# Contents

# A1. Anatomy and Physiology; Overview

**- A: Anatomy and Physiology**

**Anatomy:** Study of the body's structures
**Physiology:** Study of the body's functions

→ $Anatomy\ and\ physiology\ are\ closely\ related;\ structure\ facilitates\ function$

---

**- B: Body Systems**

1. **Integumentary**
2. **Skeletal**
3. **Muscular**
4. **Nervous**
5. **Endocrine**
6. **Cardiovascular**
7. **Lymphatic**
8. **Respiratory**
9. **Digestive**
10. **Urinary**
11. **Reproductive** (male, female)

---

**- C: Primary Function of Body Systems**

Primary function of body systems: Maintaining **homeostasis**

Primary mechanism body systems use to regulate homeostasis: **Feedback mechanism**

- Components of a feedback mechanism
    - **Receptor:** Senses the stimuli, sends a signal to the…
    - **Control Center**
        - Receives the incoming signal
        - Decides on a response
        - Sends an outgoing signal to the…
    - **Effector:** Carries out the response
- Types of feedback mechanisms
    - **Negative feedback:** Reduces the stimulus and return the body to the homeostatic **set point**
    - **Positive feedback:** Amplifies the stimulus (rare; occurs in blood clotting and childbirth)

**A1. Anatomy and Physiology; Overview**

**- D: Directional Terms**

**Directional terms**

- Used to describe the location of one organ relative to another
- Always given in reference to a body in **anatomical position**

Terms

- **Superior:** Towards the top of the body
- **Inferior:** Towards the bottom of the body
- **Anterior / ventral:** Towards the front of the body
- **Posterior / dorsal:** Towards the back of the body
- **Medial:** Towards the midline of the body
- **Lateral:** Further from the midline of the body
- **Ipsilateral:** On the same side of the midline of the body
- **Contralateral:** On opposite sides of the midline of the body
- **Proximal:** Closer to the point of attachment of the organ or limb
- **Distal:** Further from the point of attachment of the organ or limb
- **Superficial:** Closer to the surface of the body
- **Deep:** Further from the surface of the body

---

**- E: Reference Planes**

**Reference planes:** Separate the body into directional sections

- **Sagittal:** Separates the body into right and left sections
    - **Midsagittal:** Plane is aligned with the midline of the body
    - **Parasagittal:** Plane is parallel to the midline of the body, towards the side
- **Frontal / coronal:** Separates the body into anterior and posterior sections
- **Transverse / cross section:** Separates the body into superior and inferior sections
- **Oblique**

**- F: Body Cavities**

**Body cavities:** House the body's organs

- **Dorsal body cavity**
    - **Cranial cavity:** Houses the brain
    - **Spinal cavity:** Houses the spinal cord
- **Ventral body cavity**
    - **Thoracic cavity**
        - **Pleural cavities (r, l):** Houses the lungs
        - **Mediastinum:** Central area located between the pleural cavities
            - **Pericardial cavity:** Houses the heart
    - **Diaphragm:** Muscle; separates the thoracic and abdominopelvic cavities
    - **Abdominopelvic cavity**
        - **Abdominal cavity:** Houses the abdominal organs
        - **Pelvic cavity:** Houses the pelvic organs

---

**- G: Serous Membranes**

**Serous membranes:** Line body cavities not open to the exterior

- Components
    - **Parietal membrane:** Lines the inner wall of the cavity
    - **Visceral membrane:** Covers the organs located within the cavity
    - **Cavity:** The space between the parietal and visceral membranes; filled with **serous fluid**
- Serous membranes:
    - **Pericardium:** Located in the pericardial cavity
        - **Parietal Pericardium**
        - **Visceral Pericardium**
    - **Pleura:** Located in the pleural cavity
        - **Parietal Pleura**
        - **Visceral Pleura**
    - **Peritoneum:** Located in the abdominopelvic cavity
        - **Parietal Peritoneum**
        - **Visceral Peritoneum**

**- H: Abdominopelvic Quadrants**

**Abdomiopelvic quadrants:** Divide the abdominopelvic cavity into four regions by two imaginary planes

Planes

- **Median plane:** Drawn vertically through the midline of the body
- **Transumbilical plane:** Drawn horizontally at the level of the umbilicus

Regions

- **Right upper quadrant (RUQ)**
- **Left upper quadrant (LUQ)**
- **Right lower quadrant (RLQ)**
- **Left lower quadrant (LLQ)**

Primary location of abdominopelvic organs:

- RUQ
    - Right lobe of the liver
    - Gallbladder
    - Duodenum
    - Head of the pancreas
    - Right kidney and adrenal gland
    - Hepatic flexure of the colon
    - Portions of the ascending and transverse colon
- LUQ
    - Left lobe of the liver
    - Stomach
    - Spleen
    - Body and tail of the pancreas
    - Left kidney and adrenal gland
    - Splenic flexure of the colon
    - Portions of the transverse and descending colon
- RLQ
    - Cecum
    - Appendix
    - Ascending colon
    - Right ovary and fallopian tube (in females)
    - Right ureter
    - Right spermatic cord (in males)
- LLQ
    - Descending colon
    - Sigmoid colon
    - Left ovary and fallopian tube (in females)
    - Left ureter
    - Left spermatic cord (in males)

**A1. Anatomy and Physiology; Overview**

**- I: Abdominopelvic Regions**

**Abdominopelvic regions:** Divide the abdominopelvic cavity into nine regions by four imaginary lines

Lines

- **Midclavicular lines:** Two lines drawn vertically from the midpoint of each clavicle
- **Subcostal line:** Drawn horizontally just below the rib cage
- **Transtubercular line:** Drawn horizontally at the level of the iliac tubercles

Regions

- Top row
    - **Right hypochondriac region**
    - **Epigastric region**
    - **Left hypochondriac region**
- Middle row
    - **Right lumbar region**
    - **Umbilical region**
    - **Left lumbar region**
- Bottom row
    - **Right iliac / inguinal region**
    - **Hypogastric / pubic region**
    - **Left Iliac / inguinal region**

Location of abdominopelvic organs

- Right hypochondriac region
    - Right lobe of the liver
    - Gallbladder
    - Right kidney and adrenal gland
    - Portions of the small intestine
- Epigastric region
    - Stomach
    - Left lobe of the liver
    - Pancreas
    - Duodenum
    - Spleen
    - Adrenal glands
- Left hypochondriac region
    - Stomach
    - Spleen
    - Splenic flexure of the colon
    - Tail of the pancreas
    - Left kidney and adrenal gland
- Right lumbar region
    - Ascending colon
    - Right kidney

    - Portions of the small intestine
- Umbilical region
    - Jejunum and ileum
- Left lumbar region
    - Descending colon
    - Left kidney
    - Portions of the small intestine
- Right iliac / inguinal region
    - Cecum
    - Appendix
    - Ascending colon
    - Portions of the small intestine
- Hypogastric / pubic region
    - Urinary bladder
    - Sigmoid colon
    - Portions of the small intestine
    - Reproductive organs (uterus and ovaries in females, prostate in males)
- Left iliac / inguinal region
    - Descending colon
    - Sigmoid colon
    - Portions of the small intestine

# A2. Anatomy and Physiology; Tissues

**- A: Tissue Types, Overview**

Epithelial tissue
- Simple epithelium
    - Simple squamous epithelium
    - Simple cuboidal epithelium
    - Simple columnar epithelium
    - Pseudostratified columnar epithelium
- Stratified epithelium
    - Stratified squamous epithelium
    - Transitional epithelium

Connective tissue
- Bone
- Cartilage
    - Hyaline cartilage
    - Fibrocartilage
    - Elastic cartilage
- Dense
    - Dense regular fibrous tissue
    - Dense irregular fibrous tissue
- Loose
    - Areolar tissue
    - Adipose tissue
    - Reticular tissue
- Blood / lymph

Muscular tissue
- Skeletal muscle
- Cardiac muscle
- Smooth muscle

Nervous tissue

**- B: Epithelial Tissue**

Characteristics

- **Apical surface** exposed to the external environment or body cavity
- **Basal surface** attached to the **basement membrane**
    - Basement membrane: **basal lamina** (superficial)**, reticular lamina** (deep)
- Innervated but avascular; supported by underlying connective tissue
- Tightly packed cells with numerous tight junctions and desmosomes
- Highly regenerative

**Simple squamous epithelium**

- Single layer of flat cells with prominent central nuclei
- Small cytoplasm with few organelles
- Highly permeable (optimal for exchange vessels)
- Provides a smooth, frictionless surface (optimal for fluid flow)
- Location:
    - Alveoli, capillaries
    - Blood vessels, Inner heart lining
    - Serous membranes

**Simple cuboidal epithelium**

- Single layer of cuboidal cells with central nuclei
- Larger cytoplasm with more organelles for basic absorption and secretion functionality
- Provides some structural support
- Location:
    - Smaller glands (thyroid, salivary, sweat)
    - Pancreas
    - Kidney tubules
    - Ovaries

**Simple columnar epithelium**

- Single layer of column-shaped cells with nuclei aligned towards the bottom
- Larger cytoplasm with abundant organelles for advanced absorption and secretion functionality
- May contain goblet cells, cilia, and microvilli
- Location:
    - Digestive tract, gallbladder
    - Fallopian tubes, uterus
    - Portions of the respiratory tract
    - Select glands

**Pseudostratified columnar epithelium**

- Single layer of column-shaped cells with varied heights, appearing stratified
- Contains goblet cells and cilia
- Specialized for secreting mucus and expelling trapped particles
- Location:

- Respiratory tract

**Stratified squamous epithelium**

- Multiple layers of squamous cells
- Thick and tough for advanced protection against constant friction
- Locations:
    - Skin
    - Mouth, esophagus
    - Vagina, anal canal

**Transitional epithelium**

- Stratified cells that can slide past each other and change shape
- Highly stretchable
- Cells near the apical surface appear pillow-shaped when relaxed
- Location:
    - Urinary tract (urethra, ureter, bladder)

**Glandular epithelium**

- **Endocrine glands**
    - Secrete into internal blood vessels
    - Produce hormones
- **Exocrine Glands**
    - Secrete into external ducts leading to the target site
    - Produce non-hormonal secretions

**- C: Connective Tissue**

Composition: **Extracellular matrix (ECM)** with interspersed cells

- ECM components
    - Ground substance
    - Protein fibers (collagen, elastic, reticular)

**Bone (osseous tissue)**

- Hard, tough ECM made of inorganic calcium phosphate and collagen fibers

**Cartilage**

- Contains **chondrocytes** in **lacunae** (pits within the ECM)
- **Hyaline Cartilage**
    - Has a smooth, glassy appearance, due to the ECM collagen not being arranged in distinct fibers
    - Location:
        - Embryonic skeleton, growth plates, articular cartilage
        - Costal cartilage
        - Nose, trachea, larynx
- **Fibrocartilage**
    - Wavy rows of collagen fibers
    - Compressible; absorbs shock
    - Location:
        - Intervertebral disc
        - Pubic Symphysis
- **Elastic cartilage**
    - Bundles of elastic fibers
    - Location:
        - Pinnae
        - Epiglottis

**Dense connective tissue**

- **Dense regular fibrous tissue**
    - Ropes of thick, wavy, parallel-running collagen fibers
    - **Fibroblasts** are seeded throughout the ECM (not in lacunae)
    - Location:
        - Tendons, ligaments
- **Dense irregular fibrous tissue**
    - Sheets of collagen fibers arranged in irregular formation
    - Location:
        - Dermis
        - Periosteum, perichondrium

**Loose connective tissue**

- **Areolar**
    - Soft, pliable, cobwebby fibers and fibroblasts
    - “Universal packing”, “connective glue”
    - Location:

        - Beneath epithelial tissue
        - Surrounding blood vessels and nerves
- **Adipose**
    - Contains **adipocytes** (fat-storing cells)
        - A large drop of oil occupies most of the adipocyte cytoplasm
        - Nucleus is visibly pushed to the side
        - Stores fat, protects, cushions, regulates
        - Location:
            - Hypodermis
            - Surrounds the kidneys, heart, eye socket
            - Fat depots in hips, belly, breasts
            - Yellow bone marrow
- **Reticular**
    - Composed of reticular fibers and cells in a network-like structure
    - Forms the supportive meshwork for organs
    - Location:
        - Lymph nodes
        - Spleen, liver, kidneys
        - Bone marrow

**Blood (vascular tissue)**

- White blood cells, red blood cells, and platelets within a blood plasma ECM

**- D: Muscular Tissue**

Characteristic: Contracts when stimulated

Types

- **Skeletal**
  - Long, cylindrical, striated cells with multiple nuclei
  - Under voluntary control
  - Facilitates skeletal movement
- **Cardiac**
  - Shorter, branching striated cells, fitted together at intercalated discs
  - Uninucleate
  - Gap junctions at intercalated discs facilitate rapid intercellular communication, enabling simultaneous cardiac contraction
  - Involuntary
  - Located in the heart
- **Smooth**
  - Thin, spindle-shaped, non-striated cells with central nuclei
  - Uninucleate
  - Perform **peristalsis** (wave-like contractions) to move contents through tracts
  - Involuntary
  - Locations:
    - Blood and lymph vessels
    - GI tract
    - Uterus
    - Urinary tract

---

**- E: Nervous Tissue**

Characteristics:

- Specialized to receive and transmit electrical signals
- Contain **neurons** and **neuroglia**
- Located in the brain, spinal cord and nerves

**- F: Tissue Repair**

Tissue repair process

- **Inflammation:**
  - Capillaries near the damaged tissue provide clotting agents and other substances, plugging the hole and sectioning off the area
- **Granulation Tissue**
  - Intermediary granulation tissue forms
- **Regeneration / Fibrosis**
  - **Regeneration:** The damaged tissue is replaced by the same type of tissue, if possible
  - **Fibrosis:** If regeneration is not possible, the damaged tissue is replaced with dense connective scar tissue, losing functionality and elasticity

# B1. Integumentary System; Skin and Membranes

**- A: Membranes; Overview**

**Epithelial membrane**
- **Cutaneous membrane**
- **Mucosa**
- **Serous membrane**

**Connective tissue membrane**
- **Synovial membrane**

Epithelial membrane
- Epithelial tissue with an underlying layer of connective tissue

Cutaneous membrane (skin)
- Covers the body's external surface
- Layers:
  - **Epidermis:** Superficial epithelium
  - **Dermis:** Deep connective tissue

Mucosa
- Lines internal body cavities that are open to the exterior
  - Respiratory tract
  - Digestive tract
  - Urinary tract
  - Reproductive tract
- Layers:
  - Upper layer: columnar, pseudostratified, or stratified squamous epithelial tissue
  - **Lamina propria:** Underlying layer of areolar connective tissue

Serous membrane
- Lines internal body cavities that are not open to the exterior
  - **Pleura**
  - **Pericardium**
  - **Peritoneum**
- Simple squamous epithelium with a thin underlying layer of connective tissue
- Structures:
  - **Parietal membrane:** Lines the cavity walls
  - **Visceral membrane:** Covers the organs located within the cavity
  - **Serous fluid:** Fills the cavity between the parietal and visceral membranes

Synovial membrane
- Lines the **synovial cavity** within **synovial joints**

## B1. Integumentary System; Skin and Membranes

**- B: Cutaneous Membrane Overview**

**Integumentary system**

- Protects the body's exterior
- Includes the skin and its appendages (sweat and oil glands, hair, nails)

Cutaneous membrane

- Part of the integumentary system
- Functions
    - Protection
    - Thermal regulation
        - Through sweat, **vasoconstriction** and **vasodilation**
    - Waterproofing
    - Excretion
    - Vitamin D synthesis

Layers

- **Epidermis**
- **Dermis**
- **Hypodermis**

**- C: Epidermis**

Composition: Stratified squamous epithelium

Layers
- **Stratum corneum**
- **Stratum lucidum**
- **Stratum granulosum**
- **Stratum spinosum**
- **Stratum basale**

Stratum basale / stratum germinativum: Bottom layer
- **Basal cells:** Skin stem cells; produce keratinocytes
- **Keratinocytes:** Skin cells; undergo rapid mitosis; begin migrating upwards to stratum spinosum
- **Melanocytes:** Produce melanosomes
    - **Melanosome:** Sac containing melanin
    - **Melanin:** Pigment; protects keratinocytes from UV radiation
    - **Dendrites:** Melanocyte extensions; transfer melanosomes to keratinocytes in the stratum spinosum
- **Merkel /tactile cells:** Sense light touch

Stratum spinosum
- Keratinocytes
    - Actively dividing, though at a slower rate than in stratum basale
    - Connected to each other via desmosomes, giving a spiny appearance
    - Receive melanosomes
    - Begin producing keratin
        - **Keratin:** Fibrous protein; contributes toughness to skin, hair and nails
- **Dendritic / Langerhans cells:** Star-shaped immune cells

Stratum granulosum
- Primary site of keratinization
    - **Keratinization:** Keratinocytes produce keratin, flatten, and begin apoptosis (programmed cell death)

Stratum lucidum
- Only present in thick skin (palms, soles)
    - Thick skin does not have hairs
- Contains clear cells that are not yet fully keratinized cells

Stratum corneum
- Contains dead, tough, opaque, fully keratinized cells
- Apical surface cells flake off and are replaced by new keratinocytes pushed up from the lower layers

**- D: Dermis**

Composition:
- Connective tissue
- Highly vascular
- Innervated

Layers:
- **Papillary layer** (superficial)
  - Composition: Areolar connective tissue
  - Contains:
    - **Dermal papillae**
      - Small projections into the epidermis; increase dermal-epidermal surface area for substance exchange
      - Responsible for epidermis surface ridges
    - **Meissner corpuscles:** Sense steady pressure
    - Free nerve endings
- **Reticular layer** (deep)
  - Composition: Dense irregular connective tissue
  - Contains:
    - **Lamellar (Pacinian) corpuscles:** Onion-shaped sensors for deep pressure
    - Sebaceous and sudoriferous glands
    - Hair follicles

---

**- E: Cutaneous Glands**

**Sebaceous glands**
- Only found in thin skin
- Secrete sebum into hair follicles
  - **Sebum:** Oily substance; lubricates and waterproofs skin and hair

**Sudoriferous glands**
- **Eccrine gland (merocrine secretion)**
  - Standard sweat glands; secrete to the skin
- **Apocrine gland**
  - Larger glands; located in axillary and genital regions; secrete into hair follicles
  - Specialized apocrine glands:
    - **Ceruminous gland:** Located in ear canal; produces cerumen (ear wax)
    - **Mammary gland**

**- F: Hair**

Composition: Dead, highly keratinized cells

Regions:

- **Shaft:** Located above the skin surface
- **Root:** Located below the skin surface in the **follicle** sheath

Structures:

- **Follicle**
  - Cavity containing the hair root and bulb
  - Walls are composed of a superficial epithelium and deep dermal layer
- **Bulb**
  - Region at the bottom of the follicle
  - Contains the hair papilla (similar to dermal papilla) and hair matrix
- **Hair matrix**
  - Epidermal stratum basale; contains basal cells which produce the hair keratinocytes, and melanocytes
- **Arrector Pili Muscle:** Smooth muscle; pulls hair upright

---

**- G: Nail**

Composition**:** Dead, highly keratinized cells

Regions:

- **Free edge**
- **Body**
- **Root**

Structures

- **Nail matrix**
  - Epidermal stratum basale
  - Located beneath the root

**- H: Hypodermis**

Hypodermis
- Location: Deep to the dermis
- Classification: **Subcutaneous** (not part of the cutaneous membrane)
- Composition: Primarily adipose tissue
- Function: Anchors dermis to underlying muscle
- Contains: Lamellar corpuscles

---

**- I: Normal Skin Color Factors**

- **Melanin**
  - Causes yellow, brown, black
- **Carotene**
  - Causes orange / yellow
  - Obtained from select vegetables
- **Hemoglobin**
  - Causes redness
  - Factors: hematocrit, vasoconstriction / vasodilation

---

**- J: Body Temperature Regulation**

Body temperature
- Most energy released by cellular respiration is lost to heat
- The hypothalamus maintains body temperature homeostasis
  - Heat promoting mechanisms
    - **Vasoconstriction**
    - **Shivering**
  - Heat reducing mechanisms
    - **Vasodilation (radiation)**
    - **Sweating (evaporation)**
- **Fever**: Triggered by **pyrogens**

# C1. Skeletal System; Skeletal Tissue

**- A: Overview**

Bone functions

- Structure, support, movement, protection, storage (calcium; fat in yellow bone marrow), hematopoiesis (blood cell production in red bone marrow)

---

**- B: Bone Tissue**

Bone Tissue

- ECM
    - **Hydroxyapatite:** Inorganic calcium phosphate; provides hardness
    - **Collagen fibers:** Provides toughness and flexibility
- Cells
    - **Osteoprogenitor cells:** Differentiate into osteoblasts
    - **Osteoblasts:** Produce the ECM
    - **Osteocytes**
        - Mature osteoblasts embedded within ECM lacunae
        - Have extensions extending through canaliculi for communication and substance exchange

**Osteoporosis:** Condition; porous bone tissue

- Vitamin-D (synthesized by skin, liver, kidneys) is necessary for calcium absorption; deficiency can lead to osteoporosis

Types of bone tissue

- **Spongy / cancellous bone tissue**
- **Compact bone tissue**

Spongy / cancellous bone tissue

- ECM lamellae form **trabeculae** (an irregular porous network)

Compact bone tissue

- Composed of parallel extending **osteons** / **Haversian systems**
- **Osteons:** Consist of:
    - Central **Haversian canal** containing blood vessels and nerves
    - Surrounding **concentric lamellae** rings
- **Lacunae:** House osteocytes between lamellae layers, connected by **canaliculi**
- **Perforating / Volkmann's canals:** Extend perpendicular to central canals, connecting them
- **Interstitial lamellae:** Fill gaps between osteons
- **Circumferential lamellae:** Line the inner and outer bone surfaces

**- C: Bone Types and Structure**

Types of bone

- **Long** (appendicular)
- **Short** (wrist, ankle)
    - **Sesamoid** (short bone formed in tendons; e.g. patella)
- **Flat** (skull, thorax)
- **Irregular** (vertebrae, pelvis)

Bone structure

- Short, flat, irregular bones: Spongy tissue surrounded by compact tissue
- Long Bones
    - **Diaphysis**
        - Cylindrical central region
        - Composed of compact bone tissue surrounding a central **medullary cavity** containing blood vessels and nerves
    - **Epiphyses (proximal, distal)**
        - Enlarged, rounded ends
        - Composed of spongy tissue surrounded by compact tissue
    - **Epiphyseal Plate/Line**
        - Located between the diaphysis and epiphysis
        - During childhood: Composed of hyaline cartilage, functions as the growth plate
        - At adulthood: Ossifies into a line of spongy bone

Bone marrow

- **Red bone marrow:** Fills spongy bone and the medullary cavity in children; site of hematopoiesis
- **Yellow bone marrow:** Fills medullary cavity in adults; stores adipose tissue

Membranes

- **Periosteum**
    - Lines the bone exterior
    - Has an outer dense connective tissue layer and an inner osteogenic layer
- **Perforating (Sharpey's) fibers:** Attaches the periosteum to the bone
- **Endosteum**
    - Lines the bone interior (medullary cavity, trabeculae, central and perforating canals)
    - Osteogenic layer
- **Osteogenic layer**
    - Connective tissue
    - Contains **osteoprogenitors, osteoblasts** and **osteoclasts**
- **Osteoclasts**
    - Large, multinucleate cells; derived from monocytes
    - Break down bone tissue for remodeling and calcium release

**- D: Osteogenesis**

**Osteogenesis:** Bone growth

Overview:

- **Prenatal bone development**
    - **Intramembranous ossification**
    - **Endochondral ossification**
- **Postnatal bone development**
    - **Appositional growth**
    - **Longitudinal growth**
- **Bone remodeling**
    - **Bone remodeling**
    - **Response to stress**
    - **Calcium homeostasis**
    - **Fracture healing**

Intramembranous ossification: Bone formation directly from **mesenchymal tissue**

Endochondral ossification

- Begins with a hyaline cartilage model
- A **periosteal collar** forms around the diaphysis
- Ossification centers develop in the diaphysis and epiphysis
- The cartilage ossifies, aside from the cartilage at the epiphyseal plate and articular cartilage
- In adulthood, the epiphyseal plate ossifies into the epiphyseal line

Appositional growth

- Primarily occurs during childhood and adolescence
- The bone diameter increases by periosteal osteoblasts
- Endosteal osteoclasts may resorb inner bone tissue

Longitudinal growth

- Occurs in childhood and adolescence
- The diaphyseal side of the epiphyseal plate and articular cartilage ossify, while the contra-diaphyseal side grows cartilage

**- E: Bone Remodeling**

**Sprain:** Injured ligament
**Fracture:** Broken bone

**Bone remodeling**

- **General bone remodeling:** Bone tissue is continuously renewed
- **Response to stress (Wolff's Law):** Bone structure adapts to mechanical stress
- **Calcium homeostasis**
    - Hypocalcemia triggers the parathyroid gland to release **parathyroid hormone (PTH),** increasing osteoclast activity
    - Hypercalcemia trigger the thyroid gland to release **calcitonin**, increasing osteoblast activity
- **Fracture healing**
    1. **Reduction** (realignment of the broken bone)
    2. **Hematoma formation** (blood clot)
    3. **Fibrocartilage callus formation**
    4. **Bony callus formation**
    5. **Remodelling**

# C2. Skeletal System; Skeletal Structure

**- A: Axial Skeleton; Overview**

Axial skeleton
- **Skull**
- **Vertebral column**
- **Thoracic cage**

---

**- B. Skull; Bones**

Skull
- **Cranium**
- **Bones of the inner ear**
- **Facial bones**
- **Hyoid bone**

Cranium
- **Frontal**
- **Parietal (r, l)**
- **Occipital**
- **Temporal (r, l)**
- **Sphenoid**
- **Ethmoid**

Bones of the inner ear
- **Malleus**
- **Incus**
- **Stapes**

Facial bones
- **Maxilla (r, l)**
- **Mandible**
- **Zygomatic (r, l)**
- **Nasal (r, l)**
- **Lacrimal (r, l)**
- **Inferior Nasal Conchae (r, l)**
- **Vomer**
- **Palatine (r, l)**

Hyoid bone
- **Hyoid**

## C2. Skeletal System; Skeletal Structure

**- C. Vertebral Column; Bones**

Vertebral column
- **Cervical**
- **Thoracic**
- **Lumbar**
- **Sacral**
- **Coccygeal**

Cervical: **C1 - C7**
- C1: **Atlas**
- C2: **Axis**

Thoracic: **T1 - T12**

Lumbar: **L1 - L5**

Sacral: **Sacrum**

Coccygeal: **Coccyx**

---

**- D. Thoracic Cage; Bones**

Thoracic cage
- **Sternum**
- **Ribs (r, l)**

Ribs: **R1 - R12**
- R1 - R7: **True ribs**
- R8 - R12: **False ribs**
- R11 - R12: **Floating**

## C2. Skeletal System; Skeletal Structure

### - E. Appendicular Skeleton; Bones

Appendicular skeleton

- **Pectoral girdle**
- **Upper limbs**
- **Pelvic girdle**
- **Lower limbs**

Pectoral Girdle (R, L)

- **Clavicle**
- **Scapula**

Upper Limbs (R, L)

- Arm
  - **Humerus**
- Forearm
  - **Ulna**
  - **Radius**
- Hand
  - **Carpus (8 bones)**
  - **Metacarpal (5 bones)**
  - **Phalanges (14 bones)**

Pelvic Girdle (R, L)

- Coxal bone
  - **Ilium**
  - **Ischium**
  - **Pubis**

Lower Limbs (R, L)

- Thigh
  - **Femur**
- Knee
  - **Patella**
- Leg
  - **Tibia**
  - **Fibula**
- Foot
  - **Tarsus (7 bones)**
  - **Metatarsal (5 bones)**
  - **Phalanges (14 bones)**

## C2. Skeletal System; Skeletal Structure

**- F: Skull; Bony Landmarks**

Sutures

- **Coronal**
- **Sagittal**
- **Lambdoid**
- **Squamous**

Cranial Landmarks

- Occipital
    - **Foramen magnum** (medulla oblongata)
    - **Occipital condyle** (atlas)
    - **Jugular foramen** (jugular vein; cranial nerves IX, X, XI)
- Temporal
    - **External auditory / acoustic meatus** (ear canal)
    - **Internal auditory / acoustic meatus** (cranial nerves VII, VIII)
    - **Processes**
        - **Zygomatic process** (zygomatic arch)
        - **Mastoid process** (sternocleidomastoid muscle)
        - **Styloid process** (stylohyoid ligament)
    - **Mandibular fossa** (TMJ)
    - **Carotid canal** (internal carotid artery)
- Sphenoid
    - **Sella turcica** (pituitary gland)
    - **Optic foramen / canal** (optic nerve)
    - **Superior orbital fissure** (cranial nerves III, IV, VI)
    - **Foramen ovale**
- Ethmoid
    - **Crista galli** (falx cerebri)
    - **Cribriform plate, olfactory foramina** (olfactory nerve)
    - **Superior nasal conchae**
    - **Middle nasal conchae**

Facial Bones Landmarks

- Maxilla
    - **Alveolar processes**
    - **Infraorbital foramen** (infraorbital nerve)
- Zygotic
    - **Temporal process** (zygomatic arch)
- Mandible
    - **Ramus** (masseter muscle)
    - **Condyloid process** (TMJ)
    - **Coronoid process** (temporalis muscle)
    - **Alveolar processes**
    - **Mental foramen**

- **Mandibular foramen**

Skull, General

- **Nasal Bridge**
  - **Nasal bones**
- **Nasal Septum**
  - **Ethmoid perpendicular plate**
  - **Vomer**
- **Zygomatic Arch**
  - **Temporal zygomatic process**
  - **Zygomatic temporal process**
- **Hard Palate**
  - **Maxilla palatine process**
  - **Palatine horizontal plate**

Facial Sinuses

- **Frontal sinus**
- **Ethmoidal sinus**
- **Sphenoidal sinus**
- **Maxillary sinus**

Hyoid

- **Body**
- **Lesser horns** (stylohyoid ligament)
- **Greater horns**

## C2. Skeletal System; Skeletal Structure

### - G: Vertebrae; Bony Landmarks

Characteristics

- **Body / centrum**
- **Vertebral arch, pedicles, lamina**
- **Vertebral foramen** (spinal cord)
- **Superior articular process**
- **Inferior articular process**
- **Transverse processes**
- **Spinous processes**

Cervical

- Secondary concave curvature
- **Transverse process foramen** (vertebral arteries)
- Atlas: Has an **anterior arch**; does not have a body or spinous process
- Axis: **Dens**
- C3 - C6: **Bifid spinous processes**

Thoracic

- Primary convex curvature
- Have downwards-sloping spinous processes
- **Costal facets** (ribs)

Lumbar

- Secondary concave curvature
- Have a thick body
- Spinous processes are less downwards-facing than the thoracic vertebrae

Sacrum

- Primary convex curvature
- 5 fused vertebrae
- **Ala**
- **Auricular surface** (sacroiliac joint)
- **Anterior sacral foramina** (sacral nerves)
- **Posterior sacral foramina** (dorsal rami of the sacral nerves)
- **Sacral canal** (spinal nerves)
- **Median sacral crest**
- **Sacral hiatus**

Coccyx

- 4 fused vertebrae

**- H: Thoracic Cage Bony Landmarks**

Sternum

- **Manubrium**
    - **Jugular notch**
    - **Clavicular notch** (clavicle)
    - **Costal notch** (R1)
    - **Sternal angle** (R2)
- **Body** (R3 - 7)
- **Xipisternal joint**
    - **Xiphoid process**

Ribs

- **Intercostal space** (intercostal muscles)

---

**- I: Pectoral Girdle Bony Landmarks**

Clavicle

- **Sternal / medial end** (sternoclavicular joint)
- **Acromial / lateral end** (acromioclavicular joint)

Scapula

- **Coracoid process** (pectoralis minor, biceps brachii short head)
- **Suprascapular notch**
- **Superior border** (omohyoid muscle)
- **Superior angle** (levator scapulae)
- **Spine** (trapezium, deltoid)
- **Acromion** (acromioclavicular joint)
- **Medial / vertebral border** (rhomboid)
- **Inferior angle** (teres major)
- **Lateral / axillary border** (teres minor)
- **Lateral angle**
    - **Glenoid cavity / fossa** (humerus)

**- J: Upper Limbs Bony Landmarks**

Humerus

- Proximal
    - **Head** (glenoid cavity)
    - **Anatomical neck** (shoulder joint capsule)
    - **Greater tubercle** (rotator cuff muscles)
    - **Lesser tubercle** (subscapularis)
    - **Intertubercular sulcus** (biceps brachii long head tendon)
    - **Surgical neck**
- Body
    - **Radial groove** (radial nerve)
    - **Deltoid tuberosity** (deltoid muscle)
- Distal
    - **Coronoid fossa** (ulnar coronoid process)
    - **Radial fossa** (radial head)
    - **Medial epicondyle**
    - **Trochlea** (ulna)
    - **Capitulum** (radius)
    - **Lateral epicondyle**
    - **Olecranon fossa** (ulnar olecranon process)

Ulna

- Proximal
    - **Coronoid process** (humerus coronoid fossa)
    - **Trochlear notch** (humerus trochlea)
    - **Olecranon** (triceps brachii)
    - **Proximal radioulnar joint**
- Body
    - **Interosseous membrane**
- Distal
    - **Distal radioulnar joint**
    - **Ulnar styloid process**

Radius

- Proximal
    - **Head**
    - **Neck**
    - **Radial tuberosity** (biceps brachii tendon)
- Distal
    - **Radial styloid process**

**- K: Pelvic Girdle Bony Landmarks**

Pelvis
- False Pelvis
- True Pelvis
    - Inlet (pelvic brim)
    - Outlet

Coxal bone
- **Acetabulum** (hip joint)
- **Obturator Foramen** (obturator nerve and vessels)

Illium
- **Ala**
- **Iliac crest** (abdominal muscles)
- **Anterior superior iliac spine** (inguinal ligament, sartorius)
- **Anterior inferior iliac spine** (rectus femoris)
- **Iliac fossa** (iliacus)
- **Posterior superior iliac spine**
- **Auricular surface** (sacroiliac joint)
- **Posterior inferior iliac spine**
- **Greater sciatic notch** (sciatic nerve)

Ischium
- **Ischial body**
- **Ischial spine**
- **Ischial tuberosity** (hamstrings)
- **Ischial ramus**

Pubis
- **Body**
- **Inferior ramus**
- **Pubic arch**

Differences between male and female pelvises; female pelvises…
- Have a larger inlet
- Are shallower and lighter
- Ilia flare more laterally
- Sacrum is shorter and less inwardly curved
- Ischial spines are shorter and further apart
- Pubic arch is more rounded with a larger angle (over 90 degrees)

**- L: Lower Limbs Bony Landmarks**

Femur

- Proximal
    - **Head** (acetabulum)
    - **Surgical neck**
    - **Greater trochanter** (gluteus medius, minimus)
    - **Intertrochanteric crest** (quadratus femoris)
    - **Lesser trochanter** (iliopsoas muscle)
    - **Intertrochanteric line**
    - **Gluteal tuberosity** (gluteus maximus)
- Distal
    - **Medial condyle** (tibia)
    - **Medial epicondyle** (adductor magnus)
    - **Patellar surface** (patella)
    - **Lateral condyle** (tibia)
    - **Lateral epicondyle**
    - **Intercondylar fossa**

Tibia

- Proximal
    - **Medial condyle** (femur)
    - **Intercondylar eminence**
    - **Lateral condyle** (femur)
    - **Proximal tibiofibular joint**
    - **Tibial tuberosity**
- Body
    - **Anterior border**
    - **Interosseous membrane**
- Distal
    - **Medial malleolus**
    - **Distal tibiofibular joint**

Fibula

- Proximal
    - **Head** (biceps femoris)
- Distal
    - **Lateral malleolus**

# C3. Skeletal System; Joints

**- A: Overview**

**Joint (Articulation):** Junction between components of the skeletal system

**Functional Classification**
- **Synarthroses**
- **Amphiarthrosis**
- **Diarthroses**

**Structural Classification**
- **Fibrous**
    - **Suture**
    - **Gomphoses**
    - **Syndesmoses**
- **Cartilaginous**
    - **Synchondroses**
    - **Symphyses**
- **Synovial**

---

**- B: Fibrous Joints**

**Sutures**
- Synarthroses
- Short, connective fibers
- Location:
    - Skull joints

**Gomphoses**
- Synarthroses
- Location:
    - Periodontal membrane

**Syndesmoses**
- Amphiarthrosis
- Longer connective fibers
- Location:
    - Radioulnar interosseous membrane
    - Distal tibiofibular joint and interosseous membrane

**- C: Cartilaginous Joints**

**Synchondroses**

- Synarthroses
- Hyaline cartilage
- Location:
    - Epiphyseal plate
    - Sternocostal joint of the first rib

**Symphyses**

- Amphiarthrosis
- Fibrocartilage
- Location:
    - Intervertebral discs
    - Pubic symphysis

---

**- D: Synovial Joints**

Characteristics

- Diarthroses
- Bones are separated by a joint cavity filled with synovial fluid
- **Articular cartilage:** Hyaline cartilage covering the ends of the bones
- **Articular capsule:** Joint capsule, composed of an inner synovial membrane and an outer fibrous layer
- **Synovial membrane:** Areolar connective tissue
    - Contains synoviocytes which secrete synovial fluid
- **Reinforcing ligaments:** Surround the articular capsule
- **Bursae:** Synovial membrane sac filled with synovial fluid
    - Not part of the synovial joint but within the joint region
- **Tendon sheath:** Elongated bursae that ensheaths a tendon

**- E. Types of Synovial Joints**

**Plane**

- Movement: Glides; slides
- Nonaxial
- Joints:
    - Acromioclavicular
    - Intercarpal, Intertarsal
    - Zygapophysial joints
    - Costovertebral
    - Sternocostal (except for the first rib)
    - Proximal Tibiofibular

**Hinge**

- Uniaxial
- Joints:
    - Elbow
    - Tibiofemoral
    - Interphalangeal
    - Talocrural

**Pivot**

- Uniaxial
- Joints:
    - Atlantoaxial
    - Radioulnar joint (proximal and distal)

**Condylar**

- Biaxle
- Joints:
    - Temporomandibular (TMJ) (modified)
    - Atlanto-occipital
    - Radiocarpal joints
    - Metacarpophalangeal

**Saddle**

- Biaxle
- Joints:
    - First carpometacarpal joint (opposition, reposition)

**Ball and Socket**

- Multiaxle
- Joints:
    - Glenohumeral
    - Hip

# D1. Muscular System; Muscular Tissue

**- A: Types of Muscle**

Skeletal
- Striated
- Voluntary control
- Elongated, cylindrical fibers
- Multinucleate
- Facilitate skeletal movement

Cardiac
- Striated
- Involuntary control
- Branched, elongated, cylindrical  fibers, joined at intercalated discs
- Uninucleate
- Located within the wall of the heart

Smooth
- Non-striated
- Involuntary control
- Spindle-shaped cells
- Uninucleate
- Contained within the walls of hollow organs; facilitate peristalsis:
    - Digestive tract, blood vessels, respiratory system, urinary system, reproductive system

---

**- B: Skeletal Muscle Overview**

Functions
- Movement
- Posture
- Joint stabilization
- Heat generation

Properties
- Irritability (responsiveness)
- Contractility
- Extensibility
- Elasticity
- Conductivity

**D1. Muscular System; Muscular Tissue**

**- C: Skeletal Muscle Anatomy**

Supracellular Structure

- **Muscle fiber:** Individual muscular cell, surrounded by **endomysium**
- **Fascicle:** Bundle of multiple muscle fibers, surrounded by **perimysium**
- **Muscle:** Bundle of multiple fascicles, surrounded by **epimysium**
- **Epimysium** extends beyond the muscle, blending into **tendons** or **aponeuroses** which attach to bones or other tissues

Cellular Structure

- **Sarcolemma:** Myocyte plasma membrane
- **Sarcoplasm:** Myocyte cytoplasm
- **Transverse / T tubule:** Sarcolemma extension that extends into the sarcoplasm to rapidly transmit action potentials to the SR
- **Sarcoplasmic reticulum (SR):** Myocyte smooth endoplasmic reticulum; surrounds myofibrils
- **SR terminal cisternae:** Enlarged area of the SR, located on both sides of T tubules
- **Muscle triad:** T tubule flanked by two SR terminal cisternae
- **Myofibril:** Long organelle found within muscle cells
- **Sarcomere:** Basic myocyte contractile unit
- **Myofilament:** Sarcomere filaments (myosin, actin)

Sarcomere

- **M line:** Center; anchors myosin filaments
- **H zone:** Center actin-free myosin zone; disappears during full sarcomere contraction
- **Dark A band:** Entire length of myosin filaments; doesn't change in size during contraction
- **Light I band:** Myosin-free actin zone; gets smaller during contraction
    - The alternating dark and light bands give muscle fibers their striated appearance
- **Z Disc / line:** End of sarcomere; anchors actin filaments
- **Thick myosin filaments**
- **Thin actin filaments**

## D1. Muscular System; Muscular Tissue

**- D: Contraction Physiology**

Neuromuscular junction

- **Motor neuron:** Neuron that controls (potentially multiple) muscle fibers
- **Motor unit:** A motor neuron and all its associated muscle fibers
- **Neuromuscular junction:** Junction between an axon terminal and the sarcolemma; separated by a **synaptic cleft** filled with interstitial fluid
- **Motor End Plate (MEP):** Folded sarcolemma by the neuromuscular junction

Axon terminal neurotransmitter release

- An action potential reaches the axon terminal's synaptic bulb, causing voltage-gated calcium channels to open
- The calcium influx causes neurotransmitter (Acetylcholine (ACh)) release into the synaptic cleft
- ACh diffuses across the synaptic cleft and binds to sarcolemma receptors

Muscle fiber action potential

- The resting membrane potential of the sarcolemma is roughly -90 mV
- Neurotransmitters bind to sarcolemma receptors, causing ion channels to open and $Na^+$ ions to enter, depolarizing the cell
- Sufficient depolarization (-55 mV) triggers an action potential
- Acetylcholinesterase gradually breaks down the ACh, ending the stimulation

Myosin-Actin

- Using energy from ATP, myosin heads enter a "cocked back" state
- To uncock, the myosin heads need to bond with actin
- Tropomyosin fibers inhibit the actin binding site
- In the presence of calcium, troponin on the tropomyosin binds with the calcium, changing form and freeing the actin binding site
- Once the actin binding site is free, the cocked back myosin heads form **cross-bridge** connections with the actin and perform a **power stroke**, pulling the actin towards the M line, shortening the sarcomere

Sarcoplasmic Reticulum

- The sarcoplasmic reticulum (SR) stores calcium ions
- Muscular action potential causes the SR to release calcium
- Released calcium causes the myosin power stroke
- Once the power stroke is complete, new ATP bonds with the myosin, releasing the actin

**- E: Muscle Contraction**

Graded response

- Individual muscle fiber contractions follow the all-or-none principle; either they fully contract, or they do not contract at all
- However, overall muscle contraction intensity can vary, based on the frequency of the stimulation and the number of recruited motor units
    - **Temporal summation:** Sequential stimulations prevent the muscle from fully relaxing between stimuli, accumulating contractile force

Types of contraction

- **Twitch contraction:** Singular muscle contraction, followed by full relaxation
- **Tetanic contraction:** Sustained muscle contraction, caused by repeated stimuli without full relaxation in between
    - **Incomplete (unfused) tetanus:** Tetanic contraction with partial interstimulus relaxation
    - **Complete (fused) tetanus:** Tetanic contraction with no interstimulus relaxation

**Isotonic muscle contraction:** Muscle tension is greater than the load; the muscle length changes
**Isometric muscle contraction:** Load is greater than the muscle tension; muscle length does not change

Muscle fatigue

- Muscle contraction is powered by ATP
- ATP production requires oxygen
- Prolonged exercise can create an “oxygen deficit” that must be repaid post-exercise
- In the absence of oxygen, muscles can undergo **anaerobic respiration**
    - Anaerobic respiration is less efficient than aerobic respiration
    - Anaerobic respiration causes lactic acid buildup, which can lead to muscle soreness
    - Oxygen is needed to metabolize the lactic acid
- **Muscle fatigue:** Inability of a stimulated muscle to contract; caused by oxygen or ATP deficiency

# D2. Muscular System; Skeletal Muscle

**- A: Skeletal Muscle, Overview**

Skeletal Muscle Golden Rules

- Muscles generally cross at least one joint
- Most of the muscle is generally located proximal to the crossed joint
- Muscles have an **origin** and **insertion**
- Muscles can contract but cannot actively lengthen
- Muscle contraction pulls the insertion point towards the origin

---

**- B: Muscle Movements**

**Flexion**

- Decreases a joint's angle
- Generally bends anteriorly in the sagittal plane

**Extension**

- Increases a joint's angle
- Generally bends posteriorly in the sagittal plane

**Rotation:** Movement around a longitudinal axis

**Medial rotation**

- Turning of the anterior surface towards the midline

**Lateral rotation**

- Turning of the anterior surface away from the midline

**Abduction**

- Movement of a limb away from body
- Generally moves laterally in the frontal plane

**Adduction**

- Movement of a limb towards body
- Generally moves medially in the frontal plane

**Circumduction**

- Cone-shaped movement
- The proximal end of the limb is stationary; the distal end moves in a circle

**Supination**

- Rotation resulting in the palm facing forwards
- The radius is lateral to the ulna

**Pronation**

- Rotation resulting in the palm facing backwards
- The radius crosses over the ulna

**Opposition**

- Movement of the thumb and fingers towards each other

**Reposition**

- Movement of the thumb and fingers away from each other

**Inversion**

- Turning the sole of the foot to face medially

**Eversion**

- Turning the sole of the foot to face laterally

**Dorsiflexion**

- Flexing the toes upwards

**Plantar flexion**

- Extending the toes downwards

**Elevation**
**Depression**
**Protraction**
**Retraction**

**Lateral flexion**

- Bending sideways

---

**- C: Skeletal Muscle Roles**

**Prime mover (Agonist)**
**Synergist**
**Fixator (Stabilizer)**
**Antagonist**

# D3. Muscular System; Major Muscles, Origins, Insertions, and Movements

**- A: Major Skeletal Muscles, List**

Facial
- Frontalis, occipitalis
- Orbicularis oculi
- Orbicularis oris, zygomaticus, buccinator

Mastication
- Masseter, temporalis
- Digastric

Neck
- Platysma
- Sternocleidomastoid

Trunk anterior
- Pectoralis major
- Pectoralis minor
- Intercostal muscles
- External oblique
- Rectus abdominis
- Internal oblique
- Transversus abdominis

Trunk posterior
- Trapezius
- Latissimus dorsi
- Erector spinae (longissimus, iliocostalis, spinalis)
- Quadratus lumborum

Upper limbs
- Deltoid
- Biceps brachii
- Brachialis
- Brachioradialis
- Triceps brachii
- Flexor carpi, flexor digitorum
- Extensor carpi, extensor digitorum

Hip and thigh muscles
- Gluteus (maximus, medius, minimus)
- Iliopsoas (psoas major, iliacus)
- Sartorius

- Adductors
- Quadriceps (rectus femoris, vastus muscles (medialis, intermedius, lateralis))
- Hamstrings (biceps femoris (long head, short head), semimembranosus, semitendinosus)

Muscles of the lower leg

- Tibialis anterior
- Extensor digitorum longus
- Fibularis (longus, brevis, tertius)
- Soleus
- Gastrocnemius
- Calcaneal (Achilles) tendon

**- B: Frontal**

Muscles

- **Occipitalis**
  - Origin: Occipital bone
  - Insertion: Cranial aponeurosis
- **Frontalis**
  - Origin: Cranial aponeurosis
  - Insertion: Forehead skin

Movement

- Scalp mobility
  - Occipitalis
  - Frontalis

---

**- C. Ocular**

Muscles

- **Orbicularis oculi**
  - Origin: Frontal, maxilla
  - Insertion: Periorbital tissue

Movement

- Eye closure
  - Orbicularis oculi

## D3. Muscular System; Major Muscles Origin, Insertion, and Movement

**- D. Oral**

Muscles

- **Orbicularis oris**
    - Origin: Maxilla, mandible
    - Insertion: Perioral tissue
- **Buccinator**
    - Origin: Alveolar processes of the maxilla and mandible
    - Insertion: Orbicularis oris
- **Zygomaticus minor**
    - Origin: Lateral zygomatic bone
    - Insertion: Skin of upper lip
- **Zygomaticus major**
    - Origin:  Lateral zygomatic bone
    - Insertion: Orbicularis oris

Movement

- Mouth closure
    - Orbicularis oris
- Cheek compression
    - Buccinator
- Smiling
    - Zygomaticus major
    - Zygomaticus minor

## D3. Muscular System; Major Muscles Origin, Insertion, and Movement

**- E. Mastication**

Muscles

- **Temporalis**
  - Origin: Temporal fossa
  - Insertion: Coronoid process of the mandible
- **Masseter**
  - Origin: Zygomatic arch
  - Insertion: Lateral surface of the ramus of the mandible
- **Digastric**
  - Origin: Mastoid process of the temporal bone
  - Insertion: Digastric fossa of the mandible

Movement

- Mandibular elevation
  - Temporalis
  - Masseter
- Mandibular depression
  - Digastric

---

**- F. Cervical**

Muscles

- **Sternocleidomastoid**
  - Origin: Manubrium, medial clavicle
  - Insertion: Mastoid process of the temporal bone
- **Platysma**
  - Origin: Pectoral fascia
  - Insertion: Perioral tissue

Movement

- Neck flexion
  - Sternocleidomastoid (bilateral contraction)
- Neck rotation
  - Sternocleidomastoid (unilateral contraction)
- Neck skin tension
  - Platysma

## D3. Muscular System; Major Muscles Origin, Insertion, and Movement

**- G: Scapular**

Muscles

- **Pectoralis minor**
  - Origin: Anterior surface of ribs 3 - 5
  - Insertion: Coracoid process of the scapula
- **Trapezius**
  - Origin
    - Upper fibers: Occipital bone
    - Middle fibers: Spinous processes of C7 - T3
    - Lower fibers: Spinous processes of T4 - T12
  - Insertion
    - Upper fibers: Lateral clavicleClavicle (lateral)
    - Middle fibers: Superior clavicleScapula (superior)
    - Lower fibers: Medial scapula

Movement

- Scapular elevation
  - Trapezius (upper fibers)
- Scapular protraction
  - Pectoralis minor
- Scapular retraction
  - Trapezius (middle fibers)
- Scapular depression
  - Pectoralis minor
  - Trapezius (lower fibers)

## D3. Muscular System; Major Muscles Origin, Insertion, and Movement

**- H. Shoulder**

Muscles

- **Pectoralis major**
  - Origin
    - Clavicular head: Medial clavicle
    - Sternocostal head: Sternum, costal cartilage of ribs 1 - 6
  - Insertion: Proximal anteromedial humerus
- **Latissimus dorsi**
  - Origin: Spinous processes of T7 - T12, iliac crest, ribs 9 - 12
  - Insertion: Proximal anteromedial humerus
- **Deltoid**
  - Origin
    - Anterior fibers: Lateral clavicle
    - Middle fibers: Acromion of the scapula
    - Posterior fibers: Spine of the scapula
  - Insertion: Anterolateral aspect of the deltoid tuberosity of the humerus

Movement

- Humerus flexion
  - Pectoralis major (clavicular head)
  - Deltoid (anterior fibers)
- Humerus abduction
  - Deltoid (middle fibers)
- Humerus extension
  - Latissimus dorsi
  - Deltoid (posterior fibers)
  - Triceps brachii (long head)
- Humerus adduction
  - Pectoralis major
  - Latissimus dorsi
  - Triceps brachii (long head)
- Humerus medial rotation
  - Pectoralis major
  - Latissimus dorsi
  - Deltoid (anterior fibers)
- Humerus lateral rotation
  - Deltoid (posterior fibers)

## D3. Muscular System; Major Muscles Origin, Insertion, and Movement

**- I. Forearm**

Muscles

- **Biceps brachii (long head)**
    - Origin: Supraglenoid tubercle of the scapula
    - Insertion: Anteromedial aspect of the radial tuberosity
- **Biceps brachii (short head)**
    - Origin: Coracoid process of the scapula
    - Insertion: Anteromedial aspect of the radial tuberosity
- **Brachialis**
    - Origin: Distal anterior surface of the humerus
    - Insertion: Coronoid process and tuberosity of the ulna
- **Triceps brachii (long head)**
    - Origin: Infraglenoid tubercle of the scapula
    - Insertion: Olecranon process of the ulna
- **Triceps brachii (medial and lateral heads)**
    - Origin: Posterior surface of the humerus
    - Insertion: Olecranon process of the ulna
- **Brachioradialis**
    - Origin: Lateral side of the distal humerus
    - Insertion: Styloid process of the radius

Movement

- Elbow flexion
    - Biceps brachii
    - Brachialis
    - Brachioradialis
- Supination
    - Biceps brachii
- Elbow extension
    - Triceps brachii

## D3. Muscular System; Major Muscles Origin, Insertion, and Movement

**- J: Thoracic**

Muscles

- **Diaphragm**
- **External intercostal**
- **Internal intercostal**
- **Rectus abdominis**

Movement

- Inspiration
    - External intercostal
    - Diaphragm
- Forced expiration
    - Internal intercostal
    - Rectus abdominis

## D3. Muscular System; Major Muscles Origin, Insertion, and Movement

**- K. Vertebral**

Muscles

- **External oblique**
  - Origin: External surface of ribs 5 - 12
  - Insertion: Iliac crest, linea alba
- **Rectus abdominis**
  - Origin: Pubic symphysis
  - Insertion: Xiphoid process of the sternum, costal cartilage of ribs 5 - 7
- **Internal oblique**
  - Origin: Iliac crest, inguinal ligament, thoracolumbar fascia
  - Insertion: Ribs 10 - 12, linea alba, pubic crest
- **Transversus abdominis**
  - Origin: Interior surface of ribs 7 - 12, iliac crest, inguinal ligament, thoracolumbar fascia
  - Insertion: Linea alba, pubic crest
- **Erector spinae longissimus**
  - Origin: Sacrum, iliac crest, lumbar vertebrae
  - Insertion: Ribs, thoracic and cervical vertebrae, mastoid process of the temporal bone
- **Erector spinae iliocostalis**
  - Origin: Sacrum, iliac crest, lumbar vertebrae
  - Insertion: Ribs and cervical vertebrae
- **Erector spinae spinalis**
  - Origin: Upper lumbar and lower thoracic vertebrae
  - Insertion: Upper thoracic and cervical vertebrae, occipital bone
- **Quadratus lumborum**
  - Origin: Iliac crest, iliolumbar ligament
  - Insertion: Rib 12, transverse processes of L1 - L4

Movement

- Vertebral column flexion
  - External oblique
  - Rectus abdominis
  - Internal oblique
- Vertebral column rotation
  - External oblique
  - Internal oblique
- Vertebral column lateral flexion
  - External oblique
  - Internal oblique
  - Erector spinae
  - Quadratus lumborum
- Vertebral column extension
  - Erector spinae
  - Quadratus lumborum

## D3. Muscular System; Major Muscles Origin, Insertion, and Movement

**- L: Hip**

Muscles

- **Gluteus maximus**
  - Origin: Posterior ilium, sacrum, coccyx
  - Insertion: Gluteal tuberosity of the femur, iliotibial tract
- **Gluteus medius**
  - Origin: Lateral surface of the ilium
  - Insertion: Lateral aspect of the greater trochanter of the femur
- **Gluteus minimus**
  - Origin: Lateral surface of the ilium
  - Insertion: Anterior aspect of the greater trochanter of the femur
- **Psoas major**
  - Origin: Bodies and transverse processes of T12 - L5
  - Insertion: Lesser trochanter of the femur
- **Iliacus**
  - Origin: Iliac fossa
  - Insertion: Lesser trochanter of the femur
- **Sartorius**
  - Origin: Anterior superior iliac spine
  - Insertion: Proximal medial surface of the tibia
- **Adductors**
  - Origin: Ischial tuberosity, pubis
  - Insertion: Medial surface of the femur

Movement

- Hip flexion
  - Psoas major
  - Iliacus
  - Sartorius
- Hip abduction
  - Gluteus medius
  - Gluteus minimus
  - Sartorius
- Hip medial rotation
  - Gluteus medius (anterior fibers)
  - Gluteus minimus (anterior fibers)
- Hip extension
  - Gluteus maximus
  - Hamstrings
- Hip adduction
  - Adductors
- Hip lateral rotation
  - Gluteus maximus
  - Sartorius

## D3. Muscular System; Major Muscles Origin, Insertion, and Movement

**- M: Knee**

Muscles

- **Rectus femoris**
    - Origin: Anterior inferior iliac spine, superior margin of the acetabulum
    - Insertion: Tibial tuberosity (via the patellar ligament)
- **Vastus medialis**
    - Origin: Intertrochanteric line of the femur
    - Insertion: Tibial tuberosity (via the patellar ligament)
- **Vastus intermedius**
    - Origin: Anterior and lateral surfaces of the proximal femur
    - Insertion: Tibial tuberosity (via the patellar ligament)
- **Vastus lateralis**
    - Origin: Greater trochanter of the femur
    - Insertion: Tibial tuberosity (via the patellar ligament)
- **Biceps femoris (long head)**
    - Origin: Ischial tuberosity
    - Insertion: Lateral side of the head of the fibula
- **Biceps femoris (short head)**
    - Origin: Lateral surface of the femur
    - Insertion: Lateral side of the head of the fibula
- **Semimembranosus**
    - Origin: Ischial tuberosity
    - Insertion: Posterior surface of the medial condyle of the tibia
- **Semitendinosus**
    - Origin: Ischial tuberosity
    - Insertion: Medial surface of the proximal tibia

Movement

- Knee extension
    - Quadriceps
- Knee flexion
    - Hamstrings
    - Sartorius
    - Gastrocnemius
- Leg medial rotation
    - Semimembranosus
    - Semitendinosus
- Leg lateral rotation
    - Biceps femoris

**D3. Muscular System; Major Muscles Origin, Insertion, and Movement**

**- N. Foot**

Muscles

- **Tibialis anterior**
  - Origin: Lateral condyle and proximal lateral surface of the tibia
  - Insertion: Base of the first metatarsal
- **Extensor digitorum longus**
  - Origin: Lateral condyle of the tibia, proximal lateral surface of the fibula
  - Insertion: Dorsal surface of the second through fifth phalanges
- **Fibularis longus**
  - Origin: Head and proximal lateral surface of the fibula
  - Insertion: Base of the first metatarsal (via the lateral malleolus, across the sole of the foot)
- **Fibularis brevis**
  - Origin: Distal lateral surface of the fibula
  - Insertion: Lateral base of the fifth metatarsal
- **Fibularis tertius**
  - Origin: Fibula distal anterior
  - Insertion: Dorsal base of the fifth metatarsal
- **Soleus**
  - Origin: Posterior surface of the fibular head, medial border of the tibial shaft
  - Insertion: Calcaneus (via the Achilles tendon)
- **Gastrocnemius**
  - Origin: Posterior surfaces of the femur's medial and lateral condyles
  - Insertion: Calcaneus (via the Achilles tendon)

Movement

- Dorsiflexion
  - Tibialis anterior
  - Extensor digitorum longus
  - Fibularis tertius
- Plantar flexion
  - Fibularis longus
  - Fibularis brevis
  - Soleus
  - Gastrocnemius
- Inversion
  - Tibialis anterior
- Eversion
  - Fibularis longus
  - Fibularis brevis
  - Fibularis tertius

# E1. Nervous System; Overview

**- A. Nervous System; Overview**

Components

- **Sensory receptors:** Sense stimuli, send the sensory input along…
- **Sensory afferent pathways:** Carry sensory input from sensory receptors to the…
- **Control center:** Receives, processes and interprets the sensory input, decides on a response, sends the response along…
- **Motor efferent pathways:** Carry motor output from the control center to the…
- **Effectors:** Organs that performs a response

Organs

- **Peripheral nervous system (PNS)**
  - Sensory receptors
    - **Somatosensory receptors** (general receptors for pressure, temperature, pain, movement)
    - **Special sensory receptors** (eye, nose, tongue, ear (hearing, balance))
    - **Viscero**ceptors (internal sensory receptors)
  - Effectors
    - **Skeletal muscle**
    - **Cardiac muscle**
    - **Smooth muscle**
    - **Glands**
- **Central nervous system (CNS)**
  - Control center
    - **Brain**
    - **Spinal cord**

PNS systems

- **Somatic nervous system** (skeletal muscle movement; generally voluntary)
- **Autonomic nervous system** (cardiac and smooth muscle, glands; involuntary)
  - **Sympathetic** (fight or flight)
  - **Parasympathetic** (rest and digest)

Types of neurons

- **Sensory (afferent) neurons**
- **Interneurons (association neurons)**
- **Motor (efferent) neurons**

## E1. Nervous System; Overview

**- B: Nervous Tissue**

Nervous tissue cells

- **Neuron**
  - **Cell Body**
    - Cellular organelle
    - **Nissl bodies** (specialized RER)
  - **Extensions**
    - **Dendrites** (smaller extensions; receive input; generally multiple per neuron)
    - **Axon** (longer extensions; carry output; one per neuron)
      - **Axon hillock** (location of action potential generation; axon is extension of axon hillock)
      - **Axon terminal** (synapse)
      - **Myelin sheath** (often surround axons for signal integrity and speed; enables rapid **saltatory conduction**)
      - **Nodes of Ranvier** (gap between myelin sheaths)
      - **Saltatory conduction** (nerve impulses leap from node to node; faster than continuous conduction)
- **Neuroglia**
  - CNS
    - **Astrocyte** (barrier between capillaries and neurons; most abundant neuroglia)
    - **Microglial** (phagocytes)
    - **Ependymal** (line CSF cavities; produce CSF; cilia circulates CSF)
    - **Oligodendrocytes** (have processes that form the CNS myelin sheaths)
  - PNS
    - **Satellite cells** (support ganglia)
    - **Schwann cells** (form the PNS myelin sheaths)

Location

- Neurons bodies are mostly located in the CNS
- **Gray matter:** CNS neuron bodies and unmyelinated axons
- **White matter:** CNS myelinated axons (by oligodendrocytes)
- **Nuclei:** Clusters of CNS neuron bodies surrounded by white matter
- **Tract:** Bundle of CNS axons
- **Ganglia:** Clusters of PNS neuron bodies
- **Nerve:** Bundles of PNS axons

Nerve structure

- **Nerve fiber:** Individual axon
- **Endoneurium:** Surrounds individual myelinated nerve fibers
- **Fascicle:** Bundle of multiple nerve fibers
- **Perineurium:** Surrounds fascicles
- **Nerve:** Bundle of multiple fascicles
- **Epineurium:** Surrounds nerve

## E1. Nervous System; Overview

**- C. Nervous System; Physiology**

**Resting Membrane Potential**

- At rest, there is a negative voltage (-70 mV) across the cell membrane
- The plasma membrane is more permeable to $K^+$ ions than $Na^+$ ions; as $K^+$ ions are concentrated inside the cell, diffusion maintains the polarized interior
- Further electrical and ionic balance is maintained by the **sodium-potassium pump** (3 $Na^+$ out; 2 $K^+$ in)

**Graded Potential**

- Sensory stimuli cause **sensory-gated ion channels** to open, letting in $Na^+$ ions and raising the inner voltage
- The amount of the increase in the inner voltage is a graded potential, dependant on the level of stimuli

**Action Potential**

- **Threshold stimulus:** If the graded potential reaches the threshold potential (-55 mV), an **action potential** is triggered
- **"All or Nothing":** The action potential is not graded; it is either fully triggered (when the graded potential reaches the threshold potential) or not triggered at all (when the graded potential does not reach the threshold potential)
- **Depolarization:** Voltage-gated $Na^+$ ion channels open, flooding the cell with $Na^+$ ions, dramatically increasing the cell voltage (35 mV). This in turn triggers the adjacent voltage-gated channel, and so on down the axon

**Repolarization**

- **Electrical balance:** Once the action potential is propagated, $K^+$ channels open and $K^+$ ions leave the cell, lowering the voltage, repolarizing the cell
- **Hyperpolarization:** The loss of $K^+$ ions causes a brief period of hyperpolarization (-90 mV)
- **Ionic balance:** The sodium-potassium pump exchanges exterior $K^+$ with inner $Na^+$, restoring ionic balance

**Synapse:** Junction between a neuron and another neuron, muscle or gland

- Neural junctions are separated by a **synaptic cleft;** the components do not touch
- Junction communication is performed chemically via **neurotransmitters**
    - Axon terminals have **synaptic vesicles** containing neurotransmitters
    - The action potential causes **voltage-gated calcium-ion channels** to open, which trigger neurotransmitter vesicle exocytosis, releasing neurotransmitters into the synaptic cleft
    - The neurotransmitters diffuse across the synaptic cleft and bind to neurotransmitter receptors on the receiving component
    - The neurotransmitter receptors trigger a graded potential via gated channels

Neurotransmitters

- CNS synapses use a diverse range of neurotransmitters
- PNS synapses primarily use **acetylcholine (ACh)**, except for autonomic sympathetic postganglionic target organ junctions, which use **norepinephrine (noradrenaline)**

**- D. Reflex Arc**

**Reflex**

- Subset of neural activity
- Rapid, predictable response to stimuli

**Reflex arc**

- A reflex's neural pathway

Components

- **Sensory receptor**
- **Sensory neuron**
- **Integration center**
    - Different reflexes have varied numbers of neurons
- **Motor neuron**
- **Effector**

# E2. Nervous System; CNS

**- A. Brain Structures; Overview**

Brain components

- **Cerebrum**
- **Diencephalon**
- **Cerebellum**
- **Brainstem**

---

**- B. Cerebrum**

Components

- **Hemispheres (r, l)**
    - **Longitudinal fissure:** Separates the right and left hemispheres
    - The right and left hemispheres are connected via the **corpus callosum**
- **Lobes**
    - **Frontal**
    - **Parietal**
    - **Temporal**
    - **Occipital**
- **Sulci**
    - **Central sulcus:** Separates the frontal and parietal lobes
    - **Lateral sulcus:** Separates the frontal and temporal lobes
- **Cerebral cortex:** Outer layer of gray matter
- **Cerebral white matter:** Layer of white matter located deep to the cerebral cortex
- **Basal nuclei:** Clusters of gray matter located within the white matter; responsible for fine motor control

**- C. Cerebral Cortex**

Cerebral cortex

- Structures
    - **Gyri** (ridges)
    - **Sulci** (grooves)
    - **Fissures** (deeper grooves)
- Lobes
    - **Frontal lobe** (primary cognitive control)
        - **Prefrontal cortex** (complex cognitive behavior)
        - **Broca's area** (posterior inferior gyrus; speech production)
        - **Precentral gyrus - primary motor cortex**
    - **Parietal lobe** (sensory information)
        - **Postcentral gyrus - primary somatosensory gyrus**
        - **Primary vestibular cortex**
    - **Temporal lobe**
        - **Primary auditory cortex**
        - **Wernicke's area** (posterior left temporal; language comprehension)
        - **Primary olfactory cortex**
        - **Insular lobe** (deep to the temporal lobe)
            - **Primary gustatory cortex**
    - **Occipital lobe**
        - **Primary visual cortex**

**- D. Diencephalon**

**Thalamus**

- Major relay station for sensory input (except olfactory)

**Hypothalamus**

- Location: Floor of the third ventricle
- Regulates the autonomic nervous system; “master gland”
    - Endocrine system (via the pituitary gland)
    - ANS
    - Thermoregulation
    - Circadian rhythms (suprachiasmatic nucleus)
    - Hunger, thirst regulation
    - Emotions (via the limbic system)
- Adjacent structures
    - **Limbic system** (hippocampus, amygdala)
    - **Optic chiasma**
    - **Infundibulum**, connected to the **pituitary gland**

**Epithalamus**

- Location: Roof of the third ventricle
- Structures
    - **Pineal gland:** Releases melatonin
    - **Third ventricle choroid plexus**

---

**- E. Cerebellum**

Function: Fine-tunes movement, balance, posture

**- F. Brainstem**

**Midbrain**

- Tracts of nerve fibers
- Structures
    - **Cerebral peduncles:** Bulging fiber tracts
    - **Corpora quadrigemina:** Two pairs of rounded posterior protrusions
        - **Superior colliculi:** Visual reflex
        - **Inferior colliculi:** Auditory reflex

**Pons**

- Tracts of nerve fibers
- Contains
    - **Pontine respiratory group (PRG)** (smoothes transition between inhalation and exhalation)

**Medulla oblongata**

- Tracts of nerve fibers
- Merges with the spinal cord
- **Autonomic control centers**
    - **Cardiac center**
    - **Vasomotor center**
    - **Respiratory center**
    - **Swallowing center**
    - **Vomiting center**

**Reticular formation**

- Brain stem accessory; series of gray matter spanning the midbrain, pons and medulla
- Functions
    - **Reticular Activating System (RAS):** Alertness
    - Visceral organ motor control
    - Modulates pain sensation

**- G. Intracerebral Architecture**

**White matter tracts**

- **Association fibers** (intrahemispheric interregional connections)
- **Projection fibers** (spread to the cerebral cortex)
- **Commissural fibers** (corpus callosum)

**Ventricles** (filled with CSF)

- **Lateral ventricle (r, l)**
  - **Body**
  - **Anterior (frontal) horn**
  - **Posterior (occipital) horn**
  - **Inferior (temporal) horn**
- **Third ventricle**
  - Located between the two thalami
  - Connected to the fourth ventricle via the cerebral aqueduct
- **Fourth ventricle**
  - Located between the pons and medulla oblongata
  - Extends to the spinal cord central canal

---

**- H. Spinal Cord**

**White matter (funiculi):** Surrounds the gray matter

- **Posterior (dorsal) funiculus:** Ascending tracts
- **Lateral funiculus:** Mixed ascending and descending tracts
- **Anterior (ventral) funiculus:** Descending tracts

**Gray matter:** Surrounded by white matter, H-shaped

- **Posterior (dorsal) horn:** Sensory neuron axons, interneurons
- **Intermediate space:** Interneuron bodies and axons
- **Lateral horn:** Only in the thoracic and upper lumbar regions; autonomous motor neurons
- **Anterior (ventral) horn:** Somatic motor neurons

**Central canal:** Filled with CSF
**Dorsal root:** Entrance for afferent nerve fibers
**Ventral root:** Exit for efferent nerve fibers

## E2. Nervous System; CNS

### - I. CNS Protection

**Meninges** (protective tissue covering)

- **Dura mater** (tough outer layer)
    - **Periosteal** (outer dura mater layer; attaches to inner skull; not in spinal dura mater)
    - **Meningeal** (inner dura mater layer)
        - **Dural reflections** (meningeal dura mater extensions into the cranial cavity that support and compartmentalize the brain)
            - **Falx Cerebri** (longitudinal fissure)
        - **Epidural space** (space between the dura mater and surrounding bone; only in spinal column which doesn't have a periosteal layer - not in cranial)
- **Arachnoid mater** (fine, web-like fibers)
    - **Subarachnoid space** (space between arachnoid and pia maters; filled with CSF)
    - **Arachnoid trabeculae** (arachnoid fibers that extend into the subarachnoid space)
- **Pia mater** (thin innermost layer)

**Blood-Brain Barrier, Blood-Spinal Cord Barrier**

- Tight barrier, formed by the endothelial cells of CNS blood vessels, pericytes, and astrocytes

**Cerebrospinal fluid (CSF)**

- Produced in the brain ventricles' **choroid plexuses**
- Drains from the fourth ventricle to the subarachnoid space via **apertures**; some drains to the **spinal cord central canal**
- Drains from the subarachnoid space to the **dural venous sinuses** (located between the two dural layers) via **arachnoid villi (granulations)**
    - **Superior sagittal sinus:** Primary dural venous sinus

# E3. Nervous System; PNS

**- A. Division of the PNS**

**Somatic nervous system** (skeletal muscle; generally voluntary)
**Autonomic nervous system** (cardiac & smooth muscle, glands; involuntary)

The ANS has two antagonistic divisions:

- **Sympathetic** (fight or flight)
- **Parasympathetic** (rest and digest)

Organs

- Most major organs are innervated by both sympathetic and parasympathetic nerves
- The skin (sweat glands, arrector pili muscles, peripheral blood vessels) and adrenal medulla are only innervated by sympathetic nerves

---

**- B. PNS Neuron Location; Overview**

**Sensory afferent neurons**

- Bodies are located outside the CNS; axons extends into CNS; dendrites extend to the origin of stimuli
    - **Cranial sensory ganglia** (location of cranial sensory neuron bodies)
    - **Dorsal root ganglia** (location of spinal sensory neuron bodies

**Motor efferent neurons**

- Bodies are located inside the CNS; axons extends to the PNS
    - Somatic motor neuron axons extend directly to the effector
    - Autonomic CNS motor neurons are **preganglionic** and do not extend to the effector; instead, they extend to PNS **autonomic ganglia** where they synapse with **postganglionic neurons** which extend to the effector

**Interneurons**

- Processors; located in CNS neural pathways

**- C. PNS Neuron Location; Detailed**

**Sensory afferent neuron**

- Located in **dorsal root ganglia**
- Dendrites extend via the dorsal root **peripheral process** to the spinal nerve and the origin of stimuli
- Axons extend via the **dorsal root ventral process** to the spinal cord gray matter **dorsal horn** where they synapse with interneurons

**Somatic motor efferent neuron**

- Located in the gray matter **ventral horn**
- Dendrites synapse with interneurons
- Axons extend via the **ventral root** to the spinal nerve to the effector

**Autonomic preganglionic sympathetic afferent neuron**

- Located in the gray matter **lateral horn** (only present in the thoracic region)
- Dendrites synapse with interneurons
- Axons extend via the **ventral root** to the spinal nerve to the **sympathetic chain** (they may synapse on their origin level, or may travel up or down the chain)

**Autonomic postganglionic sympathetic efferent neuron**

- Located in the **sympathetic chain** lateral to the spinal cord
- Dendrites synapse with preganglionic neurons
- Axons extend (directly or through the spinal nerve) to the effector, or to synapse with other sympathetic chain neurons

**Autonomic preganglionic parasympathetic afferent neuron**

- Located in the **brainstem** and **sacral intermediate gray matter zone**
- Dendrites synapse with interneurons
- Axons extend to the spinal nerve to **terminal ganglia**

**Autonomic postganglionic parasympathetic efferent neuron**

- Located in **terminal ganglia** near the effector
- Dendrites synapse with preganglionic neurons
- Axons extend to nearby effectors

**- D. Spinal Nerves, Overview**

**31 paired spinal nerves**

- All mixed sensory and motor

**4 plexuses**

- **Cervical plexus**
  - **Phrenic nerve** (diaphragm)
- **Brachial plexus**
  - **Radial nerve** (arm, hand)
- Thoracic nerves course along the intercostal space and do not form plexuses
- **Lumbar plexus**
  - **Femoral nerve** (hip, knee)
- **Sacral plexus**
  - **Sciatic nerve** (thigh, leg, foot)

---

**- E. Spinal Nerve; Detailed**

The **dorsal root** and **ventral root** join and form the **spinal nerves**

Fibers included in the spinal nerves

- Sensory afferent dendrites
- Somatic motor efferent axons
- Autonomic motor preganglionic axons
- Autonomic motor sympathetic postganglionic axons

**White ramus communicans:** Sympathetic preganglionic branch from the spinal nerve to the sympathetic chain
**Gray ramus communicans:** Sympathetic postganglionic branch from the sympathetic chain back to the spinal nerve

The spinal nerves quickly terminate and split into **ventral** and **dorsal rami**

- **Ventral rami:** Form plexuses in their respective plexus regions
- **Dorsal rami:** Directly innervate the back

# E4. Nervous System; Cranial Nerves

**- A. Inner-Cranial Regional Classification, Overview**

Forebrain (Prosencephalon)

- **Olfactory (I)**
  - Origin: Forebrain
  - Cranial exit: Cribriform plate
- **Optic (II)**
  - Origin: Hypothalamus
  - Cranial exit: Optic canal

Midbrain (Mesencephalon)

- **Oculomotor (III)**
  - Origin: Ventral midbrain
  - Cranial exit: Superior orbital fissure (SOF)
- **Trochlear (IV)**
  - Origin: Dorsal midbrain
  - Cranial exit: SOF

Pons (Metencephalon)

- **Trigeminal (V)**
  - Origin: Lateral pons
  - Cranial exit: Sphenoid foramina

Pontomedullary Junction

- **Abducens (VI)**
  - Origin: Ventral pontomedullary junction (PMJ)
  - Cranial exit: SOF
- **Facial (VII)**
  - Origin: Ventrolateral PMJ
  - Cranial exit: Internal acoustic meatus (IAM), stylomastoid foramen (SMF)
- **Vestibulocochlear (VIII)**
  - Origin: Ventrolateral PMJ
  - Cranial exit: IAM

Medulla (Myelencephalon)

- **Glossopharyngeal (IX)**
  - Origin: Lateral medulla
  - Cranial exit: Jugular foramen (JF)
- **Vagus (X)**
  - Origin: Lateral medulla
  - Cranial exit: JF
- **Accessory (XI)**
  - Cranial root origin: Lateral medulla

    - Spinal root origin: Spinal cord
    - Cranial exit: JF
- **Hypoglossal (XII)**
    - Origin: Ventral medulla
    - Cranial exit: Hypoglossal canal

## E4. Nervous System; Cranial Nerves

**- B. Detailed Location and Function**

CN 01: Olfactory Nerve
- Pathway
    - Nasal cavity
    - Cribriform plate
    - Olfactory bulb
    - Olfactory tract
- Sensory function
    - Olfaction

CN 02: Optic Nerve
- Pathway
    - Retina
    - Optic canal
    - Optic chiasma
- Sensory function
    - Vision

CN 03: Oculomotor Nerve
- Pathway
    - Eye muscle
    - Superior orbital fissure
    - Interpeduncular fossa (ventral midbrain)
- Motor function
    - Most extraocular muscles
    - Levator palpebrae superioris
    - Sphincter pupillae

CN 04: Trochlear Nerve
- Pathway
    - Superior oblique muscle
    - Superior orbital fissure
    - Dorsal midbrain
- Motor function
    - Superior oblique muscle

CN 05: Trigeminal Nerve
- Pathway
    - Ophthalmic (V1)
        - Orbit
        - Forehead
        - Superior orbital fissure
    - Maxillary (V2)
        - Midface

        - Foramen rotundum
    - Mandibular (V3)
        - Lower face
        - Foramen ovale
    - Sensory root
        - Trigeminal ganglia
    - Motor root
        - Lateral pons
- Motor function
    - Muscles of mastication
- Sensory function
    - Sensation of the face

CN 06: Abducens Nerve

- Pathway
    - Lateral rectus muscle
    - Superior orbital fissure
    - Ventral pontomedullary junction
- Motor function
    - Lateral rectus muscle

CN 07: Facial Nerve

- Pathway
    - Facial muscles
    - Stylomastoid foramen / internal acoustic meatus
    - Ventrolateral pontomedullary junction
- Motor function
    - Muscles of facial expression
- Sensory function
    - Taste from the anterior two-thirds of the tongue
- Parasympathetic function
    - Lacrimal gland
    - Submandibular and sublingual glands

CN 08: Vestibulocochlear Nerve

- Pathway
    - Inner ear
    - Internal acoustic meatus
    - Ventrolateral pontomedullary junction
- Sensory function
    - Hearing, balance

CN 09: Glossopharyngeal Nerve

- Pathway
    - Tongue, pharynx

        - Jugular foramen
        - Lateral medulla oblongata
- Motor function
    - Pharyngeal muscles
- Sensory function
    - Taste from the posterior third of the tongue
- Parasympathetic function
    - Parotid gland

CN 10: Vagus Nerve

- Pathway
    - Abdomen
    - Thorax
    - Neck
    - Jugular foramen
    - Lateral medulla oblongata
- Parasympathetic function
    - Heart
    - Lungs
    - Digestive tract
- Sensory function
    - Sensation from the larynx and pharynx
- Motor function
    - Muscles of the larynx and pharynx

CN 11: Accessory Nerve

- Pathway
    - Neck muscles
    - Jugular foramen
    - Cranial root
        - Lateral medulla oblongata
    - Spinal root
        - Foramen magnum
        - C1 - C5
- Motor function
    - Sternocleidomastoid
    - Trapezius

CN 12: Hypoglossal Nerve

- Pathway
    - Tongue muscles
    - Hypoglossal canal
    - Ventral medulla oblongata
- Motor function
    - Muscles of the tongue

# E5. Nervous System; Special Senses

**- A. Special Senses, Overview**

**Electromagnetic Sense (phototransduction):** Photon energy absorption changes the chemical configuration of photopigment molecules

- **Visual sense**
    - Reception: **Photoreceptors** sense **light**
    - Cells: **Rods** and **cones** in the **retina**
    - Nerve: **Optic nerve (II)**

**Mechanical senses (mechanotransduction):** Mechanical energy physically bends the cell, directly opening ion channels

- **Auditory sense**
    - Reception: **Mechanoreceptors** sense **sound waves (air vibration)**
    - Cells: **Hair cells** in the **organ of Corti** in the **cochlea**
    - Nerve: **Cochlear nerve (vestibulocochlear nerve VIII)**
- **Vestibular sense**
    - Reception: **Mechanoreceptors** sense **gravitational pull** and **acceleration**
    - Cells: **Hair cells** in the **vestibular apparatus**
    - Nerve: **Vestibular nerve (vestibulocochlear nerve VIII)**

**Chemical senses**

- **Olfactory sense**
    - Reception: **Chemoreceptors** sense **odorant molecules**
    - Cells: **Olfactory receptor neurons** in the **olfactory epithelium** in the **nasal cavity**
    - Nerve: **Olfactory nerve (I)**
- **Gustatory sense**
    - Reception: **Chemoreceptors** sense **tastant molecules**
    - Cells: **Taste cells** in the **taste buds**
    - Nerve: **Facial nerve (VII), glossopharyngeal nerve (IX), vagus nerve (X)**

**- B. Olfaction**

**Olfactory mucosa / membrane**

- Location: Roof of the nasal cavity
- Contains olfactory epithelium and an underlying lamina propria

**Olfactory epithelium**

- Composed of basal cells and supporting cells
- ORNs
- **Bowman's glands** (secrete mucus that traps and dissolves odorants)

**Olfactory receptor neurons (ORNs)**

- Location: Olfactory epithelium
- Have **olfactory hairs (cilia)** with **odorant receptors** that bind to **odorants** dissolved in the mucus
- Can differentiate between a large range of odorants

**Olfactory pathway**

- ORN axons exit the nasal cavity via the **olfactory foramina** in the cribriform plate and synapse with the olfactory neurons in the **olfactory bulb**
- Olfactory bulb neurons form the **olfactory nerve (CN I)** and primarily extend to the **olfactory cortex** in the temporal lobe
- The olfactory pathway is notably the only special sense that is not routed via the thalamus

**- C. Gustation**

**Lingual** (tongue) **papillae**

- **Filiform papillae**
  - Most numerous; cover most of the tongue's surface
  - Do not contain taste buds
- **Fungiform papillae**
  - Primarily at the tip and sides of the tongue
  - Mushroom-shaped
  - Contain taste buds
- **Circumvallate papillae**
  - Large, few
  - Located towards the back of the tongue
  - Contain multiple taste buds
  - Has a surrounding trench
- **Foliate papillae**
  - Located on the sides of the posterior tongue
  - Leaf-shaped
  - Contain taste buds

**Taste buds**

- Primarily located within the lingual papillae
- Contain **gustatory cells** with microvilli (gustatory hairs) that emerge at the surface of the tongue via **taste pores** and bind with tastants dissolved in the saliva
- Can detect five tastes:
  - **Saltiness** ($Na^+$ ions)
  - **Sourness** ($H^+$ ions)
  - **Bitterness** (varied chemical makeup)
  - **Sweetness** (mostly sugars)
  - **Savoriness (umami)** (amino acids)
- The sensation of taste is heavily influenced by additional factors such as smell, texture, temperature

**Gustatory pathway**

- The gustatory cells synapse with their associated cranial nerves:
  - **Facial nerve (CN VII):** Anterior two-thirds of the tongue
  - **Glossopharyngeal nerve (CN IX):** Posterior third of the tongue
  - **Vagus nerve (CN X):** Epiglottis and pharynx
- The gustatory cranial nerves synapse at the **gustatory nucleus** in the medulla, from where the signals are primarily routed via the thalamus to the **gustatory cortex** in the insula

# E6. Nervous System; Eye

**- A. Layers**

The eye has three layers / tunics:

- **Fibrous tunic**
  - Outer layer
  - Contains:
    - **Sclera**
    - **Cornea**
- **Vascular tunic (uvea)**
  - Middle layer
  - Contains:
    - **Iris**
    - **Ciliary body**
    - **Choroid**
- **Neural tunic (retina)**
  - Inner layer
  - Contains:
    - **Retina**

---

**- B. Outer Layers**

**Conjunctiva**

- Thin, transparent sheet
- Covers the sclera and lines the inner eyelid
- Does not cover the cornea

**Fibrous tunic**

- **Sclera**
  - Outer, white connective tissue; “white of the eye”
- **Cornea**
  - Transparent
  - Located anterior to the iris and lens
  - Focuses incoming light

**- C. Vascular Layer, Chambers, Lens**

**Anterior / aqueous chamber**

- Located posterior to the cornea
- Filled with **aqueous humor**
    - Produced by the ciliary body
    - Clear fluid; provides nutrients, maintains intraocular pressure

**Vascular Layer**

- **Choroid**
    - Located towards the posterior
    - Pigmented, prevents light from scattering
- **Ciliary body**
    - Encircles the lens
    - Contains:
        - **Ciliary muscle / sphincter**
        - **Zonular fibers (suspensory ligaments)**
            - Attached to the lens to the ciliary muscle, stretching it flat
            - Ciliary muscle contraction allows the lens to bulge
    - Produces aqueous humor
- **Iris**
    - Pigmented structure
    - Contracts and dilates to adjust the amount of light entering the eye through the pupil
    - Contains:
        - **Pupil**
        - **Sphincter & dilator pupillae muscle**

**Lens**

- Located posterior to the iris
- Biconvex; convexity is adjusted by the ciliary muscle to accommodate varied focal lengths

**Accommodation:** Changing of the eye to maintain clear vision at varied distances

- **Lens accommodation:** The lens changes shape; becomes more convex for near vision
- **Pupillary reflex:** The pupils constrict for near vision

**Posterior / vitreous chamber**

- Fills the eyeball
- Filled with **vitreous humor**
    - Gel-like substance
    - Maintains intraocular pressure

**- D. Sensory Layer, Optic Nerve**

**Retina**

- **Retinal pigment epithelium (RPE)**
    - Outer layer of the retina
    - Absorbs excess light, preventing it from scattering and disturbing vision
- **Neural layer**
    - Inner layer
    - Contains:
        - **Photoreceptors**
            - Posteriormost cells
            - Rods and cones
        - **Bipolar neurons**
            - Located anterior to the photoreceptors
            - Intermediate neurons; pass signals from photoreceptors to ganglion cells
        - **Ganglion cells**
            - Anteriormost cells
            - Their axons exit the eye through the optic disc and form the optic nerve

**Retinal structures**

- **Optic disc**
    - The optic nerve exits the eye through the optic disc
    - There are no photoreceptors in the optic disc, causing a “blind spot”
- **Macula lutea**
    - Located near the center of the eye, lateral to the blind spot
    - Contain a high concentration of cones; facilitating sharp vision
- **Fovea centralis**
    - Located in the center of macula lutea
    - Contains only cones; produces the sharpest vision

**Real image:** Due to focusing of the cornea and lens, the image reaches the retina reversed left-right and upside-down

**Optic nerve pathway**

- At the **optic chiasma** the right and left optic nerve tracts meet, and the medial fibers switch sides
- From the optic chiasma, the axons form the **optic tracts**
- The optic tracts circumvent the midbrain cerebral peduncles and enter the lateral thalamus, where they synapse at the lateral geniculate nucleus (LGN)
- The signals are primarily routed via the thalamus to the **visual cortex** in the occipital lobe

**- E. Photoreceptors**

**Rods**

- Concentrated to the periphery of the eye
- Sensitive to dim light
- Detect gray tones

**Cones**

- Concentrated towards the center of the eye
- Sense high levels of detail
- Detect color

Types of cones

- **S-Cones (short wavelength):** Blue light; 420 nm
- **M-Cones (medium wavelength):** Green light; 534 nm
- **L-Cones (long wavelength):** Green and red light; 564 nm

Photopigment biochemistry

- Photoreceptor pigments are composed of **retinal** combined with various types of **opsin**
- **Retinal:** Derived from vitamin A
- **Rhodopsin:** Retinal + opsin; found in rods
- **S-photopsin:** Retinal + s-opsin; found in s-cones
- **M-photopsin:** Retinal + m-opsin; found in m-cones
- **L-photopsin:** Retinal + l-opsin; found in l-cones

**- F. Accessory Structures**

**Lacrimal Apparatus:** Produces fluid that protects and moistens the eye

- **Lacrimal gland:** Located superolateral to the eye; produces lacrimal fluid
- **Lacrimal canaliculi:** Drain lacrimal fluid from the eye into the…
- **Lacrimal sac:** Located inferomedial to the eye
- **Nasolacrimal duct:** Drains lacrimal fluid from the lacrimal sac to the nasal cavity

**Extrinsic eye muscles**

- **Superior oblique** (trochlear nerve)
- **Superior rectus**
- **Medial rectus**
- **Lateral rectus** (abducens nerve)
- **Inferior rectus**
- **Inferior oblique**

**Intrinsic eye muscles**

- **Ciliary muscles**
- **Iris muscles**
    - **Sphincter pupillae**
    - **Dilator pupillae**

Eye refractive errors

- **Myopia (nearsightedness)**
    - Distant objects appear blurry; light is focused in front of retina
    - Correction: Concave lenses; spreads light rays
- **Hyperopia (farsightedness)**
    - Close objects appear blurry; light is focused behind retina
    - Correction: Convex lenses; converges light rays

# E7. Nervous System; Ear

**- A. Ear Anatomy**

**External / outer ear**

- **Auricle / pinna:** Composed of elastic cartilage
- **External acoustic meatus / auditory canal**
  - Lined with skin
  - Contains **ceruminous** (ear wax) **glands**
- Function: Funnels sound waves towards the eardrum

**Middle ear / tympanic cavity**

- **Tympanic membrane** (eardrum)
  - Lies at the transition between the outer and middle ear
  - Transmits vibrations from the outer ear to the middle ear
- **Auditory ossicles**
  - Ossicles
    - **Malleus (hammer)**
    - **Incus (anvil)**
    - **Stapes (stirrup)**
  - Vibration is transmitted and amplified from the tympanic membrane to the malleus, to the incus, to the stapes, which strikes the oval window, transmitting the vibration to the inner ear
- **Pharyngotympanic / auditory / eustachian tube**
  - Tube between the middle ear and the nasopharynx
  - Generally collapsed; opens during yawning and swallowing to equalize pressure between the middle and outer ear (necessary for tympanic membrane function)

**Inner ear / bony labyrinth**

- Parts
  - **Cochlea**
  - **Vestibule**
  - **Semicircular canals**
- Description
  - Hollowed-out cavities within the temporal bone
  - Lined with **periosteum**
  - Filled with **perilymph**
  - Contain the **membranous labyrinth** which follows the shape of the bony labyrinth and is filled with **endolymph**

**- B. Cochlea**

Function: Auditory

Chambers

- **Scala vestibuli**
  - Upper chamber
  - Originates at the oval window
  - Terminates at the **helicotrema** (cochlear apex)
  - Filled with perilymph
- **Scala tympani**
  - Lower chamber
  - Originates at the helicotrema; the scala vestibuli loops down around the cochlear duct and transitions into the scala tympani
  - Terminates at the round window
  - Filled with perilymph
- **Cochlear duct / scala media**
  - Located between the scala vestibuli (separated by **Reissner's / vestibular membrane)** and the scala tympani (separated by the basilar membrane)
  - Filled with **endolymph**
  - Contains the organ of Corti

Cochlear duct

- **Basilar membrane**
  - Floor of the cochlear duct
  - Supports the organ of Corti
  - Primary vibrator
- **Organ of Corti / spiral organ**
  - Located on top of the basilar membrane
  - Contains
    - **Hair cells** with **stereocilia** projections; stereocilia projections extend into the tectorial membrane
    - Supporting cells
- **Tectorial membrane**
  - Located on top of the organ of Corti
  - Stationary surface against which the vibrating stereocilia bend

**- C. Audition**

Auditory transduction

- The stapes strikes the oval window, transmiting vibrations to the perilymph of the cochlea
- Vibrations in the perilymph of the scala vestibuli and scala tympani cause the basilar membrane to vibrate
- When the basilar membrane vibrates, the stereocilia of the hair cells, whose ends are embedded in the relatively stationary overlying tectorial membrane, bend
- The bending of the stereocilia opens ion channels, converting the auditory stimuli into an electrical signal

**Pitch perception**

- Pitch perception is determined by the location of the bent hair cell
- Different areas of the basilar membrane vibrate depending on the pitch
- Higher frequencies vibrate the shorter, stiffer fibers closer to the oval window
- Lower frequencies vibrate the longer, floppier fibers closer to the apex

**Auditory Pathway**

- The cochlear hair cells synapse with the **spiral ganglion cells** (located in the **spiral ganglion** in the modiolus), which form the **cochlear nerve**
- The cochlear nerve joins the vestibular nerve to form the vestibulocochlear nerve (CN VIII)
- The vestibulocochlear nerve enters the brainstem at the PMJ
- Within the brainstem, the vestibular and cochlear nerves diverge; the cochlear nerve terminates and synapses in the brainstem **cochlear nuclei**
- From the cochlear nuclei, the brain processes and routes the signals through various relay centers, ultimately routing via the thalamus to the **auditory cortex** in the temporal lobe

**- D. Vestibular Apparatus**

**Vestibule**

- Central body of inner ear
- Membranous labyrinth contains the **otolith organs** (**utricle** and **saccule)**
    - Otolith organs are regions within the membranous labyrinth with **maculae** structures
    - **Macula**
        - Composed of a basement membrane and supporting cells
        - Contain **hair cells** with **stereocilia** projections that extend into the otolithic membrane
        - **Otolithic membrane**
            - Gelatinous membrane overlying the hair cells
            - Contains embedded **otoliths** (calcium carbonate crystal granules)

**Static Equilibrium**

- Detects if the head is in a tilted position (head position relative to gravity)
- If the head is tilted, the otoliths slide to the tilted side due to gravitational pull, pulling the otolithic membrane, causing the stereocilia, whose base is stationary, to bend

**Semicircular Canals**

- Three semicircular canals orthogonally arranged above the vestibule
- **Semicircular duct:** Endolymph-filled membranous labyrinth within the semicircular canals
- **Membranous ampulla:** Large enclosed sac at the end of the semicircular ducts containing the crista ampullaris and cupula
    - **Crista ampullaris**
        - Composed of a basement membrane and supporting cells
        - Contain **hair cells** with **stereocilia** projections that extend into the cupula
    - **Cupula**
        - Gelatinous structure; sits above the crista ampullaris

**Dynamic Equilibrium**

- Detects dynamic acceleration
- When the head accelerates, and with it the crista ampullaris, the loose endolymph in the semicircular ducts lags momentarily, due to inertia; this exerts pressure on cupula, pushing it and causing the stereocilia, whose base is stationary, to bend
- The three semicircular canals extend in all three dimensions, detecting all acceleration vectors

**Vestibular Pathway**

- The macula and ampulla hair cells synapse with the **vestibular ganglion cells**, located in the **vestibular ganglion** near the internal acoustic meatus, which form the **vestibular nerve**
- The vestibular nerve joins the cochlear nerve to form the vestibulocochlear nerve (CN VIII)
- The vestibulocochlear nerve enters the brainstem at the PMJ
- Within the brainstem, the vestibular and cochlear nerves diverge; the vestibular nerve terminates and synapses in the brainstem **vestibular nuclei**
- From the vestibular nuclei, the brain processes and routes the signal to various destinations (cerebellum, spinal cord, thalamus, various cortical regions

# F1. Endocrine System

**- A. Endocrine System; Overview**

**Endocrine system**

- Regulates bodily functions via hormones circulating in the blood
- Hormones are produced and secreted by **endocrine glands**

**Hormone**

- Chemicals that regulate cellular activities
- Each hormone affects **target cells** in **target organs** that have specific protein receptors for that hormone

Types of Hormones

- **Steroid-based:** Lipid-soluble, derived from cholesterol; capable of penetrating cell membranes
- **Amino acid-based:** Lipid-insoluble, contains peptides and proteins; incapable of penetrating cell membranes

Types of Hormone Regulation

- **Direct gene activation (steroid hormone activation)**
  - Used by steroid hormones, which are capable of penetrating cell membranes
  - The hormone diffuses through the cell membrane, enters the cell, diffuses through the nuclear membrane, binds to a protein receptor; the hormone-receptor complex binds to DNA and activates a gene
- **Second messenger system (nonsteroid hormone activation)**
  - Used by non-steroid lipid insoluble hormones, which are incapable of penetrating plasma membranes
  - The hormone remains out of the cell and instead binds with a membrane protein receptor, which triggers a chain of events that results in the activation of an enzyme that produces the second messenger molecule
  - The second messenger molecule generally affects cytoplasmic activities and does not enter the nucleus

Methods of endocrine gland activation

- **Hormonal**
  - Most common method
  - Hormones activate glands to produce other hormones
  - **Tropic:** Hormone that regulates the hormone production of an endocrine gland
- **Humoral:** Activated by changes in a given substance's concentration within the blood
- **Neural**

Endocrine system regulation

- Hormone levels are primarily maintained through negative feedback - a given deficiency triggers hormone secretion; when adequate levels are reached, the gland stimulation terminates

**- B. Hypothalamus, pituitary gland**

Relation between the hypothalamus and pituitary gland:

- The pituitary gland is attached to the hypothalamus via the **infundibulum**
- Pituitary gland lobes:
  - **Anterior pituitary gland**
    - Produces its own hormones
    - Stimulated by tropic hormones released by the hypothalamus into the **hypothalamic-hypophyseal portal system:** Blood vessels that extend from the hypothalamus directly to the anterior pituitary gland
  - **Posterior pituitary gland**
    - Does not produce its own hormones
    - Stores hormones produced by the hypothalamus and carried to the posterior pituitary by **neurosecretory** cells; releases the hormones upon nerve stimuli from the hypothalamus
- The hypothalamus/pituitary release many hormones that control glandular activity throughout the body, and are referred to as the “master gland”

Anterior pituitary gland hormones

- **Thyroid stimulating hormone (TSH)**
  - Tropic hormone
  - Regulates the thyroid gland
- **Adrenocorticotropic hormone (ACTH)**
  - Tropic hormone
  - Regulates the adrenal cortex endocrine secretions
- **Follicle-stimulating hormone (FSH)**
  - Gonadotropic hormone
  - Stimulates ovarian follicle development and estrogen production in females and testes sperm production in males
- **Luteinizing hormone (LH)**
  - Gonadotropic hormone
  - Stimulates ovarian egg ovulation in females and testes androgen production in males
- **Growth hormone (GH)**
  - Affects bones and muscles
- **Prolactin**
  - Stimulates milk production in the mammary glands after childbirth

Posterior pituitary gland hormones

- **Oxytocin**
  - Stimulates uterine contractions during childbirth
  - Stimulates milk ejection from the mammary glands
- **Antidiuretic hormone (ADH) / vasopressin**
  - Increases water retention in the kidneys, raising blood pressure
  - Also increases blood pressure by stimulating vasoconstriction

**- C. Pineal, Thyroid, Parathyroid, Thymus Glands**

**Pineal gland**

- Location: Epithalamus
- Produces: **Melatonin**; a hormone that regulates sleep/wake cycles
- Stimulation: Neural; superior cervical ganglion sympathetic neurons

**Thyroid gland**

- Location: Neck; anterior to trachea, inferior to larynx
- Produces:
    - **Thyroid hormone**
        - Iodine-containing hormone; controls metabolic rate of glucose oxidation
        - Released by **thyroid follicles**
        - Stimulation: Hormonal; TSH released by the anterior pituitary
    - **Calcitonin**
        - Decreases blood calcium level by activating osteoblast activity (antagonist to PTH)
        - Released by **parafollicular cells (C cells)**
        - Stimulation: Humoral; blood calcium levels

**Parathyroid glands**

- Location: Typically four glands on the posterior thyroid
- Produce: **Parathyroid hormone (PTH):** Increases blood calcium level by activating osteoclast activity (antagonist to calcitonin)
- Stimulation: Humoral; blood calcium level

**Thymus gland**

- Location: Posterior to the sternum
- Produces: **Thymosin** - aids in immune system development
- Stimulation: Varied hormonal and immune factors

**- D. Adrenal Glands, Pancreas**

**Adrenal glands** (R, L)

- Location: Superior to the kidneys
- Contains a cortex and medulla
- **Adrenal cortex:** Outer region
    - Has three layers; each secretes a different type of **corticosteroids**
        - **Mineralocorticoids**
            - Secreted by the outermost **zona glomerulosa**
            - Primary mineralocorticoid: **Aldosterone**
            - Regulate electrolyte and water level in the blood by stimulating water and sodium retention and potassium excretion by the kidneys
        - **Glucocorticoids**
            - Secreted by the middle **zona fasciculata**
            - Primary glucocorticoid: **Cortisol**
            - Responds to long term stress
            - Triggers an increase in blood glucose level via fat and protein conversion into glucose
            - Reduces inflammation
        - **Androgens**
            - Small amount secreted by the innermost **zona reticularis**
    - Stimulation: Hormonal; ACTH released by the anterior pituitary
- **Adrenal medulla:** Inner region
    - Produces **catecholamines**:
        - **Epinephrine (adrenaline)**
        - **Norepinephrine (noradrenaline)**
            - Short term stress; “fight or flight response” - increases heart rate, blood pressure, blood glucose, dilates lungs, etc.
    - Stimulation: Neural; sympathetic nervous system

**Pancreas**

- Location: Posterior to the stomach, between the spleen and duodenum
- Has endocrine and exocrine functions
- **Pancreatic islets / Islets of Langerhans:** REgion of the pancreas that has endocrine functions; produces blood glucose regulators:
    - **Insulin**
        - Produced by beta cells
        - Stimulation: Humoral; high blood glucose levels
        - Function: Increases cell glucose uptake and metabolism
        - Antagonist: Glucagon
    - **Glucagon**
        - Produced by alpha cells
        - Stimulation: Humoral; low blood glucose levels
        - Function: Stimulates the liver to convert glycogen into glucose and release it into the bloodstream

**- E. Gonads, Placenta**

**Ovaries**

- Location: Lateral to the uterus
- Produces:
    - **Ova** (eggs)
    - **Steroid hormones**
        - **Estrogen**
            - Female sex hormone
            - Helps develop secondary female characteristic
            - Stimulates female reproductive organ maturation
            - Is one of the hormones the regulates the female reproductive cycle
        - **Progesterone**
            - Is one of the hormones the regulates the female reproductive cycle
            - Aids embryonic uterus implantation
            - Maintains the uterine lining and prevents early contractions during pregnancy
            - Prepares the breasts for lactation
- Stimulation: Hormonal; FSH and LH released by the anterior pituitary

**Testes**

- Location: Scrotum
- Produces:
    - **Sperm**
    - **Androgens** (primarily testosterone)
        - Male sex hormone
        - Helps develop secondary male characteristics
        - Stimulates mature male organ maturation
        - Help sperm production
    - Stimulation: Hormonal; FSH and LH released by the anterior pituitary

**Placenta**

- Location: Uterine wall
- Endocrine functions: Produces pregnancy related hormones (**hCG, hPL, relaxin)**; also temporarily takes over estrogen and progesterone production from the ovaries during pregnancy

**- F. Non-Classical Endocrine Organs**

**Heart**

- **Atrial Natriuretic Peptide (ANP):** Antagonist for RAAS

**Kidneys**

- **Erythropoietin:** Stimulates red blood cell production in red bone marrow
- **Renin:** Initiates the **renin-angiotensin-aldosterone system (RAAS)** which increases blood pressure and volume
- **Calcitriol:** Active form of vitamin-D; promotes calcium absorption

**Liver**

- **Insulin-like Growth Factor 1 (IGF-1):** Promoted by GH
- **Angiotensinogen:** RAAS
- **Thrombopoietin:** Promotes thrombocyte production
- **Hepcidin:** Regulates iron

**Stomach**

- **Ghrelin:** Agonist for GH

**Adipose Tissue**

- **Leptin:** Regulates energy balance
- **Adiponectin:** Regulates glucose levels and fatty acid breakdown

**Skin**

- **Vitamin D:** Synthesized from cholesterol upon sunlight exposure

# G1. CVS System; Blood

**- A. Cardiovascular System**

Components
- Heart
- Blood vessels
- Blood

---

**- B. Blood**

Functions
- Transportation
    - Nutrients
    - Gasses (O2, CO2)
    - Wastes
    - Hormones
- Protection
    - Clotting
    - Immune
- Regulation
    - Temperature
    - pH levels
    - Fluid balance

Composition: Connective tissue
- Matrix (non-living component)
    - **Plasma**
- Formed elements (living cells)
    - **Erythrocytes (red blood cells)**
    - **Leukocytes (white blood cells)**
    - **Thrombocytes (platelets)**

General proportions, visible when separated via centrifuge:
- 45% lower red layer: erythrocytes
- <1% middle buffy coat layer: leukocytes and thrombocytes
- 55% upper straw-colored layer: plasma

**Hematocrit:** Percentage of erythrocytes in a given volume of blood

Color: Bright red when oxygenated, dull red when deoxygenated
pH: Slightly basic; 7.35-7.45

**- C. Plasma**

Components
- 90% water
- 6% plasma proteins
    - **Albumin**
        - most abundant plasma protein
        - Produced by the liver
        - Maintains osmotic pressure by keeping water from leaking out of blood vessels
    - **Fibrinogen**
        - Clotting proteins - transform to fibrin mesh during blood clotting
        - Produced by the liver
    - **Globulins**
        - Immune proteins
- 4% dissolved substances
    - Nutrients
    - Wastes
    - Gasses (CO2)
    - Hormones

---

**- D. Erythrocytes**

Function
- Oxygen transport
- Transports roughly 20% of $CO_2$; the rest of the $CO_2$ is transported by the plasma

Features
- Structure: Biconcave disc
- Anucleate; cannot divide or synthesize proteins
    - Lifespan: 90 - 120 days, at the end of which they are eliminated via phagocytosis in the spleen and liver
- Contain very few organelles
- Primarily filled with hemoglobin

**Hemoglobin (Hb)**
- Iron-containing protein
- Binds strongly, yet reversibly, with oxygen
- Has a central iron and four hemoglobin chains; each chain binds with a single oxygen molecule

**- E. Leukocytes**

Features
- Capable of **diapedesis:** Passing through the blood vessel wall into peripheral tissues
- Can move through tissues via **ameboid motion**
- Function: Immune

Types
- **Granulocytes**
  - Visible features:
    - Cytoplasmic granules
    - Lobed nuclei
  - Types
    - **Neutrophils (60%)**
      - Primary responders to bacterial infections
      - Granules absorb both acidic and basic dyes and stain a combined lilac
    - **Eosinophils (4%)**
      - Defend against parasites
      - Granules absorb acidic eosin dyes and stain red
    - **Basophils (1%)**
      - Release histamine and other inflammation mediators
      - Granules absorb basic dyes and stain blue
- **Agranulocytes**
  - Lack visible cytoplasmic granules
  - Types:
    - **Lymphocytes (30%)**
      - Cytoplasm is a thin ring around the circular nucleus
      - **B Cells:** Produce antibodies as part of the adaptive immune system
      - **T Cells:** Regulate immune response and kill target cells as part of the adaptive immune system
      - **Natural Killer (NK) Cells:** Kill target cells as part of the innate immune system
    - **Monocytes (6%)**
      - Regular-sized cytoplasm; curved nucleus
      - Migrate into tissues and differentiate into **macrophages**

---

**- F. Thrombocytes**

Function: Blood clotting
Structure: Platelets are fragments of ruptured, multinucleated megakaryocytes

**- G. Hematopoiesis**

**Hematopoiesis:** Formation of blood cells

- Takes place in red bone marrow
- **Hemocytoblast stem cells (HSC)**
    - Hematopoietic stem cell
    - Form secondary stem cells:
        - **Lymphoid stem cells:** Form lymphocytes
        - **Myeloid stem cells:** Form all other types of blood cells

Hematopoiesis regulation

- Erythrocyte regulator: **Erythropoietin**, produced in the kidneys in response to low blood oxygen levels
- Leukocyte regulator: Various hormones
- Thrombocyte regulator: **Thrombopoietin**

---

**- H. Hemostasis**

**Hemostasis:** The process of stopping blood loss from damaged blood vessels through the formation of a blood clot

Steps of hemostasis

1. **Vascular spasm**
    - Blood vessels reflexively constrict to reduce blood flow
2. **Platelet plug formation**
    - Collagen fibers in the damaged blood vessel walls are exposed to blood
    - Platelets in the the blood adhere to the exposed collagen fibers
    - Anchored platelets attract additional platelets, which adhere to them and form a platelet plug
3. **Coagulation**
    - Once the platelet plug is formed, the clot begins to develop
    - Plasma fibrinogen is converted to a **fibrin** mesh that traps erythrocytes and platelets, forming a clot
        - Pathway: Damaged tissues release **tissue factor (TF)**, triggers **prothrombin** activation and conversion into **thrombin**; active thrombin then converts fibrinogen into fibrin
4. **Clot retraction**
    - The clot contracts, pulling the broken endothelium together to promote healing
5. **Thrombolysis / fibrinolysis**
    - Once the blood vessel is fully repaired, the clot is broken down and cleared

## G1. CVS System; Blood

### - I. ABO Blood Groups

**Blood groups**

- Genetically determined based on the antigens on an individual's RBCs
- An individual whose RBCs do not have a given antigen has antibodies for that antigen, and cannot receive blood from a donor with those antigens

**ABO Groups**

- Potential antigens: **Antigen A, Antigen B**
- Potential antibodies: **Anti-A, Anti-B**
- Groups:
    - **Blood Group A**
        - Antigens: Antigen A
        - Antibodies: Anti-B
        - Cannot receive: B, AB
    - **Blood Group B**
        - Antigens: Antigen B
        - Antibodies: Anti-A
        - Cannot receive: A, AB
    - **Blood Group AB**
        - Antigens: Antigen A, Antigen B
        - Antibodies: none
        - Cannot receive: none
    - **Blood Group O**
        - Antigens: none
        - Antibodies: Anti-A, Anti-B
        - Cannot receive: A, B, AB

**- J. Rh Blood Groups**

**Rh Blood Groups**

- Potential antigen: **Antigen D (Rh factor)**
- Potential antibody: **Anti-D**
- Groups
    - **Positive:** Has Antigen D
    - **Negative:** Does not have Antigen D
- Risk scenario:
    - Individuals who do not have Antigen D are not born with Anti-D antibodies; they develop Anti-D antibodies only upon exposure to Rh-positive blood
    - A significant risk exists in the following scenario:
        - An Rh-negative woman is pregnant with her second Rh-positive child
        - During the first pregnancy, exposure to the baby's Rh-positive blood can trigger the mother to produce Anti-D antibodies
        - This does not affect the first child, as the antibodies are only sufficiently produced after the first pregnancy
        - However, if a subsequent Rh-positive pregnancy occurs, the existing Anti-D antibodies can cross the placenta and harm the fetus

# G2. CVS System; Heart

**- A. Heart External Anatomy**

Heart
- Location: Thoracic cavity; inferior **mediastinum**
- Orientation: Apex faces the left hip; base faces the right shoulder

**Pericardium:** Membranes that surround the heart
- **Fibrous pericardium**
  - Outermost layer
  - Dense connective tissue layer
  - Provides protection and anchors the heart to the surrounding tissues
- **Serous pericardium:** Inner two-layered serous membrane
  - **Parietal pericardium**
    - Outer serous layer
    - Lines the inner side of the fibrous pericardium
  - **Visceral pericardium**
    - Inner serous layer
    - Directly lines the heart muscle; is the outermost layer of the heart
  - **Pericardial cavity**
    - Cavity between the visceral and parietal pericardium
    - Filled with **serous fluid**

Layers of the heart
- **Endocardium**
  - Innermost endothelial layer
- **Myocardium**
  - Middle cardiac muscle layer
- **Epicardium**
  - Outermost layer; visceral pericardium

**- B. Heart Internal Anatomy**

Overview

- The heart has two sides, which pump blood through separate circulations:
  - **Right heart:** Pumps blood through the **pulmonary circulation**
  - **Left heart:** Pumps blood through the **systemic circulation**
- Each side of the heart has two chambers:
  - **Atrium (R, L):** Receiving chamber
    - **Auricle (R, L):** Outward extension of the atria
  - **Ventricle (R, L):** Pumping chamber
- Blood pathway:
  - **Right atrium**
    - Receives deoxygenated blood from the systemic circulation
    - Drains into the right ventricle
  - **Right ventricle**
    - Receives deoxygenated blood from the right atrium
    - Pumps the blood into the pulmonary system, where it gets oxygenated by the lungs
  - **Left atrium**
    - Receives oxygenated blood from the pulmonary circulation
    - Drains into the left ventricle
  - **Left ventricle**
    - Receives oxygenated blood from the left atrium
    - Pumps the blood into the systemic circulation, where it gets deoxygenated by the body tissues

**Heart valves:** Prevent backflow

- **Atrioventricular (AV) valves:** Prevent backflow from the ventricles to the atria
  - **Right AV valve / tricuspid valve**
  - **Left AV valve / bicuspid valve / mitral valve**
  - **Subvalvular apparatus**
    - **Papillary muscles:** Contract during ventricular contraction to anchor the AV valves shut
    - **Chordae tendineae:** Attach the AV valves to the papillary muscles
- **Semilunar valves:** Prevent backflow from the great arteries to the ventricles
  - **Pulmonary semilunar valve**
  - **Aortic semilunar valve**

Inner walls

- **Interatrial septum**
- **Interventricular septum**

**- C. Blood Vessels**

Blood vessels

- **Arteries:** Carry blood away from the heart
- **Veins:** Carry blood towards the heart

**Great vessels:** Major arteries and veins that directly connect to the heart

- **Superior vena cava**
    - Returns blood from the upper body (above the diaphragm) to the right atria
- **Inferior vena cava**
    - Returns blood from the lower body (below the diaphragm) to the right atria
- **Pulmonary arteries**
    - The **pulmonary trunk** receives blood from the right ventricle and splits to the **right** and **left pulmonary arteries**
- **Pulmonary veins**
    - Four veins; return blood from the pulmonary circulation to the left atria
- **Aorta**
    - Receives blood from the left ventricle

**- D. Cardiac Cycle**

**Cardiac Cycle:** The sequence of events that takes place during a single heartbeat

**Systole:** Ventricular contraction
**Diastole:** Ventricular relaxation

Cardiac cycle events

- **Ventricular filling**
  - Occurs during late diastole and atrial systole
  - AV valves: Open
  - SL valves: Closed
  - Blood flows from the atria to the ventricles
    - First passively, due to the atrioventricular pressure gradient
    - Then actively, due to atrial contraction
- **Isovolumetric contraction**
  - Occurs during early systole and atrial diastole
  - AV valves: Closed
  - SL valves: Closed
  - Ventricular contraction begins, closing the AV valves, however, the pressure is insufficient to open the SL valves
- **Ventricular ejection**
  - Occurs during late systole
  - AV valves: Closed
  - SL valves: Open
  - Systolic pressure opens the SL valves; blood flows from the ventricles to the pulmonary trunk and aorta
- **Isovolumetric relaxation**
  - Occurs during early diastole
  - AV valves: Closed
  - SL valves: Closed
  - Diastole begins, the SL valves close; the ventricles have not yet sufficiently relaxed for the AV valves to open

**Heart sounds:** Sounds made by the closing of the heart valves

- **S1 (“lubb”)**
  - Sound of the AV valves closing
  - Occurs during isovolumetric contraction due to systole
  - Louder than S2 because the AV valves, which are shut by ventricle systolic pressure, are shut with more force than the SL valves, which are shut by passive arterial pressure
- **S2 (“dubb”)**
  - Sound of the SL valves closing
  - Occurs during isovolumetric relaxation at the end of systole

**- E. ECG**

**ECG:** Electrocardiogram

- Detects cardiac cycle events by measuring electrical activity generated by atrial and ventricular depolarization and repolarization
- A normal ECG has three waves:
    - **P Wave**
        - Atrial depolarization
        - Occurs during ventricular filling due to atrial systole
    - **QRS Complex**
        - Ventricular depolarization
        - Occurs during isovolumetric contraction due to ventricular systole
        - Overshadows simultaneous atrial repolarization (due to atrial diastole)
    - **T wave**
        - Ventricular repolarization
        - Occurs during isovolumetric relaxation due to ventricular diastole

**- F. Heart Conduction**

**Intrinsic conduction / autorhythmicity:** The heart rhythmically generates and conducts action potentials without external input from the nervous system

**Conduction Pathway**

- **Sinoatrial (SA) node / pacemaker**
  - Located in the right atrium
  - Function: Initiates the heartbeat and controls the heart rate
  - Generates the contraction impulse, causing atrial systole
  - The impulse spreads to the AV node
- **Atrioventricular (AV) node**
  - Located at the atrioventricular junction
  - Receives the impulse from the SA node
  - **AV node delay:** Delays transmitting the impulse for approximately 0.1 seconds, allowing more time for ventricular filling before ventricular systole
  - Transmits the impulse to the AV bundle
- **Atrioventricular (AV) bundle / Bundle of His**
  - Located in the superior interventricular septum
  - Receives the impulse from the AV node
  - Transmits the impulse to the bundle branches
- **Bundle branches (R, L)**
  - Located in the inferior interventricular septum
  - Receives the impulse from the AV bundle
  - Transmits the impulse to the Purkinje fibers
- **Conduction myofibers / Purkinje fibers**
  - Located throughout the ventricle walls
  - Receive the impulse from the bundle branches
  - Spread the impulse through the ventricles, causing ventricular systole

Heartbeat regulation

- Interatrial and interventricular conduction
  - **Intercalated discs:** Connect adjacent myocardial cells via gap junctions, facilitating rapid action potential transmission for simultaneous contraction
- Atrioventricular conduction
  - It is necessary for there to be a delay between atrial contraction and ventricular contraction to allow more time for ventricular filling
  - There are no gap junctions connecting the ventricular cells to the atrial cells
  - Instead, the signal is transmitted via the conduction pathway, which delays transmission at the AV node

**- G. Cardiac Output**

**Stroke Volume (SV)**

- Volume of blood pumped by the heart per ventricular contraction

**Heart Rate (HR)**

- Number of heartbeats per minute

**Cardiac Output (CO)**

- Volume of blood pumped by the heart per minute
- Equation: $CO = HR \cdot SV$

Stroke volume factors

- **Starling's Law:** The strength of the cardiac contraction depends on the amount of pre-contraction stretch

Heart rate factors

- The intrinsic SA node heart rate is roughly 100 BPM
- Factors that increase heart rate:
    - Sympathetic nervous system, due to:
        - Fight-or-flight response
        - Exercise
        - Low blood pressure
        - Decreased blood volume
    - Hormones
        - Epinephrine
        - Thyroxine
- Factors that decrease heart rate:
    - Parasympathetic nervous system, due to:
        - Rest-and-digest response
        - High blood pressure
        - Increased blood volume

**Bradycardia:** Heart rate <60 BPM

**Tachycardia:** Heart rate >100 BPM

**- H. Cardiac Muscle Action Potential**

**Pacemaker Potential**

- Overview
    - Pacemaker cells do not have a stable resting membrane potential; instead, they have a pacemaker potential phase
    - During the pacemaker potential phase, the cell gradually depolarizes until it reaches the threshold potential and triggers an action potential
    - This cycle maintains the heart's autorhythmic contractions
- Microanatomy
    - The pacemaker potential polarization triggers the **funny current:** a unique current where sodium influx and potassium efflux occur simultaneously through the same channel
    - Although both sodium and potassium flow through the channel, the rate of sodium influx is higher than that of potassium efflux, causing gradual depolarization that eventually reaches the threshold potential and triggers an action potential
    - The action potential causes voltage-gated calcium channels to open; calcium ions ($Ca^{2+}$) rush in and further depolarize the cell
    - Standard potassium-mediated repolarization follows
    - Repolarization triggers the funny current, repeating the cycle

**Prolonged Depolarization**

- Overview
    - **Plateau phase:** Cardiac contractile cells remain depolarized for a prolonged period
    - During this **refractory period**, the cell cannot be triggered by another action potential, ensuring complete cardiac muscle relaxation between contractions
- Microanatomy
    - The initial depolarization is sodium-mediated
    - Depolarization triggers the opening of calcium and potassium channels, causing a plateau phase, during which calcium flows into the cell and potassium flows out, maintaining a prolonged depolarization
    - After a period of time, the calcium channels close, more potassium channels open, and standard repolarization follows

# G3. CVS; Blood Vessels

**- A. Vascular System; Overview**

**Vascular System:** The network of blood vessels that circulates blood throughout the body

Components

- **Arteries, arterioles:** Carry blood away from the heart; feed capillaries
- **Capillaries:** Exchange substances with body tissues
- **Venules, veins:** Drain blood from capillaries; return blood to the heart

---

**- B. Blood Vessel Histology**

Blood vessel layers

- **Central lumen**
- **Tunica intima / interna**
    - Innermost layer
    - Composed of endothelium (simple squamous epithelium with basement membrane)
- **Tunica media**
    - Middle, thickest layer
    - Composed of smooth muscle
- **Tunica externa**
    - Outermost layer
    - Fibrous connective tissue
- Capillaries only have a tunica intima

**- C. Differences Between Arteries and Veins**

Source of blood pressure

- Arterial blood pressure: Driven by heart contractions
- Venous blood pressure: Driven by Numerous factors:
    - **Skeletal muscle pump:** Skeletal muscle contraction compresses veins, propelling blood towards the heart
    - **Thoracic pump:** During inhalation, thoracic pressure decreases while abdominal pressure increases, creating a gradient that pushes blood upward toward the heart
    - **One-way venous valves**
    - **Smooth muscle contraction**

Blood flow

- Arteries: High pressure; rhythmic bursts
- Veins: Low pressure; slow and steady flow

Structural differences

- Arteries:
    - Thicker walls (particularly tunica media) to withstand high pressure from the heart contractions
    - **Elastic laminae** layers; expand and recoil with each heartbeat
    - Smaller lumen
- Veins:
    - Thinner walls
    - Contain one-way valves
    - Larger lumen

**- D. Capillaries**

Capillary anatomy: Thin walls (only tunica intima), facilitating substance exchange

**Microcirculation:** Blood flow from arterioles, through capillary beds, to venules

- Arteries branch into arterioles
- Terminal arterioles branch into capillaries
- Capillaries form capillary beds, which exchange substances with the surrounding interstitial fluid
- Capillaries drain into postcapillary venules, which drain into veins

**Arteriovenous anastomoses:** Microcirculatory networks in which the capillary beds are bypassable

- **Precapillary sphincter:** Located at capillary origin; can close to prevent capillary blood flow
- **Vascular shunt:** Direct path from arteries to veins; when the precapillary sphincters are closed, blood flows through the shunt

Capillary substance exchange

- Capillaries exchange substances with the surrounding interstitial fluids
    - Oxygen and nutrients leave the blood and enter the body tissues
    - $CO^2$ and wastes leave the body tissues and enter the blood
- Substance exchange methods:
    - Passive diffusion
        - Through the endothelium: Lipid soluble products
        - Through intercellular clefts (not applicable in the brain due to the blood-brain barrier): Limited fluids and small solutes
        - **Fenestrated capillaries**
            - Located in areas where high absorption is necessary
            - Contain pores through which small solutes and fluids can flow
    - Vesicle transport: Larger substances
    - Bulk fluid flow
        - **Blood pressure / intracapillary hydrostatic pressure** forces fluid out of the capillaries
        - **Osmotic pressure / oncotic pressure** (osmotic pressure due to proteins in the blood) forces fluid into the capillaries, as blood has a higher solute concentration than interstitial fluid
        - Blood pressure is generally greater than osmotic pressure towards the arterial end of the capillary bed, forcing fluid out of the capillaries
        - Osmotic pressure is generally greater than blood pressure towards the venous end of the capillary bed, forcing fluid back in
            - Blood pressure decreases across the capillary, as blood exits and the blood volume decreases, however, oncotic pressure stays the same, as proteins do not exit the capillaries

**- E. Blood Pressure**

**Blood pressure (BP):** Pressure exerted by the blood against the blood vessel walls

- In arteries:
    - Pressure is greater closer to the heart and lower further from the heart; this pressure gradient drives arterial circulation
- In veins
    - Pressure is low
    - Pressure at the superior and inferior vena cava is 0; this pressure gradient drives venous circulation

**Systolic blood pressure:** Arterial blood pressure at peak ventricular contraction; normally 110 - 145
**Diastolic blood pressure:** Arterial blood pressure at peak ventricular relaxation; normally 75 - 85
**Hypotension:** Systolic blood pressure < 110
**Hypertension:** Systolic blood pressure > 140

Blood pressure calculation: $Blood\ pressure\ (BP)\ =\ cardiac\ output\ (CO)\ \cdot\ peripheral\ resistance\ (PR)$

**Peripheral resistance (PR):** Friction exerted on the blood by the blood vessel walls

- PR factors:
    - Size of the vessel lumen
    - Vessel length (longer vessels have higher total friction)
    - Blood volume
    - Blood viscosity / hematocrit

Blood pressure factors

- Neural factors
    - The sympathetic nervous system causes vasoconstriction (via the medulla oblongata)
    - The sympathetic and parasympathetic systems affect heart rate and stroke volume
- Renal factors
    - Blood volume regulation
        - When blood pressure is high, more fluid is excreted in urine
        - When blood pressure is low, less fluid is excreted
    - Renin release (RAAS)
        - When blood pressure is low, the kidneys release **renin**
        - Renin leads to **angiotensin II** formation, which is a vasoconstrictor, and stimulates the adrenal cortex to release **aldosterone**
        - Aldosterone enhances sodium reabsorption, which pulls water, increasing blood volume
- Temperature
    - Cold: Causes vasoconstriction
    - Heat: Causes vasodilation
- Chemicals
- Diet (sodium intake)
- Fluid loss

# G4. CVS; Blood Vessel Gross Anatomy

**- A. Arteries**

**Aorta**

- Regions:
  - **Ascending aorta**
  - **Aortic arch**
  - **Descending aorta:** Transitions at the diaphragm into the…
  - **Abdominal aorta**

Branches from the aortic arch

- **Brachiocephalic trunk:** splits into the…
  - **Right common carotid**
  - **Right subclavian**
- **Left common carotid**
- **Left subclavian**

Cerebral arteries

- The common carotid artery (r, l) splits into the…
  - **Internal carotid (r, l):** Supplies the brain
  - **External carotid (r, l):** Supplies the neck and face
- **Vertebral arteries (r, l):** Branches from the subclavian (r, l)

Arteries of the upper limbs

- The subclavian (r, l) crosses the clavicle and transitions into the **axillary (r, l)**
- The axillary (r, l) enters the arm and transitions into the **brachial (r, l)**
- The brachial (r, l) splits at the elbow into the…
  - **Radial (r, l)**
  - **Ulnar (r, l)**
- The radial (r, l) and ulnar (r, l) merge at the hand to form the **palmar arch (r, l)**

Abdominal arteries

- The abdominal aorta is located on the posterior abdominal cavity wall
- Larger, midline branches:
  - **Celiac trunk:** Located above the pancreas; divides into the…
    - **Left gastric:** Supplies the foregut
    - **Splenic**
    - **Common hepatic**
  - **Superior mesenteric:** Located below the pancreas; supplies the midgut
  - **Inferior mesenteric:** Located above the pelvis; supplies the hindgut
- Smaller, lateral branches:
  - **Renal (r, l):** Located between the celiac trunk and superior mesenteric
  - **Gonadal (r, l): Ovarian (r, l), Testicular (r, l):** Located between the superior and inferior mesenteric

Arteries of the lower limbs

- At the pelvic rim, the abdominal aorta divides into the…
    - **Right** and **left common iliac**, which each divide into the…
        - **Internal iliac (r, l):** Supplies the pelvic organs
        - **External iliac (r, l):** Supplies the lower limbs
    - The external iliac (r, l) transitions at the thigh into the…
    - **Femoral (r, l)**, which transitions at the knee into the…
    - **Popliteal (r, l)**, which splits into the…
        - **Anterior** and **Posterior tibial (r, l)**, which merge at the foot to form the **plantar arch (r, l)**
        - **Deep artery of the thigh (r, l):** Branches from the femoral artery

**- B. Veins**

Veins that drain into the right atrium:

- **Superior vena cava:** Drains the upper body
- **Inferior vena cava:** Drains the lower body
- **Coronary sinus:** Drains the coronary circulation

Superior vena cava

- The SVC drains the **right** and **left brachiocephalic**, which are formed by the…
    - **Internal jugular (r, l)** and
    - **Subclavian (r, l)**

Cranial veins

- Internal jugular (r, l): Drains blood from the head; forms the brachiocephalic (r, l) together with the subclavian (r, l)
- **External jugular (r, l):** Drains blood from the scalp and face into the subclavian (r, l)
- **Vertebral (r, l):** Drains blood from the posterior head into the brachiocephalic (r, l)

Veins of the upper limbs

- The subclavian (r, l) drains the **axillary (r, l)**
- Deep vessels: The axillary (r, l) drains the **brachial (r, l)** which splits at the elbow into the…
    - **Radial (r, l)** and **ulnar (r, l)** which merge at the hand to form the **palmar arch (r, l)**
- Superficial vessels:
    - **Basilic (r, l):** Located in the superficial medial arm; joins the brachial (r, l) to form the axillary (r, l)
    - **Cephalic (r, l)**: Located in superficial lateral arm; drains into the axillary (r, l)
        - The basilic (r, l) and cephalic (r, l) are connected by the **median cubital vein (r, l)**

Inferior vena cava

- The inferior vena cava drains the…
    - **Hepatic, renal (r, l), gonadal (r, l)**
    - **Common iliac (r, l)** which drains the…
        - **Internal iliac (r, l)**
        - **External iliac (r, l)** which drains the **femoral (r, l)** which drains the…
            - **Popliteal (r, l)** and **great saphenous (r, l)**

Hepatic portal circulation

- **Portal circulation:** Circulation containing two sets of capillaries in sequence
- **Hepatic portal circulation:** Substance-rich blood from the abdominal organs is filtered and detoxified by the liver prior to returning to the general circulation
- Gross anatomy:
    - **Hepatic portal vein:** supplies the liver; drains the…
        - **Splenic**
        - **Superior** and **inferior mesenteric**
        - **Left gastric**

**- C. Coronary Circulation**

**Coronary circulation:** Supplies the heart

**Coronary arteries**

- **Right** and **left coronary arteries:** Branch off the aorta
    - The right coronary artery divides into the…
        - **Right marginal artery:** Supplies the
            - Right ventricle
            - Inferior margin
        - **Posterior interventricular artery (PIV) / Posterior descending artery (PDA):** Supplies the
            - Inferior left ventricle
            - Posterior IVS
    - The left coronary artery divides into the…
        - **Anterior interventricular artery (AIV) / Left anterior descending (LAD):** Supplies the
            - Anterior left ventricle
            - Anterior IVS
            - Apex
        - **Circumflex artery:** Supplies the
            - Left atrium
            - Lateral and posterior left ventricle

**Coronary veins**

- **Great cardiac:** Drains areas supplied by the AIV
- **Middle cardiac:** Drains areas supplied by the PIV
- **Posterior cardiac:** Drains the posterior left ventricle
- **Small cardiac:** Drains the right atrium and right ventricle

**Coronary sinus:** Drains the cardiac veins into the right atrium

**- D. Circle of Willis**

**Circle of Willis**

- **Arterial anastomoses:** Network of linked arteries
- Circle of Willis: Circular network of arteries at the base of the brain
- Purpose: If a cranial artery is blocked, the circle provides alternative pathways for blood flow

Components

- **Basilar artery**
  - Lies on the brain stem
  - Formed by the left and right vertebral arteries
  - Divides into the…
    - **Posterior cerebral arteries (r, l):** Arch superolaterally
- **Internal carotid arteries (r, l)**
  - Arch superolaterally
  - Have branches that supply the frontal lobe:
    - **Anterior cerebral arteries (r, l)**
- **Posterior communicating arteries (r, l)**
  - Connect the anterior and posterior cerebral arteries
- **Anterior communicating artery**
  - Connects the anterior cerebral arteries

**- E. Fetal Circulation**

Overview

- A fetus's heart functions, however, the lungs and digestive organs do not
- Instead, oxygen and nutrients are supplied by the mother via the umbilical cord
- Blood is largely diverted from the nonfunctional liver and lungs

Umbilical cord

- Contains three blood vessels
    - **Umbilical vein:** Carries oxygenated, nutrient-rich blood
    - Two **umbilical arteries:** Carry deoxygenated, waste-laden blood

Fetal circulation

- The umbilical vein feeds the **ductus venosus,** which bypasses the liver
- The ductus venosus empties into the inferior vena cava which feeds the right atrium
- Most of the blood bypasses the pulmonary circulation via:
    - **Foramen ovale**
        - Flap-like opening in the interatrial septum
        - Shunts blood from the right atrium to the left atrium
    - **Ductus arteriosus**
        - Duct between the pulmonary trunk and aorta
        - Blood that is not shunted by the foramen ovale and drains into the right ventricle is pumped into the pulmonary trunk and then through the ductus arteriosus, bypassing the rest of the pulmonary circulation
- From the aorta, the blood circulates the body tissues, and drains into the umbilical arteries

Birth modifications

- At birth, the fetal heart modifications immediately seal:
    - The foramen ovale closes; the **fossa ovalis** is a visible remnant
    - The ductus arteriosus collapses and becomes the fibrous **ligamentum arteriosum**

# H1. Lymphatic System; Lymphatic Vessels and Organs

**- A. Lymphatic System; Overview**

**Lymph:** Excess interstitial fluid (IF)
**Lymphatic System:** Drains and returns lymph to the CVS

Functions

- Returns excess IF to the CVS, preventing **edema:** accumulation of excess IF
- Filters lymph
- Immune; facilitates lymphocyte surveillance and proliferation
- Carries absorbed lipids from the digestive tract to the CVS

Components

- Lymphatic vessels
- Primary lymphatic organs
    - Red bone marrow (lymphocyte production, B-lymphocyte maturation)
    - Thymus (T-lymphocyte maturation)
- Secondary lymphatic organs
    - Lymph nodes (filter lymph, house immune cells)
    - Spleen (filters blood, houses immune cells)
- Unencapsulated lymphatic organs / mucosa-associated lymphoid tissue (MALT)
    - Tonsils
    - Peyer’s patches
    - Appendix

## H1. Lymphatic System; Lymphatic Vessels and Organs

**- B. Lymphatic Vessels**

**Lymphatic vessels / lymphatics**

- Thin-walled vessels, similar to veins
- Larger lymphatic vessels have valves that prevent backflow
- Does not have an intrinsic pump, similar to veins; instead, lymph circulation is driven by:
    - Skeletal muscle pump
    - Thoracic pump
    - One-way valves
    - Smooth muscle contraction

Components

- **Lymph capillaries**
    - Located throughout body tissues
    - Absorb excess interstitial fluid
    - Similar to blood capillaries
    - Contain **minivalves:** one-way valves that open when the external interstitial pressure is greater than the internal capillary pressure, allowing fluid to flow in
    - Drain to lymphatic collecting vessels
- **Lymphatic collecting vessels**
    - Collect lymph from lymph capillaries
    - Drain to…
- **Right lymphatic duct, Thoracic duct**
    - Right lymphatic duct
        - Drains from the right arm and the right side of the head and thorax
        - Empties into the right subclavian vein
    - Thoracic duct
        - Drains from the rest of the body
        - Empties into the left subclavian vein

**- C. Lymph Nodes**

**Lymph nodes**

- Kidney-shaped
- Clustered along lymphatic vessels; large clusters are found in the inguinal, axillary and cervical regions
- Lymph flowing through lymph nodes is filtered and monitored by immune cells
- Sites for lymphocyte proliferation

Lymph node layers

- **Capsule:** Outer, fibrous capsule
    - **Trabeculae:** Extensions of the capsule that extend into the lymph node and form the internal structures
- **Cortex:** Superficial reticular tissue layer
    - **Lymphoid follicle:** Spherical structures with inner **germinal centers** where B-cells proliferate and differentiate
    - **Paracortex:** Area between cortex and medulla; contains T-cells
    - **Cortical sinuses**
- **Medulla:** Deep reticular tissue layer
    - **Medullary cords:** Strands of lymphatic tissue
    - **Medullary sinuses:** Contain macrophages that filter lymph

Lymph flow

- **Afferent vessels:** Bring lymph to the convex side of the lymph node
- **Sinuses:** Lymph flows through **sinuses** within the cortex and medulla
- **Hilum:** Lymph exits the lymph node via the **hilum**, located on the concave side of the lymph node
- **Efferent vessels:** Carry lymph away from the lymph node
    - Lymph nodes have more afferent vessels than efferent vessels, causing lymph to flow slowly through them

## H1. Lymphatic System; Lymphatic Vessels and Organs

**- D. Lymphatic Organs**

**Spleen**

- Location:
  - Inferior to the diaphragm
  - Curls around the antero[1]lateral aspect of the stomach
- Special functions:
  - Filters blood
  - Destroys old blood cells
  - Reservoir for platelets and blood

**Thymus**

- Location: Inferior mediastinum
- Larger in infants and children
- Structures:
  - **Cortex**
    - Contains lymphocytes and macrophages
    - Maturation site for T-cells
  - **Medulla**
    - Contains reticular epithelial cells that produce the thymic hormones

**Mucosa associated lymphoid tissue (MALT)**

- Protect the upper respiratory and digestive tracts from foreign matter
- Tissues:
  - **Tonsils**
    - Protect the upper digestive and respiratory tracts
    - Located within the throat mucosa
    - Types:
      - Pharyngeal
      - Palatine
      - Lingual
  - **Peyer's Patches**
    - Location: Small intestine
  - **Appendix**
    - Location: Offshoot of the proximal large intestine

1

# H2. Lymphatic System; Innate Immune System

**- A. Immune System, Overview**

**Immune System**

- Distributed functional system; not an anatomical organ system
- Two parts:
  - **Innate (non-specific) defense system**
    - Immediate, general protection
  - **Adaptive (specific) defense system**
    - Responds to substances that evaded the innate defense system
    - Highly specific for a given invasive substance
    - Non-immediate

**Antigen:** Any substance the body recognizes as foreign and triggers immune response

---

**- B. Innate Defense System**

Components

- First line of defense: Surface membrane mechanical barrier
- Second line of defense: General cellular and chemical defenses
- (Third line of defense: Adaptive defense system)

---

**- C. Surface Membrane Barriers**

Components

- **Intact skin and mucous membranes**
  - Keratinized epidermis and mucous membranes line body cavities open to the exterior
- Secretions
  - **Acid mantles and vaginal secretions:** Create acidic environments that inhibit bacterial growth
  - **Sebum:** Contains chemicals that are toxic to bacteria
  - **Mucous:** Sticky substance; traps microorganisms in the digestive and respiratory passages
  - **Gastric juices:** Contains substances that kill pathogens
  - **Saliva, lacrimal secretion:** Contain lysozyme, an enzyme that kills bacteria
- Specialized structural modifications
  - **Nasal hairs:** Trap inhaled bacteria
  - **Respiratory tract cilia:** Sweep dust and bacteria-laden mucus toward the throat

**- D. Cells and Chemicals**

Components of the Second Line of Defense
- Cells
    - **Natural Killer (NK) cells**
    - **Phagocytic cells**
- Chemicals
    - **Antimicrobial chemicals**
- General responses
    - **Inflammatory response**
    - **Fever**

Immune cells and chemicals recognize pathogens through:
- Foreign material recognition
- Identification of non-self cells
- Identification of abnormal cells (such as cancerous cells)
- Stress-induced ligands expressed by infected or damaged cells
- Immune-facilitated signals (such as antibody coating, opsonization)

Immune cell location
- Some immune cells reside in body tissues
- Others circulate in the blood and are attracted to pathogen sites via chemokines released by other immune cells and infected cells (**positive chemotaxis**)

Immune chemical location
- Some circulate the blood and are attracted to infections via positive chemotaxis
- Others are released directly at infection sites by immune cells

Immune cell actions
- Direct pathogen elimination
- Enhancement and signaling of other immune responses

---

**- E. Natural Killer (NK) Cells**

Location: Bloodstream, spleen, liver, lymph nodes
Function:
- Kill pathogenic cells (viral, cancerous):
    1. Bind to target cell
    2. Release **perforin** which forms pores in the target cell membrane
    3. Release **granzymes** which enter the target cell via the perforin pores and initiate apoptosis
- Release immune chemicals (cytokines)

**- F. Phagocytic Cells**

**Neutrophils**

- Location: Bloodstream
- Function:
    - First responders to pathogenic sites
    - Phagocytose pathogens
    - Release antimicrobial chemicals and cytokines

**Macrophages**

- Location: Peripheral tissues
- Function:
    - Phagocytose pathogens, dead cells and cellular debris
    - Release antimicrobial chemicals and cytokines
    - Present antigens to adaptive immune cells

**Dendritic Cells**

- Location: Peripheral tissues
- Function:
    - Primary pathogen presenters; capture and ingest pathogens, then travel to lymph nodes to present antigens
    - “Bridge between the innate and adaptive immune system”

**Monocytes**

- Location: Bloodstream
- Function:
    - Migrate to peripheral tissues and differentiate into macrophages and dendritic cells

**- G. Antimicrobial Chemicals**

**Complement**

- Circulates in the bloodstream in an inactive form
- Function:
    - Generally activated when bound to an antigen with antibodies
    - **Complement fixation:** Complement binds to the pathogen surface
    - **Membrane attack complexes (MAC):** The fixated complement creates MACs - pores in the pathogenic cell membrane, causing fluid to rush in and lyse the pathogenic cell
    - **Opsonization:** Complement fixation creates bonding sites that enhance phagocytosis

**Cytokines**

- Signaling proteins released by cells; many have antimicrobial properties, are secreted by immune cells, and are part of the innate or adaptive immune system
- Types:
    - **Interferon**
        - Released by virus-infected cells
        - Binds to nearby cells and prevents viral takeover
        - Mobilizes the immune response
    - **Migration inhibitory factor:** Prevents macrophages from migrating from an area
    - **Interleukin II:** Stimulates adaptive immune cell proliferation; activates NK cells
    - **Gamma interferon**
        - Enhances viral resistance
        - Activates macrophages and NK cells
        - Enhances cytotoxic T-cell activation
    - **Helper factors:** Enhance antibody formation
    - **Suppressor factors:** Suppresses the immune response once the pathogen is eliminated
    - **Chemotactic factors:** Attracts immune cells to pathogenic sites

**- H. Inflammatory Response**

**Inflammation:** General bodily response to tissue damage, including damage due to:

- Physical trauma
- Heat
- Chemicals
- Infection

Indicators

- Redness
- Heat
- Pain
- Edema

Functions

- Prevents the pathogen from spreading
- Eliminates pathogens and tissue debris
- Promotes tissue healing

Explanation of necessity:

- Healthy tissue generally prevents incoming pathogens
- Damaged tissue is more susceptible to pathogen invasion
- Thus, the inflammation of damaged tissue is necessary to deal with potential infection

**Inflammatory pathway**

- Tissue damage causes inflammatory chemicals to be released, either:
    - Directly by the damaged tissue (cytokines, kinins)
    - Indirectly, by releasing signaling molecules that signal immune cells such as mast cells and basophils to release them (histamine)
- Inflammatory chemicals cause:
    - Vasodilation
        - Causes redness and heat
            - Heat increases metabolic activity, promoting healing
        - Brings oxygen and nutrients
    - Increased vascular permeability
        - Causes edema
            - Edema causes increased tissue pressure, activating pain receptors
            - Edema and pain force rest and limit joint movement, promoting healing
        - Provides clotting proteins
            - Creates a fibrin barrier to prevent pathogen spread
            - Forms scaffolding for tissue repair
    - Neutrophil and monocyte attraction via chemotaxis
        - Neutrophils are the initial responders, but have a short life
        - Monocytes arrive second and differentiate into macrophages
        - Neutrophils and macrophages dispose of pathogens and dead tissue

## H2. Lymphatic System; Innate Immune System

### - I. Fever

Activation

- Immune cells exposed to pathogens release **pyrogens**
- Pyrogens trigger the hypothalamus to raise the body temperature

Purpose

- Inhibits nutrient availability for bacterial multiplication
    - At higher temperatures, the liver and spleen gather more nutrients
- Enhances tissue repair by increasing the metabolic rate

# H3. Lymphatic System; Adaptive Immune System

**- A. Adaptive Immune System**

Overview

- Protects against pathogens that evade the innate immune system
- Has a tailored response for each specific antigen
- **Memory cells:** Initial exposure to an antigen creates memory cells, which act more quickly and effectively upon subsequent encounters with the antigen

Parts of the adaptive immune system

- **Humoral response**
  - Mediated by B-cells
  - B-cell descendants release antibodies into body fluids
- **Cellular response**
  - Mediated by T-cells
  - Cytotoxic T-cells directly attack pathogenic cells, and indirectly attack pathogens via cytokines

---

**- B. Adaptive Immune Cells**

Primary cells:

- **B-cells**
- **Helper T-cells**
- **Cytotoxic T-cells**

Maturation

- Originate in red bone marrow from hemocytoblasts that differentiate into lymphocytes
- Initially lack **immunocompetence:** the capability to bind to antigens
- B-cells gain immunocompetence in red bone marrow
- T-cells migrate to the thymus, where they develop self tolerance and gain immunocompetence
- Mature B and T-cells seed lymphatic organs but are still naive - inactive - until they bind with an antigen and satisfy their activation requirements

**- C. Adaptive Immune Cell Activation**

B-cells

- Naive B-cells encounter an antigen, bind to it through B-cell receptors (BCR), digest it, and present it on their surface with MHC class-II molecules
- Already-active helper T-cells recognize the presented antigen and activate the B-cell

Helper T-cells

- Naive helper T-cells (CD4+ T-cells) activation requires that the antigen be presented along with MHC class-II molecules by an antigen-presenting cell (APC)
    - APCs include dendritic cells, macrophages, and already-active B-cells
- CD4+ T-cells binds to the antigen-MHC complex through T-cell receptors (TCR)
- The activation also require co-stimulation ("double-handshake") - additional interactions between the T-cell and APC
- Activated helper T-cell proliferate; some clones differentiate into memory helper T-cells

Cytotoxic T-cells

- Naive cytotoxic T-cells (CD8+ T-cells) activation requires that the antigen be presented along with MHC Class-I molecules, and requires co-stimulation
- Additionally, they require further stimulation from helper T-cells
- Activated cytotoxic T-cells proliferate; some clones differentiate into memory cytotoxic T-cells

**- D. Humoral Adaptive Immune Response**

Humoral adaptive immune response

- Mediated by B-cells
- **Clonal selection**
    - B-cells' primary immune response
    - Produces:
        - **Plasma Cells:** Produce and release antibodies
        - **Memory B-cells**

**Antibodies (Immunoglobulins)**

- Secreted by plasma cells derived from B-cells
- Released into body fluids (blood, lymph, saliva, mucus)
- Antibodies are tailored to bind with a specific antigen
- There are multiple classes of antibodies: IgM, IgA, IgD, IgG, IgE
- Antibody actions:
    - Facilitate complement fixation
    - Opsonization
    - Neutralization (by occupying binding sites)
    - **Agglutination**: Form clumped lattices of antigen-antibody complexes
    - Precipitation: Renders soluble antigens insoluble by forming large lattices
    - Attacks bacteria cilia and flagella

Humoral Immunity

- **Active immunity:** Possessing B-cells for a specific antigen
- **Passive immunity:** Possessing antibodies without B-cells for a specific antigen; immunity is limited to the lifespan of the antibodies

---

**- E. Cellular Adaptive Immune Response**

Mediator: T-cells

**Cytotoxic T-cells**

- Bind to pathogens and release perforin and granzymes
- Secrete cytokines

**Helper T-cells**

- Activate B-cells and cytotoxic T-cells
- Activate macrophages
- Secrete cytokines

**Regulatory T-cells**

- Release suppressor factors once the antigen is eliminated

# I1. Respiratory System; Respiratory Anatomy

**- A. Respiratory System; Overview**

Respiratory System

- Function: Provides oxygen to and removing carbon dioxide from the body
- Structures:
    - **Upper respiratory tract (URT)**
        - **Nose**
        - **Pharynx**
        - **Larynx**
    - **Lower respiratory tract (LRT)**
        - **Trachea**
        - **Bronchi & branches**
        - **Lungs**
- Zones:
    - **Conducting zone**
        - Structures:
            - Nose, pharynx, larynx, trachea, bronchi & branches
        - Function:
            - Passageway to conduct air to the respiratory zone
            - Cleans, moistens and warms the incoming air
    - **Respiratory zone**
        - Structures:
            - Respiratory bronchioles, alveolar ducts, alveoli
        - Function:
            - Facilitate gas exchange between the alveoli and the blood

**- B. Nose**

Structures

- **Nasal tip:** Composed of hyaline cartilage
- **External nares (nostril)**
- **Vestibule:** Naris corridor; composed of stratified squamous epithelium with nasal hairs
- **Nasal cavity**
    - **Nasal septum:** Divides the nasal cavity in two; composed of:
        - Perpendicular plate of the ethmoid bone
        - Vomer bone
        - Septal cartilage
    - **Nasal mucosa:** Lines the nasal cavity
        - Composition: Pseudostratified columnar epithelium with cilia and goblet cells
        - Goblet cells produce mucus which catches foreign particles, moisturizes the incoming air, and contains enzymes that destroy bacteria
        - Cilia sweep particle-laden mucus towards the throat
        - Sits on a network of thin-walled veins which warm the incoming air
    - **Nasal conchae:** Mucus-covered projections of the lateral walls of the nasal cavity
        - Three conchae pairs; superior, middle and inferior
            - Superior and middle conchae are projections from the ethmoid bone
            - Inferior conchae are a distinct 'inferior nasal concha' bone
        - Purpose:
            - Increase mucus surface area
            - Create air turbulence that aids in air cleaning, humidification and warming
        - **Nasal meatus:** Passageways beneath the nasal conchae
- **Palate:** Inferior wall of the nasal cavity, separating the nasal and oral cavities
    - **Hard palate:** Anterior section of the palate
        - Anterior hard palate: Palatine process of the maxillary bone
        - Posterior hard palate: Horizontal plate of the palatine bone
    - **Soft palate:** Posterior section of the palate
        - **Uvula:** Hangs from the soft palate into the oral cavity; aids in swallowing
- **Paranasal sinuses:** Sinuses in the bones surrounding the nasal cavity
    - Sinuses:
        - Frontal
        - Sphenoidal
        - Ethmoidal
        - Maxillary
    - Purpose:
        - Lighten the skull
        - Are resonance chambers for speech
        - Secrete mucus that drains into the nasal cavity
- **Nasolacrimal ducts:** Drain tears from the eye to the nasal cavity
- **Internal nares:** Lead from the nasal cavity to the nasopharynx

**- C. Pharynx**

Function: Common passageway for food and air

Structures:

- **Posterior nasal aperture**
  - The pharynx is a continuation of the nasal cavity, connected through the posterior nasal aperture
- Pharynx regions:
  - **Nasopharynx**
    - Location: From the internal nares to the uvula
    - Passageway for: Air
  - **Oropharynx**
    - Location: From the uvula to the epiglottis
    - Passageway for: Air and food
  - **Laryngopharynx**
    - Location: From the epiglottis to the cricoid cartilage
    - Passageway for: Air and food
- **Pharyngotympanic / eustachian tubes**
  - Connects the middle ear to the nasopharynx
  - The mucosae of the nasopharynx and pharyngotympanic tubes are continuous
- **Tonsils:** Infection-combating lymphoid tissue
  - **Pharyngeal tonsil (adenoid)**
    - Located in the nasopharynx roof
  - **Tubal tonsils**
    - Located in the nasopharynx, near the eustachian tube openings
  - **Palatine tonsils**
    - Located in the oropharynx, posterior to oral cavity roof
  - **Lingual tonsils**
    - Located in the oropharynx, at the base of the tongue

**- D. Larynx**

**Larynx / Voice Box**

- Location: Inferior to the anterior pharynx
- Structures:
    - **Laryngeal cartilage**
        - **Epiglottis**
            - Located above the larynx
            - During swallowing, the larynx is pulled anterosuperiorly, and the epiglottis is pulled inferoposteriorly, covering the laryngeal inlet and directing food to the esophagus
        - **Thyroid cartilage**
            - Shield-shaped cartilage; surrounds the anterior and lateral superior larynx
            - Contains the Adam's apple
        - **Cricoid cartilage**
            - Ring-shaped cartilage
            - Located below the thyroid cartilage
            - Connects the larynx to the trachea
        - Paired laryngeal cartilages: Small pairs of cartilage in the posterior larynx
            - **Arytenoid cartilages**
            - **Corniculate cartilages**
            - **Cuneiform cartilages**
    - **Vocal folds / true vocal cords**
        - Folds of laryngeal mucosa extensions
        - Vibrate with expelled air, creating vocal sounds; structures above the vocal folds shape the sound into speech
        - **Glottis:** Passageway between the vocal folds

---

**- E. Trachea**

**Trachea / Windpipe**

- Location: Inferior to the larynx, anterior to the esophagus
- Structure
    - **Tracheal cartilaginous rings**
        - 16 - 20 C-shaped hyaline cartilage rings that surround the anterior and lateral trachea; are open posteriorly
        - Purpose: Support the trachea; keep the trachea patent during respiratory pressure changes; their open posterior allows the esophagus to expand anteriorly while swallowing large food particles
    - **Trachealis:** Muscle between the trachea and esophagus
    - **Tracheal mucosa:** Innermost layer of the trachea
        - Lined with cilia that sweep upwards, propelling laden mucus towards the throat
    - **Carina:** Cartilage at the base of the trachea

**- F. Bronchi**

**Bronchi**

- The trachea divides into the **right** and **left primary bronchi**
- The primary bronchi extend obliquely towards their respective lungs
    - The right bronchus is oriented more vertically then the left
- The bronchi enter the lungs via the hilum

**Hilum**

- Area on the medial aspect of the lung where the following enter and exit:
    - Primary bronchi
    - Pulmonary arteries (one per lung) and veins (two per lung)
    - Pulmonary plexus
    - Lymphatic vessels
    - Bronchial arteries and veins

**- G. Lungs**

**Lungs**

- Location: Pleural cavity; apex is just below the clavicle, base rests on the diaphragm
- Divided into lobes by fissures
    - Left lung: Contains two lobes
        - **Left superior lobe**
        - **Oblique fissure**
        - **Left inferior lobe**
    - Right lung: Contains three lobes
        - **Right superior lobe**
        - **Horizontal fissure**
        - **Right middle lobe**
        - **Oblique fissure**
        - **Right inferior lobe**
- **Pleural membrane**
    - **Visceral pleura:** Covers the surface of the lungs
    - **Parietal pleura:** Lines the inner pleural cavity
    - **Pleural cavity:** Cavity between the visceral and parietal pleura
    - **Pleural fluid**
        - Fills the pleural cavity
        - Reduces intermembrane friction
        - Resists being pulled apart, creating negative pressure against the lung exterior; this pressure forces the lungs to expand during inhalation and prevents them from collapsing
- **Bronchial tree**
    - The right primary bronchi divides into three secondary bronchi; the left divides into two
    - Secondary bronchi divide to tertiary bronchi, etc., forming a network of progressively smaller passages
    - All but the smallest bronchi have reinforcing cartilaginous rings around their walls
    - Terminal bronchioles lead to respiratory zone structures
- **Respiratory zone structures**
    - **Respiratory bronchioles:** Lead from terminal bronchioles to alveolar ducts
    - **Alveolar ducts:** Ducts into which the alveolar sacs open
    - **Alveolar sacs:** Clusters of alveoli
    - **Alveoli**
- **Stroma**
    - Supportive tissue
    - Composed of elastic connective tissue

**- H. Alveoli**

**Alveoli (s. alveolus)**

- Function: Primary site of gas exchange
- Anatomy:
    - Composed of simple squamous epithelium
    - Exterior is covered by a network of pulmonary capillaries
- Structures:
    - **Alveolar pores:** Connect neighboring alveoli
    - **Respiratory membrane / air-blood barrier**
        - Consists of the alveolar and capillary simple squamous epithelium and their fused basement membrane
        - $O_2$ and $CO_2$ diffuse across the membrane
    - **Alveolar macrophages / dust cells:** Wander around the alveoli, capturing pathogens
    - **Surfactant-secreting cells**
        - Scattered among the alveoli squamous cells
        - Secrete **surfactant:** a lipid molecule that coats the interior surface of the alveoli, reducing surface tension, preventing the alveoli from collapsing

# I2. Respiratory System; Respiratory Physiology

**- A. Respiration; Overview**

**Respiration**

- Purpose: Providing $O_2$ to and removing $CO_2$ from the body
- Steps:
    - **Pulmonary ventilation (breathing):** Moving air in and out of the lungs
    - **External respiration:** Exchange gas between the alveoli and pulmonary capillaries
    - **Respiratory gas transport:** Transporting gas via blood between the lungs and peripheral tissues
    - **Internal respiration:** Exchanging gas between the capillaries and peripheral tissues

---

**- B. Pulmonary Ventilation**

**Pulmonary ventilation**

- Pulmonary ventilation is dependant on changes in the volume of the thoracic cavity
- Changes in volume cause changes in pressure, which cause gas to flow to equalize the pressure

**Inspiration:** Air flows into the lungs

- The diaphragm and external intercostals contract, increasing the size of the thoracic cavity and lungs
    - The diaphragm contracts from an upwards-projecting dome to a flat sheet, extending the thorax inferiorly
    - The external intercostals contract superiorly, elevating the ribs and thrusting the sternum anteriorly
    - Negative intrapleural pressure pulls the lungs to the pleural cavity wall
- Increased intrapulmonary volume decreases intrapulmonary pressure to below the external air pressure, causing external air to flow inwards to equalize the pressure

**Expiration:** Air flows out of the lungs

- Passive process: The diaphragm and external intercostals relax, decreasing the size of the thoracic cavity and intrapulmonary volume, increasing intrapulmonary pressure above the external air pressure, causing internal air to flow outwards to equalize the pressure
- **Forced expiration:** Involves internal intercostal and abdominal muscle contraction to decrease the thoracic volume

**- C. Respiratory Volume and Capacity**

**Eupnea**

- Regular quiet breathing
- 12 - 15 respirations per minute

Respiratory Volumes

- **Tidal volume (TV)**
  - Volume of air moved in and out of the lungs during eupnea
  - ≈ 500 ml
- **Inspiratory reserve volume (IRV)**
  - Volume of air beyond the TV that can be forcibly inhaled
  - ≈ 3100 ml
- **Expiratory reserve volume (ERV)**
  - Volume of air beyond the TV that can be forcibly exhaled
  - ≈ 1200 ml
- **Residual volume (RV)**
  - Volume of air that remains in the lungs after maximal exhalation
  - ≈ 1200 ml
- **Vital capacity (VC)**
  - Volume of air that can potentially be exchanged during respiration
  - $VC = TV + IRV + ERV$
- **Total lung capacity (TLC)**
  - $TLC = VC + RV$
- **Dead space volume**
  - Volume of air that occupies the respiratory conducting zone and does not participate in gas exchange
  - ≈ 150 ml

**Spirometer**

- Instrument that measures respiratory volumes

**- D. External Respiration, Respiratory Gas Transport, Internal Respiration**

**Gas Exchange**

- Gas exchange during external and internal respiration is caused by concentration gradients
- **Loading:** Adding a substance to the blood
- **Unloading:** Removing a substance from the blood
- The external air has a higher $O_2$ concentration than blood, causing $O_2$ to diffuse from the alveoli to the blood; blood has a higher $O_2$ concentration than body tissues, causing $O_2$ to diffuse from the blood to the interstitial fluid
- The same is for $CO_2$ in reverse

**Oxygen Transport**

- Oxygen is primarily transported by red blood cells, attached to hemoglobin
    - **Oxyhemoglobin ($HbO_2$):** Oxygen-hemoglobin complex
    - **Heme group**
        - Hemoglobin site of oxygen binding
        - Oxygen binds to the heme group's iron ion
        - Each molecule of hemoglobin has four heme groups
- A small amount of oxygen is transported dissolved in the blood plasma

**Carbon Dioxide Transport**

- $CO_2$ is primarily transported dissolved in the blood plasma as bicarbonate ion ($HCO_3^-$)
    - $CO_2$ internal respiration:
        - $CO_2$ diffuses from the interstitial fluid to the blood
        - The $CO_2$ enters red blood cells, where it is converted to bicarbonate ion
            - $CO_2$ bonds with $H_2O$, forming carbonic acid ($H_2CO_3$), which splits to $H^+$ ions and $HCO_3^-$
        - The bicarbonate ion diffuses from the red blood cell to the blood plasma and is transported to the lungs
    - $CO_2$ external respiration:
        - The bicarbonate ion enters the red blood cells and is converted to $CO_2$
            - $HCO_3^-$ bonds with $H^+$ ions, forming $H_2CO_3$, which splits to $H_2O$ and $CO_2$
        - The $CO_2$ diffuses to the lungs
- A small amount of $CO_2$ is carried by red blood cells, attached to hemoglobin
    - **Carbaminohemoglobin ($HbCO_2$):** CO2-hemoglobin complex
        - $CO_2$ binds to the hemoglobin amino group and does not inhibit heme-oxygen bonding

**- E. Respiratory Control**

Neural Regulation

- Respiratory muscles are controlled by the brain via the phrenic and intercostal nerves
- Controlling neural centers:
  - **Medulla oblongata ventral respiratory group (VRG)**
    - Triggers inspiration and expiration
  - **Medulla oblongata dorsal respiratory group (DRG)**
    - Integrates incoming sensory information and communicates with the VRG
  - **Pons respiratory center**
    - Communicates with the VRG; modifies inhalation and exhalation timing for refined transitions

Chemical Regulation

- $CO_2$ is a component of the bicarbonate blood buffer system
  - $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$
  - When $CO_2$ is added, the equilibrium shifts to the right, increasing the number of $H^+$ ions
  - When $CO_2$ is removed, the equilibrium shifts to the left, decreasing the number of $H^+$ ions
- **Hyperventilation**
  - **Acidosis** (high $CO_2$ and low pH levels in the blood) stimulates deeper and more rapid breaths, removing $CO_2$ and raising the pH
- **Hypoventilation**
  - **Alkalosis** (low $CO_2$ and high pH levels in the blood) stimulates slower and shallower breaths, allowing $CO_2$ to accumulate and lowering the pH

**- F. Acid / Base Imbalance**

**Metabolic acidosis**

- Acidosis to due metabolic causes (acid accumulation / bicarbonate loss)
- pH < 7.35
- $HCO_3$ < 22
- Respiratory fix: Increased $CO_2$ exhalation (increases pH)

**Metabolic alkalosis**

- Alkalosis due to metabolic causes (acid loss / bicarbonate accumulation)
- pH > 7.45
- $HCO_3$ > 23
- Respiratory fix: decreased $CO_2$ exhalation (decreases pH)

**Respiratory acidosis**

- Acidosis due to respiratory causes (insufficient $CO_2$ exhalation, causing acid accumulation)
- pH < 7.35
- $CO_2$ > 45
- Renal fix: acid excretion / bicarbonate retention

**Respiratory alkalosis**

- Alkalosis due to respiratory causes (excessive $CO_2$ exhalation, causing increased pH)
- pH > 7.45
- $CO_2$ < 35
- Renal fix: acid retention / bicarbonate excretion

# J1. Digestive System; Oral Cavity to Esophagus

**- A. Digestive System; Overview**

Digestive System

- Function
    - Obtaining nutrients from food
- Steps
    - **Ingestion:** Taking food into the mouth
    - **Propulsion:** Moving food through the GI tract
    - **Mechanical digestion:** Physically breaking down the food
        - Primarily occurs in the oral cavity (via mastication) and stomach (via churning); also occurs in the small intestine (via segmentation)
    - **Chemical digestion:** Chemically breaking down the food
        - Most chemical digestion occurs in the small intestine (via bile, pancreatic enzymes, and brush border enzymes); some begins in the stomach and oral cavity
    - **Absorption:** Absorbing the digested nutrients into the body
    - **Defecation:** Eliminating the waste products
- Organs
    - **Alimentary canal / gastrointestinal (GI) tract:** Tube from the mouth to the anus through which foodstuff travels
        - **Mouth / oral cavity**
        - **Pharynx**
        - **Esophagus**
        - **Stomach**
        - **Small intestine**
        - **Large intestine**
    - **Accessory digestive organs**
        - **Tongue**
        - **Teeth**
        - **Salivary glands**
        - **Pancreas**
        - **Liver**
        - **Gallbladder**
        - **Appendix**
- Regulation
    - Ingestion, deglutition (swallowing) and defecation are voluntary
    - All other steps are involuntary and controlled by the parasympathetic nervous system and hormones

**J1. Digestive System; Oral Cavity to Esophagus**

**- B. Oral Cavity**

Oral cavity

- Digestive functions
    - Ingestion
    - Mechanical breakdown (mastication)
    - Chemical digestion (salivary enzymes)
    - Propulsion (to the pharynx)
- Structures
    - **Oral mucosa**
        - Mucous membrane; lines the inner oral cavity
        - Composed of non-keratinized stratified squamous epithelium
    - **Labia / lips:** Protect the anterior opening
    - **Cheeks:** Form the lateral walls
    - **Hard palate:** Forms the anterior roof
    - **Soft palate:** Forms the posterior roof
        - **Uvula:** Soft palate projection; dangles into the oral cavity
    - **Tongue:** Forms the floor
        - **Lingual frenulum:** Mucus membrane fold; attaches the tongue to the floor of the oral cavity
    - **Tonsils**
        - **Palatine tonsils**
        - **Lingual tonsils**
- Activities
    - **Mastication (chewing)**
        - Food is masticated and mixed with saliva, forming **bolus**
    - **Deglutition (swallowing)**
        - **Oral phase**
            - Initial, voluntary phase; initiates swallowing
            - The tongue propels bolus to the posterior oral cavity
        - **Pharyngeal-esophageal phase**
            - All openings to the pharynx aside from the esophagus are closed
                - The soft palate and uvula elevate to close the nasopharynx opening
                - The larynx elevates and the epiglottis is pulled posteriorly to cover the laryngeal inlet
                - The tongue blocks the oral cavity opening
            - Peristalsis propels the bolus along from the pharynx to the esophagus
            - The upper esophageal sphincter relaxes, allowing bolus to enter the esophagus

**- C. Teeth**

Teeth

- Function: Mastication
- Location: Embedded within the **alveolar processes** of the maxilla and mandible
- Protruding from the **gingiva (gum)**
- Types of teeth
    - **Incisor:** Cut, slice
    - **Canine:** Tear, rip
    - **Premolar:** Crush, grind
    - **Molar:** Grind, chew
- Composition: Primarily **dentin:** Calcified connective tissue
- Regions
    - **Root:** Portion of the tooth embedded within the alveolar process
        - **Gingiva (gum):** Surrounds the root and alveolar process (protection, support)
        - **Cementum:** Calcified substance; attaches the root to the periodontal ligament
        - **Periodontal ligament:** Dense regular connective tissue; anchors the tooth to the alveolar bone
    - **Neck:** Connects the root and crown
    - **Crown:** Portion of the tooth protruding from the alveolar process
        - **Enamel:** Calcified connective tissue (harder than enamel); covers the crown
- Structures
    - **Pulp cavity:** Central cavity
        - **Pulp:** Structures within the pulp cavity; connective tissue, blood vessels, nerve fibers
        - **Root canal:** Region of pulp cavity within the root

**- D. Salivary Glands**

Salivary Glands

- Function: Secrete saliva into the oral cavity
- Types
    - **Parotid** (anterior to ears)
    - **Submandibular**
    - **Sublingual**
- Saliva
    - Mixture of mucus and serous fluid
    - Mucus
        - Moistens and binds the food into bolus
    - Serous fluid
        - Contains **salivary amylase:** enzyme that begins starch digestion
        - Contains lysozyme and antibodies
        - Dissolves food tastants, facilitating gustation
- Stimulation
    - Regulated by parasympathetic fibers of the facial and glossopharyngeal nerves
    - Primarily activated by the chemoreceptors and mechanoreceptors sensing the presence of food and mastication; can also be triggered by psychological stimuli

**- E. Pharynx**

Pharynx

- Function: Propulsion
- Layers
    - **Mucosa:** Nonkeratinized stratified squamous epithelium
    - **Submucosa**
    - **Muscular layer**
        - Inner longitudinal muscles
        - Outer circular muscles
- Digestive regions
    - **Oropharynx**
    - **Laryngopharynx**

---

**- F. Esophagus**

Esophagus

- Function: Propulsion
    - During deglutition, bolus enters the esophagus from the pharynx
    - Bolus is propelled along the esophagus by peristalsis
    - When bolus reaches the end of the esophagus, it pushes against the **lower esophageal (cardioesophageal) sphincter**, stimulating the sphincter to open and allow bolus to enter the stomach

**- G. Layers of the GI Tract**

From the esophagus onwards, the alimentary canal wall has four layers:

- **Mucosa**
  - Innermost layer
  - Mucous membrane
  - Layers:
    - **Epithelium**
      - In the esophagus: nonkeratinized stratified squamous epithelium
      - Beyond the esophagus: simple columnar epithelium
    - **Basement membrane**
    - **Lamina propria:** Areolar connective tissue
    - **Muscularis mucosa:** Thin layer of smooth muscle
- **Submucosa**
  - Dense irregular connective tissue
  - Contains:
    - Blood vessels
    - Nerve endings
    - Lymphatic vessels
    - **Peyer's patches:** GI tract MALT (mucosa-associated lymphoid tissue)
- **Muscularis externa**
  - Inner circular muscles
  - Outer longitudinal muscles
- **Serosa**
  - Outermost layer
  - Serous membrane; composed of simple squamous epithelium
  - Visceral peritoneum

Nerve plexuses

- There are two nerve plexuses located within the GI tract wall:
  - **Submucosal plexus**
  - **Myenteric plexus**

**Peritoneum**

- **Visceral peritoneum**
  - Covers the GI tract
- **Parietal peritoneum**
  - Lines the inner wall of the abdominal cavity
- **Mesenteries**
  - Two-layered extensions of the parietal peritoneum; extend from the posterior abdominal wall to the digestive organs and are continuous with the visceral peritoneum
  - Anchor the digestive organs in place
  - Store fat
  - The space between the two mesentery layers is a conduit through which blood vessels, lymphatic vessels, and nerves reach the digestive organs

# J2. Digestive System; Stomach to Anus

**- A. Stomach Anatomy**

Walls

- The muscularis externa of the stomach has a third, innermost layer of oblique muscles

Surface

- **Surface mucous cells:** Line the surface; produce alkaline mucus that covers the stomach wall to protect it from the acidic gastric juice
- **Gastric pits:** Dot the surface; contain cells that produce gastric juice
    - **Chief cells**
        - Secrete protein-digesting enzymes such as **pepsinogen**
        - Secrete **gastric lipase**
    - **Parietal cells**
        - Secrete **hydrochloric acid (HCl)**
            - Activates enzymes, such as pepsinogen to pepsin
            - Kills pathogens
            - Aids in protein digestion by denaturation
        - Secrete **intrinsic factor:** needed for vitamin B12 absorption
    - **G cells**
        - Secrete **gastrin:** hormone; secreted into the bloodstream; stimulates parietal cell HCl secretion
    - **Enteroendocrine cells**
        - Secrete digestive hormones
    - **Mucous neck cells**
        - Secrete mucus (slightly different mucus from surface mucous cells)
- **Rugae:** Folds formed by the stomach mucosa when the stomach is empty; stretch when the stomach is full

Regions and structures

- **Lower esophageal (cardioesophageal) sphincter (LES)**
- **Cardia:** Entry region
- **Fundus:** Superolateral to cardia
- **Body**
    - **Lesser curvature:** Superomedial concave curvature
    - **Lesser omentum:** Two-layered peritoneum; extends from the liver to the lesser curvature
    - **Greater curvature:** Inferolateral convex curvature
    - **Greater omentum:** Extends from the greater curvature; hangs down in front of the intestines, then folds back behind itself and attaches to the posterior abdominal wall behind the stomach
        - Contains fat (insulation, protection)
        - Contains lymphoid follicles
- **Pyloric antrum**
- **Pylorus:** Canal to the duodenum
    - **Pyloric sphincter**

**- B. Stomach Physiology**

Functional Steps

- Bolus entry
    - Bolus enters the stomach cardia through the LES
- Gastric juice secretion
    - The presence of bolus triggers mechanoreceptors and chemoreceptors, stimulating gastric juices secretion
- Mechanical digestion
    - The smooth muscles rhythmically contract, churning the bolus with gastric juices and turning it into chyme
- Chemical digestion
    - Some chemical digestion occurs in the stomach via gastric juice enzymes, including:
        - HCl-mediated protein denaturation
        - Pepsin
        - Rennin (in infants)
- Propulsion
    - Once the chyme is fully churned, peristaltic waves move it towards the pyloric sphincter
    - The pyloric sphincter only allows a small amount of chyme through at a time; the rest is propelled backwards to the stomach: **retropulsion**

Regulation

- Stomach activity is regulated by mechanoreceptors and chemoreceptors which are triggered by the presence of foodstuffs, as well as by parasympathetic neural regulation via the vagus nerve

**- C. Small Intestine Anatomy**

Location

- Abdominal cavity, inferior to stomach, suspended from the posterior abdominal wall by mesenteries

Regions

- **Duodenum**
- **Jejunum**
- **Ileum**
    - **Ileocecal valve**

Structures

- **Mucosal surface modification:** Increase surface area for nutrient absorption
    - **Circular folds / plicae circulares**
        - Corkscrew-like folds of mucosa and submucosa
    - **Villi**
        - Finger-like mucosa projections
        - Within each villus is a capillary bed, **lacteal** (lymphatic capillary) and lymphatic tissue
    - **Microvilli / brush border**
        - Plasma membrane extensions of mucosa cells
- **Duodenal papilla**
    - Entry for bile and pancreatic juices

**- D. Small Intestine Physiology**

Functional steps

- Chyme entry
    - Chyme enters the duodenum through the pyloric valve
- Digestive juice secretion
    - The presence of chyme triggers mechanoreceptors and chemoreceptors, stimulating mucosa enteroendocrine cells to secrete digestive hormones: **secretin** and **cholecystokinin (CCK)**, and mucosa cells to secrete **brush border enzymes**
    - Secretin and CCK enter the bloodstream and stimulate their target organs
        - Pancreas
            - Secretin stimulates the pancreas to secrete **bicarbonate-rich alkaline fluid**
            - CCK stimulates the pancreas to secrete **pancreatic enzymes**
        - Liver
            - Secretin stimulates the liver to increase **bile** production
        - Gallbladder
            - CCK stimulates the gallbladder to contract and release bile, and stimulates the hepatopancreatic sphincter to relax and allow bile and pancreatic juices to enter the duodenum
    - Bile and pancreatic juice enter the duodenum via the duodenal papilla
        - Bile emulsifies lipids
        - Pancreatic juice is bicarbonate-rich, neutralizing the acidic chyme from the stomach
        - Pancreatic juice contains pancreatic enzymes
- Digestion
    - The chyme is chemically digested by the digestive juices
    - **Segmentation:** Rhythmic smooth muscle contractions mix chyme with digestive enzymes (involves mechanical digestion)
- Absorption
    - Most nutrient absorption happens in the jejunum
    - Digested nutrients enter the intestinal cells through active transport
    - From the intestinal cells:
        - Most nutrients enter the capillary beds and are transported via the hepatic portal vein to the liver
        - Large lipids, however, do not immediately enter the bloodstream; instead, they enter the lacteals and are transported through the lymphatic system until they enter the bloodstream by the thoracic duct
    - Bile salts are reabsorbed in the ileum
- Elimination
    - Undigested materials enter the large intestine through the ileocecal valve

Small Intestine Activity Regulation

- Small intestinal activity is regulated by mechanoreceptors and chemoreceptors which are triggered by the presence of foodstuffs, as well as by parasympathetic neural regulation via the vagus nerve

**- E. Hepatopancreatobiliary System**

Pancreas

- Secretes pancreatic juice, which contains digestive enzymes and bicarbonate-rich alkaline fluid that neutralizes acidic chyme
- The pancreas also has endocrine functions: insulin and glucagon secretion
- The pancreatic juice drains to the **main pancreatic duct**
- Some individuals have an additional **accessory pancreatic duct** (and a **minor duodenal papilla** through which the accessory pancreatic duct drains to the duodenum)

Liver

- Secretes **bile**
- **Bile salts** emulsify fats, breaking large globules to smaller ones, increasing surface area access for lipase
- Bile salts also solubilize fats by forming **micelles**
- **Bilirubin:** Byproduct of hemoglobin metabolism; secreted in bile to be excreted with feces
    - Converted by intestinal bacteria to **stercobilin**, which give feces its color
- Drains bile to the **common hepatic duct**

Biliary System

- The **gallbladder** stores bile secreted by the liver
- Bile backs up to the **gallbladder** from the common hepatic duct via the **cystic duct**
- The cystic duct and common hepatic duct merge to form the **common bile duct**
- The common bile duct and main pancreatic duct join within the duodenum wall, forming the **hepatopancreatic ampulla**, which empties into the duodenum through the **duodenal papilla**
- Biliary system sphincters:
    - **Bile duct sphincter** (distal bile duct, before the hepatopancreatic ampulla)
    - **Main pancreatic duct sphincter** (distal main pancreatic duct, before the hepatopancreatic ampulla)
    - **Hepatopancreatic sphincter** (located around the hepatopancreatic ampulla)

**- F. Large Intestine**

Large Intestine

- Regions
  - **Ileocecal valve**
  - **Cecum**
  - **Appendix**
  - **Colon**
    - **Ascending colon**
    - **Transverse colon**
    - **Descending colon**
    - **Sigmoid colon**
  - **Rectum**
  - **Anal canal**
    - **Internal anal sphincter**
    - **External anal sphincter**
    - **Anus**
- Function
  - Absorption: absorbs water and some nutrients
  - Propulsion, elimination
- Structures
  - Does not have villi or digestive enzymes, as primary digestion and absorption occurs in the small intestine
  - **Gut microbiota**
    - Bacteria that reside in the large intestine
    - Metabolize some nutrients, synthesize vitamin K and B
    - Produce gasses and various compounds; responsible for the smell of feces
  - **Teniae coli**
    - The large intestine's longitudinal muscles do not fully surround it; instead, they run in three distinct bands - teniae coli
    - Teniae coli muscle tone causes partial constriction, creating puckered pocket-like zones in the large intestine called **haustra**
- Activities
  - Propulsion
    - The presence of feces stimulates **haustral contractions:** contractions lasting approximately one minute, occurring roughly every half hour, propelling the feces along the tract
    - **Mass movements:** Occur several times per day; long, slow contractions moving the feces through the tract to the rectum
  - Defecation
    - Mass movement propels feces into the rectum, stretching the rectum wall, triggering the defecation reflex
    - Defecation reflex stimulates the sigmoid colon and rectum to contract and the involuntary internal anal sphincter to relax, however, the external anal sphincter is under voluntary control, allowing defecation to be delayed

# J3. Digestive System; Chemical Digestion and Metabolism

**- A. Metabolism, Nutrients**

**Metabolism**

- Totality of all chemical reactions necessary to sustain life

**Catabolism**

- Chemical reaction that breaks larger molecules into smaller ones
- Releases energy, which can be captured and stored in ATP

**Anabolism**

- Chemical reaction that builds larger molecules from smaller ones
- Requires energy, generally provided by ATP

**Nutrient:** Substance obtained from food that the body uses for normal growth, maintenance or repair

- Major nutrients
    - Carbohydrates
    - Lipids
    - Proteins
- Minor nutrients
    - Vitamins
    - Minerals
- Water

**- B. Carbohydrates**

Carbohydrates

- Use
    - Broken down; released energy is captured in ATP
- Components
    - Monomers
        - Monosaccharides
            - **Glucose**
            - **Fructose**
            - **Galactose**
    - Polymers
        - Disaccharides
            - **Sucrose**
            - **Lactose**
            - **Maltose**
        - Polysaccharides
            - **Starch**
- Digestion
    - Salivary amylase and pancreatic amylase break down starch to oligosaccharides and disaccharides
    - Brush border enzymes break down oligosaccharides and disaccharides to monosaccharides
        - Oligosaccharide-digesting enzymes
            - **Dextrinase**
            - **Glucoamylase**
        - Disaccharide-digesting enzymes
            - **Sucrase**
            - **Lactase**
            - **Maltase**
- Post-absorption pathway
    - Monosaccharides enter the blood capillaries and are transported to the liver via the hepatic portal vein
    - Fructose and galactose are metabolized by the liver into substances that can undergo cellular respiration
    - Cells obtain sugars from the bloodstream and use them to manufacture ATP
- Foodsource
    - Starch: grains, legumes, root vegetables
    - Sugars: fruit, sugarcane
    - Lactose: milk
    - Glycogen: meat
    - Cellulose: common in plants, however, is indigestible by humans; provides fiber (adds bulk to feces, aiding propulsion and defecation)

**- C. Protein**

Protein

- Use
  - Broken down to amino acids which are used to create new proteins
  - Amino acids can be broken down by the liver to make ATP
- Components
  - Amino acids
- Digestion
  - Stomach chief cells secrete pepsinogen, which is activated to pepsin by HCl
  - Pepsin breaks down proteins into large polypeptides
  - Pancreatic enzymes break down large polypeptides into smaller polypeptides
    - Pancreatic enzymes:
      - **Trypsin**
      - **Chymotrypsin**
      - **Carboxypeptidase**
  - Brush border enzymes break down polypeptides into amino acids
    - Brush border enzymes:
      - **Aminopeptidase**
      - **Carboxypeptidase**
      - **Dipeptidase**
- Post-absorption pathway
  - Amino acids enter the blood capillaries and are transported to the liver via the hepatic portal vein
  - Cells obtain amino acids from the bloodstream and use them to manufacture new proteins
- Foodsource
  - **Essential amino acids**
    - Amino acids the body cannot manufacture; need to be obtained from diet
  - **Nonessential amino acids**
    - Can be manufactured by the liver
  - **Complete protein**
    - Contains all essential amino acids
    - Found in eggs, milk, fish, meat
  - **Incomplete protein**
    - Does not include all essential amino acids
    - Diets can be constructed from numerous incomplete protein to collectively include all essential amino acids

**- D. Lipid Digestion**

Lipids

- Use
    - Used to build lipid structures, such as cell membranes and myelin sheaths
    - Form adipose tissue
    - Used to manufacture lipid substances
    - Can be broken down to manufacture ATP
- Types
    - **Glycerides**
        - **Glycerol**
        - **Fatty acids**
    - **Cholesterol**
- Digestion
    - Lingual and gastric lipase perform minor initial digestion
    - Bile salts emulsify large lipid globules to smaller ones
    - Pancreatic lipase breaks down smaller globules to glycerol, fatty acids, and monoglycerides
- Post-absorption pathways
    - Glycerol, fatty acids, and monoglycerides are assembled by intestinal cells into triglycerides
    - Triglycerides and cholesterol are packaged into water-soluble **chylomicrons**, a type of **lipoprotein**
    - Chylomicrons are too large to enter the capillaries; instead, they enter the villi lacteals and are transported through the lymphatic system until they enter the bloodstream at the thoracic duct
- Foodsource
    - Glycerides
        - Primarily **triglycerides**
            - **Saturated fat:** Meat, dairy, coconut
            - **Unsaturated fat:** Seeds, nuts, vegetable oils
        - Cholesterol: Eggs, meat, milk

**- E. Lipid Metabolism**

Lipoprotein metabolic pathway

- Chylomicrons circulate in the bloodstream and encounter **lipoprotein lipase** in capillaries; the lipase removes triglycerides from the chylomicrons; the triglycerides are then absorbed by peripheral tissues
- The remaining **chylomicron remnants** are taken up by the liver and, along with endogenously synthesized lipids, are used to synthesize various lipoproteins

Cholesterol delivery

- **Low-density lipoprotein (LDL)**
  - Synthesized by the liver
  - Contain a low amount of apolipoprotein and high amount of cholesterol
  - Primary means of cholesterol delivery to peripheral tissues
  - Can deposit excess cholesterol in arteries, leading to atherosclerosis
- **High-density lipoprotein (HDL)**
  - Synthesized by the liver and intestines
  - Contain a high amount of apolipoprotein and low amount of cholesterol
  - Collects excess cholesterol from the arteries and cells and returns it to the liver
  - The liver uses cholesterol to:
    - Synthesize lipoproteins
    - Synthesize bile acid
    - Secretes excess cholesterol in bile, which is then excreted with feces

---

**- F. Nucleic Acids**

Nucleic Acids

- Use
  - Broken down to basic components which are used to build nucleic acids
  - Dietary nucleic acids only provide a minor contribution to the body's nucleic acids; most nucleic acids that the body uses are recycled through the salvage pathway or internally synthesized
- Digestion
  - Pancreatic **nuclease** breaks down nucleic acids to nucleotides
  - Brush border enzymes break down nucleotides to their base components: nitrogenous bases, pentose sugars, and phosphate ions
    - Brush border enzymes:
      - **Nucleosidases**
      - **Phosphatases**
- Post-absorption pathway
  - Nucleotide components enter the blood capillaries and are transported to the liver via the hepatic portal vein
  - Cells obtain nucleotide components from the bloodstream and use them to manufacture new nucleic acids
- Foodsource: All cells

**- G. Vitamins**

Overview
- Organic substances necessary for bodily function; mostly as coenzymes

Source
- Most vitamins are synthesized by plants, cannot be synthesized by the body, and need to be obtained through the diet
- Vitamin B12 is synthesized by bacteria and can be obtained from animal products (and perhaps gut bacteria, along with vitamin K2)
- Vitamin D is synthesized by the body (involves the skin, liver and kidneys) from cholesterol when the skin is exposed to sunlight

Types
- **Fat-soluble vitamins**
  - Digested and absorbed along dietary fats
  - Stored in adipose tissue and the liver
  - Includes: **Vitamins A, D, E** and **K**
- **Water-soluble vitamins**
  - Directly absorbed into the bloodstream
  - Excess is excreted with urine and is not stored in the body
  - Includes: **Vitamins C** and **B-complex vitamins**

---

**- H. Minerals**

Overview
- Inorganic substances necessary for bodily function

Source
- Cannot be synthesized by the body; needs to be obtained from diet
- Absorbed in the small intestine
- Absorption, storage, release and excretion are homeostatically regulated

Types
- Macrominerals: Larger amounts required
  - **Calcium, phosphorus, magnesium, sodium, potassium, chloride, sulfur**
- Trace minerals: Smaller amounts required
  - **Iron, zinc, copper, manganese, iodine, selenium, fluoride, chromium, molybdenum**

## J3. Digestive System; Chemical Digestion and Metabolism

### - I. Liver

Liver

- Location: Suspended from the diaphragm by the **falciform ligament**, a mesenteric cord
- Nutrients absorbed by the abdominal organs are brought to the liver via the hepatic portal vein
- Functions
    - Glucose
        - **Glycogenesis:** Conversion of glucose (from the bloodstream) into glycogen (to be stored in the liver); triggered by **hyperglycemia** (excess blood sugar)
        - **Glycogenolysis:** Breakdown of glycogen (stored in the liver) into glucose (to be released in the bloodstream); triggered by **hypoglycemia** (insufficient blood sugar)
        - **Gluconeogenesis:** Production of glucose from non-carbohydrate sources (lipids, glucogenic amino acids, nucleic acids)
    - Lipids
        - Produces **cholesterol** and **phospholipids**
            - Cholesterol is used by cells as a component of the plasma membrane, and to manufacture steroid hormones
        - Produces **lipoproteins**
        - **Lipogenesis:** Synthesizes lipids from carbohydrates and proteins
    - Protein
        - Synthesizes **blood plasma proteins** (albumin, clotting factors)
        - **Amino acid metabolism:** Produces non-essential amino acids
    - Bile
        - Produces **bile**
    - Detoxification
        - Detoxifies drugs and toxins
        - Converts **ammonia** to **urea**
            - Ammonia is produced by the liver during amino acid **deamination**
            - Deamination is performed for amino acid synthesis or gluconeogenesis
    - Additional metabolic functions
    - Immune function
        - Contains immune cells that filter pathogens from the blood
    - Storage
        - Glycogen
        - Vitamins (A, D, E, K, B12)
        - Minerals (iron, copper)

# K1. Urinary System; Urine Production and Excretion

**- A. Urinary System; Overview**

Function

- Filters nitrogenous wastes from the blood
- Regulates water, electrolyte and acid-base balance

Primary Functional Organ

- Kidneys: Excrete wastes and excess substances in urine

Organs

- **Kidneys (r, l)**
- **Ureters (r, l)**
- **Bladder**
- **Urethra**

**K1. Urinary System; Urine Production and Excretion**

**- B. Kidneys**

Location
- Retroperitoneal
- Superior lumbar region; T12 - L3
- Right kidney is slightly lower than the left kidney due to the liver

Structure
- Kidney shaped
- Lateral convex border
- Medial concave border
    - **Renal hilum:** Structure on medial border where ureters, renal blood vessels and nerves enter and exit

External Layers
- **Fibrous capsule:** Innermost layer; transparent
- **Perirenal fat capsule:** Middle layer; adipose tissue; cushions
- **Renal fascia:** Outermost layer; dense fibrous tissue; anchors kidneys and adrenal glands to surrounding tissues

Inner Layers
- **Renal cortex:** Outermost layer
- **Renal medulla:** Middle layer; darker than cortex
    - **Renal / medullary pyramids**
        - Triangular structures within the medulla
        - Longitudinally striped
        - Base faces cortex; apex faces pelvis
    - **Renal columns:** Cortex extensions; separates pyramids
- **Renal pelvis:** Innermost layer; collecting tube continuous with the ureter
    - **Renal calyces**
        - **Minor calyces** drain the pyramid apex collecting tubules to **major calyces** which drain to the renal pelvis

Blood Circulation
- **Renal artery:** Enters the hilum
- **Segmental arteries:** At the hilum, the renal artery splits to segmental arteries
- **Interlobar arteries:** Segmental arteries split to interlobar arteries which course through the renal columns to the cortex
- **Arcuate arteries:** At the corticomedullary junction, the segmental arteries split to arcuate arteries, which course along the base of the pyramids at the CMJ
- **Cortical radiate arteries:** Radiate from the arcuate arteries to the cortex
- **Cortical radiate veins, arcuate veins, interlobar veins,** (no segmental veins,) **renal vein**

**- C. Nephron Anatomy**

Nephron: Functional unit of the kidneys; forms urine

Nephron Components

- **Renal corpuscle**
  - **Glomerulus**
  - **Glomerular / Bowman's capsule**
- **Renal tubule**
  - **Proximal convoluted tubule (PCT)**
  - **Nephron loop / loop of Henle**
  - **Distal convoluted tubule**

Glomerulus

- Cluster of capillaries within the renal corpuscle
- **Afferent arterioles**
  - Branch from the cortical radiate arteries
  - Supply the glomerular capillaries
- **Efferent arterioles**
  - Drain the glomerular capillaries (although capillaries typically drain into venules, renal circulation has a second set of arterioles and capillaries following the initial glomerular capillaries)
  - Supply the peritubular capillaries
  - The afferent arteriole lumen is larger than the efferent arteriole lumen, causing high blood pressure in the glomerulus, driving filtration
- **Podocytes**
  - Located on the glomerular capillaries
  - **Foot processes:** Podocyte processes; wrap around the capillaries
  - **Filtration slits:** Spaces between the podocyte foot processes; forms the **glomerular filtration barrier** along with the glomerular endothelium and basement membrane

Glomerular / Bowman's capsule

- Capsule surrounding the glomerulus
- Composed of epithelium (with basement membrane)
- Continuous with the renal tubules
- Filtrate drains from the glomerular capillaries into the capsule

Nephron loop / loop of Henle

- **Descending limb:** Thin
- **Ascending limb**: Proximally thin, distally thick

**Juxtaglomerular Apparatus**

- **Macula densa**
  - Cells located in the DCT near the afferent arterioles
  - Sense solute concentration in the tubular fluid
  - Regulate JG cell renin secretion

- **Juxtaglomerular (JG) cells**
    - Located in the walls of the afferent arterioles
    - Secrete renin
    - Regulated by the macula densa cells

**Peritubular capillary bed**

- Fed by efferent arterioles
- Wrap around the renal tubules and exchange substances
- Drain to cortical radiate veins

Types of nephrons

- **Cortical nephron**
    - Majority of nephrons
    - Located within the cortex
    - Small part of the loop of Henle descends into the medulla
- **Juxtamedullary nephron**
    - Corpuscle is located near the medulla
    - Contains an extended loop of Henle that plunges deep into the medullary pyramid
    - **Vasa recta**
        - Specialized peritubular capillaries
        - Extend parallel to the loops of Henle in juxtamedullary nephrons
        - Have rung-like transverse capillaries that periodically extend between the descending and ascending limbs

**Collecting ducts**

- Collect urine from multiple nephron DCTs
- Extend through the medulla pyramids; give the pyramids their striped appearance
- Drain to the minor calyces

**- D. Nephron Physiology**

Steps of urine formation

- **Glomerular filtration**
- **Tubular reabsorption**
- **Tubular secretion**

Glomerular filtration

- Location: Renal corpuscle
- Blood plasma filters from the glomerular capillaries to the Bowman's capsule, forming **filtrate**
- Nearly all of blood plasma is filtered; only blood proteins and cells are too large to pass through the filtration barrier

Tubular reabsorption

- Location: Renal tubule; primarily the PCT
- Nearly all the initial filtrate is reabsorbed by the tubular cells, secreted into the interstitial fluid, and reabsorbed by the peritubular capillaries
- Waste and excess substances are not reabsorbed, and are excreted as urine

Tubular secretion

- Location: Renal tubule, primarily the PCT
- Substances are secreted from the peritubular capillaries, through the interstitial fluid, into the tubules, and excreted as urine
- Primarily involves substances such as drugs and toxins that were not removed during the initial filtration and require removal via active transport

**- E. Urine Concentration**

Necessity for high IF osmolarity

- ADH increases renal water reabsorption by stimulating aquaporins in the collecting ducts to open
- When the aquaporins open, the high osmolarity of the interstitial fluid (IF) causes water to move from the collecting ducts to the IF, decreasing urine output

Loop of Henle permeability

- Thin descending limb: Permeable to water but not solutes
- Thin ascending limb: Permeable to solutes but not water
- Thick ascending limb: Actively transports solutes out; not permeable to water

Loop of Henle functionality

- The thick ascending limb actively transports solutes ($Na^+$, $K^+$, $Cl^-$) out of the tubule, increasing IF
- Filtrate entering the descending limb has an osmolarity similar to blood (300 mOsm/L)
- The high IF osmolarity causes water to leave the descending limb (which is permeable to water but not solutes), concentrating the tubular filtrate
- At the hairpin turn, the concentrated filtrate has a higher osmolarity than the surrounding IF
- The high filtrate osmolarity causes solutes to leave the thin ascending limb (which is permeable to solutes but not water), diluting the tubular filtrate
- The tubular filtrate is further diluted in the thick ascending limb by active solute transport
- Filtrate leaving the ascending limb has an osmolarity lower than blood (100 mOsm/L)

Purpose of the vasa recta

- The loops of Henle create a highly osmotic medullary IF, necessary for ADH-mediated urine concentration
- Potential problem: Medullary cells require blood supply; blood flow can potentially wash out excess solutes from the IF
- Solution: The structure of the vasa recta enables it to supply the medulla without affecting the IF osmolarity

Vasa recta

- The vasa recta runs parallel to the juxtamedullary loop of Henle, and its ascending branch is parallel to its descending branch
- This ensure that the vasa recta can match the osmotic gradient created by the loop of Henle, as whatever solutes are absorbed in the descending limb are secreted in the ascending limb

Collecting duct

- The collecting duct complements the loop of Henle by reabsorbing urea into the IF, increasing the osmolarity

**- F. Urine Composition**

Urine

- Substances
    - **Nitrogenous waste**
        - **Urea:** Produced in the liver from deamination
        - **Uric acid:** Produced in the liver from purine metabolism
        - **Creatinine:** Produced by muscle tissue from creatine metabolism
        - **Ammonia**
    - **Excess solutes**
        - Normal substances: $Na^+$, $K^+$, $H^+$, bicarbonate ion
        - Abnormal substances: glucose, blood proteins, formed elements, hemoglobin, bile
- pH: 4.5 - 8
- Yellow color is due to **urochrome:** pigment resulting from hemoglobin catabolism

**- G. Urinary Tract**

**Ureters**

- Function: Drains urine from the kidneys to the bladder via peristalsis
- Continuous superiorly with the renal pelvis
- Courses retroperitoneally from the renal hilum to the posterior bladder
- Mucosa is continuous with the renal pelvis superiorly and the bladder inferiorly

**Urinary bladder**

- Function: Temporarily stores urine until micturition is convenient
- Location: Pelvis; subperitoneal; posterior to pubic symphysis
- Structures
    - **Ureteral orifices (r, l)**
        - **Ureteral orifice valve:** Bladder mucosa folds that cover the ureter opening and act as a one-way valve, preventing backflow
    - **Internal urethral orifice**
    - **Trigone:** Smooth triangular area between the three orifices; does not have folds, facilitating urine flow from the ureteral orifices to the urethral orifice
- Composition: Collapsible sac
    - Three layers of smooth muscle
    - Transitional epithelium
    - Superior aspect is covered by visceral peritoneum

**Urethra**

- Function: Carries urine from the bladder to the external opening via peristalsis
- Structures
    - **Internal urethral orifice:** Between the bladder and the urethra
        - **Internal urethral sphincter:** Smooth muscle; involuntary
    - **External urethral orifice:** Urethra external opening
        - **External urethral sphincter:** Skeletal muscle; voluntary
- Male urethra
    - Regions
        - **Prostatic urethra:** Extends through the prostate
        - **Membranous urethra:** Located between the prostate and the penis
        - **Spongy (penile) urethra:** Extends through the penis; external orifice is at the tip of the glans penis
    - Function: Also carries sperm
- Female urethra
    - External orifice is in the vulval vestibule, anterior to the vaginal opening

**- H. Micturition**

**Micturition / Voiding:** Emptying the urinary bladder

Micturition Process

- The presence of urine in the bladder stimulates stretch receptors, triggering reflex contractions
- **Reflex contractions:** Pelvic splanchnic nerve reflex arc; between the bladder stretch receptors, sacral spinal cord, and the bladder muscles
- Reflex contractions push the stored urine past the internal urethral sphincter, into the upper urethra, causing the sensation of the urge to urinate
- The external urethral sphincter is under voluntary control; the urge to urinate can be suppressed if voiding is inconvenient, and reflex contractions will temporarily cease until they are triggered again by further urine accumulation

# K2. Urinary System; Renal Regulation

**- A. Renal Regulation; Overview**

Blood composition factors

- Diet
- Metabolism
- Excretion

Renal functions

- Nitrogenous waste excretion
- Water balance
- Electrolyte balance
- Acid-base balance
- Vitamin D metabolism (in PCT)
- Erythropoietin secretion

## K2. Urinary System; Renal Regulation

**- B. Water Balance**

**Fluid Compartments:** Body compartments containing fluid

- **Intracellular fluid (ICF)**
- **Extracellular fluid (ECF)**
    - **Blood plasma, lymph**
    - **Interstitial fluid (IF)**
- **Transcellular fluid:** Located within specialized epithelium-lined structures
    - **CSF**
    - **Serous fluid**
    - **Ocular fluids**

Water volume factors

- Sources of water
    - **Diet:** 90%
    - **Cellular respiration:** 10%
- **Thirst mechanism:** Drives water intake
    - Primary mechanism: Decreased fluid volume causes increased solute concentration, which activates hypothalamic **osmoreceptors** which trigger the **thirst center**
    - Additional mechanism: Decreased fluid volume causes decreased salivary secretion, causing the mouth to be dry, increasing the thirst response
- Water loss mechanisms
    - Primary mechanism: Urine
    - Insensible water loss (through the lungs and skin)
    - Perspiration
    - Stool

Renal Water Regulation:

- When there is a low volume of body fluid, less urine is produced, due to:
    - Passive physiological mechanism:
        - Decreased fluid volume leads to lower arterial pressure, resulting in reduced glomerular filtration rate (GFR)
    - Active Hormonal Regulation:
        - Decreased fluid volume increases plasma osmolarity, which activates hypothalamic **osmoreceptors**
        - Activated osmoreceptors stimulate the posterior pituitary gland to release **antidiuretic hormone (ADH)**
        - ADH stimulates the renal duct cells to increase water reabsorption, decreasing urine production

**- C. Electrolyte Balance**

Overview

- Electrolyte source: Primarily diet
- Electrolyte regulation: The kidneys maintain electrolyte balance by selectively excreting excess electrolytes in urine

**Aldosterone:** Primary hormone regulating renal electrolyte excretion

- Gland: Produced by the adrenal cortex
- Stimulation
    - Low sodium concentration can directly stimulate the adrenal cortex to release aldosterone
    - Primary hormonal stimulation: RAAS
- Effect
    - Stimulates the renal tubule cells to reabsorb more sodium and excrete potassium
    - Increased sodium absorption causes increased water absorption

**Renin-Angiotensin-Aldosterone System (RAAS)**

- Juxtaglomerular (JG) cells are stimulated by low blood pressure or increased solute concentration to release **renin**
- Renin triggers a series of metabolic activities which result in **angiotensin-II** production
- Angiotensin-II:
    - Causes blood vessel vasoconstriction, raising blood pressure
    - Stimulates the adrenal cortex to release aldosterone, increasing sodium reabsorption and blood volume (and pressure)

**- D. Overview of Blood Volume, Pressure and Solute Regulation**

**Increased Sodium Reabsorption** (kidney tubule cells)
- Cause
    - Aldosterone
- Effect
    - Increases sodium concentration
    - Causes increases water retention, raising blood volume and pressure

**Increased Water Retention** (kidney tubule cells)
- Cause
    - ADH
    - Increased sodium reabsorption (aldosterone)
- Effect
    - Increased blood volume and pressure

**Aldosterone Secretion** (adrenal cortex)
- Cause
    - Decreased sodium levels
    - Angiotensin-II
- Effect
    - Increased sodium reabsorption

**Angiotensin-II Production** (various organs)
- Cause
    - Renin
- Effect
    - Aldosterone secretion
    - ADH release
    - Vasoconstriction

**Renin Secretion** (JG cells)
- Cause
    - Reduced filtrate volume or sodium concentration
    - Epinephrine / norepinephrine
- Effect
    - Angiotensin-II production

**Epinephrine / Norepinephrine Secretion** (adrenal medulla)
- Cause
    - Sympathetic nervous system; stress
    - Sympathetic nervous system; low blood pressure (detected by baroreceptors)
- Effect
    - Vasoconstriction
    - Increased heart rate and blood pressure

- Renin secretion

**Vasoconstriction** (blood vessels)
- Cause
  - Angiotensin-II
  - Epinephrine / norepinephrine
- Effect
  - Increases blood pressure

**ADH Release** (posterior pituitary)
- Cause
  - Sympathetic nervous system; high blood osmolarity (detected by osmoreceptors)
  - Angiotensin-II
- Effect
  - Increased water reabsorption

**Osmoreceptor Activation** (hypothalamus)
- Cause
  - High solute concentration
- Effect
  - ADH release
  - Thirst mechanism

**- E. Acid-Base Balance**

Blood pH

- Ideal pH: 7.35-7.45
- **Alkalosis:** > 7.45
- **Acidosis:** < 7.35
- **Physiological acidosis:** Between 7.0 and 7.35; technically still alkaline, but excessively acidic for blood

Source of acid

- Primary source: metabolism
- Diet

Acid-base balance systems

- **Blood buffers**
- **Respiratory regulation**
- **Renal regulation**

Blood buffers

- Timeframe: Seconds
- Buffers bind hydrogen ions in acidic conditions and release hydrogen ions in basic conditions
- Blood buffer systems:
    - Bicarbonate
    - Phosphate
    - Protein

Respiratory regulation

- Timeframe: Minutes
- Relation between $CO_2$ and $H^+$:
    - $CO_2$ and $H^+$ are on opposite sides of a reversible chemical reaction:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

    - When $CO_2$ is added, the equilibrium shifts to the right, increasing the number of $H^+$ ions
    - When $CO_2$ is removed, the equilibrium shifts to the left, decreasing the number of $H^+$ ions
- Normal breathing:
    - During normal breathing, the same amount of $CO_2$ is added by internal respiration as is removed by external respiration, keeping the net volume of $CO_2$ constant and the equation at equilibrium, and the pH level is not affected
- Acidosis respiratory compensation
    - When chemoreceptors detect low pH, the respiratory system compensates by increasing the rate and depth of breathing
    - This increases the volume of $CO_2$ output, while the volume of $CO_2$ input remains constant, resulting in a net loss of $CO_2$
    - Decreased $CO_2$ causes decreased $H^+$ ions, raising the pH
- Alkalosis respiratory compensation

- When chemoreceptors detect high pH, the respiratory system compensates by decreasing the rate and depth of breathing
- This decreases the volume of $CO_2$ output, while the volume of $CO_2$ input remains constant, resulting in a net gain of $CO_2$
- Increased $CO_2$ causes increased $H^+$ ions, lowering the pH

Renal regulation

- Timeframe: Hours or days
- Acidosis renal compensation: More $H^+$ ions are secreted and more bicarbonate ions are reabsorbed
- Alkalosis renal compensation: More bicarbonate ions are secreted and more $H^+$ ions are reabsorbed

# L1. Reproductive System; Male

**- A. Reproductive System; Overview**

Function: Produces offspring

Primary organ: **Gonads**
- Male: **Testes**
- Female: **Ovaries**

Gonad function
- Produces **gametes** (sex cells)
- Secretes **sex hormones**

Gametes
- Male: **Sperm**
- Female: **Ova** (eggs)

Sex hormones
- Male: **Testosterone**
- Female: **Estrogen** and **progesterone**

---

**- B. Male Reproductive System; Overview**

Male reproductive system
- Function
    - Produces sperm
    - Delivers sperm to the female reproductive tract
- Primary reproductive organ: Testes
    - Exocrine function: Produces sperm
    - Endocrine function: Secretes testosterone

Accessory reproductive structures: Ducts and glands that aid in sperm development and delivery

**- C. Testes**

Location: Scrotum

Structures

- **Scrotum:** Contains the testes
- **Tunica albuginea:** Fibrous connective tissue; surrounds the testes
- **Septa:** Tunica albuginea extensions; extend into the testes and divides them into wedge-shaped lobules
- **Lobules:** Wedge-shaped sections of testes; contain 1 - 4 seminiferous tubules
- **Seminiferous tubules:** Coiled tubules; create sperm
- **Interstitial cells:** Surround the seminiferous tubules; produce testosterone
- **Rete Testis:** Seminiferous tubules empty into the rete testis; rete testis empties into the epididymis
- **Spermatic cord**
    - Connective tissue sheath; connects the testes to the abdomen
    - Contains blood vessels, lymphatic vessels, nerves, and the ductus deferens

**- D. Duct System**

Male duct system: Carries sperm from the testes to the external urethral opening

Duct system structures:
- **Epididymis (r, l)**
- **Ductus deferens (r, l)**
- **Urethra**

Epididymis
- First part of the duct system
- Cup-shaped convoluted tube; hugs the posterior aspect of the testes
- Temporarily stores immature sperm; site of sperm maturation
- During ejaculation, the epididymis walls contract to expel sperm into the ductus deferens

Ductus deferens / vas deferens
- Extends from the epididymis to the urethra
- Course:
    - Superiorly and laterally, through the spermatic cord
    - Posteriorly, medially and inferiorly towards the posterior bladder
    - Crosses over the ureters
    - Expands into the **ampulla**
    - Joins with the seminal vesicle duct, forming the **ejaculatory duct**
    - Enters the superior prostate, posterior to the urethra
    - Within the prostate, empties into the urethra
- During ejaculation, propels sperm via peristalsis

Urethra
- Terminal part of the duct system
- Extends from the base of the urinary bladder to the tip of the penis
- Regions:
    - **Prostatic urethra**
        - Located within the prostate
        - Joined by the ejaculatory duct
    - **Membranous urethra**
        - Located between the prostate and the penis
    - **Spongy (penile) urethra**
        - Located within the penis corpus spongiosum
        - Opens to the exterior via the external urethral orifice

**- E. Accessory Glands**

Accessory glands function: Produce seminal and pre-seminal fluid

Accessory glands:
- **Seminal vesicles (r, l)**
- **Prostate**
- **Bulbourethral glands (r, l)**

Seminal vesicles (r, l)
- Location: Base of the urinary bladder, lateral to the ductus deferens ampulla
- Produce the majority of seminal fluid
- Join the ampulla at the entrance to the bladder, forming the ejaculatory duct

Prostate
- Encircles the prostatic urethra, immediately inferior to the bladder
- Produces **prostate fluid**, part of semen

Bulbourethral glands
- Small glands, located inferior to the prostate
- Drain into the penile urethra
- Produce pre-seminal fluid
    - Secreted into the urethra during sexual excitement, prior to ejaculation
    - Neutralizes the acidity of urine in the urethra

Semen
- Mixture of sperm and accessory gland secretions
- Transport medium for substances that enhance sperm motility and viability
    - Contains fructose, which provides sperm with energy
    - Sperm are sluggish in acidic environments; the vagina has a pH of 3.5 - 4; semen is basic and neutralizes the vaginal acidity
    - Contains antimicrobial substances
    - Contains the hormone relaxin
    - Contains enzymes that enhance sperm motility
    - Contains substances that inhibit the immune response to sperm in the female reproductive tract to sperm

**- E. External Genitalia**

Male external genitalia:

- **Scrotum**
- **Penis**

Scrotum

- Contains the testes
- Divided sac of skin
- Hangs inferiorly to the abdominal cavity
- The testes require a lower temperature than the rest of the body, necessitating an external location

Penis

- Delivers sperm to the female reproductive tract
- Structures:
    - **Root:** Located within the body, attached to the pelvic bones
    - **Shaft**
        - Body of the penis
        - Composed of three erectile tissues:
            - **Corpus cavernosum (r, l):** Superior
            - **Corpus spongiosum:** Inferior
        - Erectile tissues fill with blood during sexual excitement, causing to penis to enlarge and become rigid, aiding copulation
    - **Glans penis:** Tip of the penis
    - **Prepuce / Foreskin:** Loose skin covering; covers the proximal glans penis; frequently removed (circumcision)

**- F. Spermatogenesis**

**Spermatogenesis**: Sperm production

- Location
    - Seminiferous tubules
- Sperm development stages:
    - **Spermatogonia**
    - **Primary spermatocyte**
    - **Secondary spermatocyte**
    - **Spermatid**
    - **Spermatozoa**

Spermatogonia

- Sperm progenitor cells, located in the periphery of the seminiferous tubule
- From the mid-fetal stage to puberty, spermatogonia undergo classic mitosis, building up large reserves
- Following puberty, spermatogonia mitosis produces two distinct daughter cells:
    - **Type A Daughter Cell**: Remains in the tubule periphery, maintaining the stem cell population
    - **Type B Daughter Cell:** Begins migrating from the periphery to the lumen, becoming a primary spermatocyte

Primary spermatocyte, secondary spermatocyte

- Primary spermatocytes undergo meiosis I, forming two haploid secondary spermatocytes
- The two secondary spermatocytes undergo meiosis II, forming four haploid spermatids

Spermatid

- **Spermiogenesis:** Maturation of spermatids into spermatozoa
    - Excess cytoplasm is removed
    - The cell reshapes, forming a head, midpiece and tail

Spermatozoa

- **Spermiation:** Fully formed spermatozoa are released into the lumen of the tubules
- The spermatozoa then move to the epididymis and fully mature, gaining motility and the capability to fertilize an ovum

**- G. Sperm Components**

Sperm components

- **Head**
  - Contains the nucleus
  - **Acrosome:** Located in the head, anteriorly cupping the nucleus; contains digestive enzymes that aid in ovum penetration
- **Midpiece**
  - Contains the base of the filaments that extend to form the tail
  - Mitochondria wrap around the filaments to provide energy for motility
- **Tail**
  - Axial filaments
  - Provide motility

---

**- H. Testosterone**

Testosterone

- Produced by: Interstitial cells of the testes
- Production increases during puberty, due to LH stimulation
- Function:
  - Influences embryonic development of male reproductive structures
  - Causes the adolescent growth spurt and the maturation of reproductive organs
  - Responsible for sex drive (libido)
  - Causes secondary male characteristics:
    - Voice deepening due to larynx enlargement
    - Increased body hair, particularly in the axillary, pubic, and facial regions
    - Increased muscle mass and bone density

# L2: Reproductive System; Female Anatomy

**- A. Female Reproductive System; Overview**

Female reproductive system

- Function
    - Produces female gametes - **ova**
    - Supports embryonic and fetal development
- Primary reproductive organ: **Ovaries (r, l)**
    - Exocrine function: Produce ovum
    - Endocrine function: Secrete estrogen and progesterone
- Accessory duct system
    - **Uterine tubes (r, l)**
    - **Uterus**
    - **Vagina**

---

**- B. Ovaries**

Ovaries (r, l)

- Location:  Lateral to the uterus
- Supporting structures:
    - **Suspensory ligaments:** Attach the ovaries laterally to the pelvic wall
    - **Ovarian ligaments:** Attach the ovaries medially to the uterus
    - **Broad ligament:** Fold of peritoneum; encloses the ovaries
- Contains:
    - Developing **ovarian follicles**
    - Mature **Graafian follicles**
    - Post-ovulation structures: **corpus luteum, corpus albicans**

**- C. Duct System**

Uterine / fallopian tubes (r, l)

- Function
    - Receive the oocyte from the ovaries during ovulation
    - Transport the oocyte to the uterus
    - Site of fertilization
- Structure
    - Enclosed by the broad ligament
    - Extends from the ovaries to the uterus
    - Not continuous with the ovaries; the terminal **infundibulum** opens above the ovaries and is surrounded by **fimbriae** extensions that sweep in the expelled oocyte
    - Lined with cilia that help transport the oocyte towards the uterus

Uterus

- Location: Between the urinary bladder and the rectum
- Function: Site of embryonic and fetal development
- External structure
    - Suspended superiorly by the broad ligament
    - **Round ligament:** Attaches the uterus anteriorly to the labia majora
    - **Uterosacral ligament:** Attaches the uterus posteriorly to the sacrum
- Regions
    - **Body**
    - **Fundus:** Rounded region superior to the entrance of the uterine tubes
    - **Cervix:** Narrow outlet; opens to the vagina
- Walls
    - **Endometrium:** Inner layer
        - **Stratum functionalis**
            - Regenerates each month
            - If an egg is fertilized, it implants and develops within the endometrium; otherwise, the endometrium is shed during menstruation
        - **Stratum basale**
            - Permanent endometrial layer, deep to the stratum functionalis; generates the stratum functionalis
    - **Myometrium:** Middle muscular layer; contracts during childbirth
    - **Perimetrium:** Visceral peritoneum; covers the superior aspect of the uterus

Vagina / birth canal

- Location: Extends from the uterus to the vulva
- Function:
    - Passage for infant delivery
    - Passage for menstrual flow
    - Female organ of copulation: Receives the penis and semen during sexual intercourse
- **Hymen:** Mucosal fold; partially encloses the distal end of the vagina

**- D. External Genitalia**

External genitalia / vulva
- **Mons pubis**
- **Labia**
- **Vaginal vestibule**
    - **Urethral opening**
    - **Vaginal opening**
    - **Greater vestibular glands (r, l)**
- **Clitoris**

Mons pubis
- Fatty, rounded area overlying the pubic symphysis
- Develops pubic hair during puberty

Labia
- **Labia majora**
    - Folds of hair-covered skin
    - Enclose the labia minora and vestibule
- **Labia minora**
    - Within the labia majora, directly surrounding the vestibule
    - Folds of hair-free skin

Vaginal vestibule
- Contains:
    - Urethral opening
    - Vaginal opening
    - Greater vestibular glands: Open to the vestibule; secrete vaginal lubrication during sexual intercourse

Clitoris
- Location: Anterior to the vestibule
- Structure
    - Small, protruding structure
    - Corresponds to the male penis
    - Hooded by the **prepuce**
    - Composed of erectile tissue

**Corpus cavernosum:** Extend laterally from the clitoral base; composed of erectile tissue
**Vestibular bulbs:** Bulbs of erectile tissue, located laterally to the vaginal opening; correspond to the male corpus spongiosum
**Perineum:** Diamond-shaped region between the pubic symphysis, ischial tuberosities, and coccyx

# L3: Reproductive System; Female Reproductive Cycle

**- A. Follicular Development; Overview**

Stages of follicular development

- **Oogenesis**
  - **Oogonia**
  - **Primary oocyte**
  - **Primordial follicle**
- **Folliculogenesis**
  - **Preantral / gonadotropin-independent**
    - **Primary follicle**
    - **Secondary follicle**
  - **Antral / gonadotropin-dependant**
    - **Tertiary / antral follicle**
    - **Graafian follicle**
- **Ovulation**
- **Corpus luteum**
- **Corpus albicans**

---

**- B. Oogenesis**

**Oogenesis**

- Process of oocyte formation
- Occurs during fetal development
- All the follicles a female will have are present in the ovaries as primordial follicles at birth
- Stages:

**Oogonia**

- Oocyte progenitor cell

**Primary oocyte**

- The primary oocyte begins meiosis I, and is arrested at prophase I

**Primordial follicle**

- Early follicle
- Consists of a primary oocyte surrounded by a single layer of squamous **granulosa cells**, surrounded by a **basal lamina**
  - Function of granulosa cells:
    - Form the internal follicle structure
    - During later stages of development: Convert androgens produced by the theca interna cells into estrogen

**- C. Preantral / Gonadotropin-Independent Phase of Folliculogenesis**

**Folliculogenesis**

- Process of follicular growth and development
- Occurs in a staggered, continuous manner; at any time, the ovary contains follicles in various stages of development
- Begins with **primordial follicle recruitment / activation** and ends with ovulation or death by **atresia**

**Preantral / gonadotropin-independent phase**

- Does not require FSH stimulation; regulated by local hormones
- Takes almost a year; the dominant follicle that ovulates originates from a primordial follicle that was recruited almost a year earlier
- Stages:
    - Primary follicle
    - Secondary follicle

**Primary follicle**

- The granulosa cells become cuboidal-shaped and begin expressing **FSH receptors**
- The **zona pellucida** forms around the oocyte
    - Primary function of the zona pellucida: Facilitates and regulates sperm penetration

**Secondary follicle**

- The granulosa cells develop into stratified cuboidal epithelium
- The **theca** begins to develop around the basal lamina
    - Layers of the theca:
        - **Theca interna**
            - Consists of **theca interstitial cells:** epithelioid cells with LH receptors
            - Secretes androstenedione, which is converted by the granulosa cells into estrogen
        - Contains a **capillary network**
        - **Theca externa:** Composed of smooth muscle cells and connective tissue
- Layers of the secondary follicle:
    - Mature oocyte
    - Zona pellucida
    - Multiple layers of cuboidal granulosa cells
    - Basal lamina
    - Theca interna
    - Capillary network
    - Theca externa

**- D. Antral / Gonadotropin Dependant Phase of Follicular Development**

**Antral / gonadotropin dependant phase**

- Requires FSH stimulation
- Occurs during the follicular phase of the ovarian cycle; FSH secretion stimulates secondary follicles to develop

**Antral / tertiary follicle**

- An antrum filled with follicular fluid forms within the granulosa cells, pushing the oocyte to the side
- The granulosa cells around the oocyte and zona pellucida form the **cumulus oophorus**
    - **Corona radiata:** The innermost layer of the cumulus oophorus, directly surrounding the zona pellucida
- Granulosa cells form the **membrana granulosa** around the antrum, within the basal lamina

**Graafian / preovulatory follicle**

- The oocyte complete meiosis I, dividing into the haploid secondary oocyte and the first polar body
- The secondary oocyte begins meiosis II, and is arrested at metaphase II

---

**- E. Ovulation, Corpus Luteum and Albicans**

**Ovulation**

- By ovulation, one graafian follicle is chosen to ovulate. The remaining mature follicles undergo **atresia**
- The dominant follicle ruptures, and the oocyte is released to the fallopian tubes
  The ruptured follicle remains in the ovaries and develops into the **corpus luteum**
- If the oocyte becomes fertilized, it completes meiosis II, dividing into the haploid **ovum** and the **second polar body**; the polar bodies quickly deteriorate

**Corpus luteum and albicans**

- The corpus luteum remains in the ovaries and secretes estrogen and progesterone
- If ovulation does not result in implantation, the corpus luteum degenerates into the corpus albicans towards the end of the ovarian cycle, eventually shrinking into fibrous tissue
- If implantation occurs, the corpus luteum is maintained until the end of the first trimester, after which the placenta takes over hormone secretion and the corpus luteum degenerates into the corpus albicans

**- F. Female Sex Hormones**

**Estrogen**

- Secreted by:
  - Developing follicles (during the follicular phase)
  - Corpus luteum (during the luteal phase)
  - Placenta (during the second and third trimesters of pregnancy)
- Effects:
  - Maturation of female reproductive organs
  - Female secondary sex characteristics
    - Breast development
    - Growth of axillary and pubic hair
    - Fat deposits beneath the skin, particularly in the breasts and hips
    - Widening and lightening of the pelvis
  - Menstrual cycle
  - Metabolic effects
    - Reduces cholesterol levels
    - Increases calcium uptake

**Progesterone**

- Secreted by:
  - Corpus luteum (during the luteal phase)
  - Placenta (during the second and third trimester of pregnancy)
  - Not secreted during the follicular phase
- Effects
  - Prepares the endometrium for implantation
  - Maintains pregnancy
  - Promotes the development of mammary gland for lactation

**- G. Female Reproductive Cycle; Overview**

Female reproductive cycle

- Includes the coinciding **ovarian** and **menstrual cycles**
- Regulated by hormones
- Generally 28 days long
- Ovarian cycle phases:
    - **Follicular phase:** Days 1 - 14
    - **Ovulation:** Day 14
    - **Luteal phase:** Days 15 - 28
- Menstrual cycle phases:
    - **Menstrual phase:** Days 0 - 4
    - **Proliferative phase:** Days 5 - 14
    - **Secretory phase:** Days 15 - 28

Ovarian cycle: Cycle of follicular development

- Follicular phase: Primary follicles develop into Graafian follicles
- Ovulation: The oocyte is released into the uterine tubes
- Luteal phase: The corpus luteum secretes estrogen and progesterone

Menstrual cycle: Cycle of endometrium development and menstruation

- Menstrual phase: The endometrium stratum functionalis sloughs from the uterine wall; the detached tissue and blood pass through the vagina as menstrual flow
- Proliferative phase: The stratum functionalis regenerates from the stratum basale
- Secretory phase: The stratum functionalis develops further, due to progesterone secretion from the corpus luteum

**- H. Female Gonadotropins**

**Gonadotropin-releasing hormone (GnRH)**

- Secreted by: Hypothalamus
- Effect: Stimulates the anterior pituitary gland to secrete FSH and LH

**Follicle-stimulating hormone (FSH)**

- Secreted by: Anterior pituitary gland
- Effect: Promotes follicular development

**Luteinizing hormone (LH)**

- Secreted by: Anterior pituitary gland
- Effect: Triggers ovulation and stimulates the corpus luteum

**Human Chorionic Gonadotropin (hCG)**

- Secreted by: Blastocyst
- Effect: Maintains the corpus luteum during early pregnancy

**L3: Reproductive System; Female Reproductive Cycle**

**- I. Female Reproductive Cycle Hormonal Regulation**

Follicular phase

1) Low levels of estrogen and progesterone at the end of a cycle trigger FSH secretion, initiating the next cycle
2) FSH secretion stimulates follicular development
3) The developing follicles secrete estrogen

Proliferative phase

4) Estrogen stimulates stratum functionalis growth
5) Estrogen secretion triggers further GnRH release, in a positive feedback loop

Ovulation

6) Rising estrogen levels trigger further GnRH release, stimulating LH secretion
7) LH causes ovulation

Luteal, secretory phase

8) LH stimulates corpus luteum development and secretion
9) As follicles are no longer developing, they do not secrete estrogen; instead, the corpus luteum secretes estrogen, and progesterone
10) Progesterone stimulates further stratum functionalis development

Menstrual phase

11) Rising progesterone levels, as well as **inhibin** secretion (by the corpus luteum) inhibit LH secretion
12) Falling LH levels cause the corpus luteum to degenerate and stop estrogen and progesterone production
13) Falling estrogen and progesterone levels cause the stratum functionalis to die and slough off from the uterine wall
14) Low levels of estrogen and progesterone at the end of the cycle trigger FSH secretion, initiating the next cycle

Pregnancy

- An implanted embryo produces HCG, which maintains the corpus luteum through the first trimester of pregnancy, at which point the placenta takes over hormone production and stops producing HCG

**- J. Fertilization and Implantation**

Fertilization

- The oocyte is viable for 12 to 24 hours after ovulation, by which time it is roughly one-third of the way along the uterine tube
- If sperm is present, it is attracted to the oocyte via chemotaxis
- Many sperm compete to fertilize the oocyte

Fertilization barriers

- **Corona radiata**
  - Outermost layer
  - Penetrated by the enzyme **hyaluronidase** on the sperm surface
- **Zona pellucida**
  - Thick layer of glycoprotein
  - Penetrated by acrosomal enzymes
- **Oolemma**
  - Oocyte plasma membrane
  - Penetrated through specific receptor interactions
- **Cortical reaction**
  - Once one sperm enters the oolemma, the oocyte undergoes changes that prevent subsequent sperm from penetrating

Blastocyst development

- The oocyte completes meiosis II; the sperm and oocyte fuse, forming a diploid **zygote**
- The zygote continues down the uterine tube via ciliary action and peristalsis
- **Cleavage:** The zygote undergoes rapid mitotic division; by the time it reaches the uterus, it is a morula
- **Morula:** Ball of 16 cells
- When the embryo reaches the uterus around day 17 of the menstrual cycle, the endometrium is generally not yet fully receptive; instead, the embryo floats in the uterine cavity, nourished by uterine secretions
- The embryo continues dividing until it has roughly 100 cells, forming a blastocyst
- **Blastocyst:** Hollow, ball-like structure
  - **Trophoblast:** Outer layer
  - **Inner cell mass:** Cluster of cells within the trophoblast, towards one side
- The blastocyst produces HCG
- By around day 21 of the menstrual cycle, the endometrium is receptive, and the blastocyst implants into the endometrial lining

**- K. Embryonic Development**

Embryonic development

- The blastocyst inner cell mass forms three **primary germ layers:**
    - **Ectoderm:** Develops into the nervous system and epidermal tissue
    - **Endoderm:** Develops into the mucosae and associated glands
    - **Mesoderm:** Develops into muscle, bone, blood, and connective tissues, as well as the cardiovascular, lymphatic, and urogenital systems
- Once implanted within the uterus, the trophoblast forms:
    - **Chorionic villi:** Finger-like projections of the trophoblast; combine with uterine tissue to form the placenta
    - **Placenta:** Facilitates gas and nutrient exchange between the embryo and the mother (blood itself is not exchanged)
    - **Umbilical cord:** Connects the embryo to the placenta
    - **Amnion:** Fluid-filled sac; surrounds the embryo
- Towards the end of the first trimester, the placenta becomes the primary source of estrogen, progesterone, and other pregnancy-enhancing hormones

**Embryonic period:** From fertilization through week 8; the conceptus is called an **embryo**
**Fetal period:** From week 9 to birth; the conceptus is called a **fetus**

**- L. Childbirth**

Parturition / childbirth

- **Perinatal period**
    - During the final weeks of pregnancy, estrogen levels peak, leading to an increase in oxytocin receptors in the myometrium and reducing progesterone's inhibition of uterine contractions
- **Peripartum period**
    - Period immediately prior to childbirth
    - The fetus produces oxytocin
    - Oxytocin stimulates the placenta to produce prostaglandins
    - Oxytocin and prostaglandins stimulate uterine contractions
    - Uterine contractions stimulates oxytocin release by the posterior pituitary gland, in a positive feedback loop
- **Labor:** Series of events that expel the fetus from the uterus
    - **Dilation:** Dilation of the cervix
    - **Expulsion:** Expulsion of the infant
    - **Placental:** Within a few minutes after expulsion, the **afterbirth** (placenta and associated fetal membranes) is removed

---

**- M. Mammary Glands**

Mammary glands

- Modified sweat glands
- Present in both male and females; only functional in females
- Function: Produce milk to nourish offspring
- Structures:
    - **Breasts:** Anterior to pectoral muscle; contain the mammary glands
    - **Areola:** Pigmented area, surrounds the nipple
    - **Nipple:** Protrudes from the center of the areola
    - **Lobes:** Each mammary gland has 15 - 25 lobes that radiate around the nipple, separated by connective tissue and fat
    - **Suspensory ligaments:** Connective tissue; anchor the mammary glands to surrounding tissues
    - **Lobules:** Located within the lobes
    - **Alveolar glands:** Located within the lobules; produce milk during lactation; secrete to the lactiferous duct
    - **Lactiferous duct:** Carries milk from the lobules to the nipple
    - **Lactiferous sinus:** Dilated region of lactiferous duct deep to the areola; accumulates milk during lactation