) _____ |
| E) none of the above | VC - (TV + IRV) | 15) _____ |

## 16-20. Matching

- |                       |                                          |           |
|-----------------------|------------------------------------------|-----------|
| A) C =                | 1 / IPV                                  | 16) _____ |
| B) V <sub>min</sub> = | $\Delta V / \Delta P$                    | 17) _____ |
| C) AF =               | IPP / AR                                 | 18) _____ |
| D) IPP =              | V <sub>br</sub> x RR                     | 19) _____ |
|                       | is markedly affected by lung flexibility | 20) _____ |

## 21-25. Matching

- |                                                             |                         |           |
|-------------------------------------------------------------|-------------------------|-----------|
| A) pO <sub>2</sub> = ~100 mmHg; pCO <sub>2</sub> = ~40 mmHg | alveoli                 | 21) _____ |
| B) pO <sub>2</sub> = ~20 mmHg; pCO <sub>2</sub> = ~50 mmHg  | tissues                 | 22) _____ |
| C) pO <sub>2</sub> = ~150 mmHg; pCO <sub>2</sub> = ~<1 mmHg | atmosphere              | 23) _____ |
| D) pO <sub>2</sub> = ~40 mmHg; pCO <sub>2</sub> = ~45 mmHg  | systemic venous blood   | 24) _____ |
|                                                             | systemic arterial blood | 25) _____ |

## 26-30. Matching

- |                                                                                                                         |                                            |           |
|-------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|-----------|
| A) CO <sub>2</sub> + H <sub>2</sub> O → H <sub>2</sub> CO <sub>3</sub> → H <sup>+</sup> + HCO <sub>3</sub> <sup>-</sup> | seen in systemic tissues                   | 26) _____ |
| B) CO <sub>2</sub> + H <sub>2</sub> O ← H <sub>2</sub> CO <sub>3</sub> ← H <sup>+</sup> + HCO <sub>3</sub> <sup>-</sup> | seen in pulmonary tissues                  | 27) _____ |
| C) HCO <sub>3</sub> <sup>-</sup>                                                                                        | secreted into renal tubules                | 28) _____ |
| D) H <sup>+</sup>                                                                                                       | reabsorbed out of renal tubules            | 29) _____ |
|                                                                                                                         | occurs in cytoplasm of renal tubular cells | 30) _____ |

31-35. Matching \*\*\*\*\*

- |                                  |                                  |           |
|----------------------------------|----------------------------------|-----------|
| A) medullary inspiratory neurons | inhibit inspiratory neurons      | 31) _____ |
| B) medullary expiratory neurons  | stimulate expiratory neurons     | 32) _____ |
| C) pontine pneumotaxic neurons   | stimulate inspiratory neurons    | 33) _____ |
| D) pontine apneustic neurons     | stimulate muscles of expiration  | 34) _____ |
|                                  | stimulate muscles of inspiration | 35) _____ |

36-40. Matching

- |                               |                                             |           |
|-------------------------------|---------------------------------------------|-----------|
| A) high blood CO <sub>2</sub> | lowers pH                                   | 36) _____ |
| B) low blood CO <sub>2</sub>  | increases arterial pressure                 | 37) _____ |
|                               | makes blood more alkaline                   | 38) _____ |
|                               | increases rate and depth of respiration     | 39) _____ |
|                               | effects can be partially offset with bicarb | 40) _____ |

41-45. Matching

- |              |                                                  |           |
|--------------|--------------------------------------------------|-----------|
| A) peptidase | emulsifies fats                                  | 41) _____ |
| B) amylase   | breaks down fats in intestine                    | 42) _____ |
| C) pepsin    | breaks down protein in stomach                   | 43) _____ |
| D) lipase    | breaks down small proteins to amino acids        | 44) _____ |
| E) bile      | breaks down carbohydrates in mouth and intestine | 45) _____ |

46-50. Matching

- |                                |          |           |
|--------------------------------|----------|-----------|
| A) produced in liver           | amylase  | 46) _____ |
| B) produced in stomach         | elastase | 47) _____ |
| C) produced in pancreas        | sucrase  | 48) _____ |
| D) produced in small intestine | pepsin   | 49) _____ |
|                                | bile     | 50) _____ |

51-55. Matching

- |                                         |               |           |
|-----------------------------------------|---------------|-----------|
| A) absorbed into intestinal lymphatics  | fats          | 51) _____ |
| B) absorbed into intestinal capillaries | proteins      | 52) _____ |
| C) not absorbed through intestines      | fatty acids   | 53) _____ |
|                                         | amino acids   | 54) _____ |
|                                         | carbohydrates | 55) _____ |

56-60. Matching

- |                          |                                                |           |
|--------------------------|------------------------------------------------|-----------|
| A) osmosis               | movement of water along concentration gradient | 56) _____ |
| B) diffusion             | movement along a concentration gradient        | 57) _____ |
| C) filtration            | movement of water due to pressure              | 58) _____ |
| D) active transport      | diffusion using a carrier protein              | 59) _____ |
| E) facilitated diffusion | transport using added energy                   | 60) _____ |

61-65. Matching

- |            |                                           |           |
|------------|-------------------------------------------|-----------|
| A) 60 mmHg | net glomerular filtration pressure        | 61) _____ |
| B) 30 mmHg | glomerular capillary osmotic pressure     | 62) _____ |
| C) 20 mmHg | systemic capillary hydrostatic pressure   | 63) _____ |
| D) 10 mmHg | renal intracapsular hydrostatic pressure  | 64) _____ |
|            | glomerular capillary hydrostatic pressure | 65) _____ |

66-70. Matching

- |                                                |                                    |
|------------------------------------------------|------------------------------------|
| A) reabsorption of sodium via active transport | distal C. T. 66) _____             |
| B) reabsorption of water via diffusion         | proximal C. T. 67) _____           |
| C) A and B                                     | ascending loop of Henle 68) _____  |
| D) none of the above                           | descending loop of Henle 69) _____ |
|                                                | collecting tubules/ducts 70) _____ |

71-75. Matching

- |                                     |                                                                 |
|-------------------------------------|-----------------------------------------------------------------|
| A) reabsorption of bicarbonate ions | proximal and distal C. T. 71) _____                             |
| B) secretion of potassium           | 20% complete in loop of Henle 72) _____                         |
| C) reabsorption of water            | 60% complete in proximal C. T. 73) _____                        |
|                                     | controlled by aldosterone in distal C. T. 74) _____             |
|                                     | controlled by vasopressin in collecting tubules/ducts 75) _____ |

76-80. Matching

- |                             |                                                         |
|-----------------------------|---------------------------------------------------------|
| A) atrial stretch receptors | respond to osmolality of blood 76) _____                |
| B) juxtaglomerular cells    | respond to sodium concentration 77) _____               |
| C) adrenal cortex           | respond to potassium concentration 78) _____            |
| D) osmoreceptors            | respond to changes in venous return 79) _____           |
| E) macula densa             | respond to changes in renal pressure and flow 80) _____ |

81-85. Matching

- |                                |                                           |
|--------------------------------|-------------------------------------------|
| A) post-capillary constriction | increases arterial pressure 81) _____     |
| B) pre-capillary constriction  | increases capillary pressure 82) _____    |
| C) A and B                     | decreases capillary pressure 83) _____    |
| D) none of the above           | increases peripheral resistance 84) _____ |
|                                | increases fluid uptake by blood 85) _____ |

86-90. Matching

- |                   |                                                         |
|-------------------|---------------------------------------------------------|
| A) cortisol       | stimulates aldosterone secretion 86) _____              |
| B) glucagon       | facilitates fluid movement out of cells 87) _____       |
| C) vasopressin    | stimulates water reabsorption by kidney 88) _____       |
| D) angiotensin II | increases glucose concentration in blood 89) _____      |
| E) norepinephrine | leads to vasoconstriction via alpha receptors 90) _____ |

91-95. Matching

- |                    |                                                     |
|--------------------|-----------------------------------------------------|
| A) hyperosmolality | will lead to loss of fluid 91) _____                |
| B) hypervolemia    | elevated solute concentration 92) _____             |
|                    | will lead to accumulation of water 93) _____        |
|                    | will often increase arterial pressure 94) _____     |
|                    | is another term for elevated blood volume 95) _____ |

96-100. Matching

- |                          |                                                                        |
|--------------------------|------------------------------------------------------------------------|
| A) Respiratory Acidosis  | normal pCO <sub>2</sub> , low HCO <sub>3</sub> <sup>-</sup> 96) _____  |
| B) Respiratory alkalosis | low pCO <sub>2</sub> , low HCO <sub>3</sub> <sup>-</sup> 97) _____     |
| C) Metabolic Acidosis    | high pCO <sub>2</sub> , high HCO <sub>3</sub> <sup>-</sup> 98) _____   |
| D) Metabolic Alkalosis   | normal pCO <sub>2</sub> , high HCO <sub>3</sub> <sup>-</sup> 99) _____ |
|                          | seen with vomiting 100) _____                                          |

101-105. Matching

- |                      |                                        |            |
|----------------------|----------------------------------------|------------|
| A) visceral pleura   | covers the lungs                       | 101) _____ |
| B) parietal pleura   | lines the pleural cavities             | 102) _____ |
| C) A and B           | covers the pericardial sac             | 103) _____ |
| D) none of the above | produces the pleural fluid             | 104) _____ |
|                      | composed of simple squamous epithelium | 105) _____ |

106-110. Matching

- |                          |                                                      |            |
|--------------------------|------------------------------------------------------|------------|
| A) pulmonary capillaries | fluid leaks out of the blood                         | 106) _____ |
| B) systemic capillaries  | oxygen moves from the blood into cells               | 107) _____ |
| C) A and B               | oxygen moves from alveoli into the blood             | 108) _____ |
| D) none of the above     | carbon dioxide moves from cells into the blood       | 109) _____ |
|                          | carbon dioxide moves from the blood into the alveoli | 110) _____ |

111-115. Matching

- |                                          |                                          |            |
|------------------------------------------|------------------------------------------|------------|
| A) $O_2 + H_bH \rightarrow H_bO_2 + H^+$ | seen when blood $H^+$ is high            | 111) _____ |
| B) $O_2 + H_bH \leftarrow H_bO_2 + H^+$  | seen when blood $pO_2$ is high           | 112) _____ |
| C) none of the above                     | increases in the presence of lactic acid | 113) _____ |
|                                          | occurs in blood in systemic capillaries  | 114) _____ |
|                                          | occurs in blood in pulmonary capillaries | 115) _____ |

116-120. Matching

- |                                 |                      |            |
|---------------------------------|----------------------|------------|
| A) $1.0 \times 10^{-2} M [H^+]$ | neutral pH           | 116) _____ |
| B) $1.0 \times 10^{-6} M [H^+]$ | weakly acidic        | 117) _____ |
| C) $1.0 \times 10^{-7} M [H^+]$ | strongly acidic      | 118) _____ |
| D) $1.4 \times 10^{-7} M [H^+]$ | normal blood pH      | 119) _____ |
|                                 | found in the stomach | 120) _____ |

121-125. Matching Place the following in the order that food passes.

- |                      |            |
|----------------------|------------|
| A) jejunum           | 121) _____ |
| B) ileocecal valve   | 122) _____ |
| C) transverse colon  | 123) _____ |
| D) pyloric sphincter | 124) _____ |
| E) cardiac sphincter | 125) _____ |

126-130. Matching

- |                           |                           |            |
|---------------------------|---------------------------|------------|
| A) carbohydrate digestion | occurs in mouth           | 126) _____ |
| B) protein digestion      | occurs in stomach         | 127) _____ |
| C) fat digestion          | occurs in esophagus       | 128) _____ |
| D) all of the above       | occurs in large intestine | 129) _____ |
| E) none of the above      | occurs in small intestine | 130) _____ |

131-135. Matching

- |                    |                                                          |            |
|--------------------|----------------------------------------------------------|------------|
| A) liver           | the major site for detoxification of absorbed substances | 131) _____ |
| B) pancreas        | the major source of digestive enzymes                    | 132) _____ |
| C) stomach         | the major site for nutrient absorption                   | 133) _____ |
| D) small intestine | the major site for fluid reabsorption                    | 134) _____ |
| E) large intestine | the source of bile                                       | 135) _____ |

136-140. Matching

- |                           |                                      |      |       |
|---------------------------|--------------------------------------|------|-------|
| A) found in renal medulla | ureter                               | 136) | _____ |
| B) found in renal cortex  | renal artery                         | 137) | _____ |
| C) found in renal hilus   | renal pyramids                       | 138) | _____ |
|                           | afferent arterioles                  | 139) | _____ |
|                           | Bowman's Capsules (renal corpuscles) | 140) | _____ |

141-145. Matching

- |                      |                                                     |      |       |
|----------------------|-----------------------------------------------------|------|-------|
| A) 125 mL/min        | normal reabsorption of tubular fluids by the kidney | 141) | _____ |
| B) 124 mL/min        | urine formation by the kidney without vasopressin   | 142) | _____ |
| C) 25 mL/min         | normal filtrate formation by the kidney             | 143) | _____ |
| D) 1 mL/min          | normal urine formation by the kidney                | 144) | _____ |
| E) none of the above | normal cardiac output                               | 145) | _____ |

146-150. Matching

- |                      |                              |      |       |
|----------------------|------------------------------|------|-------|
| A) filtration        | proximal convoluted tubules  | 146) | _____ |
| B) reabsorption      | collecting tubules and ducts | 147) | _____ |
| C) none of the above | distal convoluted tubules    | 148) | _____ |
|                      | renal corpuscles             | 149) | _____ |
|                      | loop of Henle                | 150) | _____ |

151-155. Place in order the structures through which urinary filtrate passes.

- |                                 |      |       |
|---------------------------------|------|-------|
| A) loop of Henle                | 151) | _____ |
| B) capsular space               | 152) | _____ |
| C) distal convoluted tubule     | 153) | _____ |
| D) collecting tubules and ducts | 154) | _____ |
| E) proximal convoluted tubule   | 155) | _____ |

156-160. Matching

- |                                                 |                              |      |       |
|-------------------------------------------------|------------------------------|------|-------|
| A) contains ciliated columnar epithelium (PCCE) | mucosa of alveoli            | 156) | _____ |
| B) contains stratified squamous epithelium      | mucosa of trachea            | 157) | _____ |
| C) contains simple columnar epithelium          | mucosa of duodenum           | 158) | _____ |
| D) contains simple cuboidal epithelium          | mucosa of esophagus          | 159) | _____ |
| E) none of the above                            | convoluted tubules of kidney | 160) | _____ |

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.