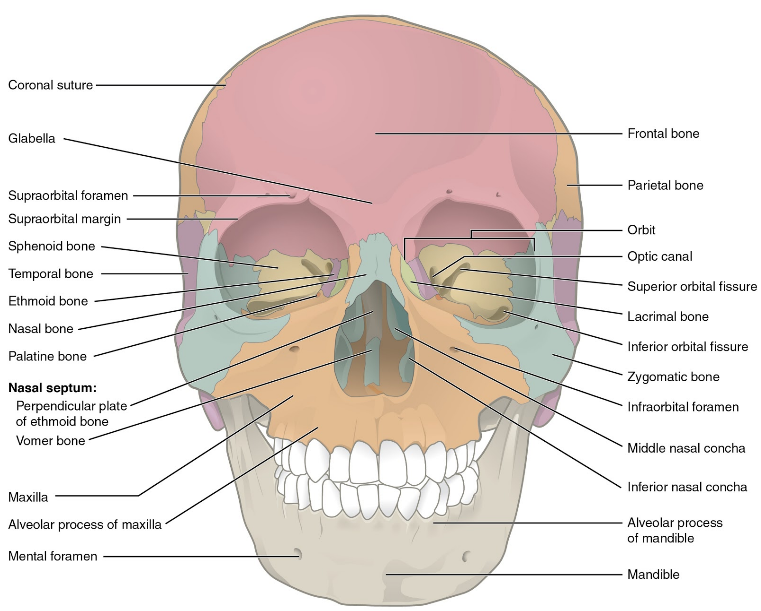
# Introduction to Human Body Systems and Related Medical Terminology

# HLTH 140

*Kurt Rutter MSN, RN, CNE*



Anterior view

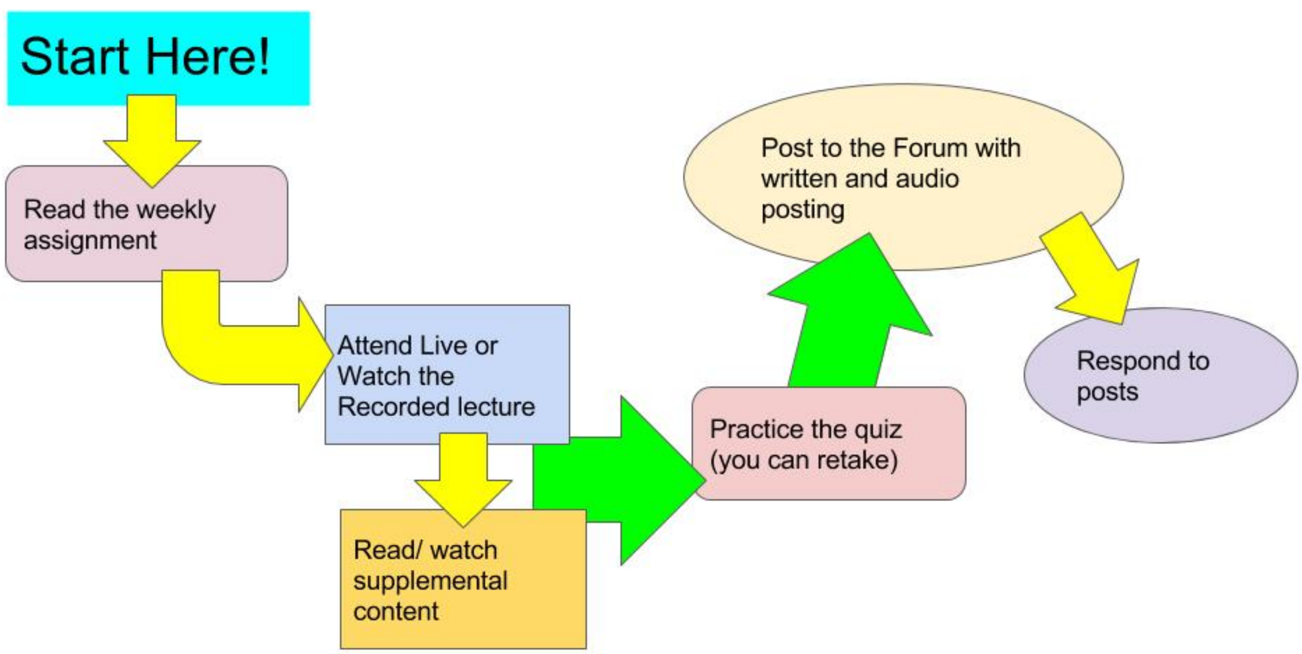
# Getting Started

# Hōʻuluʻulu Pōkole (Overview)

This course is an introduction to human body systems and the medical terminology used in many medical fields including medical assisting, coding, nursing, radiology, physical therapy, occupational therapy...the list is long.

**This text**. can be viewed entirely online within the course, or you can buy it from the Kaua`i Community College (KCC) Bookstore on the KCC campus. You can print out any part of the book you like. it is protected by a Creative Commons license allowing you or anyone to re-use, re-mix, or print anything in the book. You do need to give attribution (share credit) with the original creator.

Here is the basic flow of each week for reading , watching, and participating in the class. For example, this week the assignment is to become familiar with the tools we will use and the course syllabus.



This text, along with the online content that is an important part of the course, is intended to help you achieve the following learning outcomes:

1. Demonstrate the ability to analyze the component parts of a medical word to derive the correct medical meaning.
2. Define medical terms and abbreviations.
3. Utilize appropriate medical terminology both orally and in writing.
4. Describe the structural organization and normal function of the major body systems.

Specifically, what I would like you to be able to do is:

1. Describe structural organization of the human body
2. Identify body systems
3. Describe:
    a. body planes
    b. directional terms
    c. Quadrants
    d. body cavities
4. List major organs in each body system
5. Identify the anatomical location of major organs in each body system
6. Compare structure and function of the human body across the lifespan
7. Describe the normal function of each body system
8. Identify medical terms labeling the word parts
9. Define medical terms and abbreviations related to all body systems

This book is adapted from the OpenStax textbook *Anatomy & Physiology*, available free for download from https://openstax.org/details/anatomy-and-physiology. I would like to thank the authors and editors of Anatomy & Physiology for allowing free and open access to the text.

- Any discrepancy between information in the Anatomy & Physiology Textbook resulting from the adaptation of the textbook for this Human Body Systems and Medical Terminology course are the responsibility of adaptor (me, in this case).
- This text adaptation is an ongoing project, and comments and corrections are welcome. Please direct your comments to krutte@hawaii.edu
- This adaptation of OpenStax *Anatomy & Physiology* is a heavily edited and shortened version of the text. The original textbook is intended for health sciences majors taking a 2-semester anatomy and physiology course with a lab. I have shortened every chapter used, and omitted many chapters to focus on the basics of human body systems.
    - Review questions, quizzes and collaborative activities are all online
    - Each chapter does have a complete glossary. Some glossary terms may not be represented in the text. To look more deeply into any topic I recommend going to the OpenStax *Anatomy & Physiology* text or other online resources.
    - Khan Academy (http:www.khanacademy.org) is an excellent source for in-depth information as video presentations.
- Please enjoy the book!

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# Structural Organization of the Human Body

## Hōʻuluʻulu Pōkole (Overview)

The human body is composed of atoms, like everything else in the universe. Atoms combined together make molecules, and cells are made of those. We start at the cellular level and work up from there in this unit. We also discuss how  tissues combine to form tissues, tissues build organs, organs are parts of organ systems, which together function as an organism.

### Ke Haumana ka ʻapo (Student Learning Outcomes)

1. Define the smallest functional living unit of a human being.
2. Differentiate between cells, tissues, organs, and organ systems.
3. Learn about our class cohort as we begin this journey through human body systems

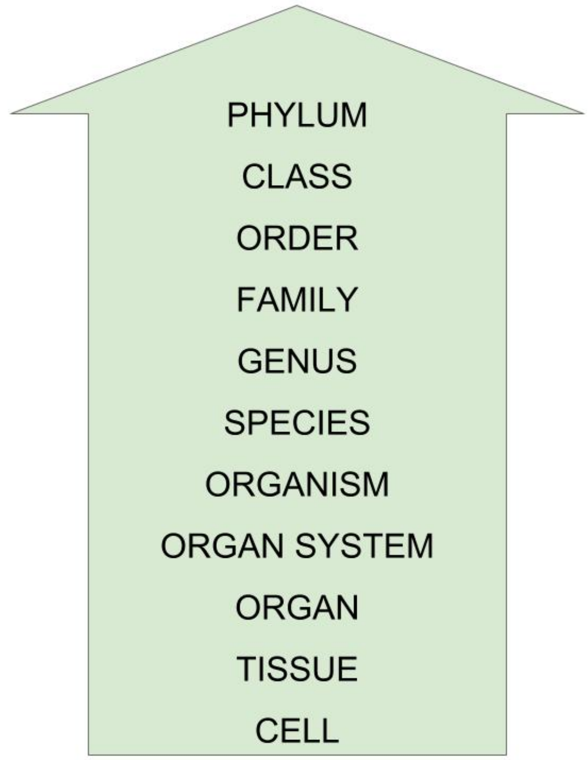
### Organization of the human body

- ❑ A cell is the smallest independently functioning unit of a living organism. Even bacteria, which are extremely small, independently-living organisms, have a cellular structure. Each bacterium is a single cell. All living structures of human anatomy contain cells, and almost all functions of human physiology are performed in cells or are initiated by cells.

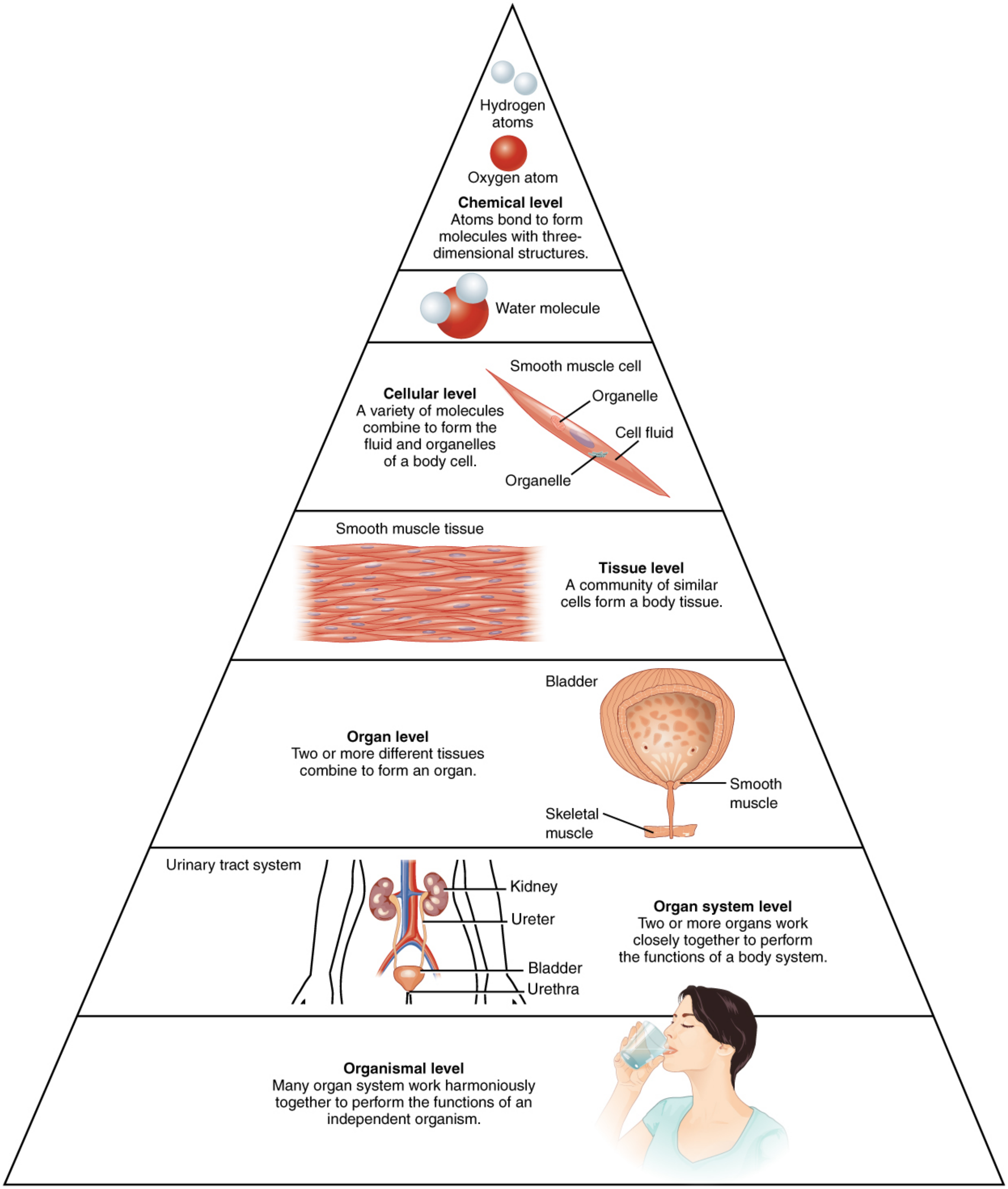
- ❑ A human cell typically consists of flexible membranes that enclose cytoplasm, a water-based cellular fluid together with a variety of tiny functioning units called organelles. In humans, as in all organisms, cells perform all functions of life.
- ❑ A tissue is a group of many similar cells (though sometimes composed of a few related types) that work together to perform a specific function.

- An organ is an anatomically distinct structure of the body composed of two or more tissue types. Each organ performs one or more specific physiological functions.

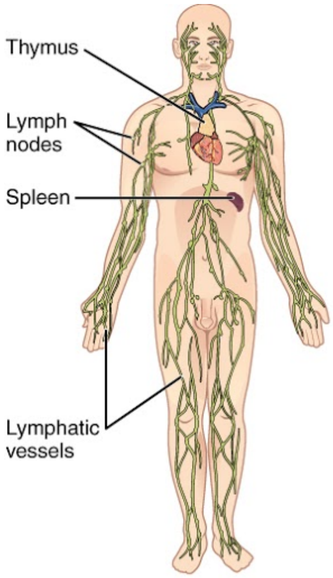
- An organ system is a group of organs that work together to perform major functions or meet physiological needs of the body.
- Organs that work together are grouped into **organ systems.** Assigning organs to organ systems can be imprecise since organs that "belong" to one system can also have functions integral to another system. In fact, most organs contribute to more than one system.
- The **organism** level is the highest level of organization for an individual. An organism is a living being that has a cellular structure and that can independently perform all physiologic functions necessary for life.




- Beyond the organism level (that's you and me) is all of us, **human** (or homo sapiens to be technical, which means smarty-pants hominid) in general. All humans are the same single species.
- Humans as a species belongs to the genus **homo**. We are the only existing members of the genus homo.
- All members of the genus Homo are part of the family of **hominidae** which includes all hominids such as australopithecus, neanderthals etc..
- Above family is the order. We all belong to the order **primates** which includes us along with orangutans, chimpanzees, bonobo, and gorillas.
- We are mammals like all primates so we are a part of the class **mammalia**.
- All mammals have spinal cords, and all living things with spinal chords belong to the phylum **chordata**
- And finally, we are animals, not plants! So we belong to the kingdom **animalia**
- It's just nice to know where we are in the scheme of things...

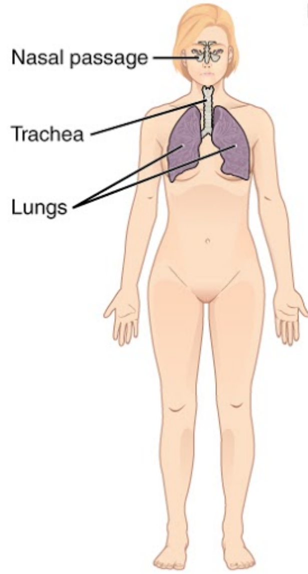


Hydrogen atoms
Oxygen atom
Chemical level
Atoms bond to form molecules with three-dimensional structures.
Water molecule
Smooth muscle cell
Cellular level
A variety of molecules combine to form the fluid and organelles of a body cell.
Organelle
Cell fluid
Organelle
Smooth muscle tissue
Tissue level
A community of similar cells form a body tissue.
Bladder
Organ level
Two or more different tissues combine to form an organ.
Smooth muscle
Skeletal muscle
Urinary tract system
Kidney
Ureter
Bladder
Urethra
Organ system level
Two or more organs work closely together to perform the functions of a body system.
Organismal level
Many organ system work harmoniously together to perform the functions of an independent organism.



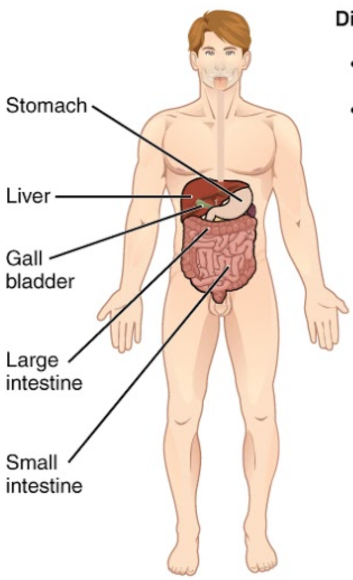

**Lymphatic System**

- Returns fluid to blood
- Defends against pathogens



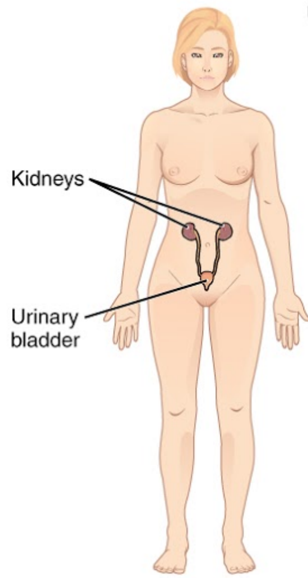

**Respiratory System**

- Removes carbon dioxide from the body
- Delivers oxygen to blood



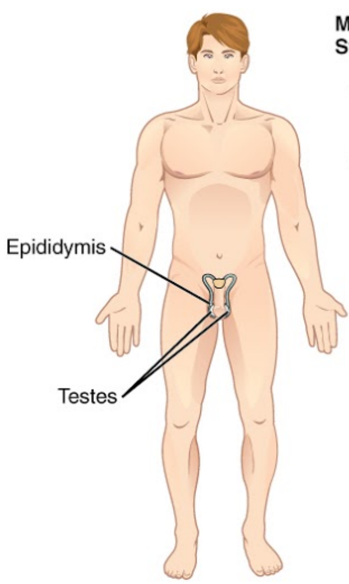

**Digestive System**

- Processes food for use by the body
- Removes wastes from undigested food



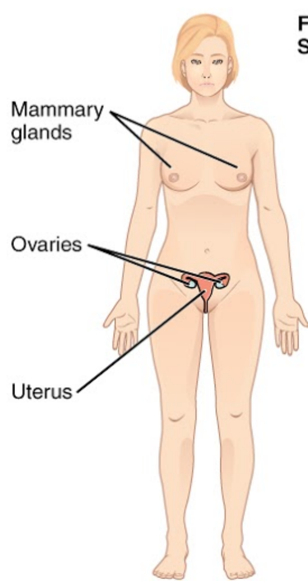

**Urinary System**

- Controls water balance in the body
- Removes wastes from blood and excretes them




**Male Reproductive System**

- Produces sex hormones and gametes
- Delivers gametes to female




**Female Reproductive System**

- Produces sex hormones and gametes
- Supports embryo/ fetus until birth
- Produces milk for infant

# Glossary

**Cell:** smallest independently functioning unit of all organisms; in animals, a cell contains cytoplasm, composed of fluid and organelles

**Organ:** functionally distinct structure composed of two or more types of tissues

**Organ system**: group of organs that work together to carry out a particular function

**Organism:** living being that has a cellular structure and that can independently perform all physiologic functions necessary for life

**Tissue:** group of similar or closely related cells that act together to perform a specific function

# Ōlelo Kauka Kukulu (Building Medical Words)

## Hōʻuluʻulu Pōkole (Overview)

Most medical words are composed of two or more parts, such as a word root and a suffix, that give the word a specific meaning. Each part of the word provides information, so if that part is taken away, the meaning of the word changes. This Chapter introduces some rules for building medical words. The video goes over these rules and also discusses where medical words used in Western medicine come from.

### Ke Haumana ka ʻapo (Student Learning Outcomes)

1. Identify the basic components of a medical word
2. Build medical words using the rules for medical word building
3. Define medical words based on the meaning of the word parts (prefix, word root, suffix)

## Basic Components of a Medical Word

**The Prefix** is not always present but when it is it usually gives the direction (up, down, beside), time (pre, post, intra), or sometimes whether the process or thing described is even there!

**The Word Root** is the middle of the word and defines what the subject of the word is, what we are referring to with the prefix and the suffix

**the Suffi**x is <u>always</u> at the end of the word and give information on how the word root is being used

## Rules for Building Medical Words

There are three basic rules for building medical words. Each part of the word tells you something about the meaning. In fact you can build a word that has a very specific meaning:

1. If the SUFFIX starts with a vowel, then it attaches directly to the WORD ROOT.
   - Example: gastritis = gastritis, inflammation of the stomach
2. If the SUFFIX starts with a consonant, then a COMBINING FORM is used.
   - Example: colon + o + scopy = colonoscopy, visually inspecting the colon

3. If two WORD ROOTS are connected together, then a COMBINING FORM is used

# Steps for Building Medical words

1. Choose the SUFFIX, or end of the word
2. Choose the WORD ROOT
3. Determine if a COMBINING FORM is needed
4. Choose  the PREFIX

As you can see, building or working out the meaning of a medical word starts at the end of the word. The SUFFIX will tell you what is happening in relation to the rest of the word. For example, in the word gastritis, -itis is the suffix, and -itis always means inflammation

-itis  = inflammation

So you know that whatever else is happening, there is inflammation going on. Next you want to look at the middle of the word. Is there a vowel (a,e,i,o,u,y)) connecting the WORD ROOT to the SUFFIX?, or is it a consonant (b,c,d,f,g,h,j,k,l,m,n,p,q,r,s,t,v,w,x,z)? In this case ,   the SUFFIX -itis starts with a vowel, so no combining form is needed.

Gastr = stomach

so "gastritis" means "inflammation of the stomach"

Gastr + itis = Gastritis

1. Then write what the word means in the explanation section

## FREE Medical Dictionaries online

WebMD Medical Dictionary. This one is from a reliable provider, WebMD, you can also enter the word in the search box to find more detailed information. No audio, but it does spell out the word phonetically to help with pronunciation

Medicinenet Med Terms. Similar to Web MEDs but the search box is right there for you. Lots of info on diseases and conditions. This one does not provide audio or how to pronounce the words though.

The Free Dictionary. The Frees dictionary has audio clips for many words (not all) that can help with pronouncing medical words. Links to other sources of information on the word are also provided, including to Wikipedia

## Practice

Suffixes associated with surgical procedures.  Look up the meaning of the following.

append/**ectomy** ______________________________________________________

arthr/o/**centesis** ______________________________________________________

lith/o/**tripsy** ______________________________________________________

rhin/o/**plasty** ______________________________________________________

arthr/o/**desis** ______________________________________________________

thromb/o/**lysis** ______________________________________________________

mast/o/**pexy** ______________________________________________________

trache/o/**stomy** ______________________________________________________

trache/o/**tomy** ______________________________________________________

Notice how the suffix in each word tells you about  the type of procedure, for example -tomy is making an incision, while -stomy is the actual hole that results from the incision. Also notice that most of the words (except appendectomy) have "o" in the middle as a combining form because the sufficx starts with a consonant. A -tome is a thing that makes the -tomy, or incision, so it must be a surgical cutting tool of some kind, like an oste/o/tome...in this case "osteo: and "tome" are both word roots, connected with a combining form, the "o".

Prefixes tell you how many, how big (or small), relative location (above, below, next to) or when.

**hyper**/tension ______________________________________________________

**hemi**/plegia ______________________________________________________

**epi**/derm/al ______________________________________________________

**post**/nat/al ______________________________________________________

**inter**/cost/al ______________________________________________________

**poly**/cyst/itis ______________________________________________________

Finally, word roots tell you what the suffix and the prefix are acting on, what the word is about. Again, notice how two word roots can be combined using a combining form, even if one or both of the word roots start with a vowel.

**cerebr**/al ______________________________

**gastr**/o/**intestin**-al ______________________________

**cyto**/logist ______________________________

pre/**ren**/al ______________________________

par/**enter**/al ______________________________

**oophor**/ectomy ______________________________

Go to Laulima to find more exercises. Completing activities online earns points for the course.

NOTES:

*Ha`awina 03: HLTH 140*

# Ala `Anakomia (Anatomical Direction)

## Hō`ulu`ulu Pōkole (Overview)

This lesson introduces terminology for direction, location, and relative position of anatomical structures. Describing the location, size, and direction of body systems and components (parts) in relation to each other is critical for health care practitioners and scientists. Every profession and vocation in health sciences uses words that precisely locate and describe human anatomy and function.

## Ke Haumana ka `apo (Student Learning Outcomes)

1. Describe the anatomical position of the body.
2. Locate the body cavities and abdominopelvic regions of the body.
3. Describe terms related to position, direction, and planes of the body and their applications
4. Recognize, define, pronounce, and spell terms correctly.

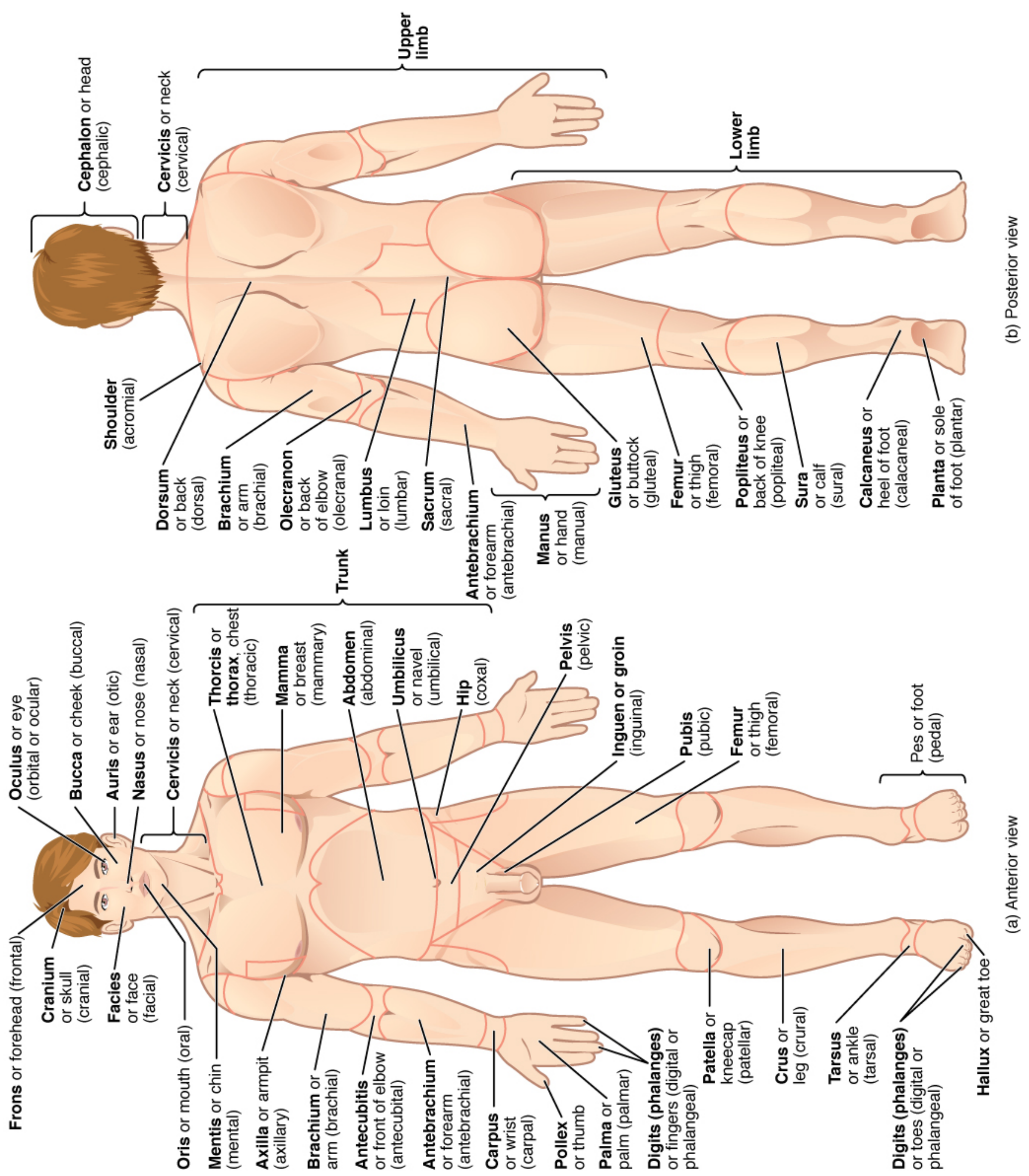
## Kūlana `Anakomia (Anatomical Position)

Describing direction in the body is an important part of using medical terms. The human body can be like a map, with  directions to find every part. But to do this we need to fist position the body in a standard way. This is called the Anatomical Position (in Hawaiian, Kūlana `Anakomia)

- the body standing upright
- the feet at shoulder width and parallel
- toes forward.
- The upper limbs are held out to each side, and
- the palms of the hands face forward

Using this standard position reduces confusion. It does not matter how the body being described is oriented, the terms are used as if it is in anatomical position. For example, a scar in the "anterior (front) carpal (wrist) region" would be present on the palm side of the wrist. The term "anterior" would be used even if the hand were palm down on a table.

## Regions of the Human Body and Anatomical Position




The human body is shown in anatomical position in an (a) anterior view and a (b) posterior view. The regions of the body are labeled in boldface.

A body that is lying down is described as either prone or supine. Prone describes a face-down orientation, and supine describes a face up orientation. These terms are sometimes used in describing the position of the body during specific physical examinations or surgical procedures.

## Regional Terms

The human body's numerous regions have specific terms to help increase precision. Notice that the term "brachium" or "arm" is reserved for the "upper arm" and "antebrachium" or "forearm" is used rather than "lower arm." Similarly, "femur" or "thigh" is correct, and "leg" or "crus" is reserved for the portion of the lower limb between the knee and the ankle. You will be able to describe the body's regions using the terms from the figure.

## Directional Terms

Directional anatomical terms are essential for describing the relative locations of different body structures. For instance, an anatomist might describe one band of tissue as "inferior to" another or a physician might describe a tumor as "superficial to" a deeper body structure. Commit these terms to memory to avoid confusion when you are studying or describing the locations of particular body parts.

- ❏ Anterior (or ventral) Describes the front or direction toward the front of the body. The toes are anterior to the foot.
- ❏ Posterior (or dorsal) Describes the back or direction toward the back of the body. The popliteus is posterior to the patella.
- ❏ Superior (or cranial) describes a position above or higher than another part of the body proper. The orbits are superior to the oris.
- ❏ Inferior (or caudal) describes a position below or lower than another part of the body proper; near or toward the tail (in humans, the coccyx, or lowest part of the spinal column). The pelvis is inferior to the abdomen.
- ❏ Lateral describes the side or direction toward the side of the body. The thumb (pollex) is lateral to the digits.
- ❏ Medial describes the middle or direction toward the middle of the body. The hallux is the medial toe.
- ❏ Proximal describes a position in a limb that is nearer to the point of attachment or the trunk of the body. The brachium is proximal to the antebrachium.
- ❏ Distal describes a position in a limb that is farther from the point of attachment or the trunk of the body. The crus is distal to the femur.
- ❏ Superficial describes a position closer to the surface of the body. The skin is superficial to the

bones.

- ❏ Deep describes a position farther from the surface of the body. The brain is deep to the skull.

Now write in your own words what each of the following terms mean: When you have the correct answer check off the box for the term above. Good work!

Anterior ___________________________________________________________________

Posterior or Dorsal _____________________________________________________________

Superior ___________________________________________________________________

Inferior ____________________________________________________________________

Lateral ____________________________________________________________________

Medial_____________________________________________________________________

Here are some Hawaiian terms for the same anatomical directions as we reviewed above, can you match it with the English term?

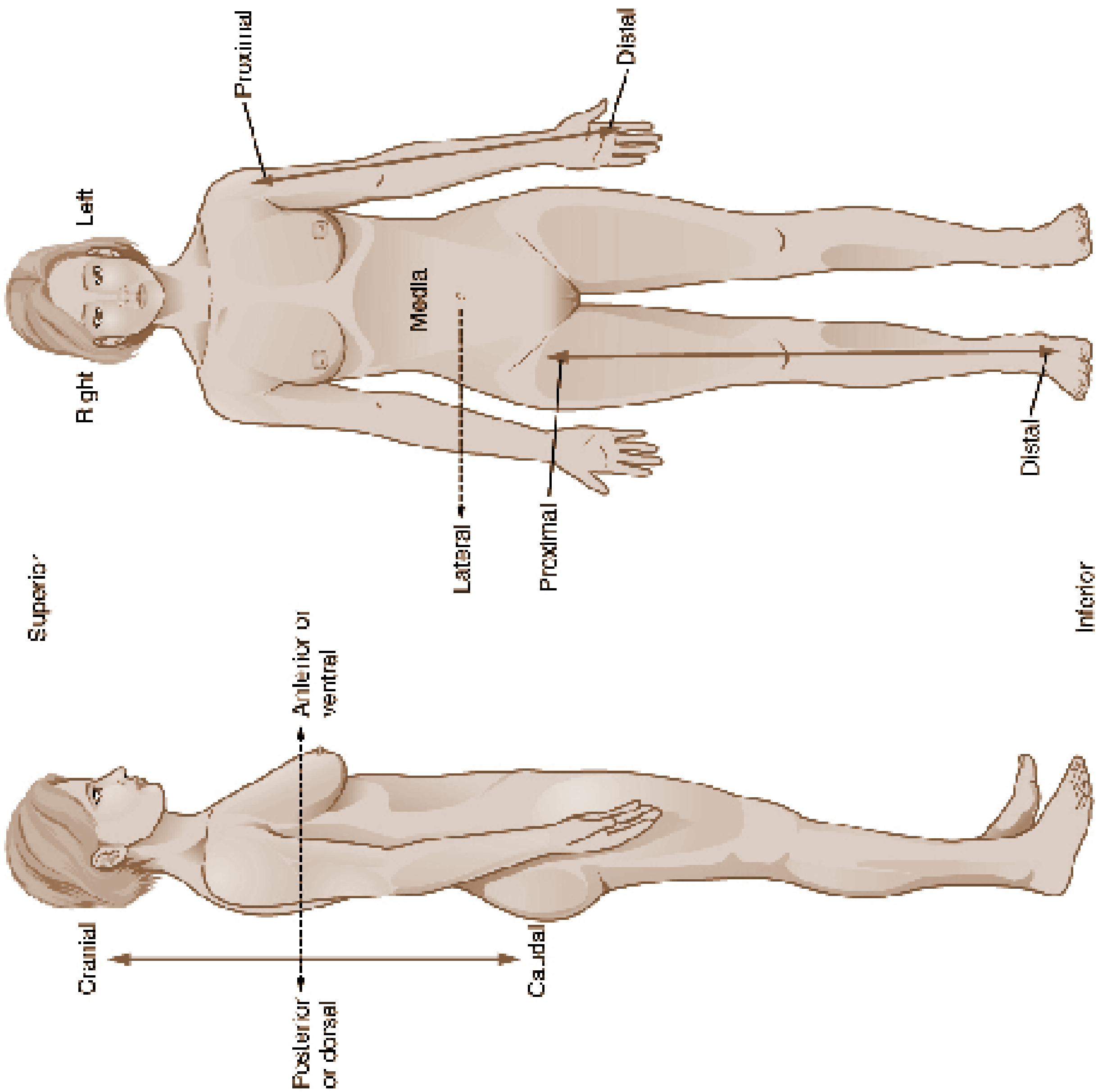
Mua_________________________________________________________________

Kua__________________________________________________________________

Luna ________________________________________________________________

Lalo__________________________________________________________________

**Directional Terms Applied to the Human Body**

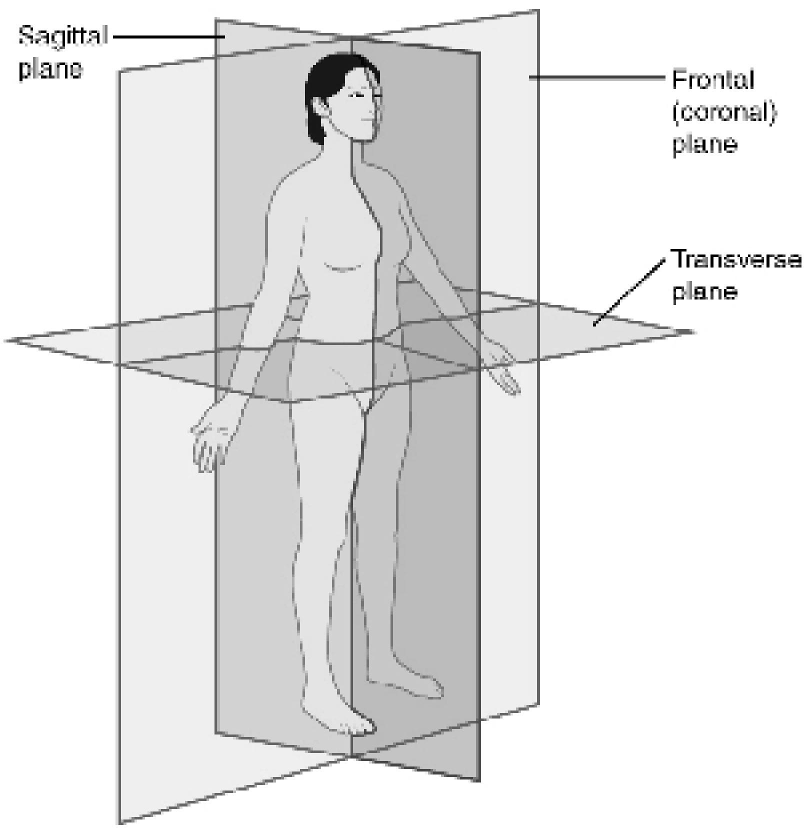



Paired directional terms are shown as applied to the human body.

## Body Planes

A section is a two-dimensional surface of a three-dimensional structure that has been cut. Modern medical imaging devices enable clinicians to obtain "virtual sections" of living bodies. We call these scans. Body sections and scans can be correctly interpreted, however, only if the viewer understands the plane along which the section was made. A plane is an imaginary two-dimensional surface that passes through the body. There are three planes commonly referred to in anatomy and medicine, as illustrated in [Figure](#).

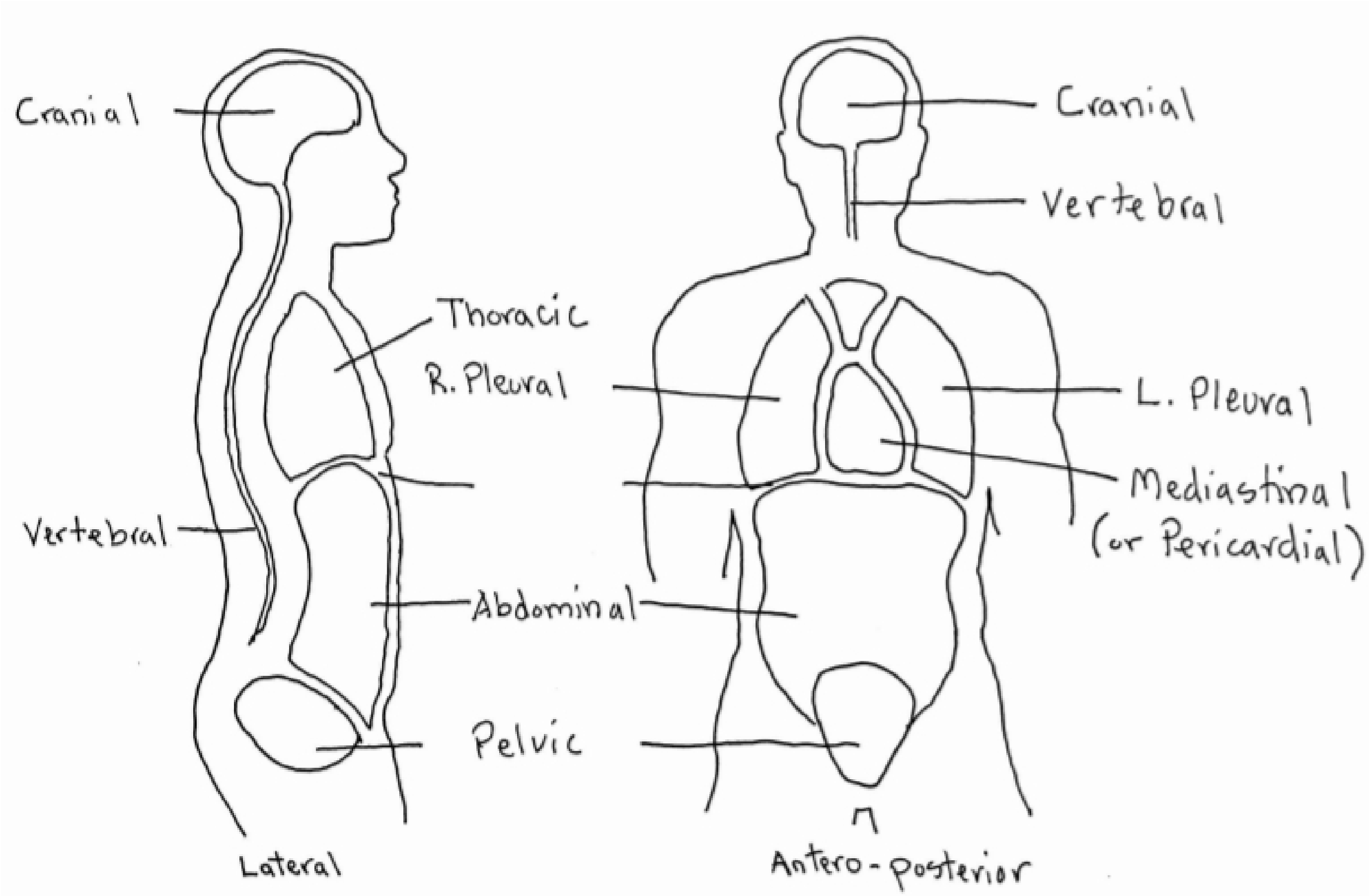
### Planes of the Body




- ❑ Sagittal plane: the plane that divides the body or an organ vertically into right and left sides.
- ❑ Frontal plane: the plane that divides the body or an organ into an anterior (front) portion and a posterior (rear) portion. The frontal plane is often referred to as a coronal plane ("Corona" is Latin for "crown.")
- ❑ **Transverse plane**: the plane that divides the body or organ horizontally into upper and lower portions. Transverse planes produce images referred to as cross sections

## Body Cavities and Serous Membranes

The body maintains its internal organization by means of membranes, sheaths, and other structures that separate compartments. The dorsal (posterior) cavity and the ventral (anterior) cavity are the largest body compartments. These cavities contain and protect delicate internal organs, and the ventral cavity allows

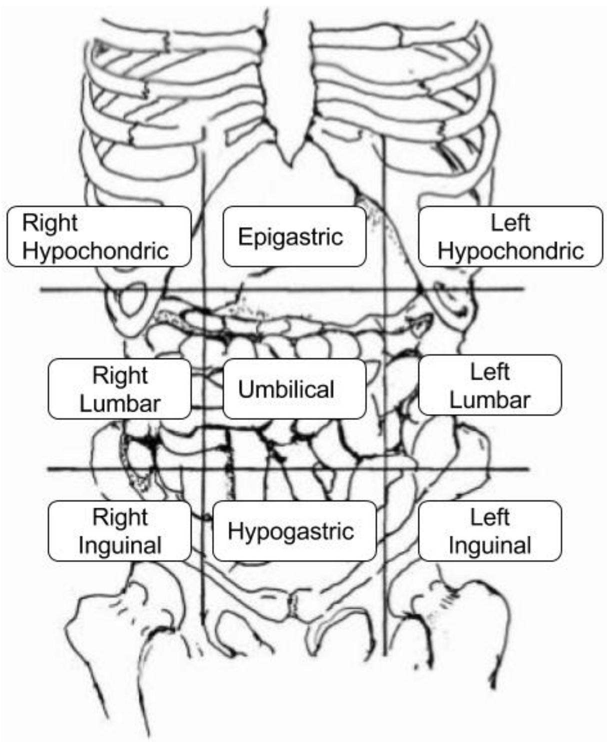


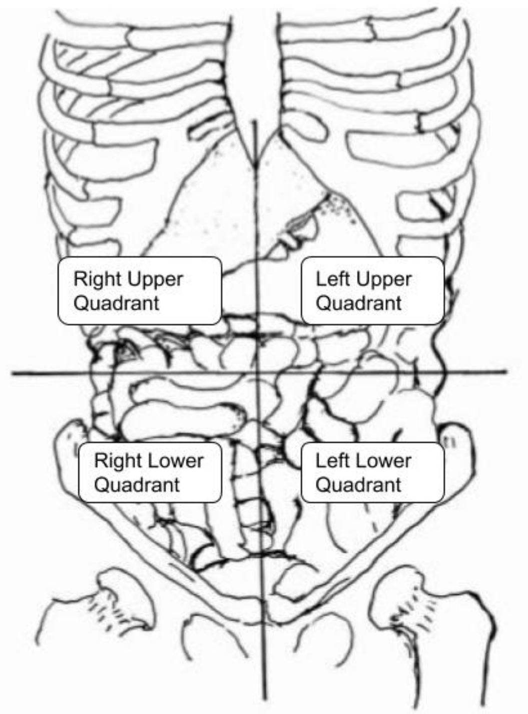

for significant changes in the size and shape of the organs

- The posterior (dorsal) and anterior (ventral) cavities are each subdivided into smaller cavities. In the posterior (dorsal) cavity, the cranial cavity houses the brain, and the spinal cavity (or vertebral cavity) encloses the spinal cord.
- The anterior (ventral) cavity has two main subdivisions: the thoracic cavity and the abdominopelvic cavity.
    - The thoracic cavity contains the lungs and the heart, which is located in the mediastinum.
    - The diaphragm forms the floor of the thoracic cavity and separates it from the more abdominopelvic cavity.
    - The abdominopelvic cavity is the largest cavity in the body.

# Abdominal Regions and Quadrants

**Regions and Quadrants of the Peritoneal Cavity**




The more detailed regional approach subdivides the cavity with one horizontal line immediately inferior to the ribs and one immediately superior to the pelvis, and two vertical lines drawn as if dropped from the midpoint of each clavicle (collarbone). There are nine resulting regions. The simpler quadrants approach, which is more commonly used in medicine, subdivides the cavity with one horizontal and one vertical line that intersect at the patient's umbilicus (navel).

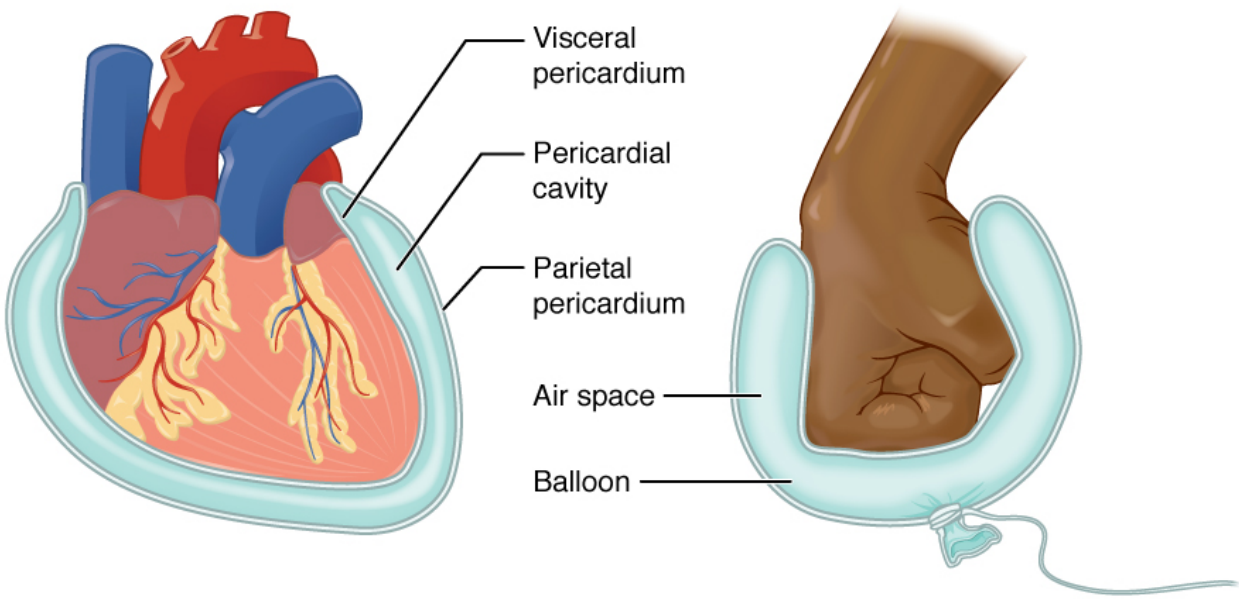
## Membranes of the Anterior (Ventral) Body Cavity

A **serous membrane** lines the body cavities and the organs in the thoracic, abdominal, and pelvic cavities. There are 2 layers:

- ❑ Parietal layer:  lines the walls of the body cavity (pariet- refers to a cavity wall).
- ❑ Visceral layer: covers the organs (the viscera).

Between the parietal and visceral layers is a very thin, fluid-filled serous space. The thin layer of fluid acts a a lubricant so organs can move without rubbing.

**Serous Membrane**



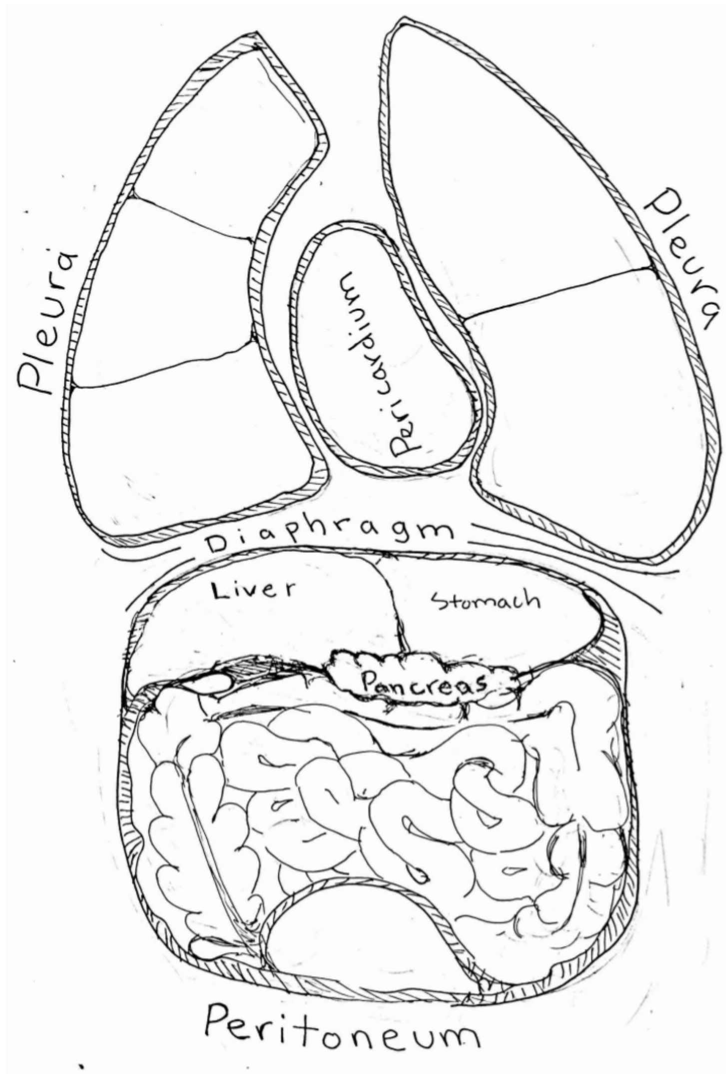

Serous membrane lines the pericardial cavity and reflects back to cover the heart—much the same way that an underinflated balloon would form two layers surrounding a fist.

There are three serous cavities.

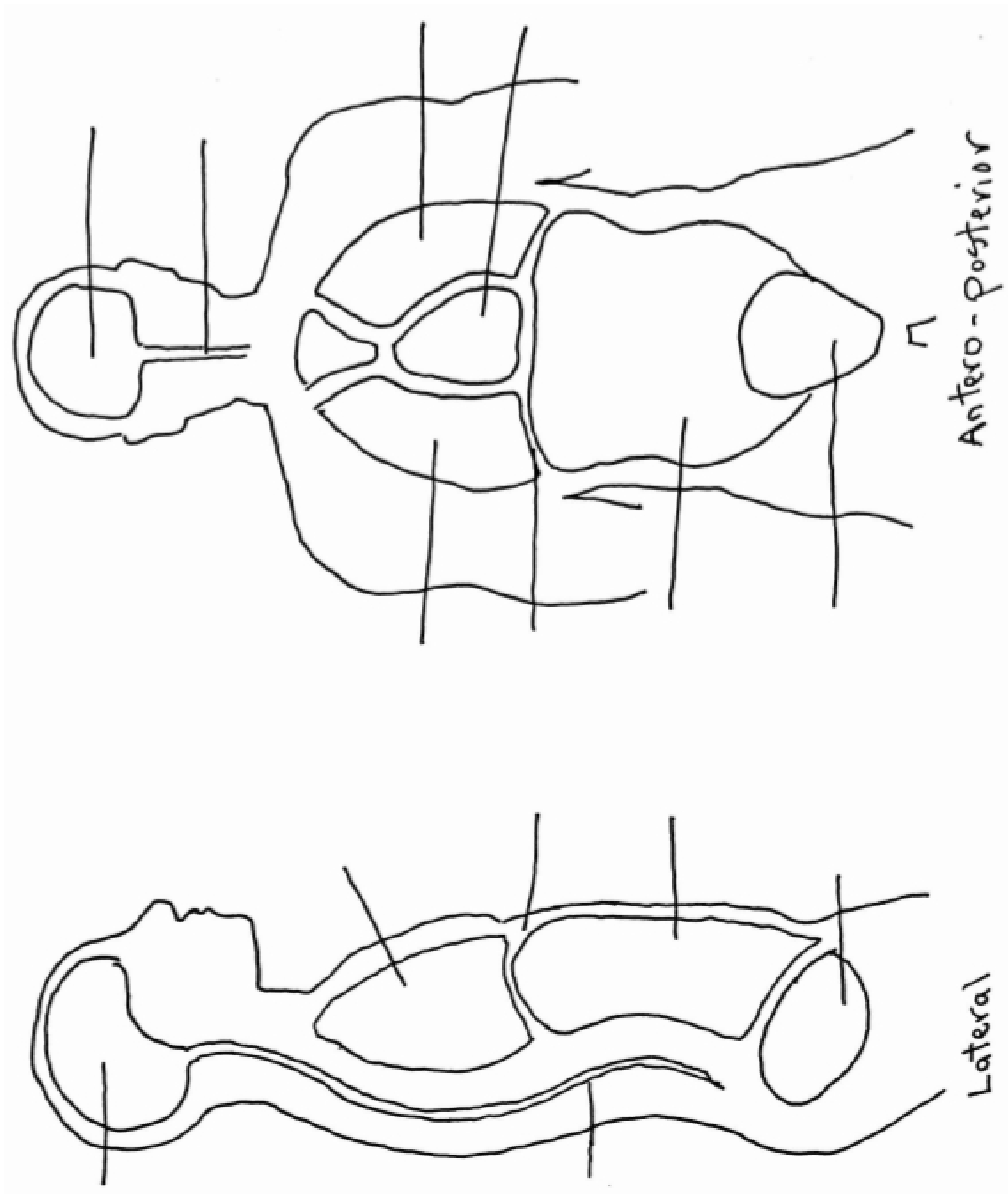
- ❑ **The pleura** is the serous membrane that surrounds the lungs in the pleural cavity

- ❑ **The pericardium** is the serous membrane that surrounds the heart in the pericardial cavity

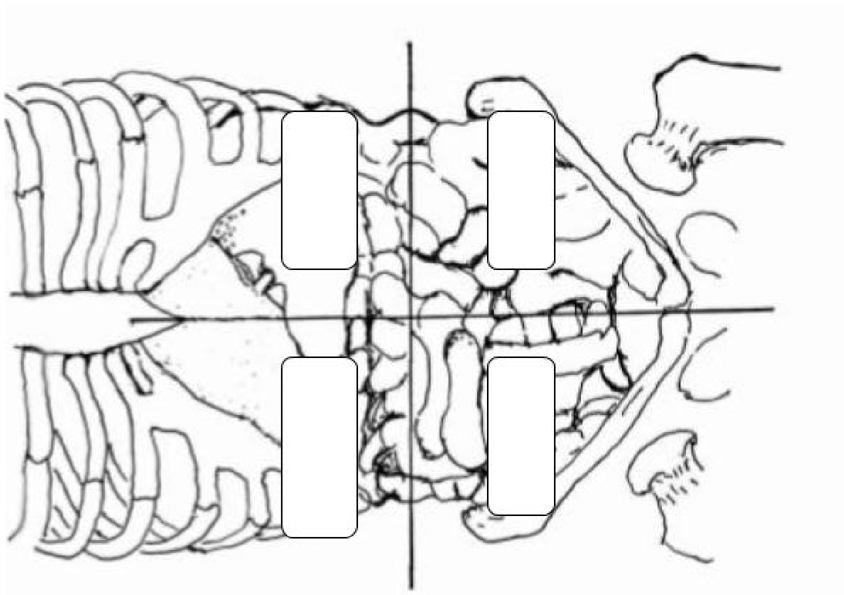
- ❑ **The peritoneum** is the serous membrane that surrounds several organs in the abdominopelvic cavity.

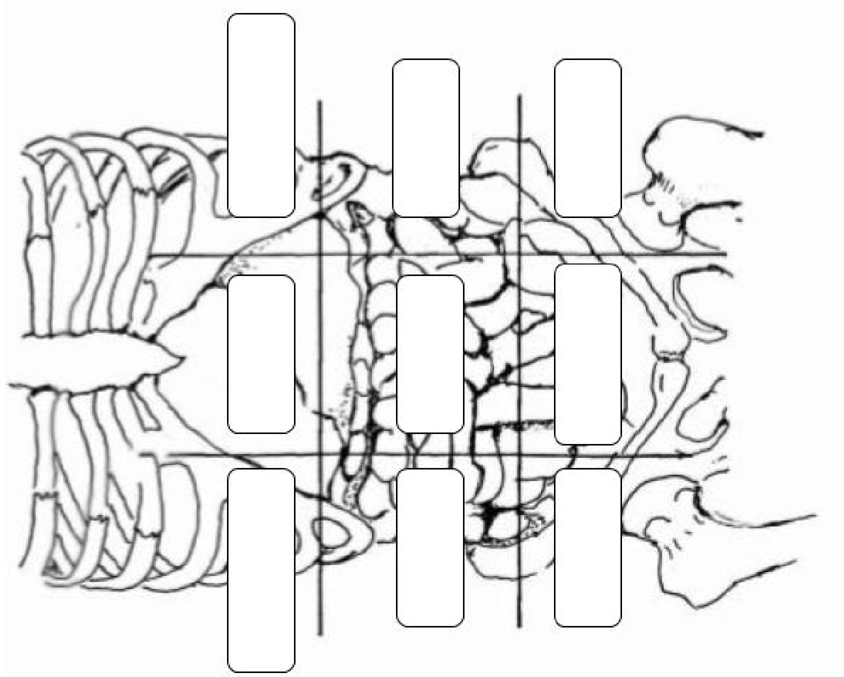



Label the body cavities! Then color them in different colors




Label the Abdominal regions. Remember Left and Right is from the patient's point of view.





## Critical Thinking Questions

In which direction would an MRI scanner move to produce sequential images of the body in the frontal plane, and in which direction would an MRI scanner move to produce sequential images of the body in the sagittal plane?

A patient comes into the emergency depart with a gunshot injury. If the bullet were to enter the body from the left side and penetrate both lungs, which three anterior thoracic body cavities would it pass through?

The patient above is going to X-ray! If the patient needed to have an anterior-posterior (AP) roentgenogram (x-ray picture), how would you position the x-ray machine?

## Glossary

**abdominopelvic cavity:** division of the anterior (ventral) cavity that houses the abdominal and pelvic viscera

**anatomical position:** standard reference position used for describing locations and directions on the human body

**anterior:** describes the front or direction toward the front of the body; also referred to as ventral **anterior cavity:** larger body cavity located anterior to the posterior (dorsal) body cavity; includes the serous membrane-lined pleural cavities for the lungs, pericardial cavity for the heart, and peritoneal cavity for the abdominal and pelvic organs; also referred to as ventral cavity

**caudal:** describes a position below or lower than another part of the body proper; near or toward the tail (in humans, the coccyx, or lowest part of the spinal column); also referred to as inferior

**cranial:** describes a position above or higher than another part of the body proper; also referred to as superior

**cranial cavity:** division of the posterior (dorsal) cavity that houses the brain

**deep:** describes a position farther from the surface of the body

**distal:** describes a position farther from the point of attachment or the trunk of the body

**dorsal:** describes the back or direction toward the back of the body; also referred to as posterior

**dorsal cavity:** posterior body cavity that houses the brain and spinal cord; also referred to the posterior body cavity

**frontal plane:** two-dimensional, vertical plane that divides the body or organ into anterior and posterior portions

**inferior:** describes a position below or lower than another part of the body proper; near or toward the tail (in humans, the coccyx, or lowest part of the spinal column); also referred to as caudal

**lateral:** describes the side or direction toward the side of the body

**medial:** describes the middle or direction toward the middle of the body

**pericardium:** sac that encloses the heart

**peritoneum:** serous membrane that lines the abdominopelvic cavity and covers the organs found there

**plane:** imaginary two-dimensional surface that passes through the body

**pleura:** serous membrane that lines the pleural cavity and covers the lungs

**posterior:** describes the back or direction toward the back of the body; also referred to as dorsal

**posterior cavity:** posterior body cavity that houses the brain and spinal cord; also referred to as dorsal cavity

**prone:** face down

**proximal:** describes a position nearer to the point of attachment or the trunk of the body

**sagittal plane:** two-dimensional, vertical plane that divides the body or organ into right and left sides

**section:** in anatomy, a single flat surface of a three-dimensional structure that has been cut through

**serous membrane:** membrane that covers organs and reduces friction; also referred to as serosa

**serosa:** membrane that covers organs and reduces friction; also referred to as serous membrane

**spinal cavity:** division of the dorsal cavity that houses the spinal cord; also referred to as vertebral cavity

**superficial:** describes a position nearer to the surface of the body

**superior:** describes a position above or higher than another part of the body proper; also referred to as cranial

**supine:** face up

**thoracic cavity:** division of the anterior (ventral) cavity that houses the heart, lungs, esophagus, and trachea

**transverse plane:** two-dimensional, horizontal plane that divides the body or organ into superior and inferior portions

**ventral**: describes the front or direction toward the front of the body; also referred to as anterior

**ventral cavity:** larger body cavity located anterior to the posterior (dorsal) body cavity; includes the serous membrane-lined pleural cavities for the lungs, pericardial cavity for the heart, and peritoneal cavity for the abdominal and pelvic organs; also referred to as anterior body cavity

# Tissue Structures

# Hōʻuluʻulu Pōkole (Overview)

This ha`awina introduces the tissues of the human body. A tissue is a collection of the same type of cell. Combinations of tissues working together create organs, organs and organ systems.

## Ke Haumana ka ʻapo (Student Learning Outcomes)

1. Identify the main types of tissue structures
2. Describe the primary functions of different types of tissues.
3. Apply terminology related to diseases, conditions, and procedures involving tissue structures
4. Apply word-building skills by constructing various medical terms related to tissue structures
5. Describe common abbreviations and symbols related to tissues
6. Recognize, define, pronounce, and spell terms correctly

Although there are many types of cells in the human body, they are organized into four broad categories of tissues: epithelial, connective, muscle, and nervous. Each of these categories is characterized by specific functions that contribute to the overall health and maintenance of the body.

- A disruption of the structure is a sign of injury or disease. Such changes can be detected through histology, the microscopic study of tissue appearance, organization, and function.

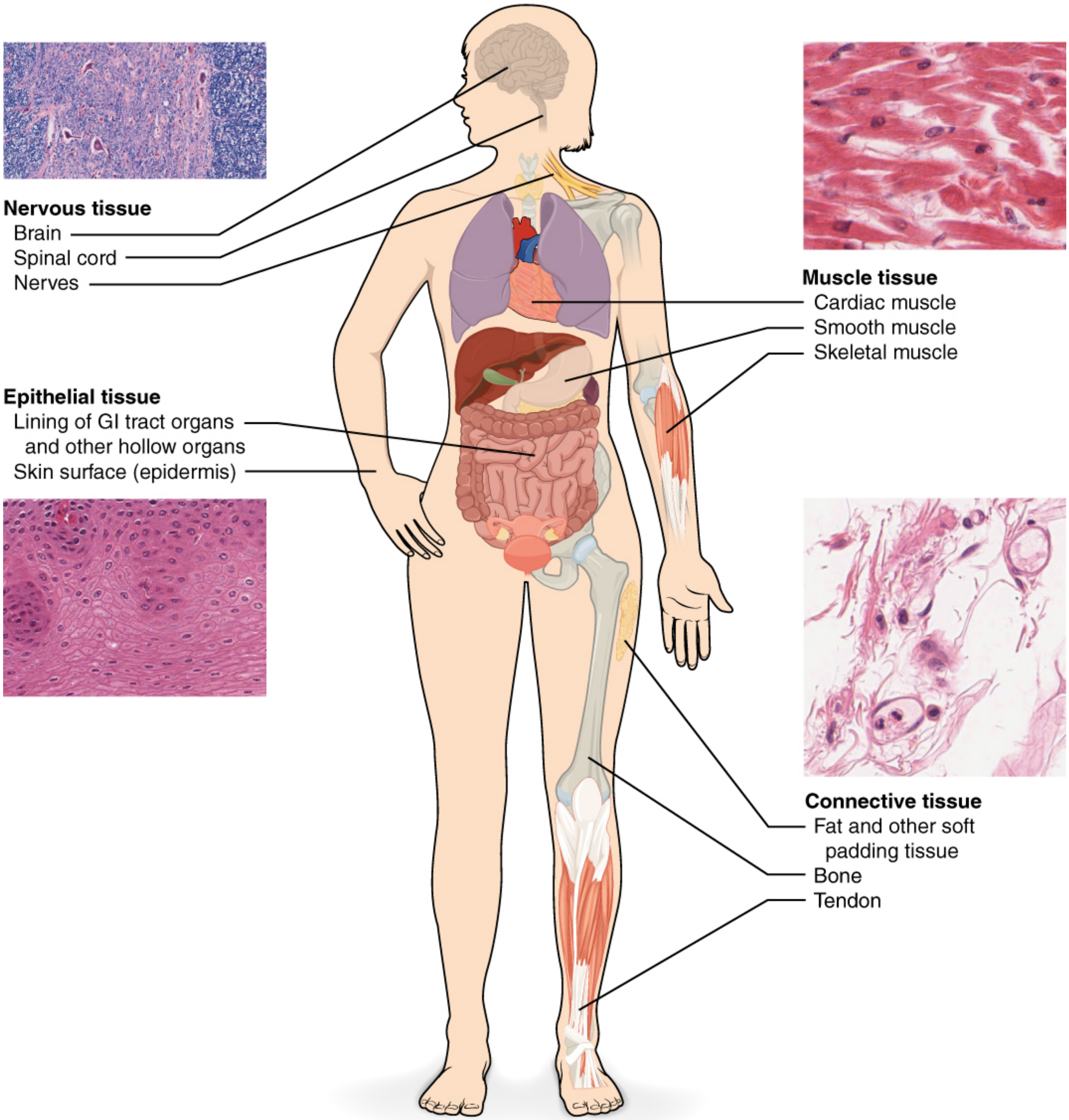
- A tissue membrane is a thin layer or sheet of cells that covers the outside of the body (for example, skin), the organs (for example, pericardium), internal passageways that lead to the exterior of the body (for example, abdominal mesenteries), and the lining of the moveable joint cavities. There are two basic types of tissue membranes: connective tissue and epithelial membranes.

## The Four Types of Tissues

- **Epithelial tissue**, also referred to as epithelium, refers to the sheets of cells that cover exterior surfaces of the body, lines internal cavities and passageways, and forms certain glands.
- **Connective tissue**, as its name implies, binds the cells and organs of the body together and functions in the protection, support, and integration of all parts of the body.

- **Muscle tissue** is excitable, responding to stimulation and contracting to provide movement, and occurs as three major types: skeletal (voluntary) muscle, smooth muscle, and cardiac muscle in the heart.
- **Nervous tissue** is also excitable, allowing the propagation of electrochemical signals in the form of nerve impulses that communicate between different regions of the body.

- The next level of organization is the organ, where several types of tissues come together to form a working unit. Just as knowing the structure and function of cells helps you in your study of tissues, knowledge of tissues will help you understand how organs function. The epithelial and connective tissues are discussed in detail in this chapter. Muscle and nervous tissues will be discussed only briefly in this chapter.

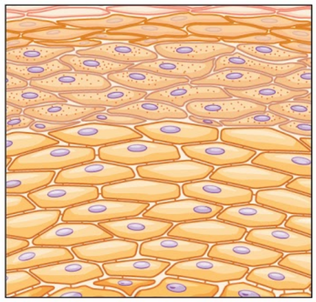
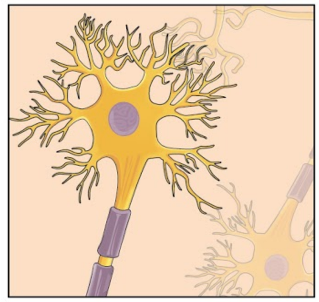
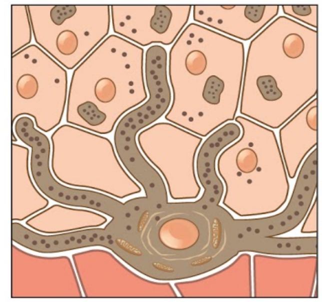
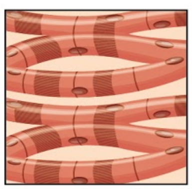
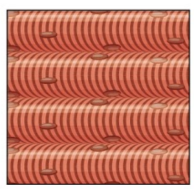
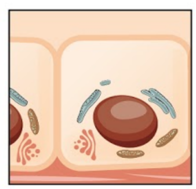
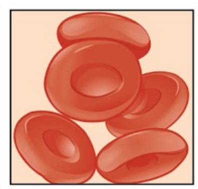
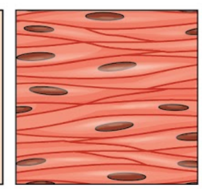
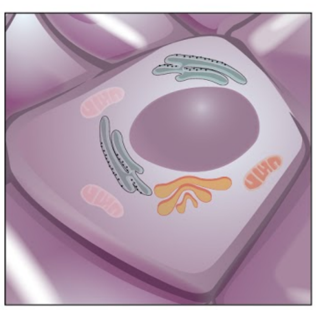
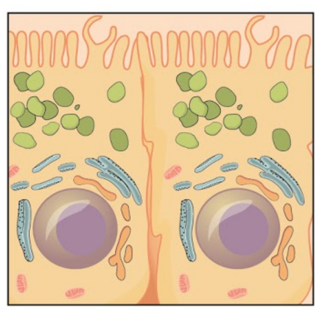
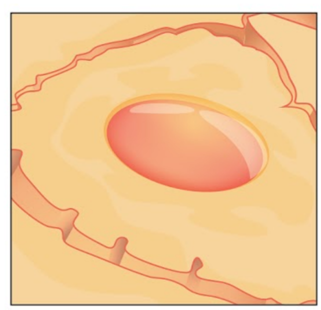



The four types of tissues are exemplified in nervous tissue, stratified squamous epithelial tissue, cardiac muscle tissue, and connective tissue in small intestine. Clockwise from nervous tissue, (Micrographs provided by the Regents of University of Michigan Medical School © 2012)

## The Origin of Tissues

The zygote, or fertilized egg, is a single cell formed by the fusion of an egg and sperm. After fertilization the zygote gives rise to rapid mitotic cycles, generating many cells to form the embryo. The first

embryonic cells generated have the ability to **differentiate** into any type of cell in the body and are called **totipotent** cells, a type of stem cell, because they can branch into any other type. Three major cell lineages are established within the embryo. the **ectoderm**, the **mesoderm**, and the **endoderm.**
Each of these lineages of embryonic cells forms the distinct germ layers from which all the tissues and organs of the human body eventually form.

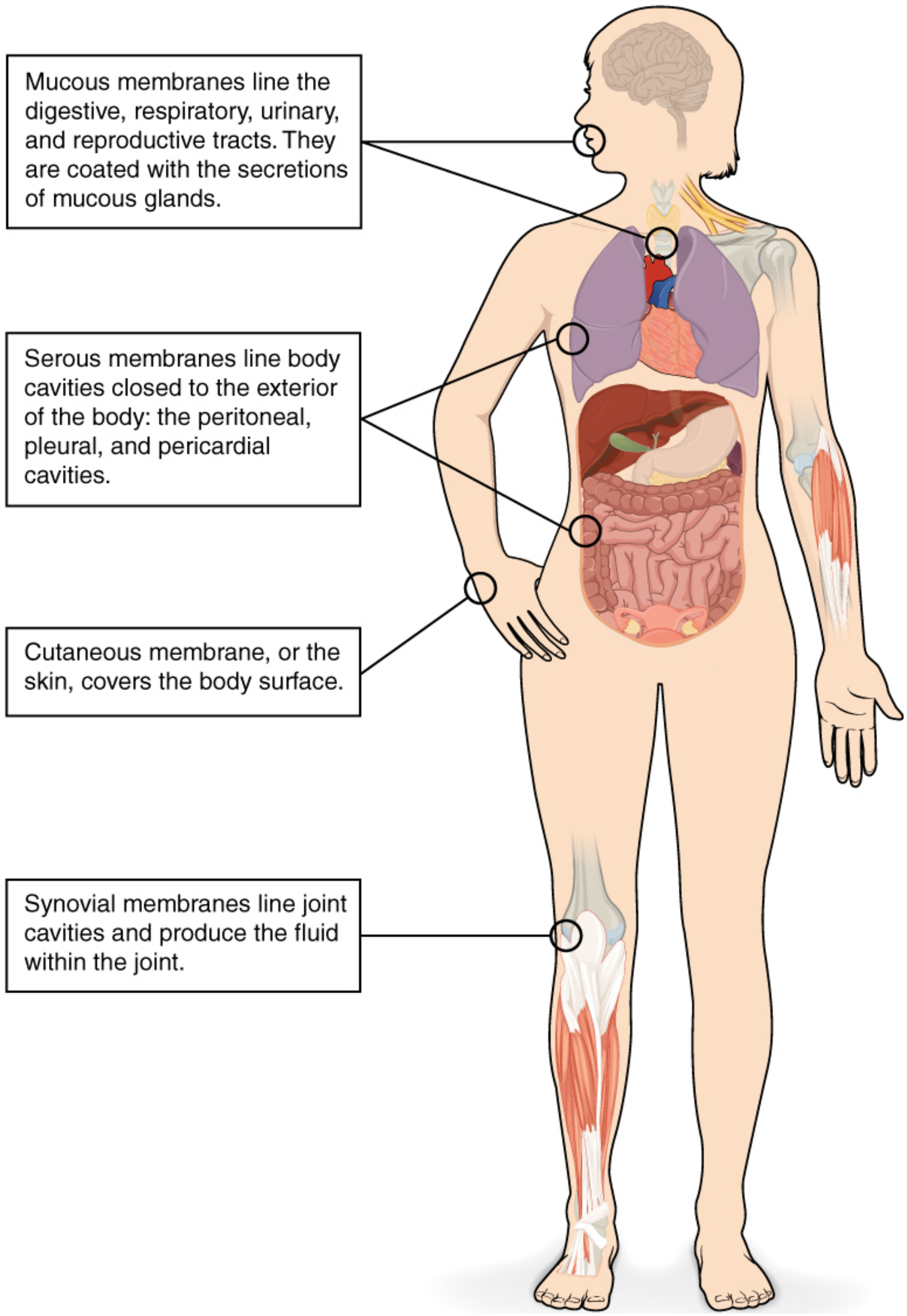
| Germ Layer | Gives rise to: |
|---|---|
| Ectoderm | Epidermis, glands on skin, some cranial bones, pituitary and adrenal medulla, the nervous system, the mouth between cheek and gums, the anus<br> Skin cells<br> Neurons<br> Pigment cell |
| Mesoderm | Connective tissues proper, bone, cartilage, blood, endothelium of blood vessels, muscle, synovial membranes, serous membranes lining body cavities, kidneys, lining of gonads<br> Cardiac muscle<br> Skeletal muscle<br> Tubule cell of kidney<br> Red blood cells<br> Smooth muscle |
| Endoderm | Lining of airways and digestive system except the mouth and distal part of digestive system (rectum and anal canal); glands (digestive glands, endocrine glands, adrenal cortex)<br> Lung cell<br> Thyroid cell<br> Pancreatic cell |

# Tissue Membranes

The two broad categories of tissue membranes in the body are (1) connective tissue membranes, which include synovial membranes, and (2) epithelial membranes, which include mucous membranes, serous membranes, and the cutaneous membrane, in other words, the skin.

## Connective Tissue Membranes

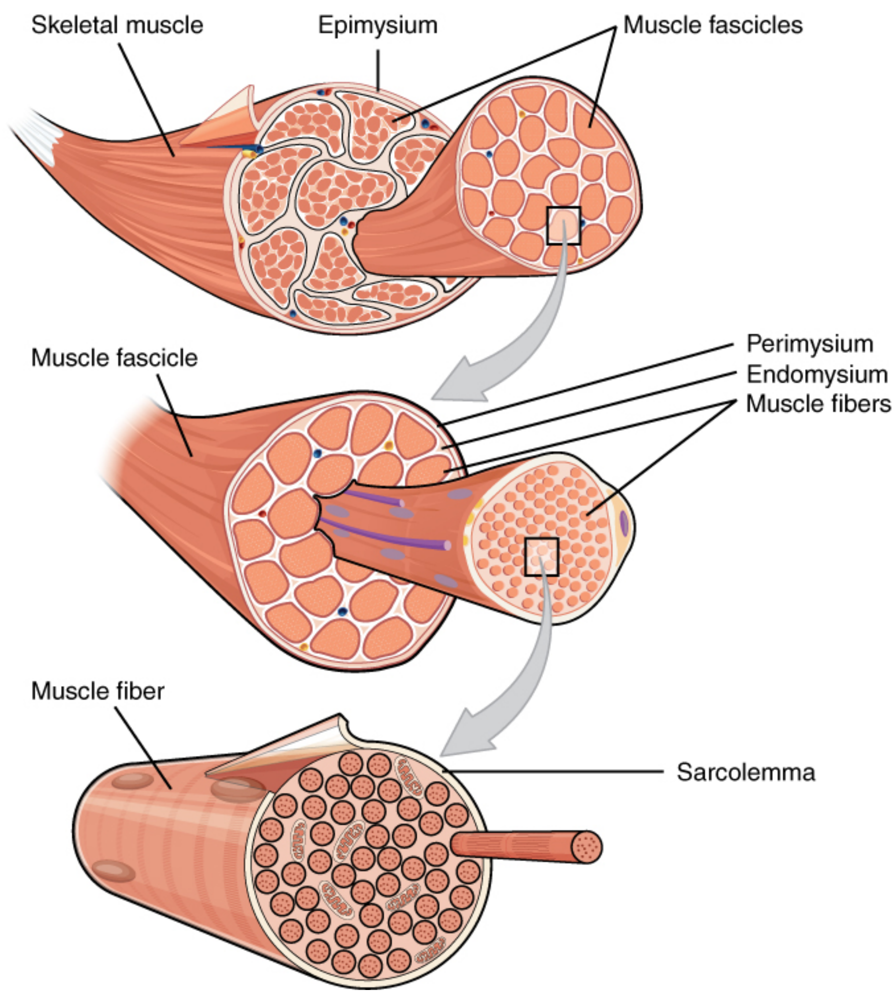
The connective tissue membrane is formed solely from connective tissue. These membranes encapsulate organs, such as the kidneys, and line our movable joints. A synovial membrane is a type of connective tissue membrane that lines the cavity of a freely movable joint. For example, synovial membranes surround the joints of the shoulder, elbow, and knee. Fibroblasts in the inner layer of the synovial membrane release hyaluronan into the joint cavity. The hyaluronan effectively traps available water to form the synovial fluid, a natural lubricant that enables the bones of a joint to move freely against one another without much friction. This synovial fluid readily exchanges water and nutrients with blood, as do all body fluids.



**Epithelial Membranes**

The epithelial membrane is composed of epithelium attached to a layer of connective tissue, for example, your skin. The mucous membrane is also a composite of connective and epithelial tissues. Sometimes called mucosae, these epithelial membranes line the body cavities and hollow passageways that open to the external environment, and include the digestive, respiratory, excretory, and reproductive tracts. Mucous, produced by the epithelial exocrine glands, covers the epithelial layer. The underlying connective tissue, called the lamina propria (literally "own layer"), help support the fragile epithelial layer.

## Muscle Tissue

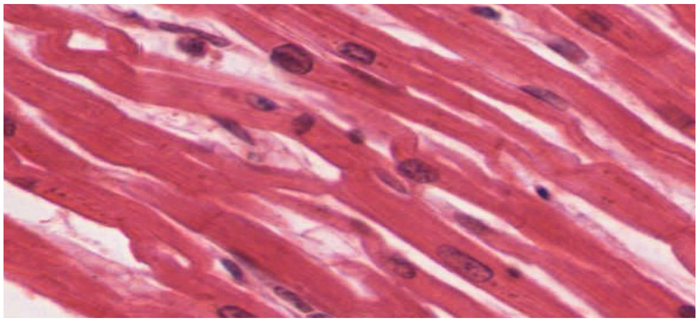



**Skeletal Muscle Tissue**

Inside each skeletal muscle, muscle fibers are organized into individual bundles, each called a **fascicle**, by a middle layer of connective tissue called the **perimysium**. This fascicular organization is common in muscles of the limbs; it allows the nervous system to trigger a specific movement of a muscle by activating a subset of muscle fibers within a bundle, or **fascicle** of the muscle. Inside each fascicle, each muscle fiber is encased in a thin connective tissue layer of collagen and reticular fibers called the **endomysium**. The endomysium contains the extracellular fluid and nutrients to support the muscle fiber. These nutrients are supplied via blood to the muscle tissue.

**Cardiac Muscle Tissue**

Cardiac muscle tissue is only found in the heart. Similar to skeletal muscle, cardiac muscle is striated and organized into sarcomeres, possessing the same banding organization as skeletal muscle and is activated by action potentials in much the same way, with a some important differences.

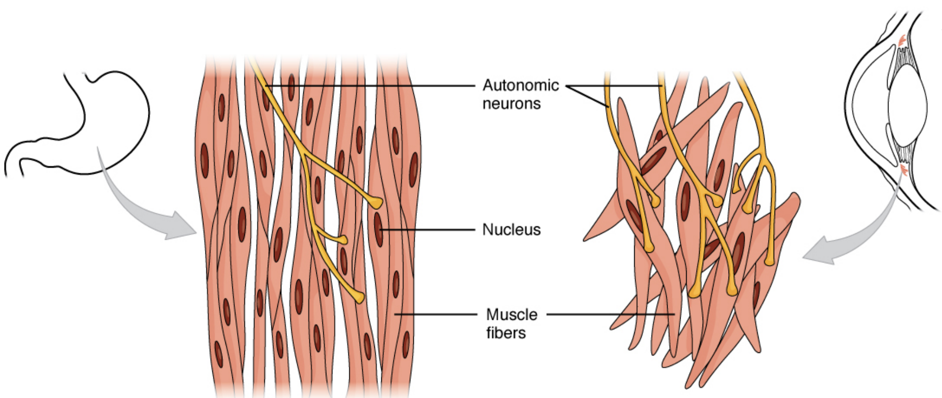


- ❑ Cardiac muscle fibers are shorter than skeletal muscle fibers and usually contain only one nucleus, which is located in the central region of the cell.
- ❑ Cardiac muscle fibers cells also are extensively branched and are connected to one another at their ends by intercalated discs.
- ❑ An intercalated disc allows the cardiac muscle cells to contract in a wave-like pattern so that the heart can work as a pump.
- ❑ And finally, cardiac muscle possesses autorhythmicity, allowing it to contract without an external signal.

(Micrograph provided by the Regents of University of Michigan Medical School © 2012)

**Smooth Muscle Tissue**

Smooth muscle (so-named because the cells do not have striations) is present in the walls of hollow organs like the urinary bladder, uterus, stomach, intestines, and in the walls of passageways, such as the arteries and veins of the circulatory system, and the tracts of the respiratory, urinary, and reproductive systems. Smooth muscle is also present in the eyes, where it functions to change the size of the iris and alter the shape of the lens; and in the skin where it causes hair to stand erect in response to cold temperature or fear.

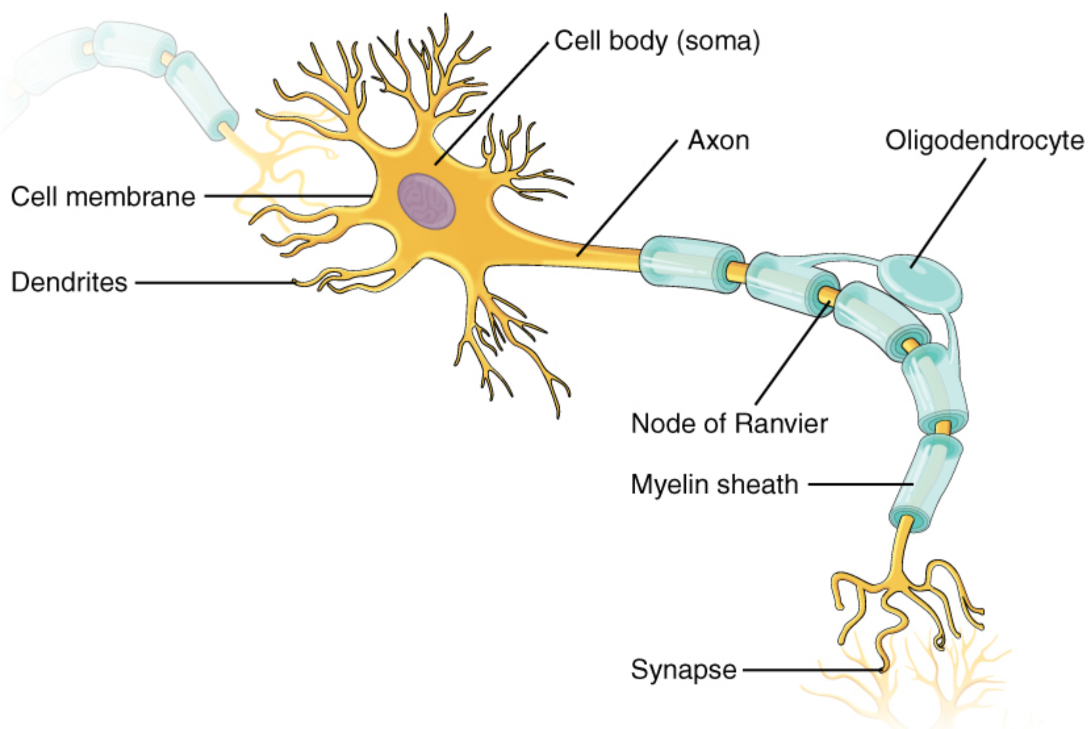


# Nervous Tissue

### Neurons

Neurons are the cells considered to be the basis of nervous tissue. They are responsible for the electrical signals that communicate information about sensations, and that produce movements in response to those stimuli, along with inducing thought processes within the brain. An important part of the function of neurons is in their structure, or shape. The three-dimensional shape of these cells makes the immense numbers of connections within the nervous system possible.

**Parts of a Neuron**: The main part of a neuron is the cell body, which is also known as the soma (soma = "body"). The cell body contains the nucleus and most of the major organelles. But what makes neurons special is that they have many extensions of their cell membranes, which are generally referred to as processes. Neurons are usually described as having one, and only one, axon—a fiber that emerges from the cell body and projects to target cells. That single axon can branch repeatedly to communicate with many target cells. It is the axon that propagates the nerve impulse, which is communicated to one or more cells. The other processes of the neuron are dendrites, which receive information from other neurons at specialized areas of contact called synapses. The dendrites are usually highly branched processes,




providing locations for other neurons to communicate with the cell body. Information flows through a neuron from the dendrites, across the cell body, and down the axon. This gives the neuron a polarity—meaning that information flows in this one direction. Figure shows the relationship of these parts to one another.

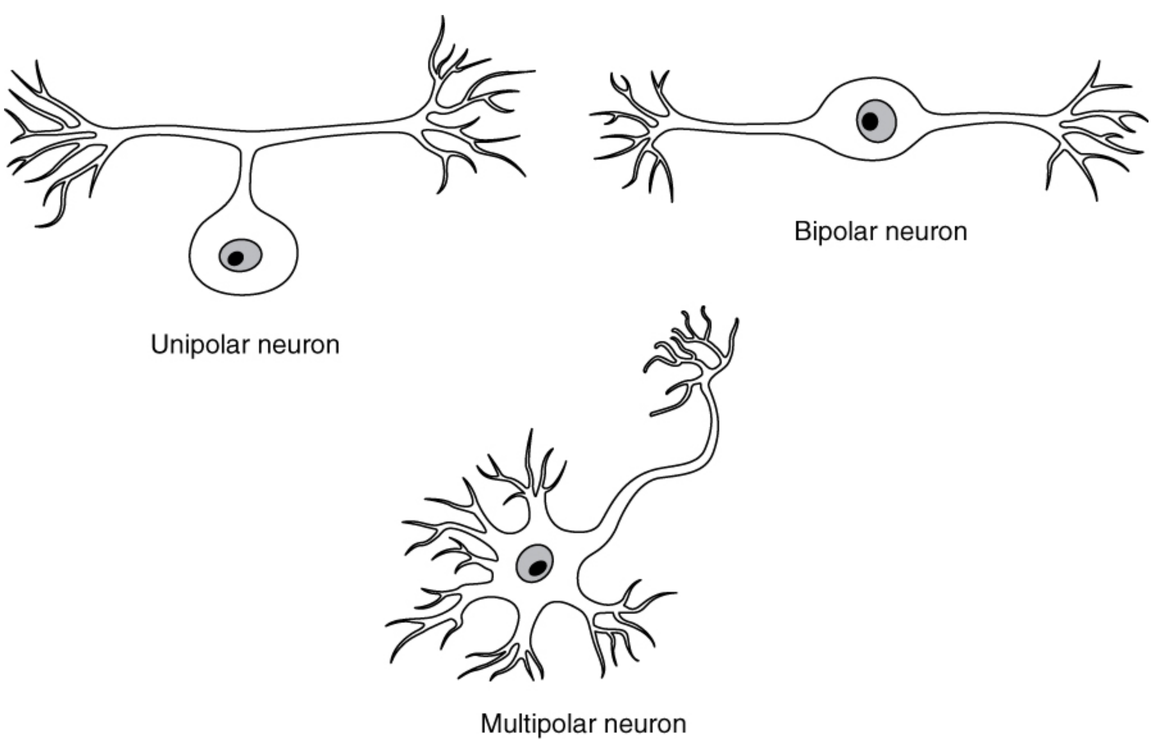
Where the axon emerges from the cell body, there is a special region referred to as the axon hillock. This is a tapering of the cell body toward the axon fiber. Within the axon hillock, the cytoplasm changes to a solution of limited components called axoplasm. Because the axon hillock represents the beginning of the axon, it is also referred to as the initial segment.

Many axons are wrapped by an insulating substance called myelin, which is actually made from glial cells. Myelin acts as insulation much like the plastic or rubber that is used to insulate electrical wires. A key difference between myelin and the insulation on a wire is that there are gaps in the myelin covering of an axon. Each gap is called a node of Ranvier and is important to the way that electrical signals travel down the axon. The length of the axon between each gap, which is wrapped in myelin, is referred to as an axon segment. At the end of the axon is the axon terminal, where there are usually several branches extending toward the target cell, each of which ends in an enlargement called a synaptic end bulb. These bulbs are what make the connection with the target cell at the synapse.

**Types of Neurons**

There are many neurons in the nervous system—a number in the trillions. And there are many different types of neurons. They can be classified by many different criteria

**Neuron Classification by Shape**



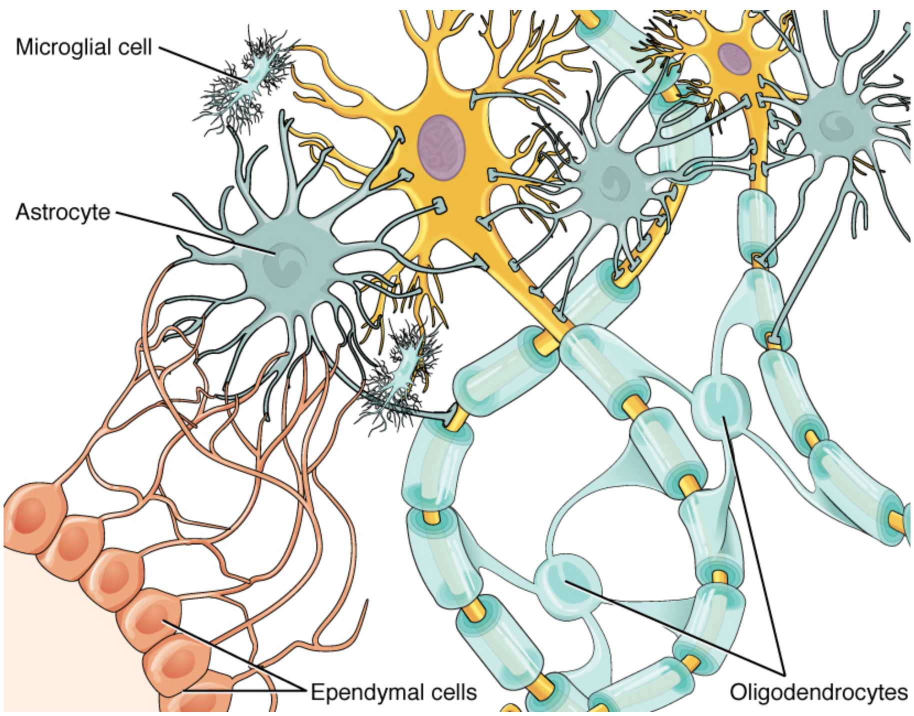

- ❑ Unipolar cells have one process that includes both the axon and dendrite. Bipolar cells have two processes, the axon and a dendrite. Multipolar cells have more than two processes, the axon and two or more dendrites. True unipolar cells are only found in invertebrate animals, so the unipolar cells in humans are more appropriately called “pseudo-unipolar” cells.

- ❑ Bipolar cells have two processes, which extend from each end of the cell body, opposite to each other. One is the axon and one the dendrite. Bipolar cells are not very common. They are found mainly in the olfactory epithelium (where smell stimuli are sensed), and as part of the retina.
- ❑ Multipolar neurons are all of the neurons that are not unipolar or bipolar. They have one axon and two or more dendrites (usually many more). With the exception of the unipolar sensory ganglion cells, and the two specific bipolar cells mentioned above, all other neurons are multipolar.

**Glial Cells:** Glial cells, or neuroglia or simply glia, are the other type of cell found in nervous tissue. They are considered to be supporting cells, and many functions are directed at helping neurons complete their function for communication. The name glia comes from the Greek word that means "glue," and was coined by the German pathologist Rudolph Virchow, who wrote in 1856: "This connective substance, which is in the brain, the spinal cord, and the special sense nerves, is a kind of glue (neuroglia) in which the nervous elements are planted." Today, research into nervous tissue has shown that there are many deeper roles that these cells play. And research may find much more about them in the future.

There are six types of glial cells. Four of them are found in the CNS and two are found in the PNS. Table outlines some common characteristics and functions.

**Glial Cells of the CNS:** One cell providing support to neurons of the CNS is the astrocyte, so named because it appears to be star-shaped under the microscope (astro- = "star"). Astrocytes have many processes extending from their main cell body (not axons or dendrites like neurons, just cell extensions). Those processes extend to interact with neurons, blood vessels, or the connective tissue covering the CNS that is called the pia mater (Figure). Generally, they are supporting cells for the neurons in the central nervous system.



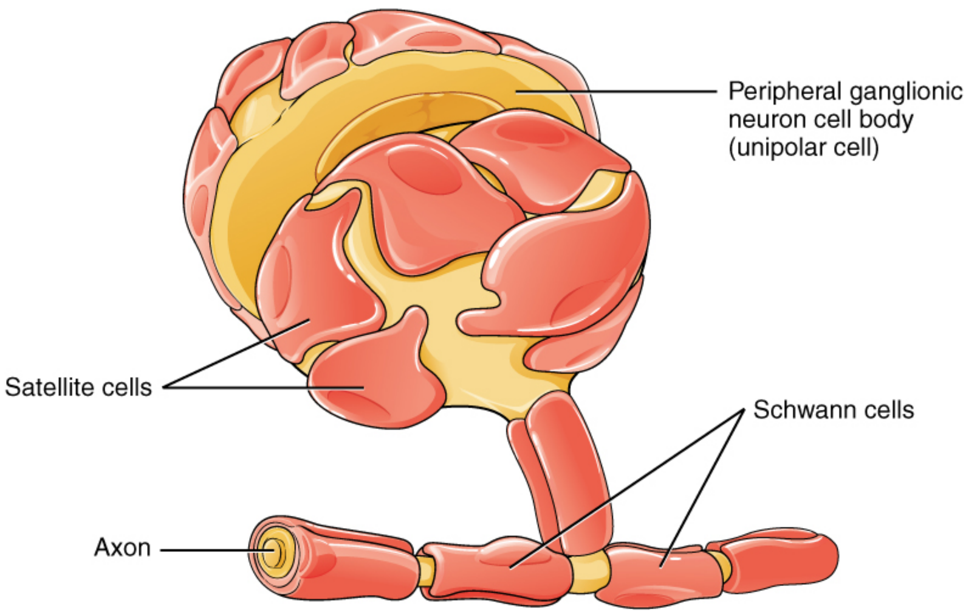

The CNS has astrocytes, oligodendrocytes, microglia, and ependymal cells that support the neurons of the CNS in several ways.

**Glial Cells of the PNS**: One of the two types of glial cells found in the PNS is the satellite cell. Satellite cells are found in sensory and autonomic ganglia, where they surround the cell bodies of neurons.

This accounts for the name, based on their appearance under the microscope. They provide support, performing similar functions in the periphery as astrocytes do in the CNS—except, of course, for establishing the BBB.

The second type of glial cell is the Schwann cell, which insulate axons with myelin in the periphery. Schwann cells are different than oligodendrocytes, in that a Schwann cell wraps around a portion of only one axon segment and no others. Oligodendrocytes have processes that reach out to multiple axon segments, whereas the entire Schwann cell surrounds just one axon segment. The nucleus and cytoplasm of the Schwann cell are on the edge of the myelin sheath. The relationship of these two types of glial cells to ganglia and nerves in the PNS is seen in [Figure](#).

**Glial Cells of the PNS**




The PNS has satellite cells and Schwann cells.

**Myelin:** The insulation for axons in the nervous system is provided by glial cells, oligodendrocytes in the CNS, and Schwann cells in the PNS. Whereas the manner in which either cell is associated with the axon segment, or segments, that it insulates is different, the means of myelinating an axon segment is mostly the same in the two situations. Myelin is a lipid-rich sheath that surrounds the axon and by doing so creates a myelin sheath that facilitates the transmission of electrical signals along the axon. The lipids are essentially the phospholipids of the glial cell membrane. Myelin, however, is more than just the membrane of the glial cell. It also includes important proteins that are integral to that membrane. Some of the proteins help to hold the layers of the glial cell membrane closely together.

# Glossary

**astrocyte**: glial cell type of the CNS that provides support for neurons and maintains the blood-brain barrier

**autorhythmicity**: heart's ability to control its own contractions

**axon hillock**: tapering of the neuron cell body that gives rise to the axon

**axon segment**: single stretch of the axon insulated by myelin and bounded by nodes of Ranvier at either end (except for the first, which is after the initial segment, and the last, which is followed by the axon terminal)

**axon terminal**: end of the axon, where there are usually several branches extending toward the target cell

**axoplasm**: cytoplasm of an axon, which is different in composition than the cytoplasm of the neuronal cell body

**bipolar**: shape of a neuron with two processes extending from the neuron cell body—the axon and one dendrite

**blood-brain barrier (BBB)**: physiological barrier between the circulatory system and the central nervous system that establishes a privileged blood supply, restricting the flow of substances into the CNS

**cerebrospinal fluid (CSF)**: circulatory medium within the CNS that is produced by ependymal cells in the choroid plexus filtering the blood

**choroid plexus**: specialized structure containing ependymal cells that line blood capillaries and filter blood to produce CSF in the four ventricles of the brain

**connective tissue**: type of tissue that serves to hold in place, connect, and integrate the body's organs and systems

**connective tissue membrane**: connective tissue that encapsulates organs and lines movable joints

**cutaneous membrane**: skin; epithelial tissue made up of a stratified squamous epithelial cells that cover the outside of the body

**desmosome**: cell structure that anchors the ends of cardiac muscle fibers to allow contraction to occur

**ectoderm**: outermost embryonic germ layer from which the epidermis and the nervous tissue derive

**endoderm**: innermost embryonic germ layer from which most of the digestive system and lower respiratory system derive

**ependymal cell**: glial cell type in the CNS responsible for producing cerebrospinal fluid

**epithelial membrane**: epithelium attached to a layer of connective tissue

**epithelial tissue**: type of tissue that serves primarily as a covering or lining of body parts, protecting the body; it also functions in absorption, transport, and secretion

**histology**: microscopic study of tissue architecture, organization, and function

**intercalated disc**: part of the sarcolemma that connects cardiac tissue, and contains gap junctions and desmosomes

**initial segment**: first part of the axon as it emerges from the axon hillock, where the electrical signals known as action potentials are generated

**lamina propria**: areolar connective tissue underlying a mucous membrane

**mesoderm**: middle embryonic germ layer from which connective tissue, muscle tissue, and some epithelial tissue derive

**microglia**: glial cell type in the CNS that serves as the resident component of the immune system

**mucous membran**e: tissue membrane that is covered by protective mucous and lines tissue exposed to the outside environment

**multipolar**: shape of a neuron that has multiple processes—the axon and two or more dendrites

**muscle tissu**e: type of tissue that is capable of contracting and generating tension in response to stimulation; produces movement.

**myelin sheath**: lipid-rich layer of insulation that surrounds an axon, formed by oligodendrocytes in the CNS and Schwann cells in the PNS; facilitates the transmission of electrical signals

**nervous tissue**: type of tissue that is capable of sending and receiving impulses through electrochemical signals.

**node of Ranvier**: gap between two myelinated regions of an axon, allowing for strengthening of the electrical signal as it propagates down the axon

**oligodendrocyte**: glial cell type in the CNS that provides the myelin insulation for axons in tracts

**satellite cell**: glial cell type in the PNS that provides support for neurons in the ganglia

**Schwann cell**: glial cell type in the PNS that provides the myelin insulation for axons in nerves

**serous membrane**: type of tissue membrane that lines body cavities and lubricates them with serous fluid

**synapse**: narrow junction across which a chemical signal passes from neuron to the next, initiating a new electrical signal in the target cell

**synaptic end bulb**: swelling at the end of an axon where neurotransmitter molecules are released onto a target cell across a synapse

**synovial membrane**: connective tissue membrane that lines the cavities of freely movable joints, producing synovial fluid for lubrication

**tissue**: group of cells that are similar in form and perform related functions

**tissue membrane**: thin layer or sheet of cells that covers the outside of the body, organs, and internal cavities

**totipotent**: embryonic stem cells that have the ability to differentiate into any type of cell and organ in the body

**unipolar**: shape of a neuron which has only one process that includes both the axon and dendrite

**ventricle**: central cavity within the brain where CSF is produced and circulates

# *Ha`awina 06: HLTH 140*

# (Integumentary System)

## Hō`ulu`ulu Pōkole (Overview)

This lesson is about the integumentary system which includes the skin on the outside of the body as well as the lining of the digestive system and protective lining of organs. We focus on the skin, which protects the outside of the body and is continuous (connected to) the internal epithelium lining the digestive tract, mouth, nose, eye sockets, etc.

## Ke Haumana ka `apo (Student Learning Outcomes)

1. Describe the type of medical treatment the dermatologist provides.
2. Identify integumentary system structures
3. Describe the primary functions of the integumentary system.
4. Apply terminology related to diseases, conditions, and procedures involving the integumentary system.
5. Apply word-building skills by constructing various medical terms related to the integumentary system.
6. Describe common abbreviations and symbols related to the integumentary system.
7. Recognize, define, pronounce, and spell terms correctly.

## The Skin

The skin is an epithelial membrane also called the cutaneous membrane. It is a stratified squamous epithelial membrane resting on top of connective tissue. The apical surface of this membrane is exposed to the external environment and is covered with dead, keratinized cells that help protect the body from desiccation and pathogens.

- ❑ The skin is the largest organ of the body
- ❑ The main functions of the skin are:
  - ❑ Protection from infection
  - ❑ Protection from dehydration
  - ❑ Protection from radiation (ultraviolet and infrared, for example)
  - ❑ Maintain correct body temperature

So you can see that the skin is mainly for protection and to help regulate our internal temperature.

## Protection from infection

The skin forms a continuous membrane between the inside of our body and the outside world. The most important way the skin protects from infection is by being intact, without breaks from abrasion, cuts, or other **lesions**. To protect the body from infection the skin maintains a slightly acidic **pH**. pH is a measure of acidity. For bacteria and fungi this is a hostile environment. For example, Normal pH for human blood is between 7.35 and 7.45 while skin pH is generally between 5.4 and 5.9, but varies between individuals.

The skin is also highly protected by the immune system, which maintains large reservoirs of anti-infective agents that can be activated by responding to signals of damage by cells. This starts the process of **inflammation**, one of the body's primary defenses against infection. But inflammation is also active in several autoimmune diseases, which is when the body's immune system attacks the tissues of the body itself. We will talk about this phenomenon in relation to several organ systems, and focus on it in the lesson on the immune system.

Khan Academy video of auto immune response

## Protection from dehydration

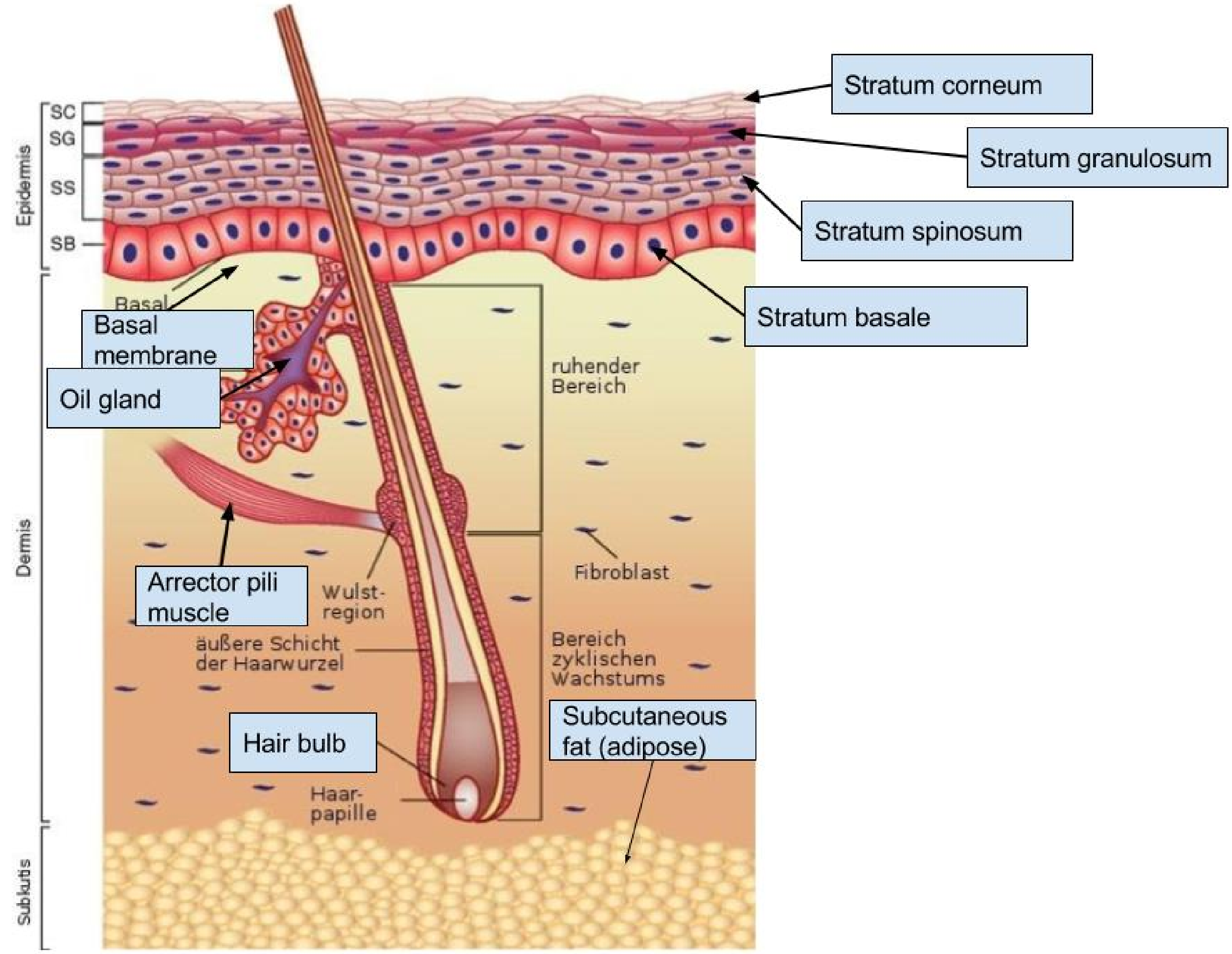
Because it is on the outside of the body, the skin drys out continuously. To prevent drying, the skin has oil producing glands called **sebaceous glands**

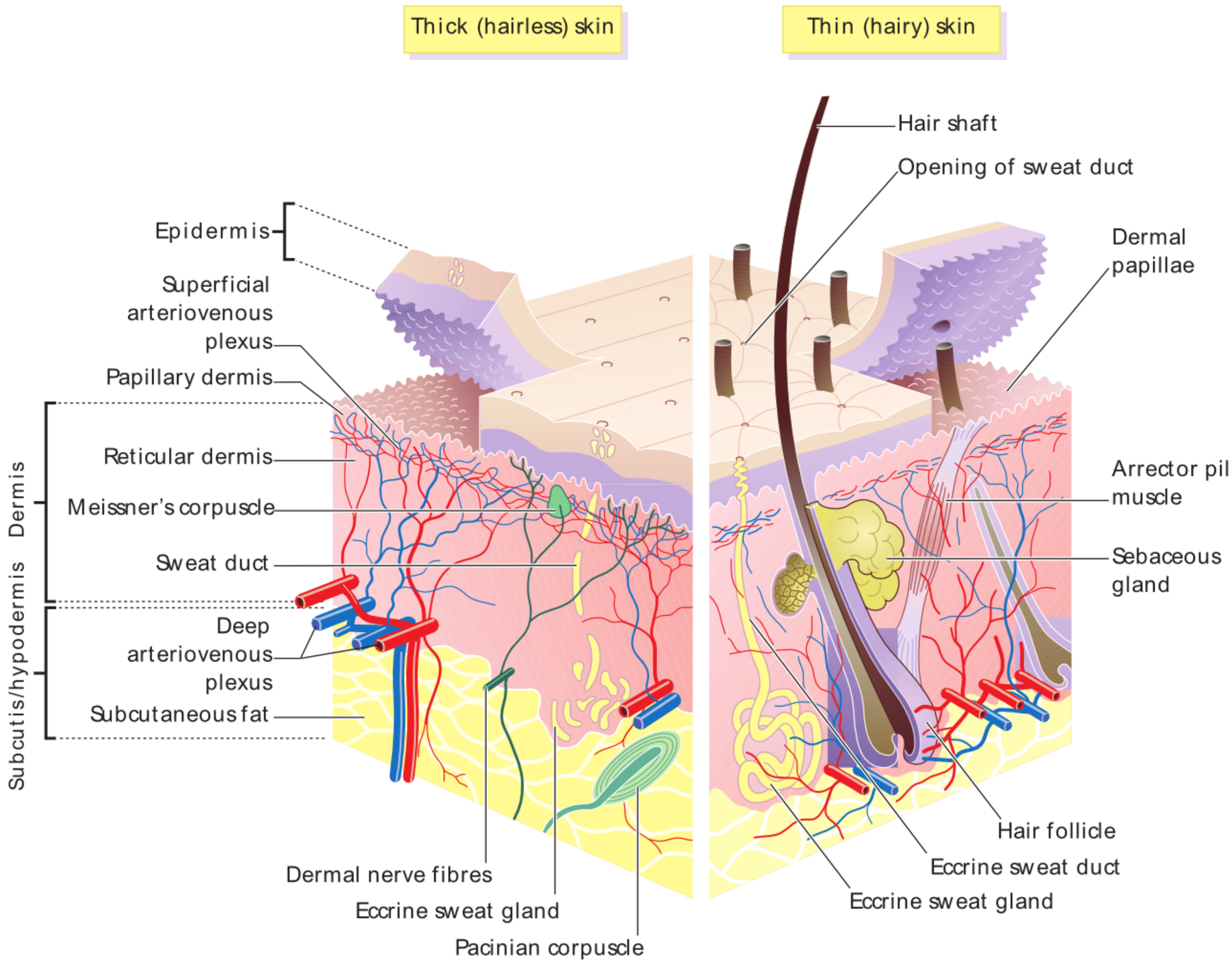
Skin cells of the epidermis originate in the basal membrane (the stratum basale), and migrate upward as they mature, becoming flatter and drier, keratinizing as new skin cells are created and push up from beneath. The top layer of skin forms a protective semi-waterproof barrier, protecting the rest of the epidermis from drying out. The layers of the epidermis are the:

- Stratum corneum
- Stratum granulosum
- Stratum Spinale
- Stratum basale

For more about the skin see the slides presentation and the video on the integumentary system.

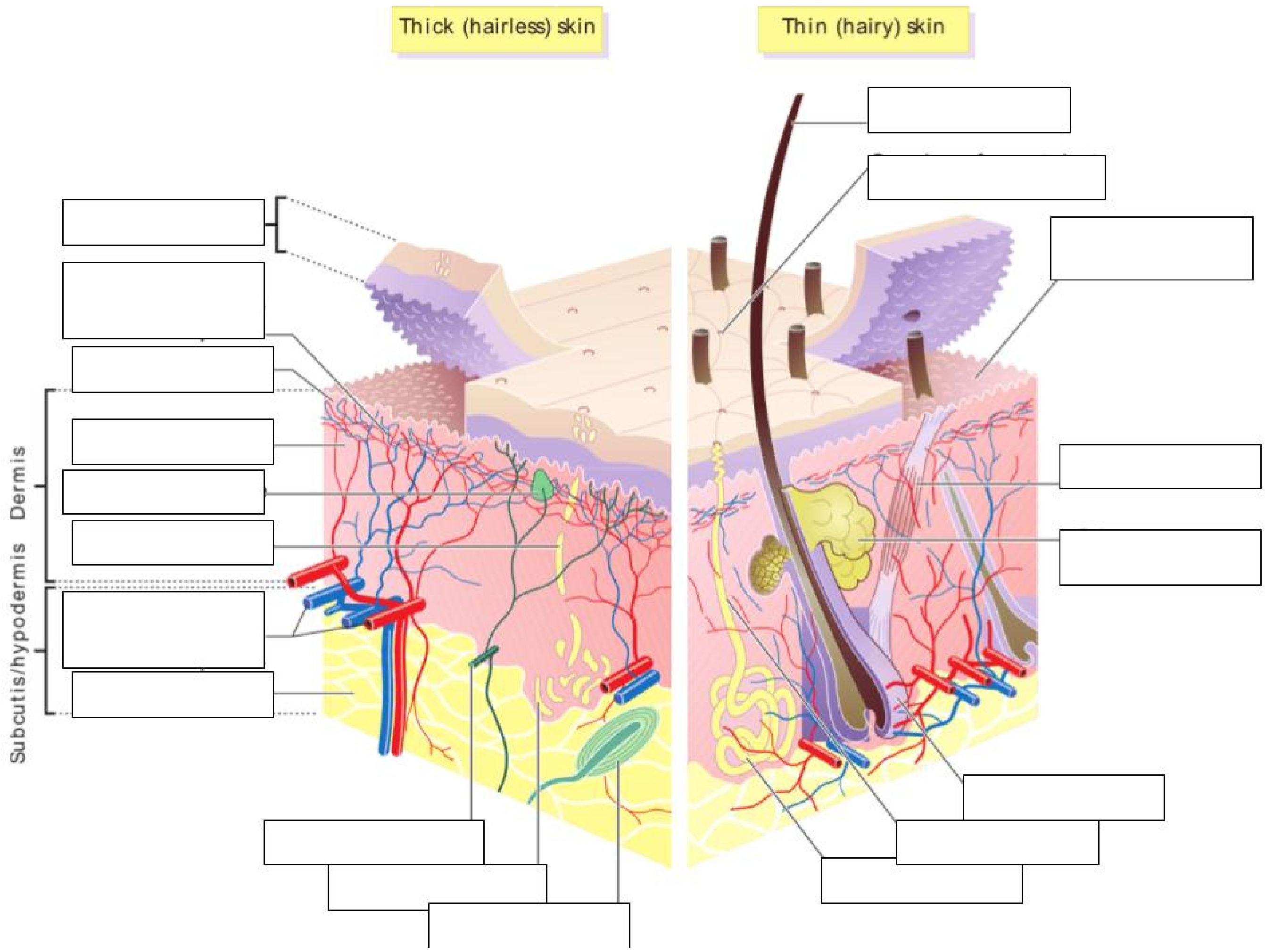
**Layers of the Skin**



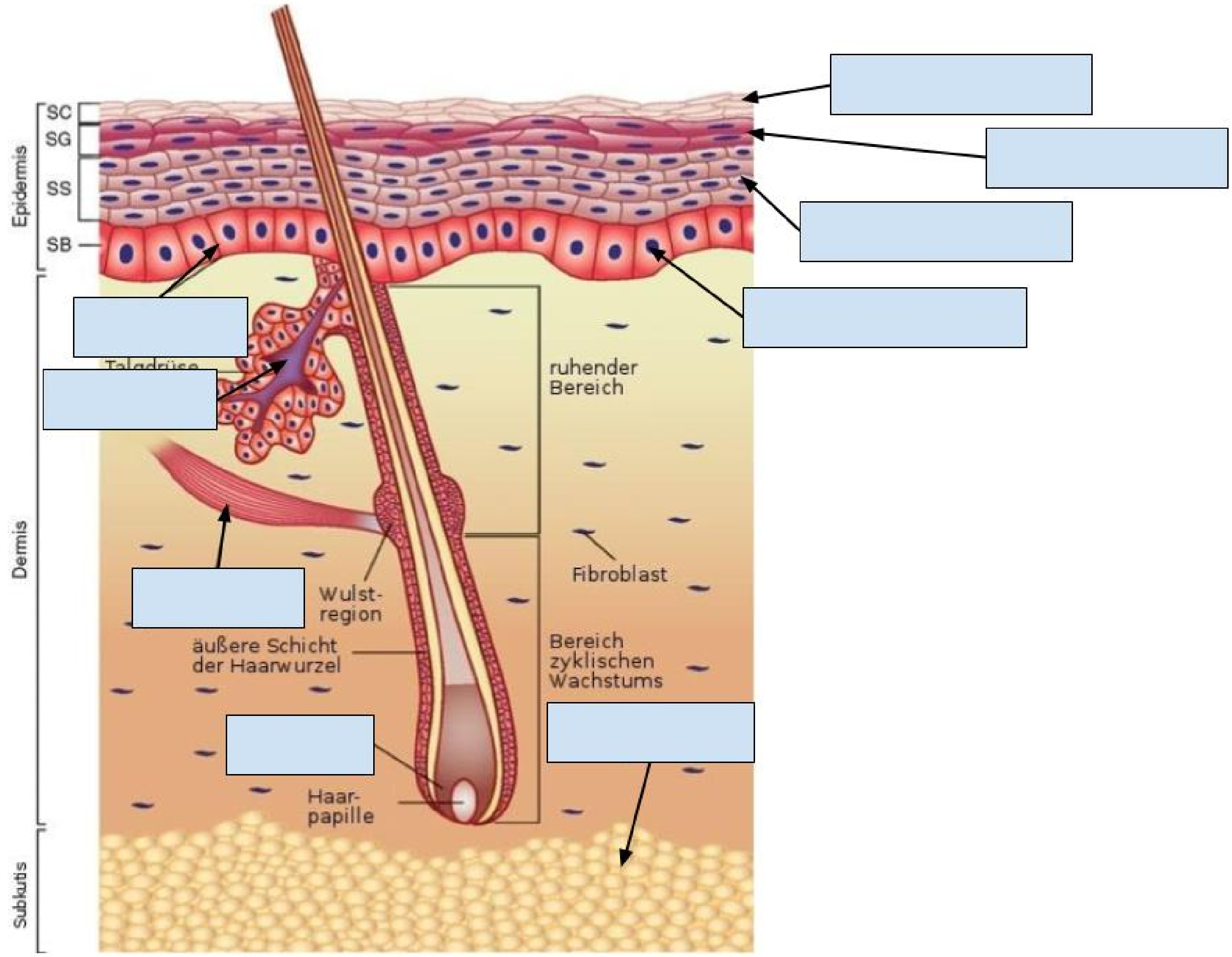



## Labeling Practice

| | | |
|---|---|---|
| Epidermis | Eccrine sweat gland | Superficial arteriovenous plexus |
| Deep arteriovenous plexus | Hair follicle | Sebaceous gland |
| Meissner's corpuscle | Reticular dermis | Arrector pili muscle |
| Sweat duct | Dermal nerve fibers | Subcutaneous fat |
| Dermal papillae | Hair shaft | Opening of sweat duct |



Thick (hairless) skin
Thin (hairy) skin
Dermis
Subcutis/hypodermis






# Glossary

**inflammation**: The process of activating immune system cells to enclose and attack infectious agents.

**lesion**: a non-naturally occurring break or discontinuity of the skin or any membrane or surface

**pH**: A measure of the hydrogen ion activity in a substance. A pH of 7 is neutral. A pH below 7 is acid and and pH above 7 is alkaline.

**sebaceous glands**: oil producing glands in the skin

# *Ha`awina 06: HLTH 140*

# (Digestive System)

## Hō`ulu`ulu Pōkole (Overview)

This lesson introduces body structure and terminology for the digestive system. You will examine the anatomy and functions of the three main organs of the upper alimentary canal—the mouth, pharynx, and esophagus—as well as three associated accessory organs—the tongue, salivary glands, and teeth.

## Ke Haumana ka `apo (Student Learning Outcomes)

1. Describe the type of medical treatment the gastroenterologist provides.
2. Identify digestive structures by labeling them on anatomical illustrations.
3. Describe the primary functions of the digestive system.
4. Apply the medical terminology of diseases, conditions, and procedures related to the digestive system.
5. Utilize word-building skills by constructing medical terms related to the digestive system.
6. Describe common abbreviations and symbols related to the digestive system.
7. Recognize, define, pronounce, and spell terms correctly.

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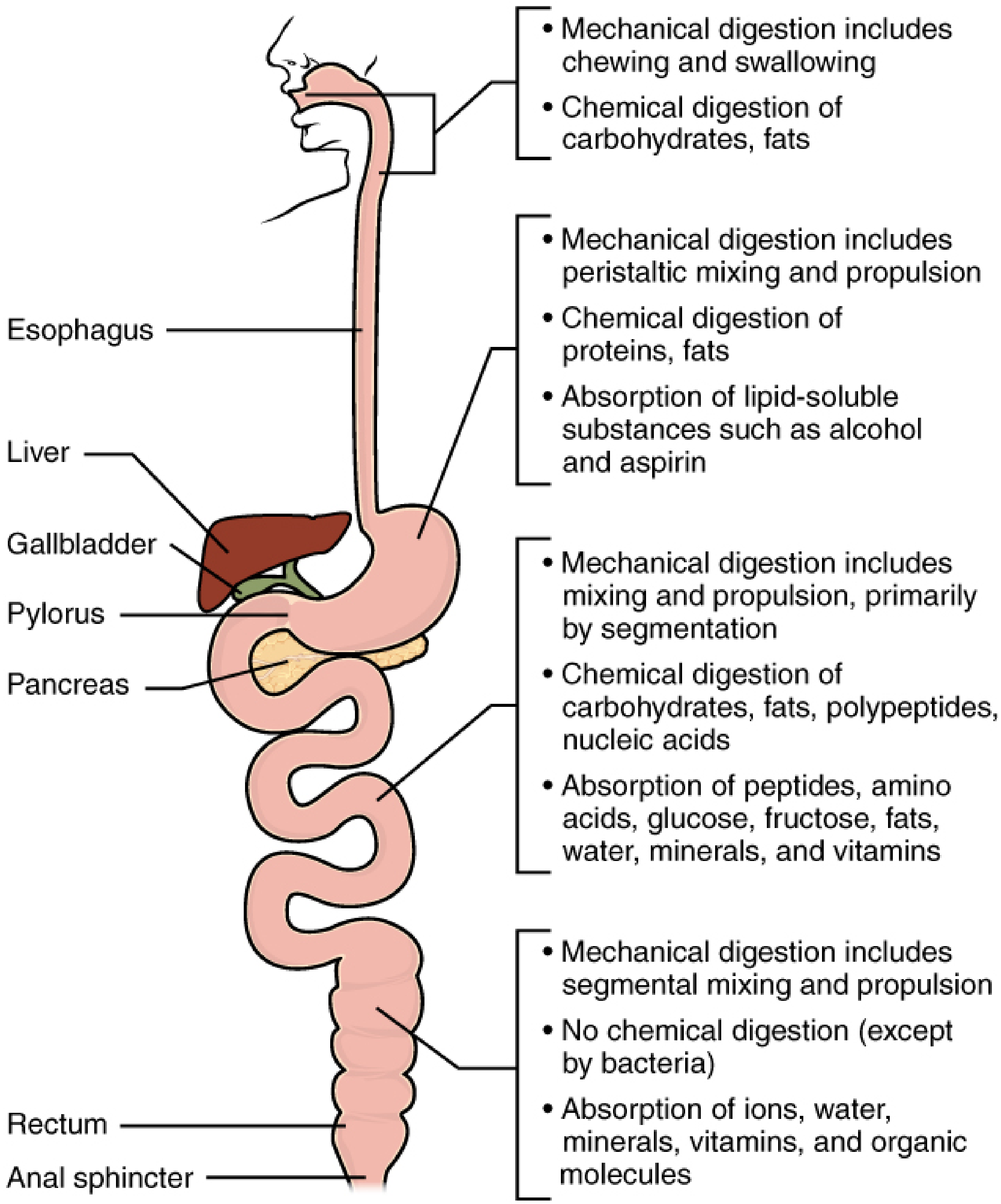
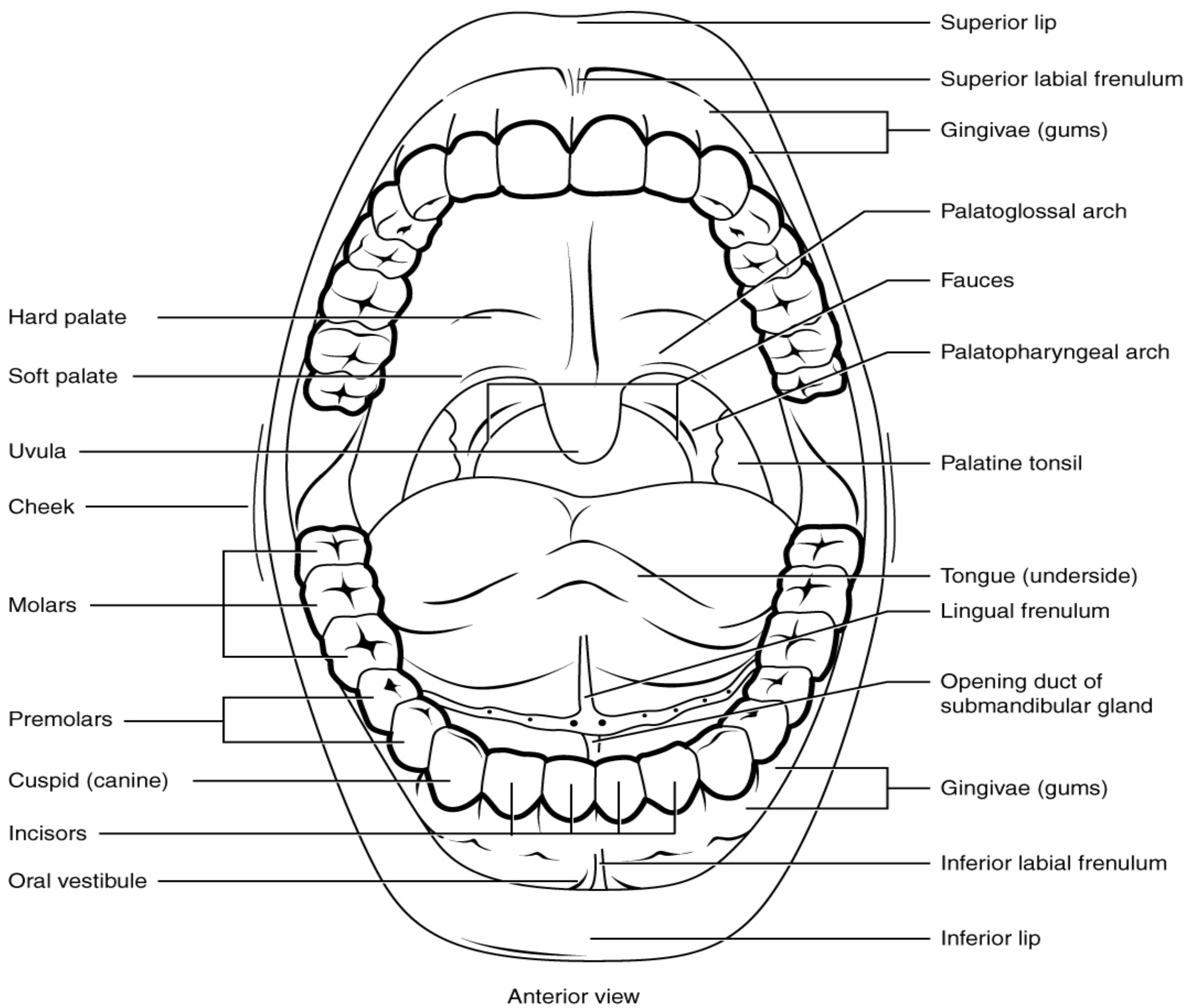
## The Mouth, Pharynx, and Esophagus



When you are chewing, you do not find it difficult to breathe simultaneously. The next time you have food in your mouth, notice how the arched shape of the roof of your mouth allows you to handle both digestion and respiration at the same time. This arch is called the **palate**. The anterior region of the palate serves as a wall (or septum) between the oral and nasal cavities as well as a rigid shelf against which the tongue can push food. It is created by the **maxillary** and **palatine** bones of the skull and, given its bony structure, is known as the **hard palate.** If you run your tongue along the roof of your mouth, you'll notice that the hard palate ends in the posterior oral cavity, and the tissue becomes fleshier. This part of the palate, known as the **soft palate**, is composed mainly of skeletal muscle.

**Mouth**

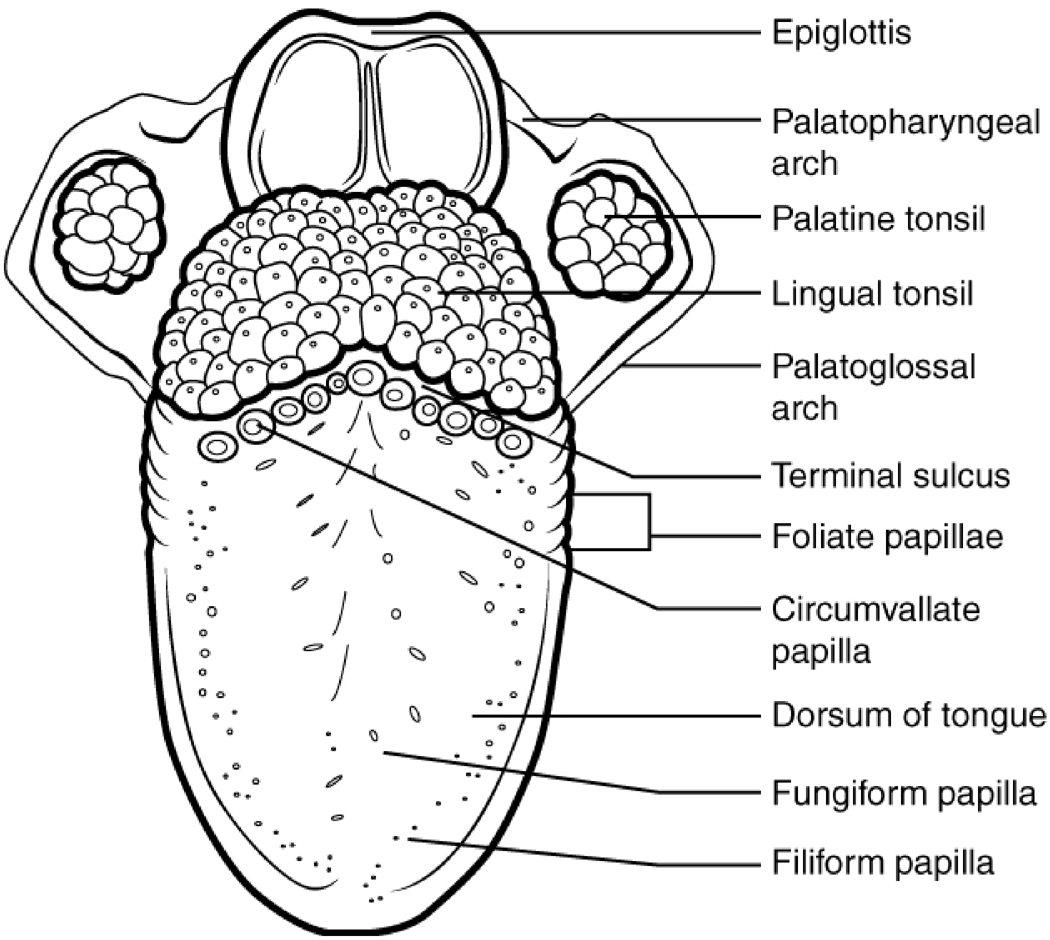



The mouth includes the lips, tongue, palate, gums, and teeth.
A fleshy bead of tissue called the **uvula** drops down from the center of the posterior edge of the soft palate. When you swallow, the soft palate and uvula move upward, helping to keep foods and liquid from entering the nasal cavity.

## The Tongue

The tongue is attached to the mandible, the styloid processes of the temporal bones, and the hyoid bone. The hyoid is unique in that it only distantly/indirectly articulates with other bones. The tongue is positioned over the floor of the oral cavity. A medial septum extends the entire length of the tongue, dividing it into symmetrical halves.

The top and sides of the tongue are studded with papillae, extensions of lamina propria of the mucosa, which are covered in stratified squamous epithelium. Fungiform papillae, which are mushroom shaped, cover a large area of the tongue. Filiform papillae are long and thin. Fungiform papillae contain taste buds, and filiform papillae have touch receptors that help the tongue move food around in the mouth. The filiform papillae create an abrasive surface that performs mechanically, much like a cat's rough tongue that is used for grooming. Tongue



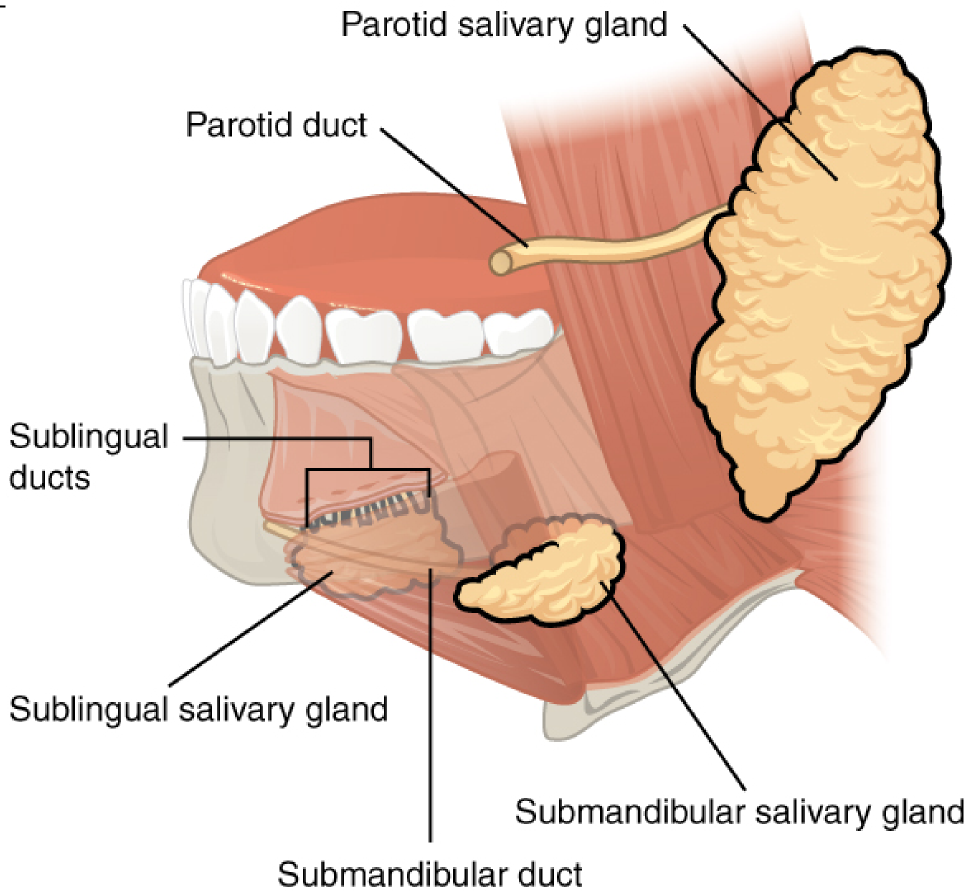

This **superior** view of the tongue shows the locations and types of lingual papillae.

## The Salivary Glands

Many small salivary glands are housed within the mucous membranes of the mouth and tongue. These minor exocrine glands are constantly secreting saliva, either directly into the oral cavity or indirectly through ducts, even while you sleep. In fact, an average of 1 to 1.5 liters of saliva is secreted each day.

**Focus on Mumps**

Mumps Infections of the nasal passages and pharynx can attack any salivary gland. The parotid glands are the usual site of infection with the virus that causes mumps (paramyxovirus). Mumps manifests by enlargement and inflammation of the parotid glands, causing a characteristic swelling between the ears and the jaw. Symptoms include fever and throat pain, which can be severe when swallowing acidic substances such as orange juice.




In about one-third of men who are past puberty, mumps also causes testicular inflammation, typically affecting only one testis and rarely resulting in sterility. With the increasing use and effectiveness of mumps vaccines, the incidence of mumps has decreased dramatically. According to the U.S. Centers for Disease Control and Prevention (CDC), the number of mumps cases dropped from more than 150,000 in 1968 to fewer than 1700 in 1993 to only 11 reported cases in 2011.

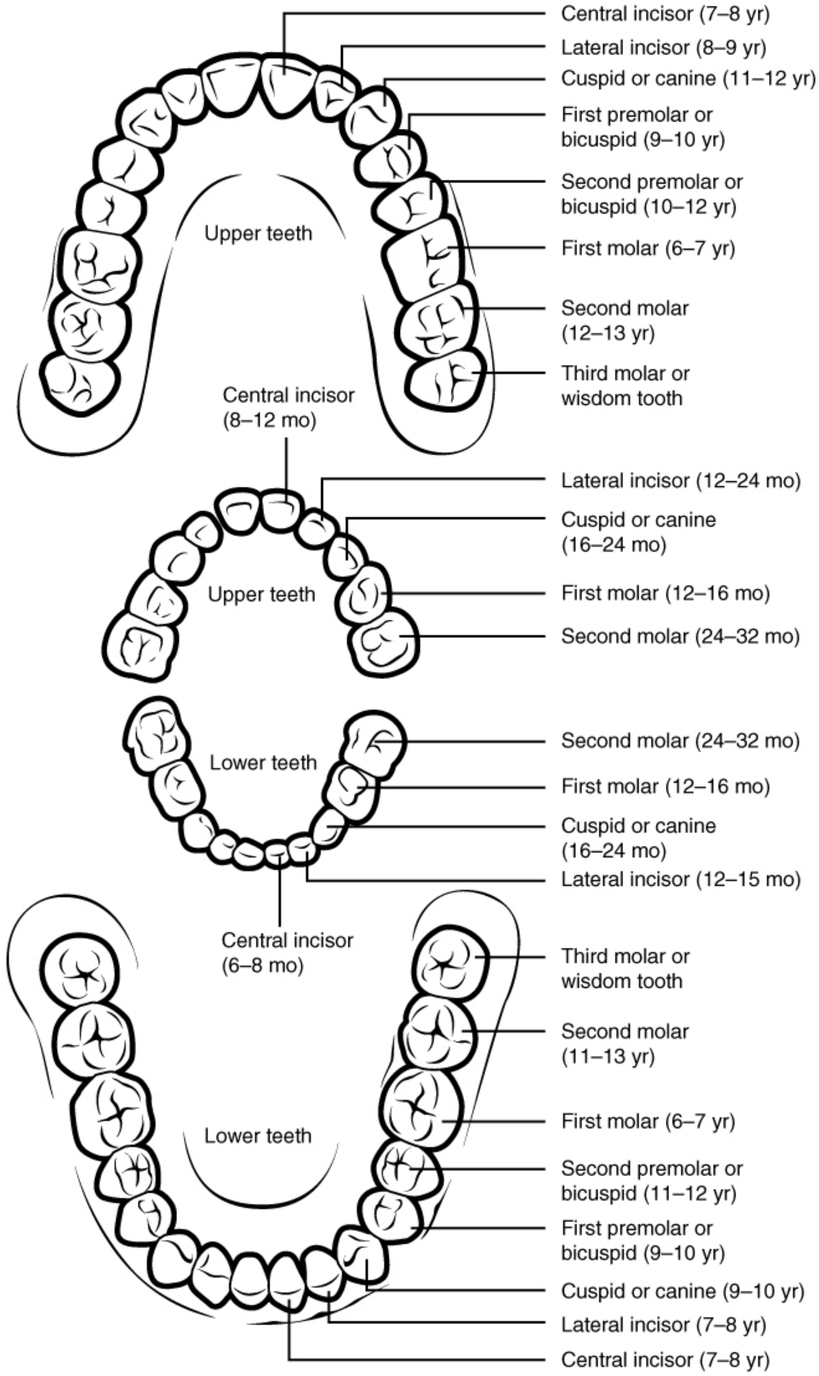
## The Teeth

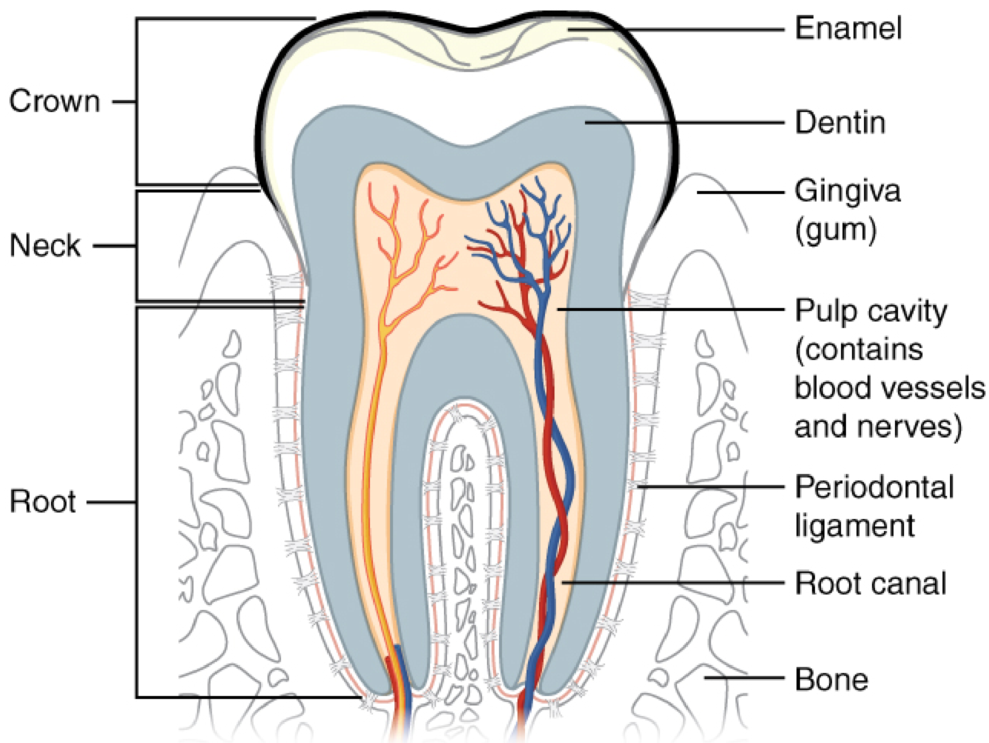
The teeth, or **dentes** (singular = **dens**), are organs similar to bones that you use to tear, grind, and otherwise mechanically break down food.

**Types of Teeth**

During the course of your lifetime, you have two sets of teeth (one set of teeth is a dentition). Your 20 deciduous teeth, or baby teeth, first begin to appear at about 6 months of age. Between approximately age 6 and 12, these teeth are replaced by 32 permanent teeth. Moving from the center of the mouth toward the side, these are as follows ([Figure](#)):

- ❑ The eight incisors, four top and four bottom, are the sharp front teeth you use for biting into food.
- ❑ The four cuspids (or canines) flank the incisors and have a pointed edge (cusp) to tear up food. These fang-like teeth are superb for piercing tough or fleshy foods.
- ❑ Posterior to the cuspids are the eight premolars (or bicuspids), which have an overall flatter shape with two rounded cusps useful for mashing foods.
- ❑ The most posterior and largest are the 12 molars, which have several pointed cusps used to crush food so it is ready for swallowing. The third members are commonly referred to as the wisdom teeth.






**Anatomy of a Tooth**

The teeth are secured in the alveolar processes (sockets) of the maxilla and the mandible. **Gingivae** (commonly called the gums) are soft tissues that line the alveolar processes and surround the necks of the teeth. Teeth are also held in their sockets by a connective tissue called the periodontal ligament.

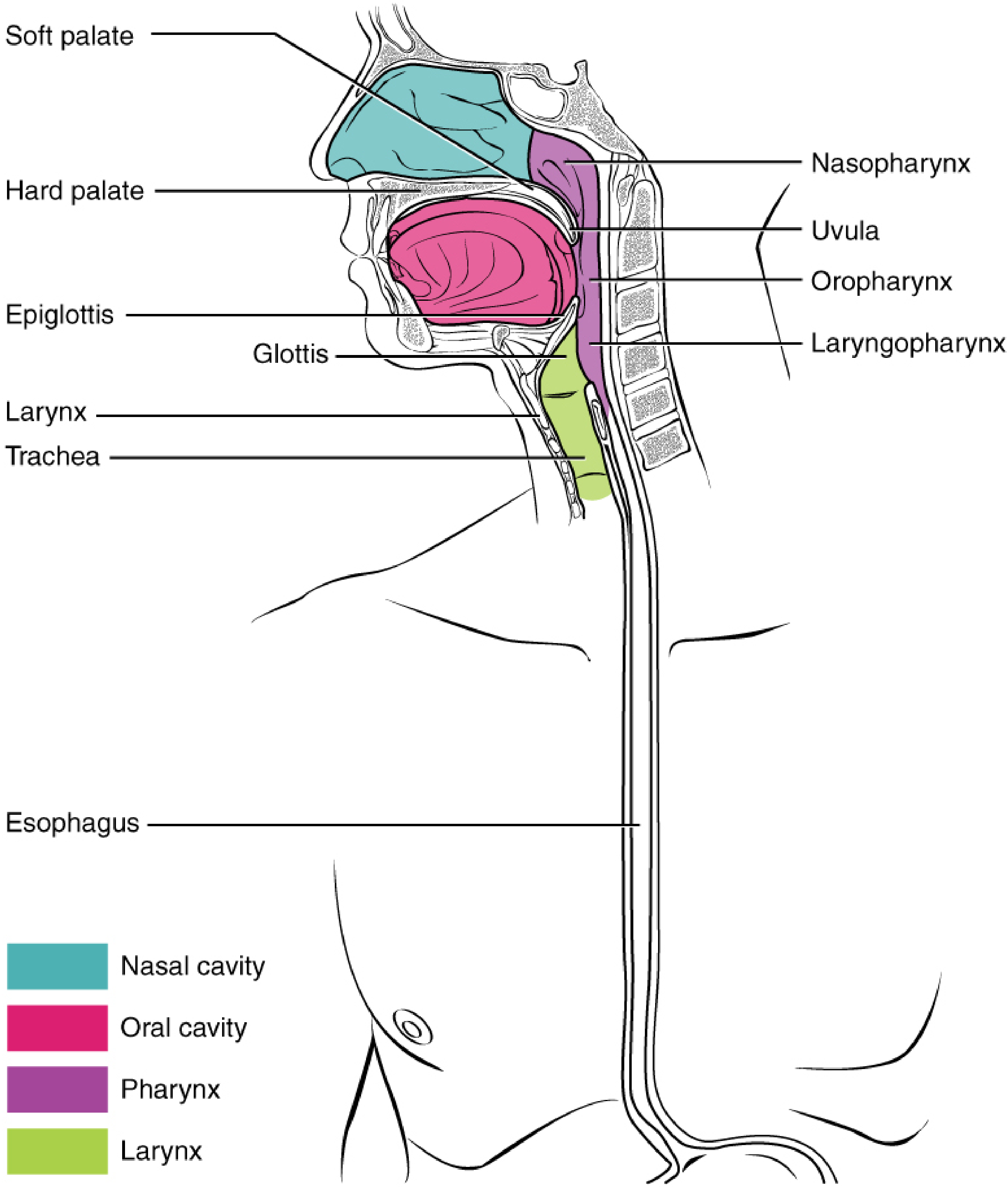
The two main parts of a tooth are the crown, which is the portion projecting above the gum line, and the root, which is embedded within the maxilla and mandible. Both parts contain an inner pulp cavity, containing loose connective tissue through which run nerves and blood vessels. The region of the pulp cavity that runs through the root of the tooth is called the root canal. Surrounding the pulp cavity is dentin, a bone-like tissue. In the root of each tooth, the dentin is covered by an even harder bone-like layer called cementum. In the crown of each tooth, the dentin is covered by an outer layer of enamel, the hardest substance in the body.

## The Pharynx

The pharynx (throat) is involved in both digestion and respiration. It receives food and air from the mouth, and air from the nasal cavities. When food enters the pharynx, involuntary muscle contractions close off the air passageways.

A short tube of skeletal muscle lined with a mucous membrane, the pharynx runs from the posterior oral and nasal cavities to the opening of the esophagus and larynx. It has three subdivisions. The most superior, the nasopharynx, is involved only in breathing and speech. The other two subdivisions, the oropharynx and the laryngopharynx, are used for both breathing and digestion.

**Pharynx**

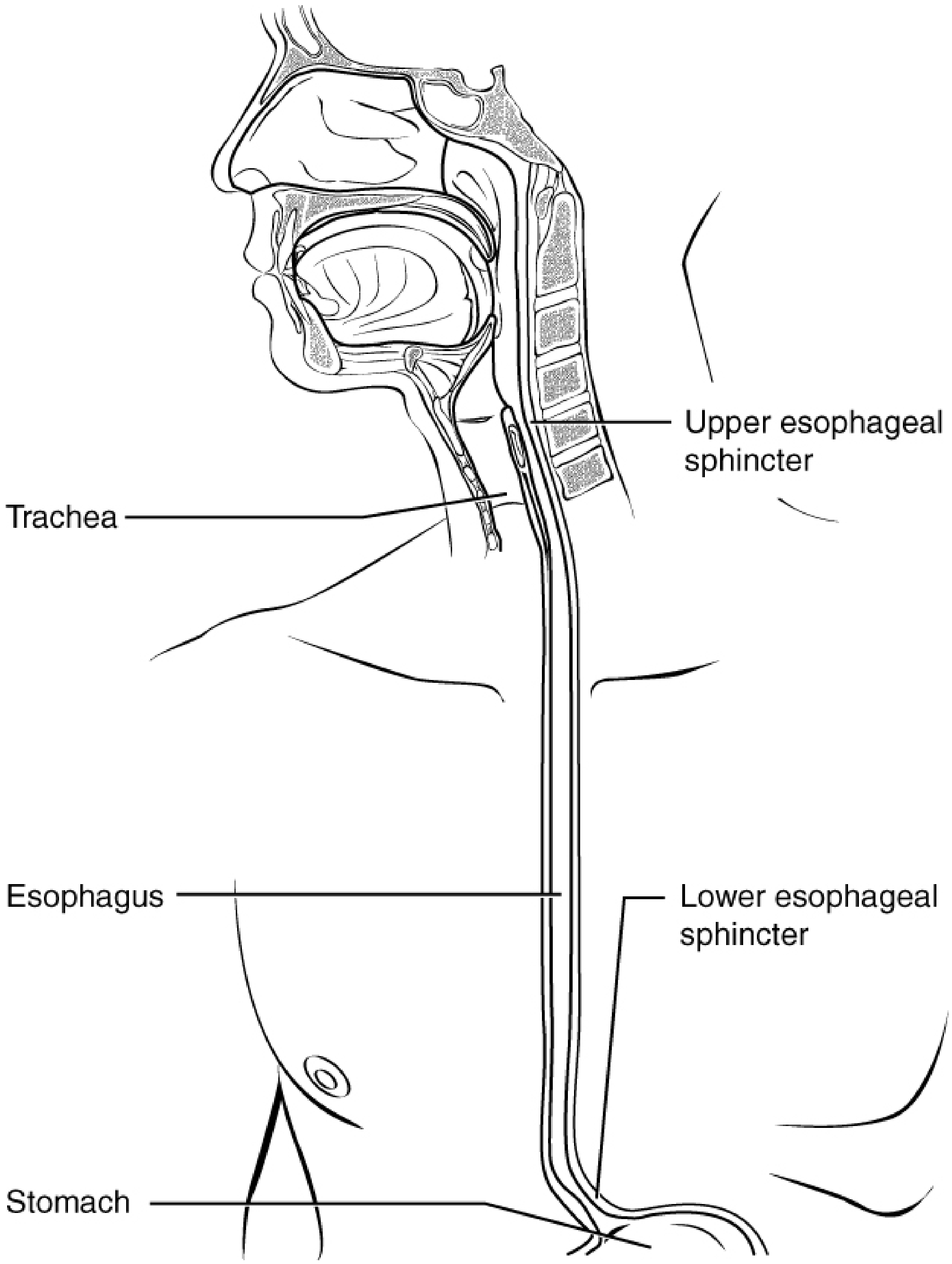



The pharynx runs from the nostrils to the esophagus and the larynx.

## The Esophagus

The esophagus is a muscular tube that connects the pharynx to the stomach. It is approximately 25.4 cm (10 in) in length, located posterior to the trachea, and remains in a collapsed form when not engaged in swallowing.

**Esophagus**




The upper esophageal sphincter controls the movement of food from the pharynx to the esophagus. The lower esophageal sphincter controls the movement of food from the esophagus to the stomach.

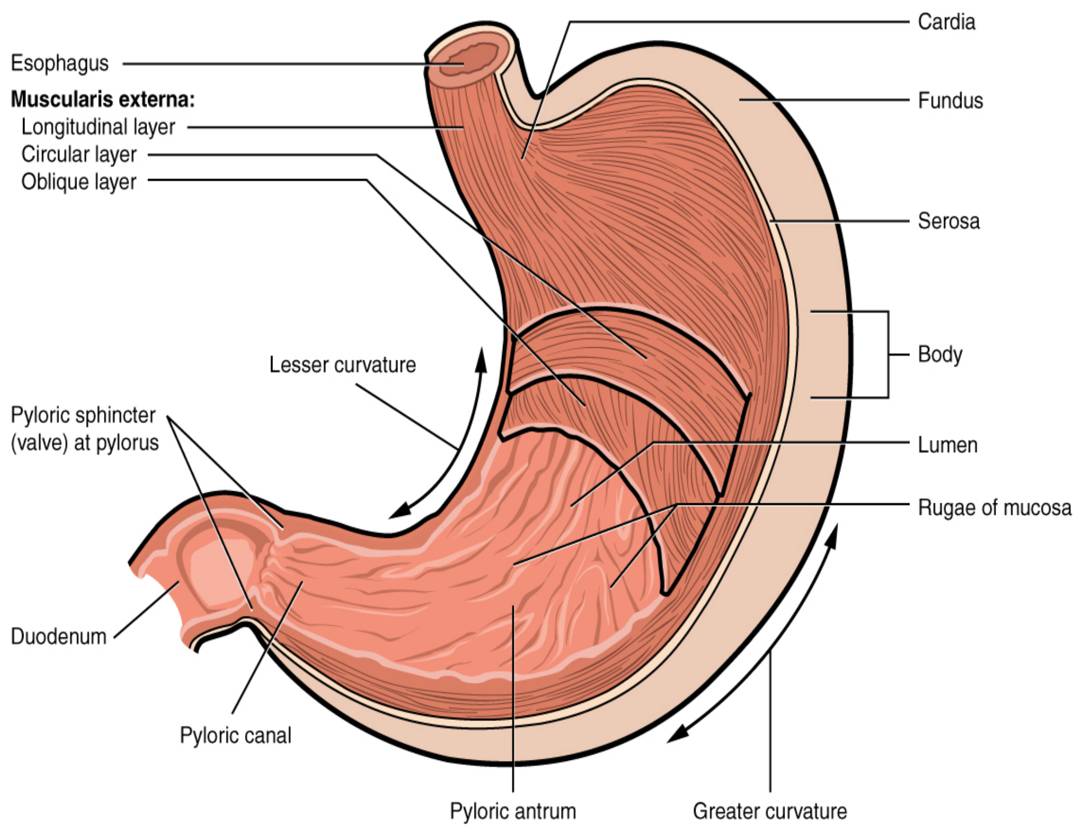
# The Stomach

The stomach plays several important roles in chemical digestion, including the continued digestion of carbohydrates and the initial digestion of proteins and triglycerides.

- Little if any nutrient absorption occurs in the stomach, with the exception of the negligible amount of nutrients in alcohol.
- The stomach links the esophagus to the first part of the small intestine (the duodenum). The empty stomach is only about the size of your fist, but can stretch to hold as much as 4 liters of food and fluid, or more than 75 times its empty volume, and then return to its resting size when empty.
- Although you might think that the size of a person's stomach is related to how much food that individual consumes, body weight does not correlate with stomach size.
- An important function of the stomach is to serve as a temporary holding chamber. You can ingest a meal far more quickly than it can be digested and absorbed by the small intestine..

## Structure

There are four main regions in the stomach: the cardia, fundus, body, and pylorus (Figure). The smooth muscle pyloric sphincter is located at this latter point of connection and controls stomach emptying. In the absence of food, the stomach deflates inward, and its mucosa and submucosa fall into a large fold called a ruga.




## Histology (Tissue Structure)

**Histology of the Stomach**

The stomach wall is adapted for the functions of the stomach. In the epithelium, gastric pits lead to gastric glands that secrete gastric juice. The gastric glands (one gland is shown enlarged on the right) contain different types of cells that secrete a variety of enzymes, including hydrochloride acid, which activates the protein-digesting enzyme pepsin.

The stomach mucosa's epithelial lining consists only of surface mucus cells, which secrete a protective coat of alkaline mucus. A vast number of gastric pits dot the surface of the epithelium, giving it the appearance of a well-used pincushion, and mark the entry to each gastric gland, which secretes a complex digestive fluid referred to as gastric juice.

- ***Parietal cells***— are among the most highly differentiated of the body's epithelial cells. These relatively large cells produce both **hydrochloric acid (HCl)** and intrinsic factor.
  - HCl is responsible for the high acidity (pH 1.5 to 3.5) of the stomach contents and is needed to activate the protein-digesting enzyme, pepsin.
  - Intrinsic factor is necessary for the absorption of vitamin B12.
- ***Chief cells***— secrete pepsinogen, the inactive proenzyme form of pepsin. HCl is necessary for the conversion of pepsinogen to pepsin.
- ***Mucous neck cells***— secrete thin, acidic mucus that is much different from the mucus secreted by the goblet cells of the surface epithelium. The role of this mucus is not currently known.
- ***Enteroendocrine cells***— secrete gastrin.

## The Small and Large Intestines

The word intestine is derived from a Latin root meaning "internal," and indeed, the two organs together nearly fill the interior of the abdominal cavity. In addition, called the small and large bowel, or colloquially the "guts," they constitute the greatest mass and length of the alimentary canal and, with the exception of ingestion, perform all digestive system functions.

## The Small Intestine

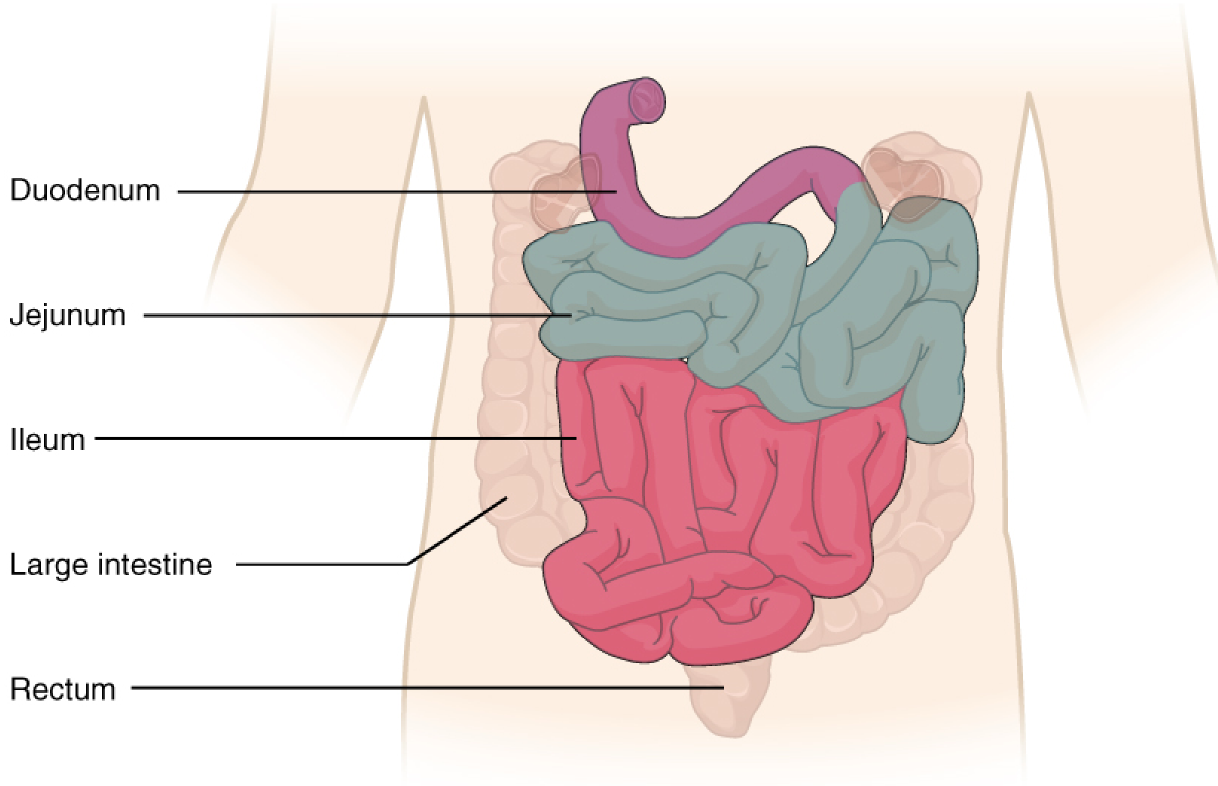
Chyme released from the stomach enters the small intestine, which is the primary digestive organ in the body. Not only is this where most digestion occurs, it is also where practically all absorption occurs. The longest part of the alimentary canal, the small intestine is about 3.05 meters (10 feet) long in a living person (but about twice as long in a cadaver due to the loss of muscle tone). Since this makes it about five times longer than the large intestine, you might wonder why it is called “small.” In fact, its name derives from its relatively smaller diameter of only about 2.54 cm (1 in), compared with 7.62 cm (3 in) for the large intestine. As we’ll see shortly, in addition to its length, the folds and projections of the lining of the small intestine work to give it an enormous surface area, which is approximately 200 $m^2$, more than 100 times the surface area of your skin. This large surface area is necessary for complex processes of digestion and absorption that occur within it.

**Structure of the Small Intestine**

The coiled tube of the small intestine is subdivided into three regions. From proximal (at the stomach) to distal, these are the duodenum, jejunum, and ileum (Figure).

- The shortest region is the 25.4-cm (10-in) duodenum, which begins at the pyloric sphincter. Just past the pyloric sphincter, it bends **posteriorly** behind the **peritoneum**, becoming **retroperitoneal**, and then makes a C-shaped curve around the head of the **pancreas** before ascending anteriorly again to return to the peritoneal cavity and join the jejunum.
- The **jejunum** is about 0.9 meters (3 feet) long (in life) and runs from the duodenum to the ileum. Jejunum means “empty” in Latin and supposedly was so named by the ancient Greeks who noticed it was always empty at death. No clear demarcation exists between the jejunum and the final segment of the small intestine, the ileum.
- The **ileum** is the longest part of the small intestine, measuring about 1.8 meters (6 feet) in length. It is thicker, more vascular, and has more developed mucosal folds than the jejunum.
    - The ileum joins the cecum, the first portion of the large intestine, at the ileocecal sphincter (or valve).
    - The jejunum and ileum are tethered to the posterior abdominal wall by the mesentery.
- The large intestine frames these three parts of the small intestine.

**Small Intestine**



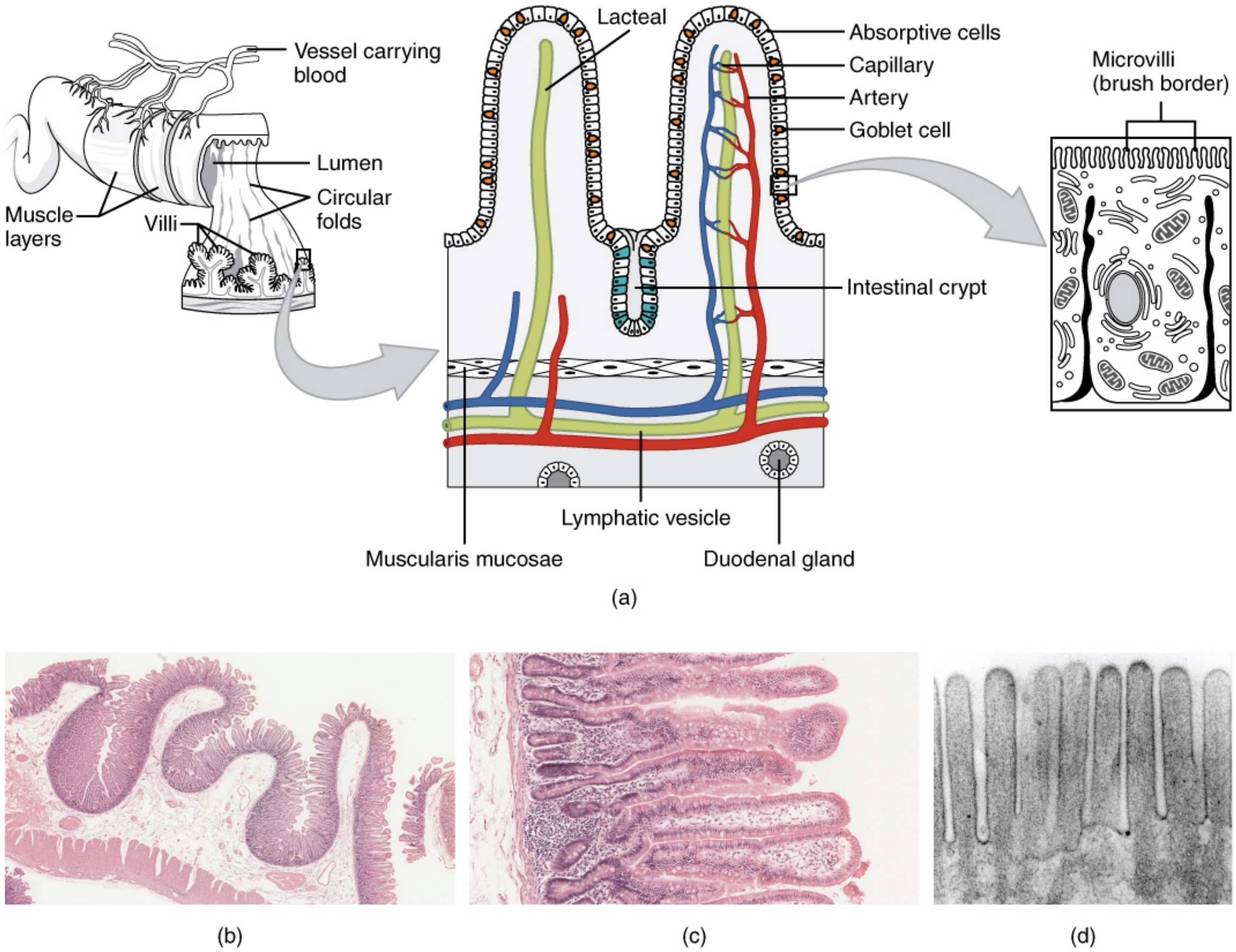

The three regions of the small intestine are the duodenum, jejunum, and ileum.

Parasympathetic nerve fibers from the vagus nerve and sympathetic nerve fibers from the thoracic splanchnic nerve provide extrinsic innervation to the small intestine. The superior mesenteric artery is its main arterial supply. Veins run parallel to the arteries and drain into the **superior mesenteric** vein. Nutrient-rich blood from the small intestine is then carried to the liver via the hepatic portal vein.

**Histology of the Small Intestine**

The wall of the small intestine is composed of the same four layers typically present in the alimentary system. However, three features of the mucosa and submucosa are unique. These features, which increase the absorptive surface area of the small intestine more than 600-fold, include circular folds, villi, and microvilli (Figure). These adaptations are most abundant in the proximal two-thirds of the small intestine, where the majority of absorption occurs.

### Histology of the Small Intestine




(a) The absorptive surface of the small intestine is vastly enlarged by the presence of circular folds, villi, and microvilli. (b) Micrograph of the circular folds. (c) Micrograph of the villi. (d) Electron micrograph of the microvilli. From left to right, LM x 56, LM x 508, EM x 196,000. (credit b-d: Micrograph provided by the Regents of University of Michigan Medical School © 2012)

**Circular folds-** a circular fold is a deep ridge in the mucosa and submucosa. Beginning near the proximal part of the duodenum and ending near the middle of the ileum, these folds facilitate absorption. Their shape causes the chyme to spiral, rather than move in a straight line, through the small intestine. Spiraling slows the movement of chyme and provides the time needed for nutrients to be fully absorbed.

**Villi-** Within the circular folds are small (0.5–1 mm long) hairlike vascularized projections called villi (singular = villus) that give the mucosa a furry texture. There are about 20 to 40 villi per square millimeter, increasing the surface area of the epithelium tremendously. The mucosal epithelium, primarily composed of absorptive cells, covers the villi.

**Microvilli**- As their name suggests, microvilli (singular = microvillus) are much smaller (1 $\mu$m) than villi. They are cylindrical apical surface extensions of the plasma membrane of the mucosa's epithelial cells, and are supported by microfilaments within those cells. Although their small size makes it difficult to see each microvillus, their combined microscopic appearance suggests a mass of bristles, which is termed the brush border. Fixed to the surface of the microvilli membranes are enzymes that finish digesting carbohydrates and proteins. There are an estimated 200 million microvilli per square millimeter of small intestine.

## The Large Intestine

The large intestine is the terminal part of the alimentary canal. The primary function of this organ is to finish absorption of nutrients and water, synthesize certain vitamins, form feces, and eliminate feces from the body.

### Structure

The large intestine runs from the appendix to the anus. It frames the small intestine on three sides. Despite its being about one-half as long as the small intestine, it is called large because it is more than twice the diameter of the small intestine, about 3 inches.

### Subdivisions

The large intestine is subdivided into four main regions: the **cecum**, the **colon**, the **rectum**, and the **anus**. The ileocecal valve, located at the opening between the ileum and the large intestine, controls the flow of chyme from the small intestine to the large intestine.

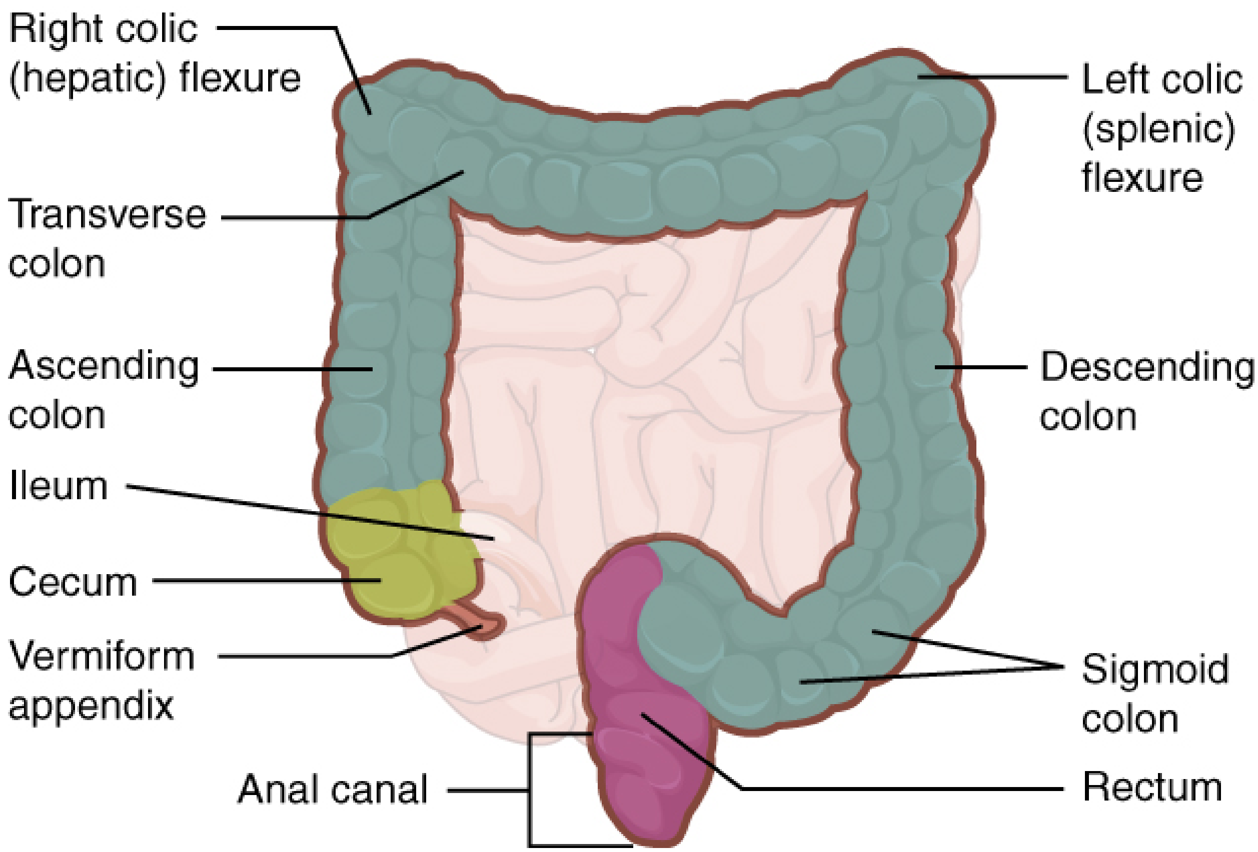
### Cecum

The first part of the large intestine is the cecum, a sac-like structure that is suspended inferior to the ileocecal valve. It is about 6 cm (2.4 in) long, receives the contents of the ileum, and continues the absorption of water and salts. The appendix (or vermiform appendix) is a winding tube that attaches to the cecum. Although the 7.6-cm (3-in) long appendix contains lymphoid tissue, suggesting an immunologic function, this organ is generally considered vestigial. However, at least one recent report postulates a survival advantage conferred by the appendix: In diarrheal illness, the appendix may serve as a bacterial reservoir to repopulate the enteric bacteria for those surviving the initial phases of the illness. Moreover, its twisted anatomy provides a haven for the accumulation and multiplication of enteric bacteria. The mesoappendix, the mesentery of the appendix, tethers it to the mesentery of the ileum.

### Colon

The cecum blends seamlessly with the colon. Upon entering the colon, the food residue first travels up the ascending colon on the right side of the abdomen. At the inferior surface of the liver, the colon bends to form the right colic flexure (hepatic flexure) and becomes the transverse colon. The region defined as hindgut begins with the last third of the transverse colon and continues on. Food residue passing through the transverse colon travels across to the left side of the abdomen, where the colon angles sharply immediately inferior to the spleen, at the left colic flexure (splenic flexure). From there, food residue passes through the descending colon, which runs down the left side of the posterior abdominal wall. After entering the pelvis inferiorly, it becomes the s-shaped sigmoid colon, which extends medially to the midline (Figure). The ascending and descending colon, and the rectum (discussed next) are located in the retroperitoneum. The transverse and sigmoid colon are tethered to the posterior abdominal wall by the mesocolon.

**Large Intestine**

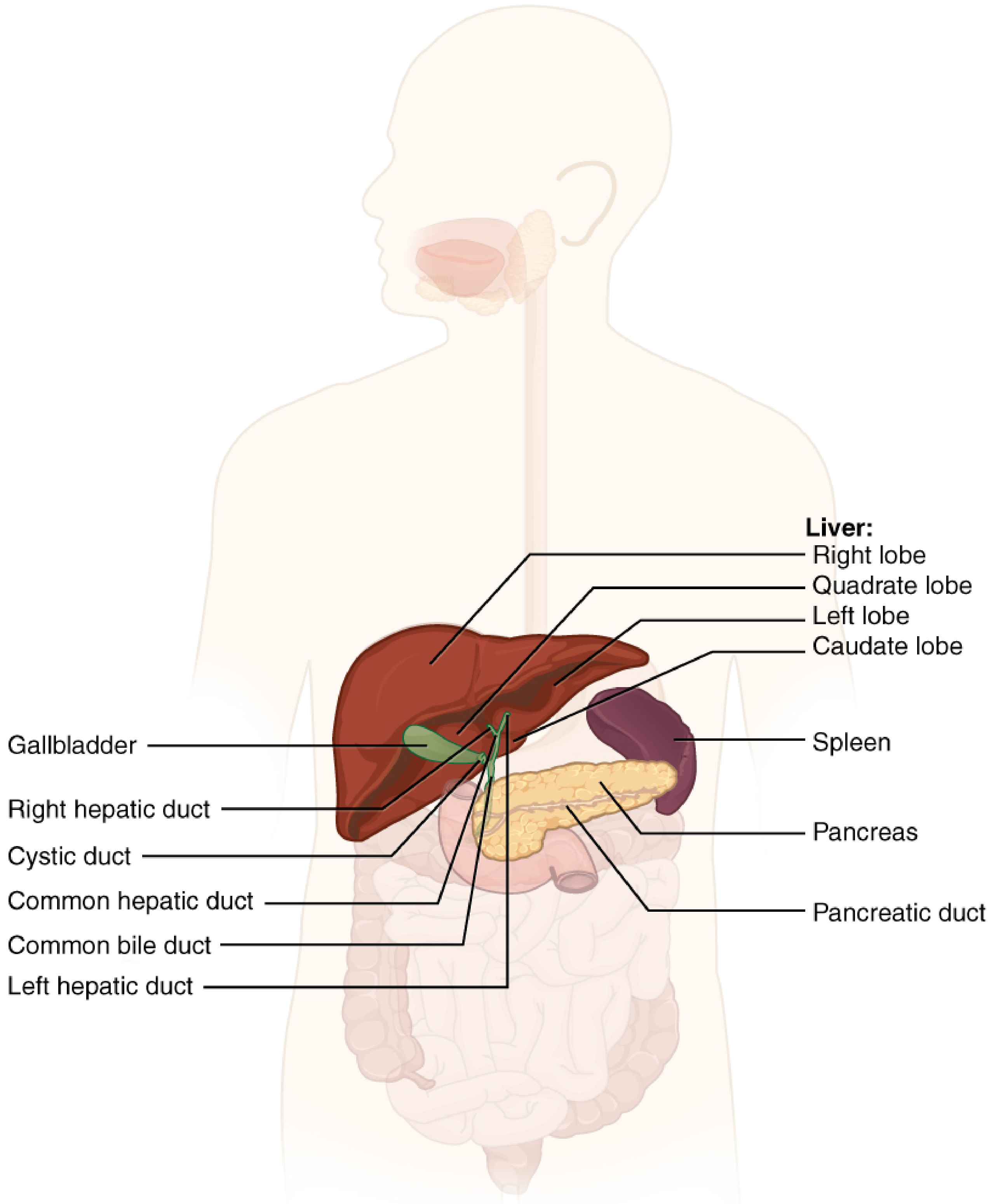



**The large intestine includes the cecum, colon, and rectum.**

## Accessory Organs of Digestion: The Liver, Pancreas, and Gallbladder

The liver, pancreas, and gallbladder are considered accessory digestive organs, but their roles in the digestive system are vital. Chemical digestion in the small intestine relies on the activities of three accessory digestive organs: the liver, pancreas, and gallbladder (Figure). The digestive role of the liver is to produce bile and export it to the duodenum. The gallbladder primarily stores, concentrates, and releases bile. The pancreas produces pancreatic juice, which contains digestive enzymes and bicarbonate ions, and delivers it to the duodenum.

**Accessory Organs of Digestion**

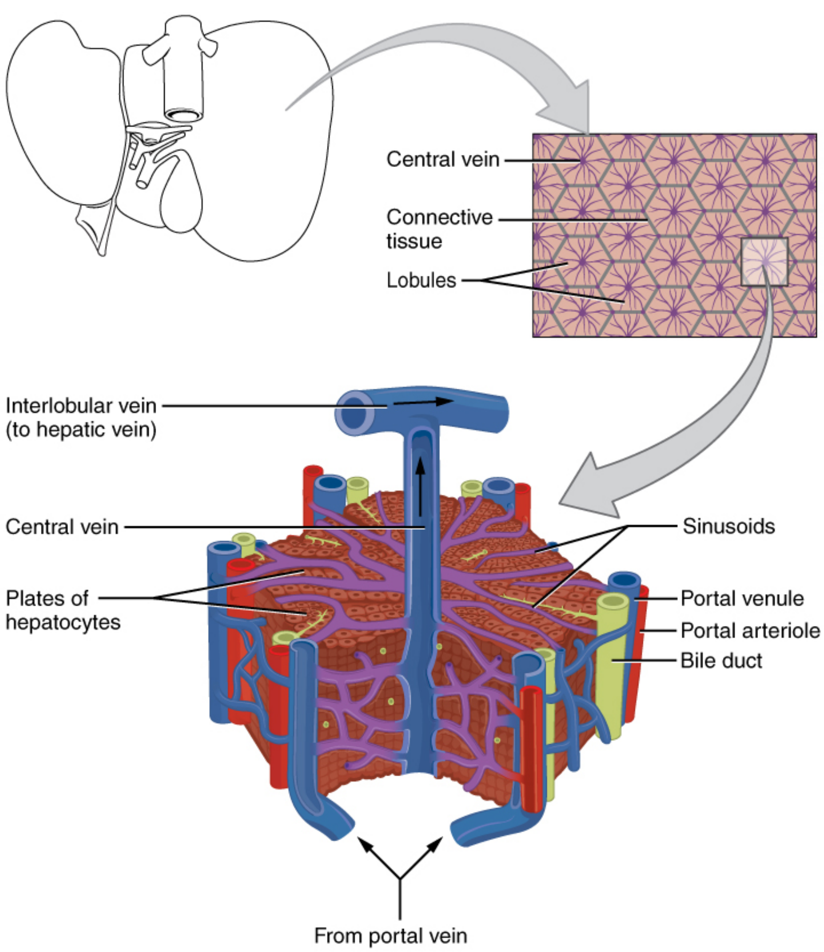


## The Liver

The liver lies inferior to the diaphragm in the right upper quadrant of the abdominal cavity and receives protection from the surrounding ribs.

The liver is divided into two primary lobes: a large right lobe and a much smaller left lobe. The hepatic portal is where the hepatic artery and hepatic portal vein enter the liver.

- ❑ The hepatic artery delivers oxygenated blood from the heart to the liver.
- ❑ The hepatic portal vein delivers partially deoxygenated blood containing nutrients absorbed from the small intestine and actually supplies more oxygen to the liver than do the much smaller hepatic arteries.
- ❑ In addition to nutrients, **drugs and toxins** are also absorbed.
- ❑ After processing the bloodborne nutrients and toxins, the liver releases nutrients needed by other cells back into the blood, which drains into the central vein and then to the **inferior vena cava**.
- ❑ All blood from the alimentary canal passes through the liver.



**Histology**

The liver has three main components: hepatocytes, bile canaliculi, and hepatic sinusoids.

- A **hepatocyte** is the liver's main cell type, accounting for around 80 percent of the liver's volume. These cells play a role in a wide variety of secretory, metabolic, and endocrine functions.
- **Bile canaliculus** (plural = **canaliculi**) accumulate the bile produced by hepatocytes. From here, bile flows first into bile ductules and then into bile ducts leading to the **common hepatic duct**. This duct then joins with the cystic duct from the **gallbladder**, forming the **common bile duct** through which bile flows into the small intestine. Materials such as bilirubin are processed and excreted into the bile canaliculi. Other materials including proteins, lipids, and carbohydrates are processed and secreted into the sinusoids or just stored in the cells until called.
- **Hepatic sinusoids** combine and send blood to a central vein, and eventually into the inferior vena cava. The hepatic sinusoids also contain star-shaped **reticuloendothelial** cells (**Kupffer cells**), phagocytes that remove dead red and white blood cells, bacteria, and other foreign material that enter the sinusoids.

**Bile**

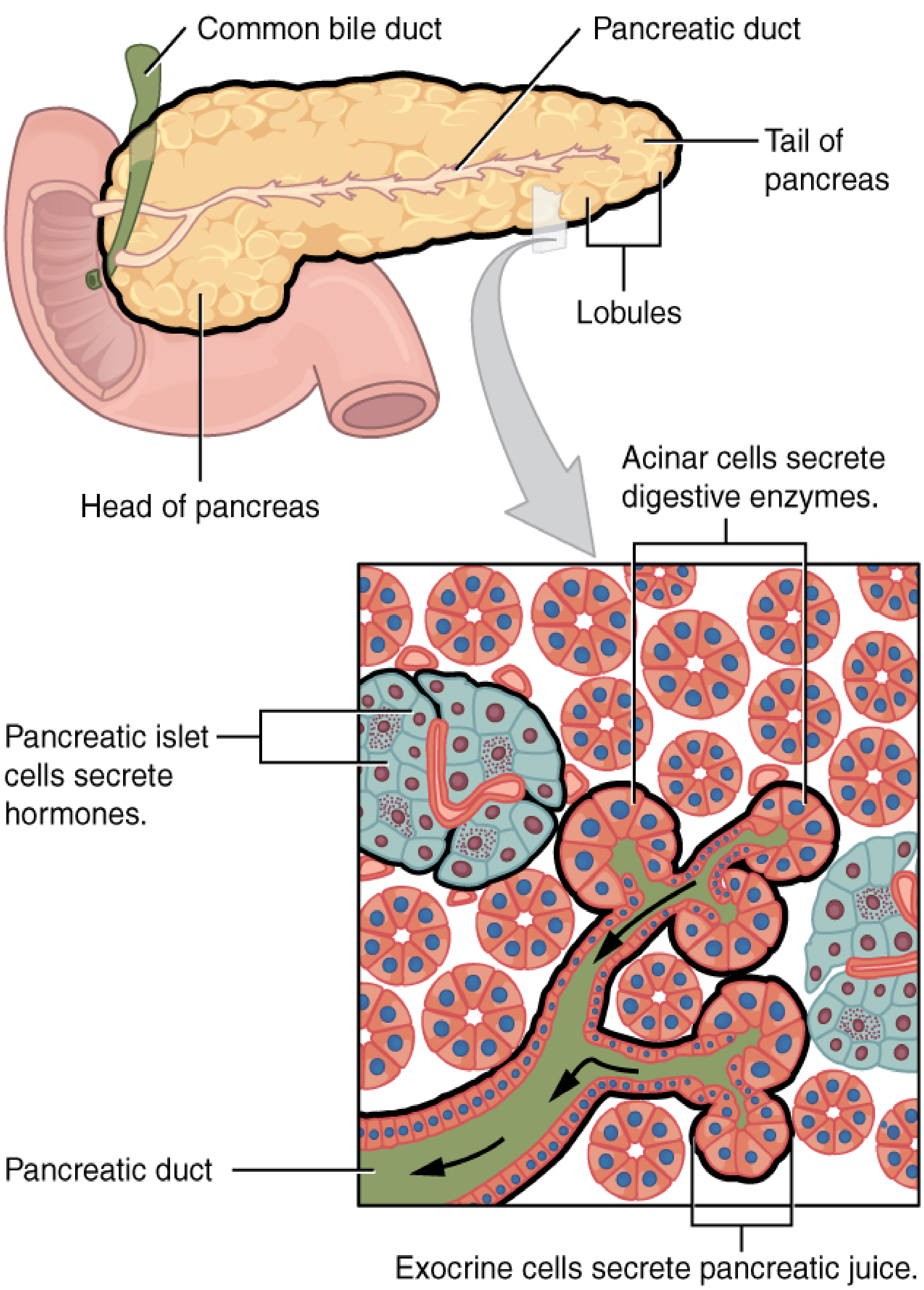
Bile is a mixture secreted by the liver to accomplish the emulsification of lipids in the small intestine.

Hepatocytes secrete about one liter of bile each day. A yellow-brown or yellow-green alkaline solution (pH 7.6 to 8.6), bile is a mixture of water, bile salts, bile pigments, phospholipids (such as lecithin), electrolytes, cholesterol, and triglycerides. Bile salts act as emulsifying agents, so they are also important for the absorption of digested lipids.

- Bilirubin, the main bile pigment, is a waste product produced when the spleen removes old or damaged red blood cells from the circulation. These breakdown products, including proteins, iron, and toxic bilirubin, are transported to the liver via the splenic vein of the hepatic portal system.
- In the liver, proteins and iron are recycled, whereas bilirubin is excreted in the bile. It accounts for the green color of bile.
- Bilirubin is eventually transformed by intestinal bacteria into stercobilin, a brown pigment that gives your stool its characteristic color! In some disease states, bile does not enter the intestine, resulting in white ('acholic') stool with a high fat content, since virtually no fats are broken down or absorbed.
- Between meals, bile is produced but diverted to the gallbladder, where it is concentrated and stored until the next meal. That is the primary function of the gallbladder.

## The Pancreas

The soft, oblong, glandular pancreas lies transversely in the retroperitoneum behind the stomach. Its head is nestled into the "c-shaped" curvature of the duodenum with the body extending to the left about 15.2 cm (6 in) and ending as a tapering tail in the hilum of the spleen. It is a curious mix of exocrine (secreting digestive enzymes) and endocrine (releasing hormones into the blood) functions (Figure).




Exocrine and Endocrine Pancreas

The pancreas has

- a head,
- a body,
- and a tail. It delivers pancreatic juice to the duodenum through the pancreatic duct.

The **exocrine** part of the pancreas arises as little grape-like cell clusters, each called an **acinus** (plural = **acini**), located at the terminal ends of pancreatic ducts. These acinar cells secrete enzyme-rich pancreatic juice into tiny merging ducts that form two dominant ducts.

The larger duct fuses with the common bile duct (carrying bile from the liver and gallbladder) just before entering the duodenum via a common opening (the **hepatopancreatic ampulla**).

Scattered through the sea of exocrine acini are small islands of endocrine cells, the **islets of Langerhans**. These vital cells produce the hormones pancreatic polypeptide, **insulin**, **glucagon**, and somatostatin.

**Pancreatic Juice**

The pancreas produces over a liter of pancreatic juice each day (pH 7.1 to 8.2), which serves to buffer (counteract) the acidic gastric juice in chyme, inactivate pepsin from the stomach, and create an optimal environment for the activity of pH-sensitive digestive enzymes in the small intestine.

- Pancreatic enzymes are active in the digestion of sugars, proteins, and fats.
- The pancreas produces protein-digesting enzymes in their inactive forms. These enzymes are activated in the duodenum. If produced in an active form, they would digest the pancreas (which is exactly what occurs in the disease, pancreatitis).
- The intestinal brush border enzyme enteropeptidase stimulates the activation of trypsin from trypsinogen of the pancreas, which in turn changes the pancreatic enzymes procarboxypeptidase and chymotrypsinogen into their active forms, carboxypeptidase and chymotrypsin.

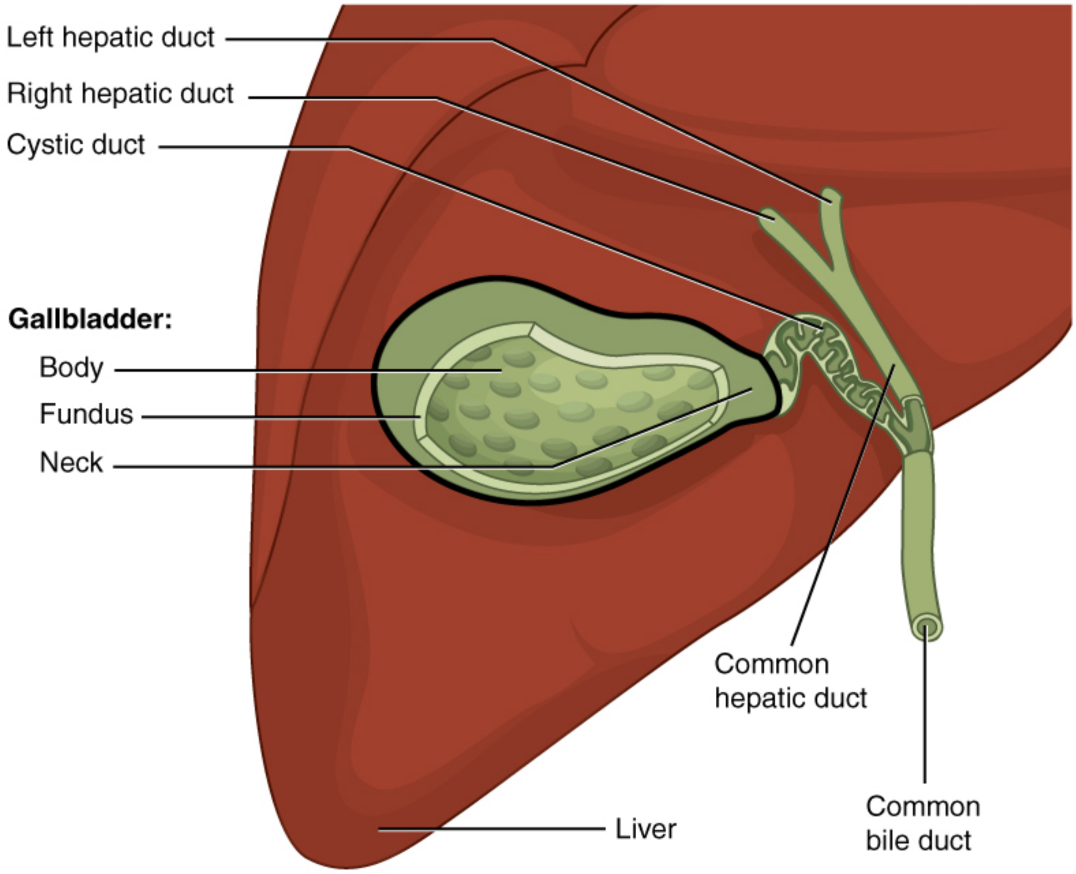
**Pancreatic Secretion**

Regulation of pancreatic secretion is the job of hormones and the parasympathetic nervous system. The entry of acidic chyme into the duodenum stimulates the release of secretin, which in turn causes the duct cells to release bicarbonate-rich pancreatic juice.

## The Gallbladder

The gallbladder is 8–10 cm (~3–4 in) long and is nested in a shallow area on the posterior aspect of the right lobe of the liver. This muscular sac stores, concentrates, and, when stimulated, propels the bile into the duodenum via the common bile duct. It is divided into three regions. The fundus is the widest portion and tapers medially into the body, which in turn narrows to become the neck. The neck angles slightly superiorly as it approaches the hepatic duct. The cystic duct is 1–2 cm (less than 1 in) long and turns inferiorly as it bridges the neck and hepatic duct.

**Gallbladder**




The gallbladder stores and concentrates bile, and releases it into the two-way cystic duct when it is needed by the small intestine.

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# Glossary

**The Mouth, Pharynx, and Esophagus**

**bolus**: mass of chewed food

**cementum**: bone-like tissue covering the root of a tooth

**crown**: portion of tooth visible superior to the gum line

**cuspid**: (also, **canine**) pointed tooth used for tearing and shredding food

**deciduous tooth**: one of 20 “baby teeth”

**deglutition**: three-stage process of swallowing

**dens**: tooth

**dentin**: bone-like tissue immediately deep to the enamel of the crown or cementum of the root of a tooth

**dentition**: set of teeth

**enamel**: covering of the dentin of the crown of a tooth

**esophagus**: muscular tube that runs from the pharynx to the stomach

**fauces**: opening between the oral cavity and the oropharynx

**gingiva**: gum

**incisor**: midline, chisel-shaped tooth used for cutting into food

**labium**: lip

**labial frenulum**: midline mucous membrane fold that attaches the inner surface of the lips to the gums

**laryngopharynx**: part of the pharynx that functions in respiration and digestion

**lingual frenulum**: mucous membrane fold that attaches the bottom of the tongue to the floor of the mouth

**lingual lipase**: digestive enzyme from glands in the tongue that acts on triglycerides

**lower esophageal sphincter**: smooth muscle sphincter that regulates food movement from the esophagus to the stomach

**molar**: tooth used for crushing and grinding food

**oral cavity**: (also, buccal cavity) mouth

**oral vestibule**: part of the mouth bounded externally by the cheeks and lips, and internally by the gums and teeth

**oropharynx**: part of the pharynx continuous with the oral cavity that functions in respiration and digestion

**palatoglossal arch**: muscular fold that extends from the lateral side of the soft palate to the base of the tongue

**palatopharyngeal arch**: muscular fold that extends from the lateral side of the soft palate to the side of the pharynx

**parotid gland**: one of a pair of major salivary glands located inferior and anterior to the ears

**permanent tooth**: one of 32 adult teeth

**pharynx**: throat

**premolar**: (also, bicuspid) transitional tooth used for mastication, crushing, and grinding food

**pulp cavity**: deepest portion of a tooth, containing nerve endings and blood vessels

**root**: portion of a tooth embedded in the alveolar processes beneath the gum line

**saliva**: aqueous solution of proteins and ions secreted into the mouth by the salivary glands

**salivary amylase**: digestive enzyme in saliva that acts on starch

**salivary gland**: an exocrine gland that secretes a digestive fluid called saliva

**salivation**: secretion of saliva

**soft palate**: posterior region of the bottom portion of the nasal cavity that consists of skeletal muscle

**sublingual gland**: one of a pair of major salivary glands located beneath the tongue

**submandibular gland**: one of a pair of major salivary glands located in the floor of the mouth

**tongue**: accessory digestive organ of the mouth, the bulk of which is composed of skeletal muscle

**upper esophageal sphincter**: skeletal muscle sphincter that regulates food movement from the pharynx to the esophagus

**voluntary phase**: initial phase of deglutition, in which the bolus moves from the mouth to the oropharynx

**Accessory Organs of Digestion**

**accessory duct**: (also, **duct of Santorini**) duct that runs from the pancreas into the duodenum

**acinus**: cluster of glandular epithelial cells in the pancreas that secretes pancreatic juice in the pancreas

**bile**: alkaline solution produced by the liver and important for the emulsification of lipids

**bile canaliculus**: small duct between hepatocytes that collects bile

**bilirubin**: main bile pigment, which is responsible for the brown color of feces

**central vein**: vein that receives blood from hepatic sinusoids

**common bile duct**: structure formed by the union of the common hepatic duct and the gallbladder's cystic duct

**ommon hepatic duct**: duct formed by the merger of the two hepatic ducts

**cystic ducct**: duct through which bile drains and enters the gallbladder

**enterohepatic circulation**: recycling mechanism that conserves bile salts

**enteropeptidase**: intestinal brush-border enzyme that activates trypsinogen to trypsin

**gallbladder**: accessory digestive organ that stores and concentrates bile

**hepatic artery**: artery that supplies oxygenated blood to the liver

**hepatic lobule**: hexagonal-shaped structure composed of hepatocytes that radiate outward from a central vein

**hepatic portal vein**: vein that supplies deoxygenated nutrient-rich blood to the liver

**hepatic sinusoid**: blood capillaries between rows of hepatocytes that receive blood from the hepatic portal vein and the branches of the hepatic artery

**hepatic vein**: vein that drains into the inferior vena cava

**hepatocytes:** major functional cells of the liver

**liver**: largest gland in the body whose main digestive function is the production of bile

**pancreas**: accessory digestive organ that secretes pancreatic juice

**pancreatic juice**: secretion of the pancreas containing digestive enzymes and bicarbonate

**porta hepatis** or **hepatic portal**: "gateway to the liver" where the hepatic artery and hepatic portal vein enter the liver

**portal triad**: bile duct, hepatic artery branch, and hepatic portal vein branch

**reticuloendothelial cell**: (also, **Kupffer cell**) phagocyte in hepatic sinusoids that filters out material from venous blood from the alimentary canal

**The Small and Large Intestines**

**anal canal**: final segment of the large intestine

**anal column**: long fold of mucosa in the anal canal

**anal sinus**: recess between anal columns

**appendix**: (**vermiform appendix**) coiled tube attached to the cecum

**ascending colon**: first region of the colon

**bacterial flora**: bacteria in the large intestine

**brush border**: fuzzy appearance of the small intestinal mucosa created by microvilli

**cecum**: pouch forming the beginning of the large intestine

**circular fold**: (also, plica circulare) deep fold in the mucosa and submucosa of the small intestine

**colon**: part of the large intestine between the cecum and the rectum

**descending colon**: part of the colon between the transverse colon and the sigmoid colon

**duodenal gland**: (also, Brunner’s gland) mucous-secreting gland in the duodenal submucosa

**duodenum**: first part of the small intestine, which starts at the pyloric sphincter and ends at the jejunum

**epiploic appendage**: small sac of fat-filled visceral peritoneum attached to teniae coli

**external anal sphincter**: voluntary skeletal muscle sphincter in the anal canal

**feces**: semisolid waste product of digestion

**flatus**: gas in the intestine

**gastrocolic reflex**: propulsive movement in the colon activated by the presence of food in the stomach

**gastroileal reflex**: long reflex that increases the strength of segmentation in the ileum

**haustrum**: small pouch in the colon created by tonic contractions of teniae coli

**haustral contraction**: slow segmentation in the large intestine

**hepatopancreatic ampulla**: (also, **ampulla of Vater**) bulb-like point in the wall of the duodenum where the bile duct and main pancreatic duct unite

**hepatopancreatic sphincter**: (also, **sphincter of Oddi**) sphincter regulating the flow of bile and pancreatic juice into the duodenum

**ileocecal sphincter**: sphincter located where the small intestine joins with the large intestine

**ileum**: end of the small intestine between the jejunum and the large intestine

**internal anal sphincter**: involuntary smooth muscle sphincter in the anal canal

**intestinal gland**: (also, crypt of Lieberkühn) gland in the small intestinal mucosa that secretes intestinal juice

**intestinal juice**: mixture of water and mucus that helps absorb nutrients from chyme

**jejunum**: middle part of the small intestine between the duodenum and the ileum

**lacteal**: lymphatic capillary in the villi

**large intestine**: terminal portion of the alimentary canal

**left colic flexure**: (also, splenic flexure) point where the transverse colon curves below the inferior end of the spleen

**main pancreatic duct**: (also, **duct of Wirsung**) duct through which pancreatic juice drains from the pancreas

**major duodenal papilla**: point at which the hepatopancreatic ampulla opens into the duodenum

**mass movement**: long, slow, peristaltic wave in the large intestine

**mesoappendix**: mesentery of the appendix

**microvillus**: small projection of the plasma membrane of the absorptive cells of the small intestinal mucosa

**migrating motility complex**: form of peristalsis in the small intestine

**motilin**: hormone that initiates migrating motility complexes

**pectinate line**: horizontal line that runs like a ring, perpendicular to the inferior margins of the anal sinuses

**rectal valve**: one of three transverse folds in the rectum where feces is separated from flatus

**rectum**: part of the large intestine between the sigmoid colon and anal canal

**right colic flexure**: (also, hepatic flexure) point, at the inferior surface of the liver, where the ascending colon turns abruptly to the left

**saccharolytic** fermentation: anaerobic decomposition of carbohydrates

**sigmoid colon**: end portion of the colon, which terminates at the rectum

**small intestine**: section of the alimentary canal where most digestion and absorption occurs

**tenia coli**: one of three smooth muscle bands that make up the longitudinal muscle layer of the muscularis in all of the large intestine except the terminal end

**transverse colon**: part of the colon between the ascending colon and the descending colon

**Valsalva's maneuver**: voluntary contraction of the diaphragm and abdominal wall muscles and closing of the glottis, which increases intra-abdominal pressure and facilitates defecation

**villus**: projection of the mucosa of the small intestine

*Ha`awina 03: HLTH 140*

# The Genitourinary System

## Hō`ulu`ulu Pōkole (Overview)

The genitourinary system includes the kidneys, ureters, bladder, and urethra. First we will look at the genitourinary system as a whole, then the anatomy of the organs that together make up the genitourinary system. We will also look a little bit into the microscopic structures that make the system function.

## Ke Haumana ka `apo (Student Learning Outcomes)

1. Identify the most important urinary structures
2. Describe the primary functions of the urinary system.
3. Apply terminology of diseases, conditions, and procedures related to the urinary system.
4. Utilize word-building skills by constructing medical terms related to the urinary system.
5. Describe common abbreviations and symbols related to the urinary system.
6. Recognize, define, pronounce, and spell terms correctly.

## Gross Anatomy of Urine Transport

**Summary**

This section will start with urine excretion so we can trace the pathway of urine through the entire organ system.

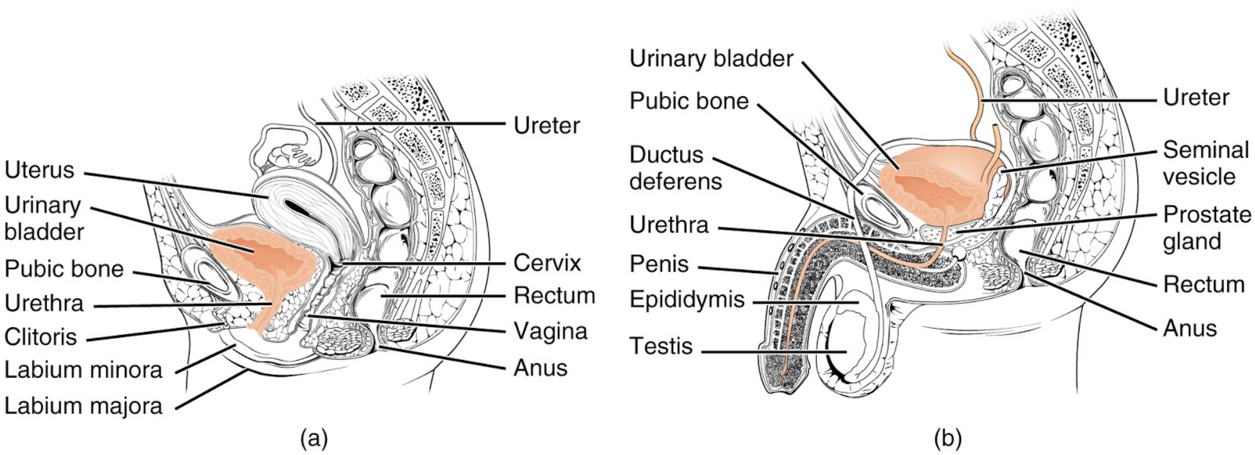
- ❑ Urine is a fluid of variable composition that requires specialized structures to remove it from the body safely and efficiently.
- ❑ Blood is filtered, and the filtrate is transformed into urine at a relatively constant rate throughout the day.
- ❑ This processed liquid is stored until a convenient time for excretion.
- ❑ All structures involved in the transport and storage of the urine are large enough to be visible to the naked eye.
- ❑ This transport and storage system not only stores the waste, but it protects the tissues from damage due to the wide range of pH and osmolarity of the urine, prevents infection by foreign organisms,

and for the male, provides reproductive functions.

## Urethra

The urethra transports urine from the bladder to the outside of the body for disposal. The urethra is the only urologic organ that shows any significant anatomic difference between males and females; all other urine transport structures are identical (Figure).

Female and Male Urethras




The urethra in both males and females begins inferior and central to the two ureteral openings forming the three points of a triangular-shaped area at the base of the bladder called the trigone (Greek tri- = "triangle" and the root of the word "trigonometry"). The urethra tracks posterior and inferior to the pubic symphysis (see Figurea). In both males and females, the proximal urethra is lined by transitional epithelium, whereas the terminal portion is a nonkeratinized, stratified squamous epithelium. In the male, pseudostratified columnar epithelium lines the urethra between these two cell types. Voiding is regulated by an involuntary autonomic nervous system-controlled internal urinary sphincter, consisting of smooth muscle and voluntary skeletal muscle that forms the external urinary sphincter below it.

### Female Urethra

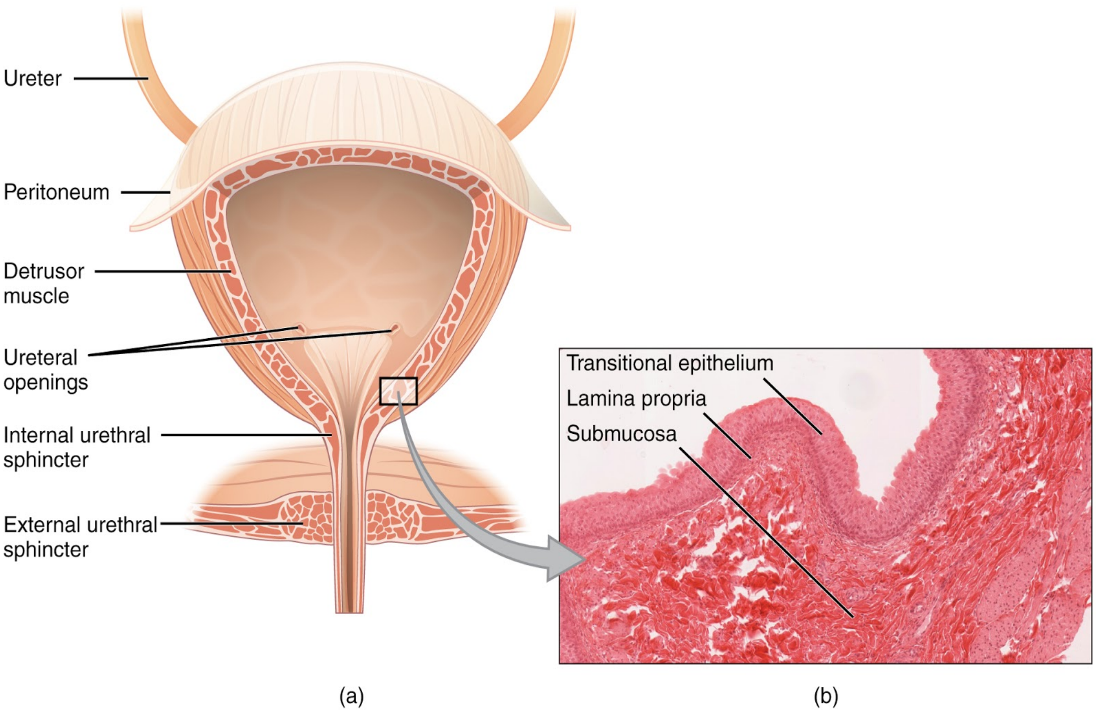
The external urethral orifice is embedded in the anterior vaginal wall inferior to the clitoris, superior to the vaginal opening (introitus), and medial to the labia minora. Its short length, about 4 cm, is less of a barrier to fecal bacteria than the longer male urethra and the best explanation for the greater incidence of UTI in women. Voluntary control of the external urethral sphincter is a function of the pudendal nerve. It arises in the sacral region of the spinal cord, traveling via the S2–S4 nerves of the sacral plexus.

### Male Urethra

The male urethra passes through the prostate gland immediately inferior to the bladder before passing below the pubic symphysis. The length of the male urethra varies between men but averages 20 cm in length. It is divided into four regions: the preprostatic urethra, the prostatic urethra, the membranous urethra, and the spongy or penile urethra. Mucous glands are found along much of the length of the urethra and protect the urethra from extremes of urine pH. Innervation is the same in both males and females.

## Bladder

The urinary bladder collects urine from both ureters (Figure). The bladder lies anterior to the uterus in females, posterior to the pubic bone and anterior to the rectum. In males, the anatomy is similar, minus the uterus, and with the addition of the prostate inferior to the bladder. The bladder is partially retroperitoneal (outside the peritoneal cavity) with its peritoneal-covered "dome" projecting into the abdomen when the bladder is distended with urine.




(a) Anterior cross section of the bladder.

(b) The detrusor muscle of the bladder

(Micrograph provided by the Regents of the University of Michigan Medical School 2012)

The bladder is a highly distensible organ comprised of irregular crisscrossing bands of smooth muscle collectively called the detrusor muscle. The interior surface is made of transitional cellular epithelium that is structurally suited for the large volume fluctuations of the bladder. When empty, it resembles columnar epithelia, but when stretched, it "transitions" (hence the name) to a squamous appearance (see Figure). Volumes in adults can range from nearly zero to 500–600 mL.

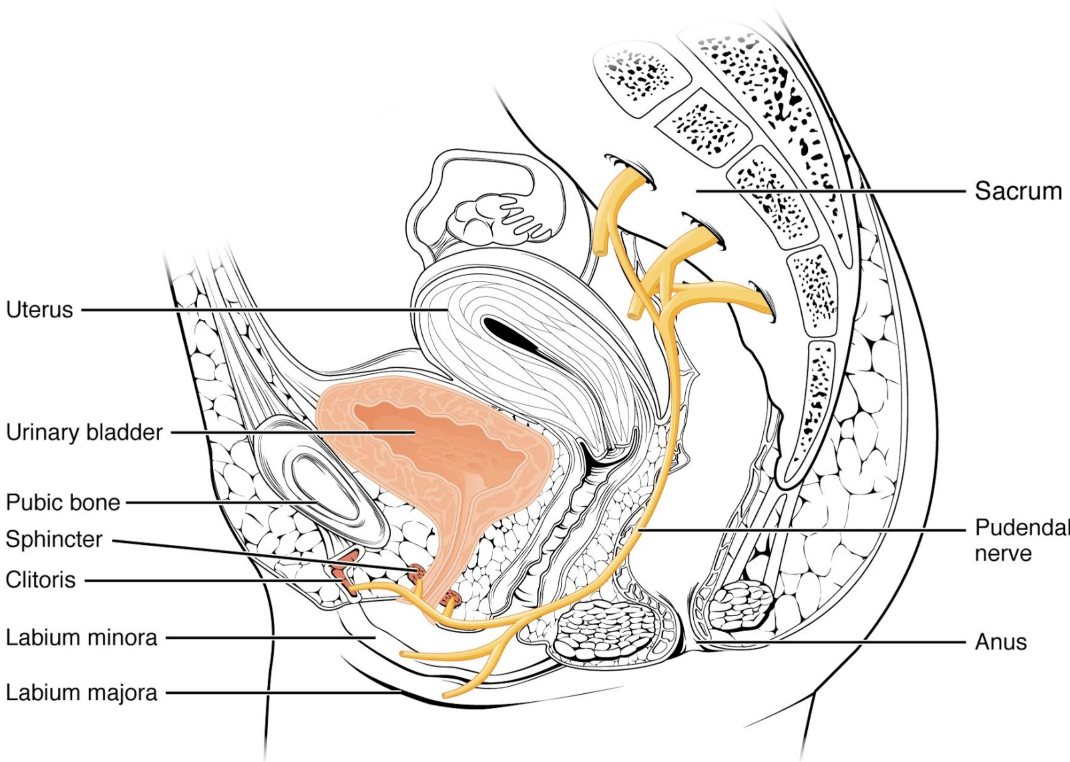
### Micturition Reflex

**Micturition** is a less-often used, but proper term for urination or voiding. It results from an interplay of involuntary and voluntary actions by the internal and external urethral sphincters. When bladder volume reaches about 150 mL, an urge to void is sensed but is easily overridden. Voluntary control of urination relies on consciously preventing relaxation of the external urethral sphincter to maintain urinary continence. As the bladder fills, subsequent urges become harder to ignore. Ultimately, voluntary constraint fails with resulting incontinence, which will occur as bladder volume approaches 300 to 400 mL.

Normal micturition is a result of stretch receptors in the bladder wall that transmit nerve impulses to the sacral region of the spinal cord to generate a spinal reflex. The resulting parasympathetic neural outflow causes contraction of the detrusor muscle and relaxation of the involuntary internal urethral sphincter. At the same time, the spinal cord inhibits somatic motor neurons, resulting in the relaxation of the skeletal muscle of the external urethral sphincter. The micturition reflex is active in infants but with maturity, children learn to override the reflex by asserting external sphincter control, thereby delaying voiding (potty training). This reflex may be preserved even in the face of spinal cord injury that results in paraplegia or quadriplegia. However, relaxation of the external sphincter may not be possible in all cases, and therefore, periodic catheterization may be necessary for bladder emptying.

Nerves involved in the control of urination include the hypogastric, pelvic, and pudendal (Figure). Voluntary micturition requires an intact spinal cord and functional pudendal nerve arising from the sacral micturition center. Since the external urinary sphincter is voluntary skeletal muscle, actions by cholinergic neurons maintain contraction (and thereby continence) during filling of the bladder. At the same time, sympathetic nervous activity via the hypogastric nerves suppresses contraction of the detrusor muscle. With further bladder stretch, afferent signals traveling over sacral pelvic nerves activate parasympathetic neurons. This activates efferent neurons to release acetylcholine at the neuromuscular junctions, producing detrusor contraction and bladder emptying.

Nerves Innervating the Urinary System




## Ureters

The kidneys and ureters are completely **retroperitoneal**, and the bladder has a peritoneal covering only over the dome. As urine is formed, it drains into the calyces of the kidney, which merge to form the funnel-shaped renal pelvis in the hilum of each kidney. The renal pelvis narrows to become the ureter of each kidney. As urine passes through the ureter, it is propelled by waves of peristalsis. As the ureters enter the pelvis, they sweep laterally, hugging the pelvic walls. As they approach the bladder, they turn

(Micrograph provided by the Regents of the University of Michigan Medical School © 2012)

medially and pierce the bladder wall obliquely. This is important because it creates an one-way valve (a physiological sphincter rather than an anatomical sphincter) that allows urine into the bladder but prevents reflux of urine from the bladder back into the ureter. Children born lacking this oblique course of the ureter through the bladder wall are susceptible to “vesicoureteral reflux,” which dramatically increases their risk of serious UTI. Pregnancy also increases the likelihood of reflux and UTI.

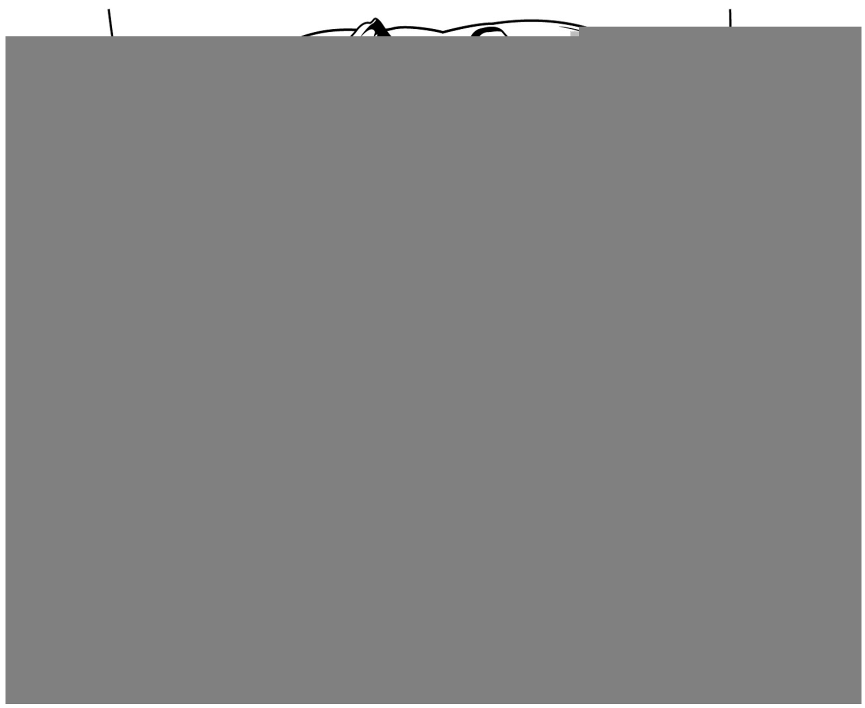
The ureters are approximately 30 cm long. The inner mucosa is lined with transitional epithelium (Figure) and scattered goblet cells that secrete protective mucus. The muscular layer of the ureter consists of longitudinal and circular smooth muscles that create the peristaltic contractions to move the urine into the bladder without the aid of gravity. Finally, a loose adventitial layer composed of collagen and fat anchors the ureters between the parietal peritoneum and the posterior abdominal wall.

# Anatomy of the Kidney

The kidneys lie on either side of the spine in the retroperitoneal space between the parietal peritoneum and the posterior abdominal wall, well protected by muscle, fat, and ribs. They are roughly the size of your fist, and the male kidney is typically a bit larger than the female kidney. The kidneys are well vascularized, receiving about 25 percent of the cardiac output at rest.

## External Anatomy

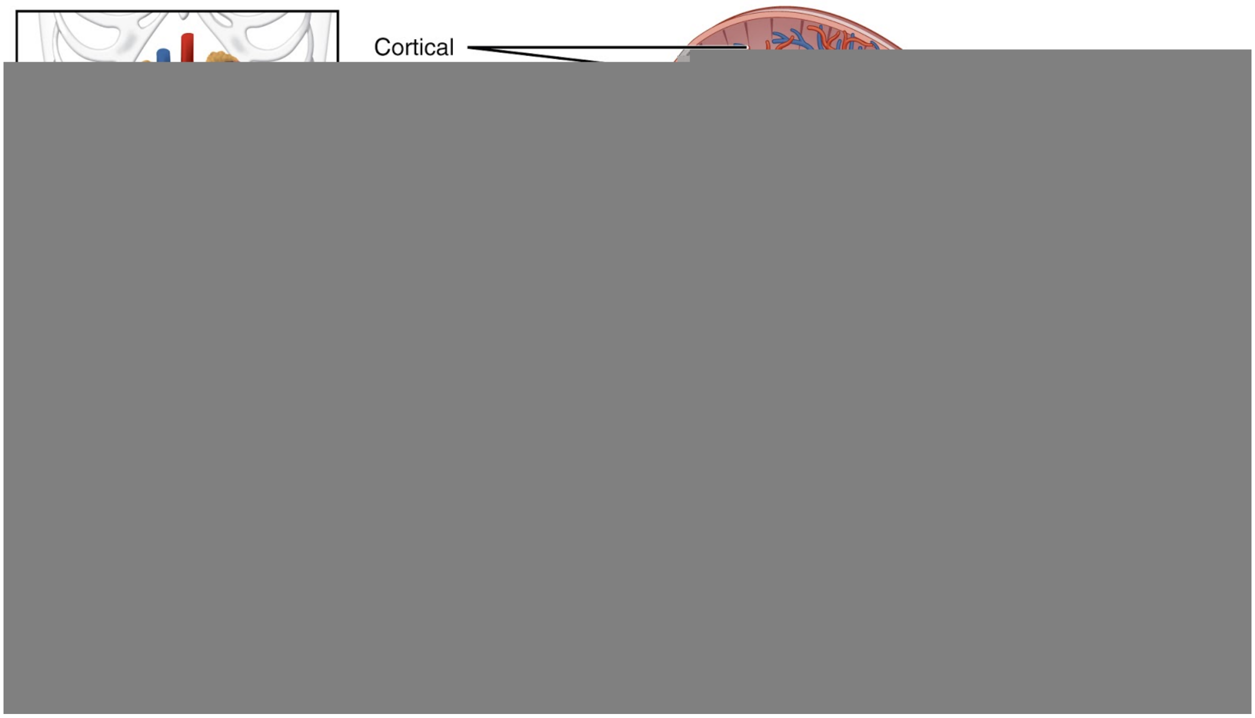
The left kidney is located at about the T12 to L3 vertebrae, whereas the right is lower due to slight displacement by the liver. Upper portions of the kidneys are somewhat protected by the eleventh and twelfth ribs (Figure). Each kidney weighs about 125–175 g in males and 115–155 g in females. They are about 11–14 cm in length, 6 cm wide, and 4 cm thick, and are directly covered by a fibrous capsule composed of dense, irregular connective tissue that helps to hold their shape and protect them. This capsule is covered by a shock-absorbing layer of adipose tissue called the renal fat pad, which in turn is encompassed by a tough renal fascia. The fascia and, to a lesser extent, the overlying peritoneum serve to firmly anchor the kidneys to the posterior abdominal wall in a retroperitoneal position.The kidneys are slightly protected by the ribs and are surrounded by fat for protection (not shown).



## Internal Anatomy

A frontal section through the kidney reveals an outer region called the renal cortex and an inner region called the medulla (Figure). The renal columns are connective tissue extensions that radiate downward from the cortex through the medulla to separate the most characteristic features of the medulla, the renal pyramids and renal papillae. The papillae are bundles of collecting ducts that transport urine made by nephrons to the calyces of the kidney for excretion. The renal columns also serve to divide the kidney into 6–8 lobes and provide a supportive framework for vessels that enter and exit the cortex. The pyramids and renal columns taken together constitute the kidney lobes.

**Left Kidney**




**Renal Hilum**

The renal hilum is the entry and exit site for structures servicing the kidneys: vessels, nerves, lymphatics, and ureters. The medial-facing hila are tucked into the sweeping convex outline of the cortex. Emerging from the hilum is the renal pelvis, which is formed from the major and minor calyxes in the kidney. The smooth muscle in the renal pelvis funnels urine via peristalsis into the ureter. The renal arteries form directly from the descending aorta, whereas the renal veins return cleansed blood directly to the inferior vena cava. The artery, vein, and renal pelvis are arranged in an anterior-to-posterior order.

**Nephrons and Vessels**

**Blood Flow in the Kidney**

**Nephrons** are the “functional units” of the kidney; they cleanse the blood and balance the constituents of the circulation. The afferent arterioles form a tuft of high-pressure capillaries about 200 µm in diameter, the glomerulus. The rest of the nephron consists of a continuous sophisticated tubule whose proximal end surrounds the glomerulus in an intimate embrace—this is **Bowman’s capsule**. The glomerulus and Bowman’s capsule together form the **renal corpuscle**. These glomerular capillaries filter the blood based on particle size. After passing through the renal corpuscle, the capillaries form a second arteriole, the **efferent arteriole** (Figure). These will next form a capillary network around the more distal portions of the nephron tubule, the **peritubular capillaries** and **vasa recta**, before returning to the venous system. As the glomerular filtrate progresses through the nephron, these capillary networks recover most of the solutes and water, and return them to the circulation.

**Blood Flow in the Nephron**

The two capillary beds are clearly shown in this figure. The efferent arteriole is the connecting vessel between the glomerulus and the peritubular capillaries and vasa recta.

Visit this link to view an interactive tutorial of the flow of blood through the kidney.

### Cortex

In a dissected kidney, it is easy to identify the cortex; it appears lighter in color compared to the rest of the kidney. All of the renal corpuscles as well as both the proximal convoluted tubules (PCTs) and distal convoluted tubules are found here. Some nephrons have a short loop of Henle that does not dip beyond the cortex. These nephrons are called cortical nephrons. About 15 percent of nephrons have long loops of Henle that extend deep into the medulla and are called juxtamedullary nephrons.

## Glossary

**anatomical sphincter**: smooth or skeletal muscle surrounding the lumen of a vessel or hollow organ that can restrict flow when contracted

**detrusor muscle**: smooth muscle in the bladder wall; fibers run in all directions to reduce the size of the organ when emptying it of urine

**external urinary sphincter**: skeletal muscle; must be relaxed consciously to void urine

**internal urinary sphincte**r: smooth muscle at the juncture of the bladder and urethra; relaxes as the bladder fills to allow urine into the urethra

**incontinence**: loss of ability to control micturition

**micturition**: also called urination or voiding

**physiological sphincter**: sphincter consisting of circular smooth muscle indistinguishable from adjacent muscle but possessing differential innervations, permitting its function as a sphincter; structurally weak

**retroperitoneal**: outside the peritoneal cavity; in the case of the kidney and ureters, between the parietal peritoneum and the abdominal wall

**sacral micturition center**: group of neurons in the sacral region of the spinal cord that controls urination; acts reflexively unless its action is modified by higher brain centers to allow voluntary urination

**trigone**: area at the base of the bladder marked by the two ureters in the posterior–lateral aspect and the urethral orifice in the anterior aspect oriented like points on a triangle

**urethra**: transports urine from the bladder to the outside environment

## Kidneys

**Bowman's capsule**: cup-shaped sack lined by a simple squamous epithelium (parietal surface) and specialized cells called podocytes (visceral surface) that participate in the filtration process; receives the filtrate which then passes on to the PCTs

**calyces**: cup-like structures receiving urine from the collecting ducts where it passes on to the renal pelvis

**cortical nephrons**: nephrons with loops of Henle that do not extend into the renal medulla

**distal convoluted tubules**: portions of the nephron distal to the loop of Henle that receive hyposmotic filtrate from the loop of Henle and empty into collecting ducts

**efferent arteriole**: arteriole carrying blood from the glomerulus to the capillary beds around the convoluted tubules and loop of Henle; portion of the portal system

**glomerulus**: tuft of capillaries surrounded by Bowman's capsule; filters the blood based on size

**juxtamedullary nephrons**: nephrons adjacent to the border of the cortex and medulla with loops of Henle that extend into the renal medulla

**loop of Henle**: descending and ascending portions between the proximal and distal convoluted tubules; those of cortical nephrons do not extend into the medulla, whereas those of juxtamedullary nephrons do extend into the medulla

**nephrons**: functional units of the kidney that carry out all filtration and modification to produce urine; consist of renal corpuscles, proximal and distal convoluted tubules, and descending and ascending loops of Henle; drain into collecting ducts

**medulla**: inner region of kidney containing the renal pyramids

**peritubular capillaries**: second capillary bed of the renal portal system; surround the proximal and distal convoluted tubules; associated with the vasa recta

**proximal convoluted tubule**s (PCTs): tortuous tubules receiving filtrate from Bowman's capsule; most active part of the nephron in reabsorption and secretion

**renal column**s: extensions of the renal cortex into the renal medulla; separates the renal pyramids; contains blood vessels and connective tissues

**renal corpuscle**: consists of the glomerulus and Bowman's capsule

**renal cortex**: outer part of kidney containing all of the nephrons; some nephrons have loops of Henle extending into the medulla

**renal fat pad**: adipose tissue between the renal fascia and the renal capsule that provides protective cushioning to the kidney

**renal hilum**: recessed medial area of the kidney through which the renal artery, renal vein, ureters, lymphatics, and nerves pass

**renal papillae**: medullary area of the renal pyramids where collecting ducts empty urine into the minor calyces

**renal pyramids**: six to eight cone-shaped tissues in the medulla of the kidney containing collecting ducts and the loops of Henle of juxtamedullary nephrons

**vasa recta**: branches of the efferent arterioles that parallel the course of the loops of Henle and are continuous with the peritubular capillaries; with the glomerulus, form a portal system

*Ha`awina 08: HLTH 140*

# The Female Reproductive System

## Hō`ulu`ulu Pōkole (Overview)

The female reproductive system functions to produce gametes and reproductive hormones. But the female reproductive system has the additional task of supporting the developing fetus and delivering it to the outside world. Unlike its male counterpart, the female reproductive system is located primarily inside the pelvic cavity (Figure). Recall that the ovaries are the female gonads. The gamete they produce is called an oocyte. We'll discuss the production of oocytes in detail shortly. First, let's look at some of the structures of the female reproductive system.

## Ke Haumana ka `apo (Student Learning Outcomes)

1. Identify female reproductive structures,
2. Describe the primary functions of the female reproductive systems
3. Apply word building skills by constructing medical terms related to reproductive systems.
4. Describe common abbreviations used to describe reproductive structures, functions, and medical procedures.
5. Recognize, define, pronounce and spell medical terminology related to the reproductive system correctly

# Anatomy of the Female Reproductive System

**Female Reproductive System**

The major organs of the female reproductive system are located inside the pelvic cavity.

## External Female Genitals

The external female reproductive structures are referred to collectively as the **vulva** (Figure). The **mons pubis** is a pad of fat that is located at the anterior, over the pubic bone. After puberty, it becomes covered in pubic hair. The **labia majora** (labia = "lips"; majora = "larger") are folds of hair-covered skin that begin just posterior to the mons pubis. The thinner and more pigmented **labia minora** (labia = "lips"; minora = "smaller") extend medial to the labia majora. Although they naturally vary in shape and size from woman to woman, the labia minora serve to protect the female urethra and the entrance to the female reproductive tract.

The superior, anterior portions of the labia minora come together to encircle the **clitoris** (or **glans clitoris**), an organ that originates from the same cells as the **glans penis** and has abundant nerves that make it important in sexual sensation and orgasm. The **hymen** is a thin membrane that sometimes partially covers the entrance to the **vagina**. An intact hymen cannot be used as an indication of "virginity"; even at birth, this is only a partial membrane, as menstrual fluid and other secretions must be able to exit the body, regardless of penile–vaginal intercourse. The vaginal opening is located between the opening of the urethra and the anus. It is flanked by outlets to the **Bartholin's glands** (or **greater vestibular glands**).

**The Vulva**

The external female genitalia are referred to collectively as the vulva.

### Vagina

The vagina is a muscular canal (approximately 10 cm long) that serves as the entrance to the reproductive tract. It also serves as the exit from the uterus during menses and childbirth. The outer walls of the anterior and posterior vagina are formed into longitudinal columns, or ridges, and the superior portion of the vagina—called the **fornix**—meets the protruding **uterine cervix**. The walls of the vagina are lined with an outer, fibrous adventitia; a middle layer of smooth muscle; and an inner mucous membrane with transverse folds called **rugae**. Together, the middle and inner layers allow the expansion of the vagina to accommodate **intercourse** and **childbirth**. The thin, perforated hymen can partially surround the opening to the vaginal orifice. The hymen can be ruptured with strenuous physical exercise, penile–vaginal intercourse, and childbirth. The Bartholin's glands and the lesser vestibular glands (located near the clitoris) secrete mucus, which keeps the vestibular area moist.

The vagina is home to a normal population of microorganisms that help to protect against infection by pathogenic bacteria, yeast, or other organisms that can enter the vagina. In a healthy woman, the most predominant type of vaginal bacteria is from the genus **Lactobacillus**. This family of beneficial bacterial flora secretes lactic acid, and thus protects the vagina by maintaining an acidic pH (below 4.5). Potential pathogens are less likely to survive in these acidic conditions. Lactic acid, in combination with other vaginal secretions, makes the vagina a self-cleansing organ.

### Ovaries

The ovaries are the female gonads (see Figure). Paired ovals, they are each about 2 to 3 cm in length, about the size of an almond. The ovaries are located within the pelvic cavity. The ovary comprises an outer covering of cuboidal epithelium called the **ovarian surface epithelium** that is superficial to a dense connective tissue covering called the **tunica albuginea**. Beneath the tunica albuginea is the **cortex**, or outer portion, of the organ. The cortex is composed of a tissue framework called the **ovarian stroma** that forms the bulk of the adult ovary. **Oocytes** develop within the outer layer of this stroma, each surrounded by supporting cells. This grouping of an oocyte and its supporting cells is called a **follicle**. Beneath the cortex lies the **inner ovarian medulla**, the site of blood vessels, lymph vessels, and the nerves of the ovary.

## The Ovarian Cycle

The ovarian cycle is a set of changes in a female's oocytes and ovarian follicles. During a woman's reproductive years, it is a roughly 28-day cycle that can be correlated with, but is not the same as, the menstrual cycle (discussed shortly). The cycle includes two interrelated processes: oogenesis (the production of female gametes) and folliculogenesis (the growth and development of ovarian follicles).

### Oogenesis

The process begins with the **ovarian stem cells**, or **oogonia** (Figure). Oogonia are formed during fetal development, and divide via **mitosis**, much like spermatogonia in the testis. Unlike spermatogonia, however, oogonia form **primary oocytes** in the fetal ovary prior to birth. These primary oocytes are then arrested in this stage of **meiosis I**, only to resume it years later, beginning at puberty and continuing until the woman is near **menopause** (the cessation of a woman's reproductive functions). The number of primary oocytes present in the ovaries declines from one to two million in an infant, to approximately 400,000 at puberty, to zero by the end of menopause.

The initiation of **ovulation**—the release of an oocyte from the ovary—marks the transition from puberty into reproductive maturity for women. From then on, throughout a woman's reproductive years, ovulation occurs approximately once every 28 days. Just prior to ovulation, a surge of luteinizing hormone triggers the resumption of meiosis in a primary oocyte. This initiates the transition from primary to secondary oocyte. However, as you can see in Figure, this cell division does not result in two identical cells. Instead, the cytoplasm is divided unequally, and one daughter cell is much larger than the other. This larger cell, the secondary oocyte, eventually leaves the ovary during ovulation. The smaller cell, called the first polar body, may or may not complete meiosis and produce second polar bodies; in either case, it eventually disintegrates. Therefore, even though oogenesis produces up to four cells, only one survives.

**Oogenesis**

The unequal cell division of oogenesis produces one to three polar bodies that later degrade, as well as a single haploid ovum, which is produced only if there is penetration of the secondary oocyte by a sperm cell.

Meiosis of a secondary oocyte is completed only if a sperm succeeds in penetrating its barriers. Meiosis II then resumes, producing one haploid ovum that, at the instant of fertilization by a (haploid) sperm, becomes the first diploid cell of  a zygote. Thus, the ovum can be thought of as a brief, transitional, haploid stage between the diploid oocyte and diploid zygote. Sperm contribute only DNA at fertilization —not cytoplasm. Therefore, the cytoplasm and all of the cytoplasmic organelles in the developing embryo are of maternal origin. This includes mitochondria, which contain their own DNA.

## The Uterine Tubes

The uterine tubes (also called fallopian tubes or oviducts) serve as the conduit of the oocyte from the ovary to the uterus (Figure). Each of the two uterine tubes is close to, but not directly connected to, the ovary and divided into sections. The isthmus is the narrow medial end of each uterine tube that is connected to the uterus. The wide distal infundibulum flares out with slender, finger-like projections called fimbriae. The middle region of the tube, called the ampulla, is where fertilization often occurs. The uterine tubes also have three layers: an outer serosa, a middle smooth muscle layer, and an inner mucosal layer. In addition to its mucus-secreting cells, the inner mucosa contains ciliated cells that beat in the direction of the uterus, producing a current that will be critical to move the oocyte.

Following ovulation, the secondary oocyte surrounded by a few granulosa cells is released into the peritoneal cavity. The nearby uterine tube, either left or right, receives the oocyte. Unlike sperm, oocytes lack **flagella**, and therefore cannot move on their own. So how do they travel into the uterine tube and toward the uterus? High concentrations of estrogen that occur around the time of ovulation induce contractions of the smooth muscle along the length of the uterine tube. These contractions occur every 4 to 8 seconds, and the result is a coordinated movement that sweeps the surface of the ovary and the pelvic cavity. Current flowing toward the uterus is generated by coordinated beating of the cilia that line the outside and lumen of the length of the uterine tube. These cilia beat more strongly in response to the high estrogen concentrations that occur around the time of ovulation. As a result of these mechanisms, the oocyte–granulosa cell complex is pulled into the interior of the tube. Once inside, the muscular contractions and beating cilia move the oocyte slowly toward the uterus. When fertilization does occur, sperm typically meet the egg while it is still moving through the ampulla.

If the oocyte is successfully fertilized, the resulting zygote will begin to divide into two cells, then four, and so on, as it makes its way through the uterine tube and into the uterus. There, it will implant and continue to grow. If the egg is not fertilized, it will simply degrade—either in the uterine tube or in the uterus, where it may be shed with the next menstrual period.

## The Uterus and Cervix

The uterus is the muscular organ that nourishes and supports the growing embryo (see Figure). Its average size is approximately 5 cm wide by 7 cm long (approximately 2 in by 3 in) when a female is not pregnant. It has three sections. The portion of the uterus superior to the opening of the uterine tubes is called the fundus. The middle section of the uterus is called the body of uterus (or corpus). The cervix is the narrow inferior portion of the uterus that projects into the vagina. The cervix produces mucus secretions that become thin and stringy under the influence of high systemic plasma estrogen concentrations, and these secretions can facilitate sperm movement through the reproductive tract.

The wall of the uterus is made up of three layers. The most superficial layer is the serous membrane, or perimetrium, which consists of epithelial tissue that covers the exterior portion of the uterus. The middle layer, or myometrium, is a thick layer of smooth muscle responsible for uterine contractions. Most of the uterus is myometrial tissue, and the muscle fibers run horizontally, vertically, and diagonally, allowing the powerful contractions that occur during labor and the less powerful contractions (or cramps) that help to expel menstrual blood during a woman's period.

The innermost layer of the uterus is called the endometrium. The endometrium contains a connective tissue lining, the lamina propria, which is covered by epithelial tissue that lines the lumen. Structurally, the endometrium consists of two layers: the stratum basalis and the stratum functionalis (the basal and functional layers). The stratum functionalis layer contains the glandular portion of the lamina propria and the endothelial tissue that lines the uterine lumen. It is the stratum functionalis that grows and thickens in response to increased levels of estrogen and progesterone. It is only the stratum functionalis layer of the endometrium that sheds during menstruation.

As long as a functional **corpus luteum** is present in the ovary, the endometrial lining is prepared for implantation. Indeed, if an embryo implants, signals are sent to the corpus luteum to continue secreting progesterone to maintain the endometrium, and thus maintain the pregnancy. If an embryo does not implant, no signal is sent to the corpus luteum and it degrades, ceasing progesterone production and ending the luteal phase. Without progesterone, endometrial tissue dies and blood, pieces of the endometrial tissue, and white blood cells are shed during **menses**.

## The Menstrual Cycle

The timing of the menstrual cycle starts with the first day of menses, referred to as day one of a woman's period. Cycle length is determined by counting the days between the onset of bleeding in two subsequent cycles. Because the average length of a woman's menstrual cycle is 28 days, this is the time period used to identify the timing of events in the cycle. However, the length of the menstrual cycle varies among women, and even in the same woman from one cycle to the next, typically from 21 to 32 days.

### Menses Phase

The menses phase of the menstrual cycle is the phase during which the lining is shed; that is, the days that the woman menstruates. Although it averages approximately five days, the menses phase can last from 2 to 7 days, or longer. The menses phase occurs during the early days of the follicular phase of the ovarian cycle, when progesterone, FSH, and LH levels are low.

### Proliferative Phase

Once menstrual flow ceases, the endometrium begins to proliferate again, marking the beginning of the proliferative phase of the menstrual cycle (see Figure). It occurs when the granulosa and theca cells of the tertiary follicles begin to produce increased amounts of estrogen. These rising estrogen concentrations stimulate the endometrial lining to rebuild. In a typical 28-day menstrual cycle, ovulation occurs on day 14. Ovulation marks the end of the proliferative phase as well as the end of the follicular phase.

### Secretory Phase

In addition to prompting the LH surge, high estrogen levels increase the uterine tube contractions that facilitate the pick-up and transfer of the ovulated oocyte. High estrogen levels also slightly decrease the acidity of the vagina, making it more hospitable to sperm. In the ovary, the luteinization of the granulosa cells of the collapsed follicle forms the progesterone-producing corpus luteum, marking the beginning of the **luteal phase** of the ovarian cycle. In the uterus, progesterone from the corpus luteum begins the secretory phase of the menstrual cycle, in which the endometrial lining prepares for implantation (see Figure). Over the next 10 to 12 days, the endometrial glands secrete a fluid rich in glycogen. If fertilization has occurred, this fluid will nourish the ball of cells now developing from the zygote. At the same time, the spiral arteries develop to provide blood to the thickened stratum functionalis.

If no pregnancy occurs within approximately 10 to 12 days, the corpus luteum will degrade into the **corpus albicans**. Levels of both estrogen and progesterone will fall, and the endometrium will grow thinner. Prostaglandins will be secreted that cause constriction of the spiral arteries, reducing oxygen supply. The endometrial tissue will die, resulting in menses—or the first day of the next cycle.

## The Breasts

Whereas the breasts are located far from the other female reproductive organs, they are considered accessory organs of the female reproductive system. The function of the breasts is to supply milk to an infant in a process called lactation. The external features of the breast include a nipple surrounded by a pigmented areola (Figure), whose coloration may deepen during pregnancy. The areola is typically circular and can vary in size from 25 to 100 mm in diameter. The areolar region is characterized by small, raised areolar glands that secrete lubricating fluid during lactation to protect the nipple from chafing. When a baby nurses, or draws milk from the breast, the entire areolar region is taken into the mouth.

Breast milk is produced by the mammary glands, which are modified sweat glands. The milk itself exits the breast through the nipple via 15 to 20 **lactiferous ducts** that open on the surface of the nipple. These lactiferous ducts each extend to a lactiferous sinus that connects to a glandular lobe within the breast itself that contains groups of milk-secreting cells in clusters called alveoli (see Figure). The clusters can change in size depending on the amount of milk in the alveolar lumen. Once milk is made in the alveoli, stimulated **myoepithelial** cells that surround the alveoli contract to push the milk to the **lactiferous sinuses**. From here, the baby can draw milk through the lactiferous ducts by **suckling**. The lobes themselves are surrounded by fat tissue, which determines the size of the breast; breast size differs between individuals and does not affect the amount of milk produced. Supporting the breasts are multiple bands of connective tissue called suspensory ligaments that connect the breast tissue to the dermis of the overlying skin.

**Anatomy of the Breast**

During lactation, milk moves from the alveoli through the lactiferous ducts to the nipple.

During the normal hormonal fluctuations in the menstrual cycle, breast tissue responds to changing levels of estrogen and progesterone, which can lead to swelling and breast tenderness in some individuals, especially during the secretory phase. If pregnancy occurs, the increase in hormones leads to further development of the mammary tissue and enlargement of the breasts.

Female Reproductive System Review

The external female genitalia are collectively called the vulva. The vagina is the pathway into and out of the uterus. The man's penis is inserted into the vagina to deliver sperm, and the baby exits the uterus through the vagina during childbirth.

The ovaries produce oocytes, the female gametes, in a process called oogenesis. As with spermatogenesis, meiosis produces the haploid gamete (in this case, an ovum); however, it is completed only in an oocyte that has been penetrated by a sperm. In the ovary, an oocyte surrounded by supporting cells is called a follicle. In folliculogenesis, primordial follicles develop into primary, secondary, and tertiary follicles. Early tertiary follicles with their fluid-filled antrum will be stimulated by an increase in FSH, a gonadotropin produced by the anterior pituitary, to grow in the 28-day ovarian cycle. Supporting granulosa and theca cells in the growing follicles produce estrogens, until the level of estrogen in the bloodstream is high enough that it triggers negative feedback at the hypothalamus and pituitary. This results in a reduction of FSH and LH, and most tertiary follicles in the ovary undergo atresia (they die). One follicle, usually the one with the most FSH receptors, survives this period and is now called the dominant follicle. The dominant follicle produces more estrogen, triggering positive feedback and the LH surge that will induce ovulation. Following ovulation, the granulosa cells of the empty follicle luteinize and transform into the progesterone-producing corpus luteum. The ovulated oocyte with its surrounding granulosa cells is picked up by the infundibulum of the uterine tube, and beating cilia help to transport it through the tube toward the uterus. Fertilization occurs within the uterine tube, and the final stage of meiosis is completed.

The uterus has three regions: the fundus, the body, and the cervix. It has three layers: the outer perimetrium, the muscular myometrium, and the inner endometrium. The endometrium responds to estrogen released by the follicles during the menstrual cycle and grows thicker with an increase in blood vessels in preparation for pregnancy. If the egg is not fertilized, no signal is sent to extend the life of the corpus luteum, and it degrades, stopping progesterone production. This decline in progesterone results in the sloughing of the inner portion of the endometrium in a process called menses, or menstruation.

The breasts are accessory sexual organs that are utilized after the birth of a child to produce milk in a process called lactation. Birth control pills provide constant levels of estrogen and progesterone to negatively feed back on the hypothalamus and pituitary, and suppress the release of FSH and LH, which inhibits ovulation and prevents pregnancy.

# Glossary

**alveoli**: (of the breast) milk-secreting cells in the mammary gland

**ampulla**: (of the uterine tube) middle portion of the uterine tube in which fertilization often occurs

**antrum**: fluid-filled chamber that characterizes a mature tertiary (antral) follicle

**areola**: highly pigmented, circular area surrounding the raised nipple and containing areolar glands that secrete fluid important for lubrication during suckling

**Bartholin's glands**: (also, greater vestibular glands) glands that produce a thick mucus that maintains moisture in the vulva area; also referred to as the greater vestibular glands

**body of uterus**: middle section of the uterus

**broad ligament**: wide ligament that supports the uterus by attaching laterally to both sides of the uterus and pelvic wall

**cervix**: elongate inferior end of the uterus where it connects to the vagina

**clitoris**: (also, glans clitoris) nerve-rich area of the vulva that contributes to sexual sensation during intercourse

**corpus albicans**: nonfunctional structure remaining in the ovarian stroma following structural and functional regression of the corpus luteum

**corpus luteum**: transformed follicle after ovulation that secretes progesterone

**endometrium**: inner lining of the uterus, part of which builds up during the secretory phase of the menstrual cycle and then sheds with menses

**fimbriae**: fingerlike projections on the distal uterine tubes

**follicle**: ovarian structure of one oocyte and surrounding granulosa (and later theca) cells

**folliculogenesis**: development of ovarian follicles from primordial to tertiary under the stimulation of gonadotropins

**fundus**: (of the uterus) domed portion of the uterus that is superior to the uterine tubes

**granulosa cells**: supportive cells in the ovarian follicle that produce estrogen

**hymen**: membrane that covers part of the opening of the vagina

**infundibulum**: (of the uterine tube) wide, distal portion of the uterine tube terminating in fimbriae

**isthmus**: narrow, medial portion of the uterine tube that joins the uterus

**labia majora**: hair-covered folds of skin located behind the mons pubis

**labia minora**: thin, pigmented, hairless flaps of skin located medial and deep to the labia majora

**lactiferous ducts**: ducts that connect the mammary glands to the nipple and allow for the transport of milk

**lactiferous sinus**: area of milk collection between alveoli and lactiferous duct

**mammary glands**: glands inside the breast that secrete milk

**menarche**: first menstruation in a pubertal female

**menses**: shedding of the inner portion of the endometrium out though the vagina; also referred to as menstruation

**menses phase**: phase of the menstrual cycle in which the endometrial lining is shed

**menstrual cycle**: approximately 28-day cycle of changes in the uterus consisting of a menses phase, a proliferative phase, and a secretory phase

**mons pubis**: mound of fatty tissue located at the front of the vulva

**myometrium**: smooth muscle layer of uterus that allows for uterine contractions during labor and expulsion of menstrual blood

**oocyte**: cell that results from the division of the oogonium and undergoes meiosis I at the LH surge and meiosis II at fertilization to become a haploid ovum

**oogenesis**: process by which oogonia divide by mitosis to primary oocytes, which undergo meiosis to produce the secondary oocyte and, upon fertilization, the ovum

**oogonia**: ovarian stem cells that undergo mitosis during female fetal development to form primary oocytes

**ovarian cycle**: approximately 28-day cycle of changes in the ovary consisting of a follicular phase and a luteal phase

**ovaries**: female gonads that produce oocytes and sex steroid hormones (notably estrogen and progesterone)

**ovulation**: release of a secondary oocyte and associated granulosa cells from an ovary

**ovum**: haploid female gamete resulting from completion of meiosis II at fertilization

**perimetrium**: outer epithelial layer of uterine wall

**polar body**: smaller cell produced during the process of meiosis in oogenesis

**primary follicles**: ovarian follicles with a primary oocyte and one layer of cuboidal granulosa cells

**primordial follicles**: least developed ovarian follicles that consist of a single oocyte and a single layer of flat (squamous) granulosa cells

**proliferative phase**: phase of the menstrual cycle in which the endometrium proliferates

**rugae**: (of the vagina) folds of skin in the vagina that allow it to stretch during intercourse and childbirth

**secondary follicles**: ovarian follicles with a primary oocyte and multiple layers of granulosa cells

**secretory phase**: phase of the menstrual cycle in which the endometrium secretes a nutrient-rich fluid in preparation for implantation of an embryo

**suspensory ligaments**: bands of connective tissue that suspend the breast onto the chest wall by attachment to the overlying dermis

**tertiary follicles**: (also, antral follicles) ovarian follicles with a primary or secondary oocyte, multiple layers of granulosa cells, and a fully formed antrum

**theca cells**: estrogen-producing cells in a maturing ovarian follicle

**uterine tube**s: (also, **fallopian tubes** or **oviducts**) ducts that facilitate transport of an ovulated oocyte to the uterus

**uterus**: muscular hollow organ in which a fertilized egg develops into a fetus

**vagina**: tunnel-like organ that provides access to the uterus for the insertion of semen and from the uterus for the birth of a baby

**vulva**: external female genitalia

*Ha`awina 08: HLTH 140*

# The Male Reproductive System

## Hō`ulu`ulu Pōkole (Overview)

The function of the male reproductive system is to produce sperm and transfer them to the female reproductive tract. The paired testes are a crucial component in this process, as they produce both sperm and androgens, the hormones that support male reproductive physiology. In humans, the most important male androgen is testosterone. Several accessory organs and ducts aid the process of sperm maturation and transport the sperm and other seminal components to the penis, which delivers sperm to the female reproductive tract. In this section, we examine each of these different structures, and discuss the process of sperm production and transport.

## Ke Haumana ka `apo (Student Learning Outcomes)

1. Identify male reproductive structures,
2. Describe the primary functions of the male reproductive systems
3. Apply word building skills by constructing medical terms related to reproductive systems.
4. Describe common abbreviations used to describe reproductive structures, functions, and medical procedures.
5. Recognize, define, pronounce and spell medical terminology related to the reproductive system correctly.

**Male Reproductive System**

The structures of the male reproductive system include the **testes**, the **epididymides**, the penis, and the ducts and glands that produce and carry **semen**. Sperm exit the **scrotum** through the **ductus deferens**, which is bundled in the **spermatic cord**. The **seminal vesicles** and **prostate gland** add fluids to the **sperm** to create semen.

## Scrotum

The testes are located in a skin-covered, highly pigmented, muscular sack called the scrotum that extends from the body behind the penis (see Figure). This location is important in sperm production, which occurs within the testes, and proceeds more efficiently when the testes are kept 2 to 4°C below core body temperature.

The dartos muscle makes up the subcutaneous muscle layer of the scrotum (Figure). It continues internally to make up the scrotal septum, a wall that divides the scrotum into two compartments, each housing one testis. Descending from the internal oblique muscle of the abdominal wall are the two cremaster muscles, which cover each testis like a muscular net. By contracting simultaneously, the dartos and cremaster muscles can elevate the testes in cold weather (or water), moving the testes closer to the body and decreasing the surface area of the scrotum to retain heat. Alternatively, as the environmental temperature increases, the scrotum relaxes, moving the testes farther from the body core and increasing scrotal surface area, which promotes heat loss. Externally, the scrotum has a raised medial thickening on the surface called the raphae.

The Scrotum and Testes

This anterior view shows the structures of the scrotum and testes.

## Testes

The testes (singular = testis) are the male gonads—that is, the male reproductive organs. They produce both sperm and androgens, such as testosterone, and are active throughout the reproductive lifespan of the male.

Paired ovals, the testes are each approximately 4 to 5 cm in length and are housed within the scrotum (see Figure). They are surrounded by two distinct layers of protective connective tissue (Figure). The outer **tunica vaginalis** is a serous membrane that has both a **parietal** and a thin **visceral** layer. Beneath the tunica vaginalis is the **tunica albuginea**, a tough, white, dense connective tissue layer covering the testis itself. Not only does the tunica albuginea cover the outside of the testis, it also invaginates to form septa that divide the testis into 300 to 400 structures called **lobules**. Within the lobules, sperm develop in structures called **seminiferous tubules**. During the seventh month of the developmental period of a male fetus, each testis moves through the abdominal musculature to descend into the scrotal cavity. This is called the "descent of the testis." **Cryptorchidism** is the clinical term used when one or both of the testes fail to descend into the scrotum prior to birth.

**Anatomy of the Testis**

This sagittal view shows the seminiferous tubules, the site of sperm production. Formed sperm are transferred to the epididymis, where they mature. They leave the epididymis during an ejaculation via the ductus deferens.

The tightly coiled seminiferous tubules form the bulk of each testis. They are composed of developing sperm cells surrounding a lumen, the hollow center of the tubule, where formed sperm are released into the duct system of the testis. Specifically, from the lumens of the seminiferous tubules, sperm move into the straight tubules (or tubuli recti), and from there into a fine meshwork of tubules called the rete testes. Sperm leave the rete testes, and the testis itself, through the 15 to 20 efferent ductules that cross the tunica albuginea.

Inside the seminiferous tubules are six different cell types. These include supporting cells called sustentacular cells, as well as five types of developing sperm cells called germ cells. Germ cell development progresses from the basement membrane—at the perimeter of the tubule—toward the lumen. Let's look more closely at these cell types.

### Sertoli Cells

Surrounding all stages of the developing sperm cells are elongate, branching Sertoli cells. Sertoli cells are a type of supporting cell called a sustentacular cell, or sustentocyte, that are typically found in epithelial tissue. Sertoli cells secrete signaling molecules that promote sperm production and can control whether germ cells live or die. They extend physically around the germ cells from the peripheral basement membrane of the seminiferous tubules to the lumen. Tight junctions between these sustentacular cells create the blood–testis barrier, which keeps bloodborne substances from reaching the germ cells and, at the same time, keeps surface antigens on developing germ cells from escaping into the bloodstream and prompting an autoimmune response.

### Germ Cells

The least mature cells, the spermatogonia (singular = spermatogonium), line the basement membrane inside the tubule. Spermatogonia are the stem cells of the testis, which means that they are still able to differentiate into a variety of different cell types throughout adulthood. Spermatogonia divide to produce primary and secondary spermatocytes, then spermatids, which finally produce formed sperm. The process that begins with spermatogonia and concludes with the production of sperm is called spermatogenesis.

### Spermatogenesis

As just noted, spermatogenesis occurs in the seminiferous tubules that form the bulk of each testis (see Figure). The process begins at puberty, after which time sperm are produced constantly throughout a man's life. One production cycle, from spermatogonia through formed sperm, takes approximately 64 days. A new cycle starts approximately every 16 days, although this timing is not synchronous across the seminiferous tubules. Sperm counts—the total number of sperm a man produces—slowly decline after age 35, and some studies suggest that smoking can lower sperm counts irrespective of age.

The process of spermatogenesis begins with mitosis of the diploid spermatogonia (Figure). Because these cells are diploid (2n), they each have a complete copy of the father's genetic material, or 46 chromosomes. However, mature gametes are haploid (1n), containing 23 chromosomes—meaning that daughter cells of spermatogonia must undergo a second cellular division through the process of meiosis.

## Spermatogenesis

(a) Mitosis of a spermatogonial stem cell involves a single cell division that results in two identical, diploid daughter cells (spermatogonia to primary spermatocyte). Meiosis has two rounds of cell division: primary spermatocyte to secondary spermatocyte, and then secondary spermatocyte to spermatid. This produces four haploid daughter cells (spermatids). (b) In this electron micrograph of a cross-section of a seminiferous tubule from a rat, the lumen is the light-shaded area in the center of the image. The location of the primary spermatocytes is near the basement membrane, and the early spermatids are approaching the lumen (tissue source: rat). EM × 900. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

Two identical diploid cells result from spermatogonia mitosis. One of these cells remains a **spermatogonium**, and the other becomes a primary spermatocyte, the next stage in the process of spermatogenesis. As in mitosis, DNA is replicated in a primary spermatocyte, before it undergoes a cell division called meiosis I. During meiosis I each of the 23 pairs of chromosomes separates. This results in two cells, called secondary spermatocytes, each with only half the number of chromosomes. Now a second round of cell division (meiosis II) occurs in both of the secondary spermatocytes. During meiosis II each of the 23 replicated chromosomes divides, similar to what happens during mitosis. Thus, meiosis results in separating the chromosome pairs. This second meiotic division results in a total of four cells with only half of the number of chromosomes. Each of these new cells is a spermatid. Although haploid, early spermatids look very similar to cells in the earlier stages of spermatogenesis, with a round shape, central nucleus, and large amount of cytoplasm. A process called spermiogenesis transforms these early spermatids, reducing the cytoplasm, and beginning the formation of the parts of a true sperm. The fifth stage of germ cell formation—spermatozoa, or formed sperm—is the end result of this process, which occurs in the portion of the tubule nearest the lumen. Eventually, the sperm are released into the lumen and are moved along a series of ducts in the testis toward a structure called the epididymis for the next step of sperm maturation.

## Structure of Formed Sperm

Sperm are smaller than most cells in the body; in fact, the volume of a sperm cell is 85,000 times less than that of the female gamete. Approximately 100 to 300 million sperm are produced each day, whereas women typically ovulate only one oocyte per month. As is true for most cells in the body, the structure of sperm cells speaks to their function. Sperm have a distinctive head, mid-piece, and tail region (Figure). The head of the sperm contains the extremely compact haploid nucleus with very little cytoplasm. These qualities contribute to the overall small size of the sperm (the head is only 5 µm long). A structure called the acrosome covers most of the head of the sperm cell as a "cap" that is filled with lysosomal enzymes important for preparing sperm to participate in fertilization. Tightly packed mitochondria fill the mid-piece of the sperm. ATP produced by these mitochondria will power the flagellum, which extends from the neck and the mid-piece through the tail of the sperm, enabling it to move the entire sperm cell. The central strand of the flagellum, the axial filament, is formed from one centriole inside the maturing sperm cell during the final stages of spermatogenesis.

Structure of Sperm

Sperm cells are divided into a head, containing DNA; a mid-piece, containing mitochondria; and a tail, providing motility. The acrosome is oval and somewhat flattened.

## Sperm Transport

To fertilize an egg, sperm must be moved from the seminiferous tubules in the testes, through the epididymis, and—later during ejaculation—along the length of the penis and out into the female reproductive tract.

## Role of the Epididymis

From the lumen of the seminiferous tubules, the immotile sperm are surrounded by testicular fluid and moved to the epididymis (plural = epididymides), a coiled tube attached to the testis where newly formed sperm continue to mature (see Figure). Though the epididymis does not take up much room in its tightly coiled state, it would be approximately 6 m (20 feet) long if straightened. It takes an average of 12 days for sperm to move through the coils of the epididymis, with the shortest recorded transit time in humans being one day. Sperm enter the head of the epididymis and are moved along predominantly by the contraction of smooth muscles lining the epididymal tubes. As they are moved along the length of the epididymis, the sperm further mature and acquire the ability to move under their own power. Once inside the female reproductive tract, they will use this ability to move independently toward the unfertilized egg. The more mature sperm are then stored in the tail of the epididymis (the final section) until ejaculation occurs.

## Duct System

During ejaculation, sperm exit the tail of the epididymis and are pushed by smooth muscle contraction to the ductus deferens (also called the vas deferens). The ductus deferens is a thick, muscular tube that is bundled together inside the scrotum with connective tissue, blood vessels, and nerves into a structure called the spermatic cord (see Figure and Figure). Because the ductus deferens is physically accessible within the scrotum, surgical sterilization to interrupt sperm delivery can be performed by cutting and sealing a small section of the ductus (vas) deferens. This procedure is called a vasectomy, and it is an effective form of male birth control. Although it may be possible to reverse a vasectomy, clinicians consider the procedure permanent, and advise men to undergo it only if they are certain they no longer wish to father children..

From each epididymis, each ductus deferens extends superiorly into the abdominal cavity through the inguinal canal in the abdominal wall. From here, the ductus deferens continues posteriorly to the pelvic cavity, ending posterior to the bladder where it dilates in a region called the ampulla (meaning "flask").

Sperm make up only 5 percent of the final volume of semen, the thick, milky fluid that the male ejaculates. The bulk of semen is produced by three critical accessory glands of the male reproductive system: the seminal vesicles, the prostate, and the bulbourethral glands.

## Seminal Vesicles

As sperm pass through the **ampulla** of the **ductus deferens** at ejaculation, they mix with fluid from the associated **seminal vesicle** (see Figure). The paired seminal vesicles are glands that contribute approximately 60 percent of the semen volume. Seminal vesicle fluid contains large amounts of fructose, which is used by the sperm mitochondria to generate ATP to allow movement through the female reproductive tract.

The fluid, now containing both sperm and seminal vesicle secretions, next moves into the associated ejaculatory duct, a short structure formed from the ampulla of the ductus deferens and the duct of the seminal vesicle. The paired ejaculatory ducts transport the seminal fluid into the next structure, the prostate gland.

## Prostate Gland

As shown in Figure, the centrally located prostate gland sits anterior to the rectum at the base of the bladder surrounding the prostatic urethra (the portion of the urethra that runs within the prostate). About the size of a walnut, the prostate is formed of both muscular and glandular tissues. It excretes an alkaline, milky fluid to the passing seminal fluid—now called semen—that is critical to first coagulate and then decoagulate the semen following ejaculation. The temporary thickening of semen helps retain it within the female reproductive tract, providing time for sperm to utilize the fructose provided by seminal vesicle secretions. When the semen regains its fluid state, sperm can then pass farther into the female reproductive tract.

The prostate normally doubles in size during puberty. At approximately age 25, it gradually begins to enlarge again. This enlargement does not usually cause problems; however, abnormal growth of the prostate, or benign prostatic hyperplasia (BPH), can cause constriction of the urethra as it passes through the middle of the prostate gland, leading to a number of lower urinary tract symptoms, such as a frequent and intense urge to urinate, a weak stream, and a sensation that the bladder has not emptied completely. By age 60, approximately 40 percent of men have some degree of BPH. By age 80, the number of affected individuals has jumped to as many as 80 percent. Treatments for BPH attempt to relieve the pressure on the urethra so that urine can flow more normally. Mild to moderate symptoms are treated with medication, whereas severe enlargement of the prostate is treated by surgery in which a portion of the prostate tissue is removed.

## Bulbourethral Glands

The final addition to semen is made by two bulbourethral glands (or Cowper's glands) that release a thick, salty fluid that lubricates the end of the urethra and the vagina, and helps to clean urine residues from the penile urethra. The fluid from these accessory glands is released after the male becomes sexually aroused, and shortly before the release of the semen. It is therefore sometimes called pre-ejaculate. It is important to note that, in addition to the lubricating proteins, it is possible for bulbourethral fluid to pick up sperm already present in the urethra, and therefore it may be able to cause pregnancy.

## The Penis

The **penis** is the male organ of **copulation** (sexual intercourse). It is flaccid for non-sexual actions, such as urination, and turgid and rod-like with sexual arousal. When erect, the stiffness of the organ allows it to penetrate into the vagina and deposit semen into the female reproductive tract.

Cross-Sectional Anatomy of the Penis

Three columns of erectile tissue make up most of the volume of the penis.

The shaft of the penis surrounds the urethra (Figure). The shaft is composed of three column-like chambers of **erectile tissue** that span the length of the shaft. Each of the two larger lateral chambers is called a **corpus cavernosum** (plural = **corpora cavernosa**). Together, these make up the bulk of the penis. The corpus spongiosum, which can be felt as a raised ridge on the erect penis, is a smaller chamber that surrounds the spongy, or penile, urethra. The end of the penis, called the **glans penis**, has a high concentration of nerve endings, resulting in very sensitive skin that influences the likelihood of **ejaculation** (see Figure). The skin from the shaft extends down over the glans and forms a collar called the **prepuce** (or **foreskin**). The foreskin also contains a dense concentration of nerve endings, and both lubricate and protect the sensitive skin of the glans penis. A surgical procedure called **circumcision,** often performed for religious or social reasons, removes the prepuce, typically within days of birth.

## Testosterone

Testosterone, an androgen, is a steroid hormone produced by Leydig cells. The alternate term for Leydig cells, interstitial cells, reflects their location between the seminiferous tubules in the testes. In male embryos, testosterone is secreted by Leydig cells by the seventh week of development, with peak concentrations reached in the second trimester. This early release of testosterone results in the anatomical differentiation of the male sexual organs. In childhood, testosterone concentrations are low. They increase during puberty, activating characteristic physical changes and initiating spermatogenesis.

### Functions of Testosterone

The continued presence of testosterone is necessary to keep the male reproductive system working properly, and Leydig cells produce approximately 6 to 7 mg of testosterone per day. Testicular steroidogenesis (the manufacture of androgens, including testosterone) results in testosterone concentrations that are 100 times higher in the testes than in the circulation. Maintaining these normal concentrations of testosterone promotes spermatogenesis, whereas low levels of testosterone can lead to infertility. In addition to intratesticular secretion, testosterone is also released into the systemic circulation and plays an important role in muscle development, bone growth, the development of secondary sex characteristics, and maintaining libido (sex drive) in both males and females. In females, the ovaries secrete small amounts of testosterone, although most is converted to estradiol. A small amount of testosterone is also secreted by the adrenal glands in both sexes.

# Glossary

**blood–testis barrier**: tight junctions between Sertoli cells that prevent bloodborne pathogens from gaining access to later stages of spermatogenesis and prevent the potential for an autoimmune reaction to haploid sperm

**bulbourethral glands**: (also, **Cowper's glands**) glands that secrete a lubricating mucus that cleans and lubricates the urethra prior to and during ejaculation

**corpus cavernosum**: either of two columns of erectile tissue in the penis that fill with blood during an erection

**corpus spongiosum**: (plural = corpora cavernosa) column of erectile tissue in the penis that fills with blood during an erection and surrounds the penile urethra on the ventral portion of the penis

**ductus deferens**: (also, vas deferens) duct that transports sperm from the epididymis through the spermatic cord and into the ejaculatory duct; also referred as the vas deferens

**ejaculatory duct**: duct that connects the ampulla of the ductus deferens with the duct of the seminal vesicle at the prostatic urethra

**epididymis**: (plural = epididymides) coiled tubular structure in which sperm start to mature and are stored until ejaculation

**gamete**: haploid reproductive cell that contributes genetic material to form an offspring

**glans penis**: bulbous end of the penis that contains a large number of nerve endings

**gonadotropin-releasing hormone** (GnRH): hormone released by the hypothalamus that regulates the production of follicle-stimulating hormone and luteinizing hormone from the pituitary gland

**gonads**: reproductive organs (testes in men and ovaries in women) that produce gametes and reproductive hormones

**inguinal canal**: opening in abdominal wall that connects the testes to the abdominal cavity

**Leydig cells**: cells between the seminiferous tubules of the testes that produce testosterone; a type of interstitial cell

**penis**: male organ of copulation

**prepuce**: (also, **foreskin**) flap of skin that forms a collar around, and thus protects and lubricates, the glans penis; also referred as the foreskin

**prostate gland**: doughnut-shaped gland at the base of the bladder surrounding the urethra and contributing fluid to semen during ejaculation

**scrotum**: external pouch of skin and muscle that houses the testes

**semen**: ejaculatory fluid composed of sperm and secretions from the seminal vesicles, prostate, and bulbourethral glands

**seminal vesicl**e: gland that produces seminal fluid, which contributes to semen

**seminiferous tubules**: tube structures within the testes where spermatogenesis occurs

**Sertoli cells**: cells that support germ cells through the process of spermatogenesis; a type of sustentacular cell

**sperm**: (also, spermatozoon) male gamete

**spermatic cord**: bundle of nerves and blood vessels that supplies the testes; contains ductus deferens

**spermatid**: immature sperm cells produced by meiosis II of secondary spermatocytes

**Spermatocyte**: cell that results from the division of spermatogonium and undergoes meiosis I and meiosis II to form spermatids

**spermatogenesis**: formation of new sperm, occurs in the seminiferous tubules of the testes

**spermatogonia**: (singular = spermatogonium) diploid precursor cells that become sperm

**spermiogenesis**: transformation of spermatids to spermatozoa during spermatogenesis

**testes**: (singular = **testis**) male gonads

*Ha`awina 09: HLTH 140*

# The Cardiovascular System

## Hō`ulu`ulu Pōkole (Overview)

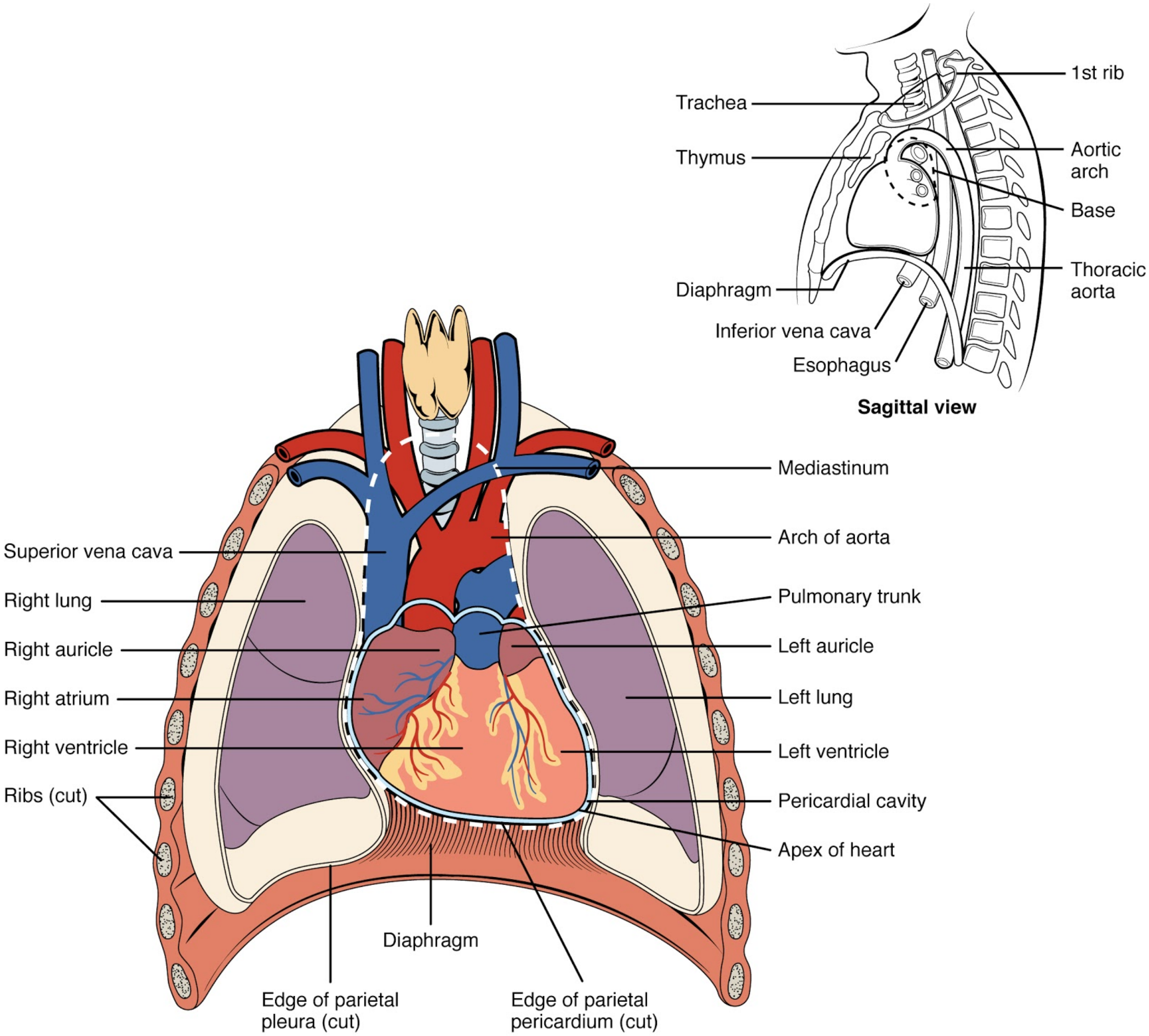
## Ke Haumana ka `apo (Student Learning Outcomes)

1. Describe the type of medical treatment the cardiologist, vascular surgeon, and immunologist provide.
2. Describe the primary functions of the cardiovascular and lymphatic systems.
3. Describe diseases, conditions, and procedures related to the cardiovascular and lymphatic systems.
4. Apply word-building skills by constructing various medical terms related to the cardiovascular and lymphatic systems.
5. Describe common abbreviations and symbols related to the cardiovascular and lymphatic systems.
6. Recognize, define, pronounce, and spell terms correctly.

## Location of the Heart

The human heart is located within the **thoracic cavity**, medially between the lungs in the space known as the **mediastinum**. Within the mediastinum, the heart is separated from the other mediastinal structures by a tough membrane known as the **pericardium**, or **pericardial sac**, and sits in its own space called the **pericardial cavity**. The dorsal surface of the heart lies near the bodies of the vertebrae, and its anterior surface sits deep to the **sternum** and **costal cartilages**. The great veins, **the superior** and **inferior venae cavae**, and the great arteries, the **aorta** and **pulmonary trunk**, are attached to the superior surface of the heart, called the **base**. The base of the heart is located at the level of the third costal cartilage, as seen in Figure. The inferior tip of the heart, the **apex**, lies just to the left of the sternum between the junction of the fourth and fifth ribs near their articulation with the costal cartilages. The right side of the heart is deflected anteriorly, and the left side is deflected posteriorly. It is important to remember the position and orientation of the heart when placing a **stethoscope** on the chest of a patient and listening for heart sounds, and also when looking at images taken from a midsagittal perspective. The slight deviation of the apex to the left is reflected in a depression in the medial surface of the inferior lobe of the left lung, called the cardiac notch.

## Position of the Heart in the Thorax




The heart is located within the thoracic cavity, medially between the lungs in the mediastinum. It is about the size of a fist, is broad at the top, and tapers toward the base.

## EVERYDAY CONNECTION: CPR

The position of the heart in the torso between the vertebrae and sternum (see Figure for the position of the heart within the thorax) allows for individuals to apply an emergency technique known as cardiopulmonary resuscitation (CPR) if the heart of a patient should stop. By applying pressure with the flat portion of one hand on the sternum in the area between the line at **T4 and T9** , it is possible to manually compress the blood within the heart enough to push some of the blood within it into the pulmonary and systemic circuits. This is particularly critical for the brain, as irreversible damage and death of neurons occur within minutes of loss of blood flow. Current standards call for compression of the chest at least 5 cm deep and at a rate of 100 compressions per minute,When performed by untrained or overzealous individuals, CPR can result in broken ribs or a broken sternum, and can inflict additional severe damage on the patient. It is also possible, if the hands are placed too low on the sternum, to manually drive the xiphoid process into the liver, a consequence that may prove fatal for the patient. Proper training is essential. This proven life-sustaining technique is so valuable that virtually all medical personnel as well as concerned members of the public should be certified and routinely recertified in its application. CPR courses are offered at a variety of locations, including colleges, hospitals, the American Red Cross, and some commercial companies. They normally include practice of the compression technique on a mannequin.

## Shape and Size of the Heart

A typical heart is approximately the size of your fist: 12 cm (5 in) in length, 8 cm (3.5 in) wide, and 6 cm (2.5 in) in thickness. Given the size difference between most members of the sexes, the weight of a female heart is approximately 250–300 grams (9 to 11 ounces), and the weight of a male heart is approximately 300–350 grams (11 to 12 ounces). The heart of a well-trained athlete, especially one specializing in aerobic sports, can be considerably larger than this. Cardiac muscle responds to exercise in a manner similar to that of skeletal muscle. That is, exercise results in the addition of protein **myofilaments** that increase the size of the individual cells without increasing their numbers, a concept called **hypertrophy**. Hearts of athletes can pump blood more effectively at lower rates than those of nonathletes.

Enlarged hearts are not always a result of exercise; they can result from pathologies, such as **hypertrophic cardiomyopathy**.

## Chambers and Circulation through the Heart

The human heart consists of four chambers: The left side and the right side each have one **atrium** and one **ventricle**. Each of the upper chambers, the right atrium (plural = **atria**) and the left atrium, acts as a receiving chamber and contracts to push blood into the lower chambers, the **right ventricle** and the **left ventricle**. The ventricles serve as the primary pumping chambers of the heart, propelling blood to the lungs or to the rest of the body.

There are two distinct but linked circuits in the human circulation called the pulmonary and systemic circuits.The **pulmonary circuit** transports blood to and from the lungs, where it picks up **oxygen** and delivers **carbon dioxide** for exhalation. The **systemic circuit** transports oxygenated blood to virtually all of the tissues of the body and returns relatively **deoxygenated blood** and carbon dioxide to the heart to be sent back to the pulmonary circulation.

The right ventricle pumps deoxygenated blood into the **pulmonary trunk**, which leads toward the lungs and **bifurcates** (splits into two branches) into the left and right **pulmonary arteries**. These vessels in turn branch many times before reaching the **pulmonary capillaries**, where gas exchange occurs: Carbon dioxide exits the blood and oxygen enters. The pulmonary trunk arteries and their branches are the only arteries in the body that carry deoxygenated blood. Highly oxygenated blood returning from the pulmonary capillaries in the lungs passes through a series of vessels that join together to form the **pulmonary veins**—the only (post-natal) veins in the body that carry highly oxygenated blood. The pulmonary veins conduct blood into the left atrium, which pumps the blood into the left ventricle, which in turn pumps oxygenated blood into the aorta and on to the many branches of the systemic circuit.

Eventually, these vessels will lead to the systemic capillaries, where exchange with the tissue fluid and cells of the body occurs.The blood exiting the systemic capillaries is lower in oxygen concentration than when it entered. The **capillaries** will ultimately unite to form **venules**, joining to form ever-larger veins, eventually flowing into the two major systemic veins, the **superior vena cava** and the **inferior vena cava**, which return blood to the right atrium, which pumps blood into the right ventricle.

# Membranes, Surface Features, and Layers

Our exploration of more in-depth heart structures begins by examining the membrane that surrounds the heart, the prominent surface features of the heart, and the layers that form the wall of the heart. Each of these components plays its own unique role in terms of function.

## Membranes

The membrane that directly surrounds the heart and defines the pericardial cavity is called the pericardium or pericardial sac. The pericardium literally translates as "around the heart," consists of two distinct sublayers: the sturdy outer **fibrous pericardium** and the inner **serous pericardium**. The fibrous pericardium is made of tough, dense connective tissue that protects the heart and maintains its position in the **thorax**.

The more delicate serous pericardium consists of two layers: the **parietal pericardium**, which is fused to the fibrous pericardium, and an inner **visceral pericardium**, or **epicardium**, which is fused to the heart and is part of the heart wall. The pericardial cavity, filled with about 5 ml of lubricating serous fluid, lies between the epicardium and the pericardium.

**DISORDERS OF THE…Heart: Cardiac Tamponade**

If excess fluid builds within the pericardial space, it can lead to a condition called cardiac tamponade, or pericardial tamponade. With each contraction of the heart, more fluid—in most instances, blood—accumulates within the pericardial cavity. In order to fill with blood for the next contraction, the heart must relax. However, the excess fluid in the pericardial cavity puts pressure on the heart and prevents full relaxation, so the chambers within the heart contain slightly less blood as they begin each heart cycle. Over time, less and less blood is ejected from the heart. If the fluid builds up slowly, as in hypothyroidism, the pericardial cavity may be able to expand gradually to accommodate this extra volume. Some cases of fluid in excess of one liter within the pericardial cavity have been reported. Rapid accumulation of as little as 100 mL of fluid following trauma may trigger cardiac tamponade. Other common causes include myocardial rupture, pericarditis, cancer, or even cardiac surgery. Removal of this excess fluid requires insertion of drainage tubes into the pericardial cavity. Premature removal of these drainage tubes, for example, following cardiac surgery, or clot formation within these tubes are causes of this condition. Untreated, cardiac tamponade can lead to death
.

## Surface Features of the Heart

Inside the pericardium, the surface features of the heart are visible, including the four chambers. There is a superficial leaf-like extension of the atria near the superior surface of the heart, one on each side, called an auricle—a name that means "ear like"—because its shape resembles the external ear of a human (Figure). Auricles are relatively thin-walled structures that can fill with blood and empty into the atria or upper chambers of the heart. You may also hear them referred to as atrial appendages. Also prominent is a series of fat-filled grooves, each of which is known as a sulcus (plural = sulci), along the superior surfaces of the heart. Major coronary blood vessels are located in these sulci. The deep coronary sulcus is located between the atria and ventricles. Located between the left and right ventricles are two additional sulci that are not as deep as the coronary sulcus. The anterior interventricular sulcus is visible on the anterior surface of the heart, whereas the posterior interventricular sulcus is visible on the posterior surface of the heart. Figure illustrates anterior and posterior views of the surface of the heart.

**External Anatomy of the Heart**

## Layers

The wall of the heart is composed of three layers of unequal thickness. From superficial to deep, these are the epicardium, the myocardium, and the endocardium (see Figure). The outermost layer of the wall of the heart is also the innermost layer of the pericardium, the epicardium, or the visceral pericardium discussed earlier.

The middle and thickest layer is the myocardium, made largely of cardiac muscle cells. It is built upon a framework of collagenous fibers, plus the blood vessels that supply the myocardium and the nerve fibers that help regulate the heart. It is the contraction of the myocardium that pumps blood through the heart and into the major arteries. The muscle pattern is elegant and complex, as the muscle cells swirl and spiral around the chambers of the heart. They form a figure 8 pattern around the atria and around the bases of the great vessels. Deeper ventricular muscles also form a figure 8 around the two ventricles and proceed toward the apex. More superficial layers of ventricular muscle wrap around both ventricles. This complex swirling pattern allows the heart to pump blood more effectively than a simple linear pattern would. Figure illustrates the arrangement of muscle cells.

**Heart Musculature**

The swirling pattern of cardiac muscle tissue contributes significantly to the heart's ability to pump blood effectively.

Although the ventricles on the right and left sides pump the same amount of blood per contraction, the muscle of the left ventricle is much thicker and better developed than that of the right ventricle. In order to overcome the high resistance required to pump blood into the long systemic circuit, the left ventricle must generate a great amount of pressure. The right ventricle does not need to generate as much pressure, since the pulmonary circuit is shorter and provides less resistance. Figure illustrates the differences in muscular thickness needed for each of the ventricles.

**Differences in Ventricular Muscle Thickness**

The **myocardium** in the left ventricle is significantly thicker than that of the right ventricle. Both ventricles pump the same amount of blood, but the left ventricle must generate a much greater pressure to overcome greater resistance in the systemic circuit. The ventricles are shown in both relaxed and contracting states. Note the differences in the relative size of the lumens, the region inside each ventricle where the blood is contained.

The innermost layer of the heart wall, the **endocardium**, is joined to the myocardium with a thin layer of connective tissue. The endocardium lines the chambers where the blood circulates and covers the heart valves. It is made of simple squamous epithelium called endothelium, which is continuous with the endothelial lining of the blood vessels (see Figure).

## Internal Structure of the Heart

Recall that the heart's contraction cycle follows a dual pattern of circulation—the pulmonary and systemic circuits—because of the pairs of chambers that pump blood into the circulation. In order to develop a more precise understanding of cardiac function, it is first necessary to explore the internal anatomical structures in more detail.

### Septa of the Heart

The word **septum** is derived from the Latin for "something that encloses;" in this case, a septum (plural = **septa**) refers to a wall or partition that divides the heart into chambers. The septa are physical extensions of the myocardium lined with endocardium. Located between the two atria is the **interatrial septum**. Normally in an adult heart, the interatrial septum bears an oval-shaped depression known as the **fossa ovalis**, a remnant of an opening in the fetal heart known as the foramen ovale. The **foramen ovale** allowed blood in the fetal heart to pass directly from the right atrium to the left atrium, allowing some blood to bypass the pulmonary circuit. Within seconds after birth, a flap of tissue known as the **septum primum** that previously acted as a valve closes the foramen ovale and establishes the typical cardiac circulation pattern. Between the two ventricles is a second septum known as the **interventricular septum**. It is thicker than the interatrial septum, since the ventricles generate far greater pressure when they contract.

The septum between the atria and ventricles is known as the **atrioventricular** septum. It is marked by the presence of four openings that allow blood to move from the atria into the ventricles and from the ventricles into the pulmonary trunk and aorta. Located in each of these openings between the atria and ventricles is a valve, a specialized structure that ensures one-way flow of blood. The valves between the atria and ventricles are known generically as **atrioventricular valves**. The valves at the openings that lead to the pulmonary trunk and aorta are known generically as **semilunar valves**.

**Internal Structures of the Heart**

**Cardiac Muscle Tissue**

Remember from the lesson on tissue structure that heart muscle is similar to skeletal muscle, except for 2 main features:

- ❑ Autorhythmicity: Heart muscle will depolarize and create a heart beat automatically
- ❑ Intercalated discs can be seen a dark bands within cardiac muscle

## DISORDERS OF THE…Heart: Heart Defects

**Patent Foramen Ovale** occurs when the septum primum does not close at birth, and the fossa ovalis is unable to fuse. The word patent is from the Latin root **patens** for “open.” It may be benign or asymptomatic, perhaps never being diagnosed, or in extreme cases, it may require surgical repair to close the opening permanently.

**Coarctation of the aorta** is a congenital abnormal narrowing of the aorta that is normally located at the insertion of the ligamentum arteriosum, the remnant of the fetal shunt called the ductus arteriosus.

**A patent ductus arteriosus** is a congenital condition in which the ductus arteriosus fails to close. The condition may range from severe to benign. Failure of the ductus arteriosus to close results in blood flowing from the higher pressure aorta into the lower pressure pulmonary trunk.

**Tetralogy of Fallot** is a congenital condition that may also occur from exposure to unknown environmental factors; it occurs when there is an opening in the interventricular septum caused by blockage of the pulmonary trunk, normally at the pulmonary semilunar valve. This allows blood that is relatively low in oxygen from the right ventricle to flow into the left ventricle and mix with the blood that is relatively high in oxygen. Symptoms include a distinct heart murmur, low blood oxygen percent saturation, dyspnea or difficulty in breathing, polycythemia, broadening (clubbing) of the fingers and toes, and in children, difficulty in feeding or failure to grow and develop. It is the most common cause of cyanosis following birth. The term “tetralogy” is derived from the four components of the conditionCongenital Heart Defects

## Right Atrium

The right atrium serves as the receiving chamber for blood returning to the heart from the systemic circulation. The two major systemic veins, the superior and inferior venae cavae, and the large coronary vein called the coronary sinus that drains the heart myocardium empty into the right atrium. The superior vena cava drains blood from regions superior to the diaphragm: the head, neck, upper limbs, and the thoracic region. It empties into the superior and posterior portions of the right atrium. The inferior vena cava drains blood from areas inferior to the diaphragm: the lower limbs and abdominopelvic region of the body.

## Right Ventricle

The right ventricle receives blood from the right atrium through the tricuspid valve. Each flap of the valve is attached to strong strands of connective tissue, the **chordae tendineae**, literally "tendinous cords," or sometimes more poetically referred to as "heart strings." There are several chordae tendineae associated with each of the flaps. They connect each of the flaps to a **papillary muscle** that extends from the inferior ventricular surface. There are three papillary muscles in the right ventricle, called the anterior, posterior, and septal muscles, which correspond to the three sections of the valves.

**Chordae Tendineae and Papillary Muscles**

## Left Atrium

After exchange of gases in the pulmonary capillaries, blood returns to the left atrium high in oxygen via one of the four pulmonary veins. While the left atrium does not contain pectinate muscles, it does have an auricle that includes these pectinate ridges. Blood flows nearly continuously from the pulmonary veins back into the atrium, which acts as the receiving chamber, and from here through an opening into the left ventricle. Most blood flows passively into the heart while both the atria and ventricles are relaxed, but toward the end of the ventricular relaxation period, the left atrium will contract, pumping blood into the ventricle. This atrial contraction accounts for approximately 20 percent of ventricular filling. The opening between the left atrium and ventricle is guarded by the mitral valve.

### Left Ventricle

Recall that, although both sides of the heart will pump the same amount of blood, the muscular layer is much thicker in the left ventricle compared to the right (see Figure). Like the right ventricle, the left also has trabeculae carneae, but there is no moderator band. The mitral valve is connected to papillary muscles via chordae tendineae. There are two papillary muscles on the left—the anterior and posterior—as opposed to three on the right.

**The left ventricle is the major pumping chamber for the systemic circuit; it ejects blood into the aorta through the aortic semilunar valve.**

## Heart Valve Structure and Function

A transverse section through the heart slightly above the level of the atrioventricular septum reveals all four heart valves along the same plane (Figure). The valves ensure unidirectional blood flow through the heart. Between the right atrium and the right ventricle is the right **atrioventricular valve**, or **tricuspid valve**. It typically consists of three flaps, or leaflets, made of endocardium reinforced with additional connective tissue..

Located at the opening between the left atrium and left ventricle is the **mitral valve**, also called the **bicuspid valve** or the **left atrioventricular valve**. Structurally, this valve consists of two cusps, known as the anterior medial cusp and the posterior medial cusp, compared to the three cusps of the tricuspid valve. In a clinical setting, the valve is referred to as the mitral valve, rather than the bicuspid valve.

**Blood Flow from the Left Atrium to the Left Ventricle**

(a) A transverse section through the heart illustrates the four heart valves. The two atrioventricular valves are open; the two semilunar valves are closed. The atria and vessels have been removed. (b) A frontal section through the heart illustrates blood flow through the mitral valve. When the mitral valve is open, it allows blood to move from the left atrium to the left ventricle. The aortic semilunar valve is closed to prevent backflow of blood from the aorta to the left ventricle.

Figure a shows the atrioventricular valves closed while the two semilunar valves are open. This occurs when the ventricles contract to eject blood into the pulmonary trunk and aorta. Closure of the two atrioventricular valves prevents blood from being forced back into the atria. This stage can be seen from a frontal view in Figureb.

**Blood Flow from the Left Ventricle into the Great Vessels**

(a) A transverse section through the heart illustrates the four heart valves during ventricular contraction. The two atrioventricular valves are closed, but the two semilunar valves are open. The atria and vessels have been removed. (b) A frontal view shows the closed mitral (bicuspid) valve that prevents backflow of blood into the left atrium. The aortic semilunar valve is open to allow blood to be ejected into the aorta.

## DISORDERS OF THE....Heart Valves

When heart valves do not function properly, they are often described as incompetent and result in valvular heart disease, which can range from benign to lethal. Some of these conditions are congenital, that is, the individual was born with the defect, whereas others may be attributed to disease processes or trauma. Some malfunctions are treated with medications, others require surgery, and still others may be mild enough that the condition is merely monitored since treatment might trigger more serious consequences.

Valvular disorders are often caused by **carditis**, or inflammation of the heart. One common trigger for this inflammation is rheumatic fever, or scarlet fever, an autoimmune response to the presence of a bacterium, Streptococcus pyogenes, normally a disease of childhood.

While any of the heart valves may be involved in valve disorders, **mitral regurgitation** is the most common,

When a valve malfunctions, the flow of blood to a region will be disrupted.resulting in insufficient flow of blood to this region. The specific type of **insufficiency** is named for the valve involved: **aortic insufficiency**, **mitral insufficiency**, **tricuspid insufficiency**, or **pulmonary insufficiency**.

- If one of the cusps of the valve is forced backward by the force of the blood, the condition is referred to as a **prolapsed valve**. Using a stethoscope, the disruption to the normal flow of blood produces a heart murmur.
- **Stenosis** is a condition in which the heart valves become rigid and may calcify over time. The loss of flexibility of the valve interferes with normal function and may cause the heart to work harder to propel blood through the valve, which eventually weakens the heart. **Aortic stenosis** affects approximately 2 percent of the population over 65 years of age.

**Auscultation**, or listening to a patient's heart sounds, is one of the most useful diagnostic tools, since it is proven, safe, and inexpensive. The term auscultation is derived from the Latin for "to listen," and the technique has been used for diagnostic purposes as far back as the ancient Egyptians.

Visit this site for a free download, including excellent animations and audio of heart sounds.

http://openstaxcollege.org/l/heartsounds

CAREER CONNECTIONS

**Cardiologist**

Cardiologists are medical doctors that specialize in the diagnosis and treatment of diseases of the heart. After completing 4 years of medical school, cardiologists complete a three-year residency in internal medicine followed by an additional three or more years in cardiology. Following this 10-year period of medical training and clinical experience, they qualify for a rigorous two-day examination administered by the Board of Internal Medicine that tests their academic training and clinical abilities, including diagnostics and treatment. After successful completion of this examination, a physician becomes a board-certified cardiologist. Some board-certified cardiologists may be invited to become a Fellow of the American College of Cardiology (FACC). This professional recognition is awarded to outstanding physicians based upon merit, including outstanding credentials, achievements, and community contributions to cardiovascular medicine.

Visit this site to learn more about cardiologists.

http://openstaxcollege.org/l/cardiologist

**Cardiovascular Technologist/Technician**

Cardiovascular technologists/technicians are trained professionals who perform a variety of imaging techniques, such as sonograms or echocardiograms, used by physicians to diagnose and treat diseases of the heart. Nearly all of these positions require an associate degree, and these technicians earn a median salary of $49,410 as of May 2010, according to the U.S. Bureau of Labor Statistics. Growth within the field is fast, projected at 29 percent from 2010 to 2020. There is a considerable overlap and complementary skills between cardiac technicians and vascular technicians, and so the term cardiovascular technician is often used. Special certifications within the field require documenting appropriate experience and completing additional and often expensive certification examinations. These subspecialties include Certified Rhythm Analysis Technician (CRAT), Certified Cardiographic Technician (CCT), Registered Congenital Cardiac Sonographer (RCCS), Registered Cardiac Electrophysiology Specialist (RCES), Registered Cardiovascular Invasive Specialist (RCIS), Registered Cardiac Sonographer (RCS), Registered Vascular Specialist (RVS), and Registered Phlebology Sonographer (RPhS).

Visit this site for more information on cardiovascular technologists/technicians.

http://openstaxcollege.org/l/cardiotech

# Coronary Circulation

Like all other cells, a cardiomyocyte requires a reliable supply of oxygen and nutrients, and a way to remove wastes, so it needs a dedicated, complex, and extensive coronary circulation. And because of the critical and nearly ceaseless activity of the heart throughout life, this need for a blood supply is even greater than for a typical cell. However, **coronary circulation is not continuous; rather, it cycles, reaching a peak when the heart muscle is relaxed and nearly ceasing while it is contracting.**

## Coronary Arteries

Coronary arteries supply blood to the myocardium and other components of the heart. The first portion of the aorta after it arises from the left ventricle gives rise to the **coronary arteries**. There are three dilations in the wall of the aorta just superior to the aortic semilunar valve. Two of these, the **left posterior aortic sinus** and **anterior aortic sinus**, give rise to the left and right coronary arteries, respectively.

- ❏ The **left coronary artery** distributes blood to the left side of the heart, the left atrium and ventricle, and the interventricular septum.
- ❏ The **circumflex artery** arises from the left coronary artery and follows the coronary sulcus to the left. Eventually, it will fuse with the small branches of the right coronary artery.
- ❏ The larger anterior interventricular artery, also known as the **left anterior descending artery** (LAD), is the second major branch arising from the left coronary artery. It follows the anterior interventricular sulcus around the pulmonary trunk. Along the way it gives rise to numerous smaller branches that interconnect with the branches of the posterior interventricular artery, forming **anastomoses**. An anastomosis is an area where vessels unite to form interconnections that normally allow blood to circulate to a region even if there may be partial blockage in another branch.
- ❏ The **right coronary artery** proceeds along the coronary sulcus and distributes blood to the right atrium, portions of both ventricles, and the heart conduction system. On the posterior surface of the heart, the right coronary artery gives rise to the posterior interventricular artery, also known as the **posterior descending artery**. It runs along the posterior portion of the interventricular sulcus toward the apex of the heart, giving rise to branches that supply the interventricular septum and portions of both ventricles.

**Coronary Circulation**

## Coronary Veins

**Coronary veins** drain the heart and generally parallel the large surface arteries. The great cardiac vein can be seen initially on the surface of the heart following the interventricular sulcus, but it eventually flows along the coronary sulcus into the coronary sinus on the posterior surface. The **great cardiac vein** initially parallels the anterior interventricular artery and drains the areas supplied by this vessel. The **posterior cardiac vein** parallels and drains the areas supplied by the marginal artery branch of the circumflex artery. The **middle cardiac vein** parallels and drains the areas supplied by the posterior interventricular artery. The **small cardiac vein** parallels the right coronary artery and drains the blood from the posterior surfaces of the right atrium and ventricle. The **coronary sinus** is a large, thin-walled vein on the posterior surface of the heart.

## DISEASES OF THE…Heart: Myocardial Infarction

Myocardial infarction (MI) is the formal term for what is commonly referred to as a heart attack. It normally results from a lack of blood flow (ischemia) and oxygen (hypoxia) to a region of the heart, resulting in death of the cardiac muscle cells. An MI often occurs when a coronary artery is blocked by the buildup of atherosclerotic plaque consisting of lipids, cholesterol and fatty acids, and white blood cells, primarily macrophages. It can also occur when a portion of an unstable atherosclerotic plaque travels through the coronary arterial system and lodges in one of the smaller vessels. The resulting blockage restricts the flow of blood and oxygen to the myocardium and causes death of the tissue. MIs may be triggered by excessive exercise, in which the partially occluded artery is no longer able to pump sufficient quantities of blood, or severe stress, which may induce spasm of the smooth muscle in the walls of the vessel.

In the case of acute MI, there is often sudden pain beneath the sternum (retrosternal pain) called angina pectoris, often radiating down the left arm in males but not in female patients. Until this anomaly between the sexes was discovered, many female patients suffering MIs were misdiagnosed and sent home. In addition, patients typically present with difficulty breathing and shortness of breath (dyspnea), irregular heartbeat (palpations), nausea and vomiting, sweating (diaphoresis), anxiety, and fainting (syncope), although not all of these symptoms may be present. Many of the symptoms are shared with other medical conditions, including anxiety attacks and simple indigestion, so differential diagnosis is critical. It is estimated that between 22 and 64 percent of MIs present without any symptoms.

An MI can be confirmed by examining the patient's ECG, which frequently reveals alterations in the ST and Q components. Some classification schemes of MI are referred to as ST-elevated MI (STEMI) and non-elevated MI (non-STEMI). In addition, echocardiography or cardiac magnetic resonance imaging may be employed. Common blood tests indicating an MI include elevated levels of creatine kinase MB (an enzyme that catalyzes the conversion of creatine to phosphocreatine, consuming ATP) and cardiac troponin (the regulatory protein for muscle contraction), both of which are released by damaged cardiac muscle cells.

Immediate treatments for MI are essential and include administering supplemental oxygen, aspirin that helps to break up clots, and nitroglycerin administered sublingually (under the tongue) to facilitate its absorption. Longer-term treatments include injections of thrombolytic agents such as streptokinase that dissolve the clot, the anticoagulant heparin, balloon angioplasty and stents to open blocked vessels, and bypass surgery to allow blood to pass around the site of blockage.

Risk factors for MI include cardiovascular disease, age, smoking, high blood levels of the low-density lipoprotein (LDL, often referred to as "bad" cholesterol), low levels of high-density lipoprotein (HDL, or "good" cholesterol), hypertension, diabetes mellitus, obesity, lack of physical exercise, chronic kidney disease, excessive alcohol consumption, and use of illegal drugs.

## DISEASES OF THE…Heart: Atherosclerotic Coronary Artery Disease

In this **coronary angiogram** (X-ray), the dye makes visible two occluded coronary arteries. Such blockages can lead to decreased blood flow (ischemia) and insufficient oxygen (hypoxia) delivered to the cardiac tissues. If uncorrected, this can lead to cardiac muscle death (myocardial infarction).

Risk factors include smoking, family history, hypertension, obesity, diabetes, high alcohol consumption, lack of exercise, stress, and hyperlipidemia or high circulating levels of lipids in the blood.

**Angioplasty** is a procedure in which the occlusion is mechanically widened with a balloon. A specialized catheter with an expandable tip is inserted into a superficial vessel, normally in the leg, and then directed to the site of the occlusion. At this point, the balloon is inflated to compress the plaque material and to open the vessel to increase blood flow. Then, the balloon is deflated and retracted. A **stent** consisting of a specialized mesh is typically inserted at the site of occlusion to reinforce the weakened and damaged walls. Coronary artery bypass surgery (CABG) may also be performed. This surgical procedure grafts a replacement vessel obtained from another, less vital portion of the body to bypass the occluded area.

# Conduction System of the Heart

A fully developed adult heart maintains the capability of generating its own electrical impulse, triggered by the fastest cells, as part of the cardiac conduction system. The components of the cardiac conduction system include the sinoatrial node, the atrioventricular node, the atrioventricular bundle, the atrioventricular bundle branches, and the Purkinje cells (Figure).

**Conduction System of the Heart**

Specialized conducting components of the heart include the **sinoatrial node**, the **internodal pathways**, the **atrioventricular node**, the **atrioventricular bundle**, the right and left **bundle branches**, and the **Purkinje fibers**.

## Sinoatrial (SA) Node

Normal cardiac rhythm is established by the **sinoatrial** (SA) node, a specialized clump of myocardial conducting cells located in the superior and posterior walls of the right atrium in close proximity to the orifice of the superior vena cava. The SA node has the highest inherent rate of **depolarization** and is known as the **pacemaker of the heart**. It initiates the sinus rhythm, or normal electrical pattern followed by contraction of the heart.

**Cardiac Conduction**

(1) The sinoatrial (SA) node and the remainder of the conduction

system are at rest. (2) The SA node initiates the action potential, which sweeps across the atria. (3) After reaching the atrioventricular node, there is a delay of approximately 100 ms that allows the atria to complete pumping blood before the impulse is transmitted to the atrioventricular bundle. (4) Following the delay, the impulse travels through the atrioventricular bundle and bundle branches to the Purkinje fibers, and also reaches the right papillary muscle via the moderator band. (5) The impulse spreads to the contractile fibers of the ventricle. (6) Ventricular contraction begins.

The electrical event, the wave of depolarization, is the trigger for muscular contraction. The wave of depolarization begins in the right atrium, and the impulse spreads across the superior portions of both atria and then down through the contractile cells. The contractile cells then begin contraction from the superior to the inferior portions of the atria, efficiently pumping blood into the ventricles.

## Atrioventricular (AV) Node

The **atrioventricular** (AV) node is a second clump of specialized **myocardial conductive cells**, located in the inferior portion of the right atrium within the atrioventricular septum. The septum prevents the impulse from spreading directly to the ventricles without passing through the AV node. There is a critical pause before the AV node depolarizes and transmits the impulse to the atrioventricular bundle (see Figure, step 3). This delay in transmission is partially attributable to the small diameter of the cells of the node, which slow the impulse. Also, conduction between nodal cells is less efficient than between conducting cells. These factors mean that it takes the impulse approximately 100 ms to pass through the node. This pause is critical to heart function, as it allows the atrial cardiomyocytes to complete their contraction that pumps blood into the ventricles before the impulse is transmitted to the cells of the ventricle itself. With extreme stimulation by the SA node, the AV node can transmit impulses maximally at 220 per minute. This establishes the typical maximum heart rate in a healthy young individual. Damaged hearts or those stimulated by drugs can contract at higher rates, but at these rates, the heart can no longer effectively pump blood.

## Atrioventricular Bundle (Bundle of His), Bundle Branches, and Purkinje Fibers

Arising from the AV node, the **atrioventricular bundle**, or **bundle of His**, proceeds through the interventricular septum before dividing into two **atrioventricular bundle branches**, commonly called the left and right bundle branches. The **left bundle branch** has two **fascicles**. The left bundle branch supplies the left ventricle, and the right bundle branch the right ventricle. Since the left ventricle is much larger than the right, the left bundle branch is also considerably larger than the right. The **Purkinje fibers** are additional myocardial conductive fibers that spread the impulse to the myocardial contractile cells in the ventricles. They extend throughout the myocardium from the apex of the heart toward the atrioventricular septum and the base of the heart. The total time elapsed from the initiation of the impulse in the SA node until depolarization of the ventricles is approximately 225 ms.

## Electrocardiogram

The **electrocardiogram** (ECG), also commonly abbreviated EKG (K coming kardiology, from the German term for cardiology). The standard **electrocardiograph** (the instrument that generates an ECG) uses 3, 5, or 12 leads. The 12-lead electrocardiograph uses 10 electrodes placed in standard locations on the patient's skin (Figure). In continuous ambulatory electrocardiographs, the patient wears a small, portable, battery-operated device known as a **Holter monitor**, or simply a Holter, that continuously monitors heart electrical activity, typically for a period of 24 hours during the patient's normal routine.

**Standard Placement of ECG Leads**
In a 12-lead ECG, six electrodes are placed on the chest, and four electrodes are placed on the limbs.

There are five prominent points on the ECG: the **P wave**, the **QRS complex**, and the **T wave**. The small P wave represents the depolarization of the atria. The atria begin contracting approximately 25 ms after the start of the **P wave**. The **QRS complex** represents the depolarization of the ventricles, which requires a much stronger electrical signal because of the larger size of the ventricular cardiac muscle. The ventricles begin to contract as the QRS reaches the peak of the **R wave**. Lastly, the **T wave** represents the repolarization of the ventricles. The repolarization of the atria occurs during the QRS complex, which masks it on an ECG.

Visit this site for a more detailed analysis of ECGs.

**Electrocardiogram**
**A normal tracing shows the P wave, QRS complex, and T wave. Also indicated are the PR, QT, QRS, and ST intervals, plus the P-R and S-T segments.**

## Glossary

**anastomosis**: (plural = anastomoses) area where vessels unite to allow blood to circulate even if there may be partial blockage in another branch
**anterior cardiac veins**: vessels that parallel the small cardiac arteries and drain the anterior surface of the right ventricle; bypass the coronary sinus and drain directly into the right atrium

**anterior interventricular artery**: (also, left anterior descending artery or LAD) major branch of the left coronary artery that follows the anterior interventricular sulcus

**anterior interventricular sulcus**: sulcus located between the left and right ventricles on the anterior surface of the heart

**aortic valve**: (also, aortic semilunar valve) valve located at the base of the aorta

**atrioventricular bundle**: (also, **bundle of His**) group of specialized myocardial conductile cells that transmit the impulse from the AV node through the interventricular septum; form the left and right atrioventricular bundle branches

**atrioventricular bundle branches**: (also, left or right bundle branches) specialized myocardial conductile cells that arise from the bifurcation of the atrioventricular bundle and pass through the interventricular septum; lead to the Purkinje fibers and also to the right papillary muscle via the moderator band

**atrioventricular (AV) node**: clump of myocardial cells located in the inferior portion of the right atrium within the atrioventricular septum; receives the impulse from the SA node, pauses, and then transmits it into specialized conducting cells within the interventricular septum

**atrioventricular septum**: cardiac septum located between the atria and ventricles; atrioventricular valves are located here

**atrioventricular valves**: one-way valves located between the atria and ventricles; the valve on the right is called the tricuspid valve, and the one on the left is the mitral or bicuspid valve

**atrium**: (plural = **atria**) upper or receiving chamber of the heart that pumps blood into the lower chambers just prior to their contraction; the right atrium receives blood from the systemic circuit that flows into the right ventricle; the left atrium receives blood from the pulmonary circuit that flows into the left ventricle

**auricle**: extension of an atrium visible on the superior surface of the heart

**autorhythmicity**: ability of cardiac muscle to initiate its own electrical impulse that triggers the mechanical contraction that pumps blood at a fixed pace without nervous or endocrine control
**Bachmann's bundle**(also, **interatrial band**) group of specialized conducting cells that transmit the impulse directly from the SA node in the right atrium to the left atrium

**bundle of His**: (also, **atrioventricular bundle**) group of specialized myocardial conductile cells that transmit the impulse from the AV node through the interventricular septum; form the left and right atrioventricular bundle branches

**bicuspid valve**: (also, mitral valve or left atrioventricular valve) valve located between the left atrium and ventricle; consists of two flaps of tissue

**cardiac notch**: depression in the medial surface of the inferior lobe of the left lung where the apex of the heart is located

**cardiac skeleton**: (also, skeleton of the heart) reinforced connective tissue located within the atrioventricular septum; includes four rings that surround the openings between the atria and ventricles, and the openings to the pulmonary trunk and aorta; the point of attachment for the heart valves

**cardiomyocyte**: muscle cell of the heart

**chordae tendineae**: string-like extensions of tough connective tissue that extend from the flaps of the atrioventricular valves to the papillary muscles

**circumflex artery**: branch of the left coronary artery that follows coronary sulcus

**coronary arteries**: branches of the ascending aorta that supply blood to the heart; the left coronary artery feeds the left side of the heart, the left atrium and ventricle, and the interventricular septum; the right coronary artery feeds the right atrium, portions of both ventricles, and the heart conduction system

**coronary sinus:** large, thin-walled vein on the posterior surface of the heart that lies within the atrioventricular sulcus and drains the heart myocardium directly into the right atrium

**coronary sulcus**: sulcus that marks the boundary between the atria and ventricles

**coronary veins**: vessels that drain the heart and generally parallel the large surface arteries

**electrocardiogram (ECG)**: surface recording of the electrical activity of the heart that can be used for diagnosis of irregular heart function; also abbreviated as EKG

**endocardium**: innermost layer of the heart lining the heart chambers and heart valves; composed of endothelium reinforced with a thin layer of connective tissue that binds to the myocardium

**endothelium**: layer of smooth, simple squamous epithelium that lines the endocardium and blood vessels

**epicardial coronary arteries**: surface arteries of the heart that generally follow the sulci

**epicardium**: innermost layer of the serous pericardium and the outermost layer of the heart wall

**foramen ovale**: opening in the fetal heart that allows blood to flow directly from the right atrium to the left atrium, bypassing the fetal pulmonary circuit

**fossa ovalis**:oval-shaped depression in the interatrial septum that marks the former location of the foramen ovale

**great cardiac vein**: vessel that follows the interventricular sulcus on the anterior surface of the heart and flows along the coronary sulcus into the coronary sinus on the posterior surface; parallels the anterior interventricular artery and drains the areas supplied by this vessel

**heart block**: interruption in the normal conduction pathway

**hypertrophic cardiomyopathy**: pathological enlargement of the heart, generally for no known reason
**inferior vena cava**: large systemic vein that returns blood to the heart from the inferior portion of the body

**interatrial band**: (also, **Bachmann's bundle**) group of specialized conducting cells that transmit the impulse directly from the SA node in the right atrium to the left atrium

**interatrial septum**: cardiac septum located between the two atria; contains the fossa ovalis after birth

**intercalated disc**: physical junction between adjacent cardiac muscle cells; consisting of desmosomes, specialized linking proteoglycans, and gap junctions that allow passage of ions between the two cells

**internodal pathways**: specialized conductile cells within the atria that transmit the impulse from the SA node throughout the myocardial cells of the atrium and to the AV node

**interventricular septum**: cardiac septum located between the two ventricles

**left atrioventricular valve**: (also, mitral valve or bicuspid valve) valve located between the left atrium and ventricle; consists of two flaps of tissue

**marginal arteries**: branches of the right coronary artery that supply blood to the superficial portions of the right ventricle

**mesothelium**: simple squamous epithelial portion of serous membranes, such as the superficial portion of the epicardium (the visceral pericardium) and the deepest portion of the pericardium (the parietal pericardium)

**middle cardiac vein:** vessel that parallels and drains the areas supplied by the posterior interventricular artery; drains into the great cardiac vein

**mitral valve**: (also, left atrioventricular valve or bicuspid valve) valve located between the left atrium and ventricle; consists of two flaps of tissue

**moderator band**: band of myocardium covered by endocardium that arises from the inferior portion of the interventricular septum in the right ventricle and crosses to the anterior papillary muscle; contains conductile fibers that carry electrical signals followed by contraction of the heart

**myocardial conducting cells**: specialized cells that transmit electrical impulses throughout the heart and trigger contraction by the myocardial contractile cells

**myocardial contractile cells**: bulk of the cardiac muscle cells in the atria and ventricles that conduct impulses and contract to propel blood

**myocardium**: thickest layer of the heart composed of cardiac muscle cells built upon a framework of primarily collagenous fibers and blood vessels that supply it and the nervous fibers that help to regulate it

**P wave**: component of the electrocardiogram that represents the depolarization of the atria

**pacemaker**: cluster of specialized myocardial cells known as the SA node that initiates the sinus rhythm

**papillary muscle**: extension of the myocardium in the ventricles to which the chordae tendineae attach

**pectinate muscles**: muscular ridges seen on the anterior surface of the right atrium
**pericardial cavity**: cavity surrounding the heart filled with a lubricating serous fluid that reduces friction as the heart contracts

**pericardial sac**: (also, pericardium) membrane that separates the heart from other mediastinal structures; consists of two distinct, fused sublayers: the fibrous pericardium and the parietal pericardium

**pericardium**: (also, pericardial sac) membrane that separates the heart from other mediastinal structures; consists of two distinct, fused sublayers: the **fibrous pericardium** and the **parietal pericardium**

**posterior cardiac vein**: vessel that parallels and drains the areas supplied by the marginal artery branch of the circumflex artery; drains into the great cardiac vein

**posterior interventricular artery**: (also, posterior descending artery) branch of the right coronary artery that runs along the posterior portion of the interventricular sulcus toward the apex of the heart and gives rise to branches that supply the interventricular septum and portions of both ventricles

**posterior interventricular sulcus**: sulcus located between the left and right ventricles on the anterior surface of the heart
**pulmonary arteries**: left and right branches of the pulmonary trunk that carry deoxygenated blood from the heart to each of the lungs

**pulmonary capillaries**: capillaries surrounding the alveoli of the lungs where gas exchange occurs: carbon dioxide exits the blood and oxygen enters

**pulmonary circuit**: blood flow to and from the lungs
pulmonary trunk: large arterial vessel that carries blood ejected from the right ventricle; divides into the left and right pulmonary arteries

**pulmonary valve**: (also, pulmonary semilunar valve, the pulmonic valve, or the right semilunar valve) valve at the base of the pulmonary trunk that prevents backflow of blood into the right ventricle; consists of three flaps

**pulmonary veins**: veins that carry highly oxygenated blood into the left atrium, which pumps the blood into the left ventricle, which in turn pumps oxygenated blood into the aorta and to the many branches of the systemic circuit

**Purkinje fibers**: specialized myocardial conduction fibers that arise from the bundle branches and spread the impulse to the myocardial contraction fibers of the ventricles

**QRS complex**: component of the electrocardiogram that represents the depolarization of the ventricles and includes, as a component, the repolarization of the atria

**right atrioventricular valve**: (also, tricuspid valve) valve located between the right atrium and ventricle; consists of three flaps of tissue

**semilunar valves**: valves located at the base of the pulmonary trunk and at the base of the aorta
**septum**: (plural = septa) walls or partitions that divide the heart into chambers

**septum primum**: flap of tissue in the fetus that covers the foramen ovale within a few seconds after birth

**sinoatrial (SA) node**: known as the pacemaker, a specialized clump of myocardial conducting cells located in the superior portion of the right atrium that has the highest inherent rate of depolarization that then spreads throughout the heart

**sinus rhythm**: normal contractile pattern of the heart

**small cardiac vein**: parallels the right coronary artery and drains blood from the posterior surfaces of the right atrium and ventricle; drains into the great cardiac vein
**sulcus**: (plural = sulci) fat-filled groove visible on the surface of the heart; coronary vessels are also located in these areas

**spontaneous depolarization**: (also, **prepotential depolarization**) the mechanism that accounts for the autorhythmic property of cardiac muscle; the membrane potential increases as sodium ions diffuse through the always-open sodium ion channels and causes the electrical potential to rise

**superior vena cava**: large systemic vein that returns blood to the heart from the superior portion of the body

**systemic circuit**: blood flow to and from virtually all of the tissues of the body

**T wave**: component of the electrocardiogram that represents the repolarization of the ventricles

**trabeculae carneae**: ridges of muscle covered by endocardium located in the ventricles

**tricuspid valve**: term used most often in clinical settings for the right atrioventricular valve

**valve**: in the cardiovascular system, a specialized structure located within the heart or vessels that ensures one-way flow of blood

**ventricle**: one of the primary pumping chambers of the heart located in the lower portion of the heart; the left ventricle is the major pumping chamber on the lower left side of the heart that ejects blood into the systemic circuit via the aorta and receives blood from the left atrium; the right ventricle is the major pumping chamber on the lower right side of the heart that ejects blood into the pulmonary circuit via the pulmonary trunk and receives blood from the right atrium

# The Respiratory System

## Hō`ulu`ulu Pōkole (Overview)

In this lesson we will learn about the major structures of the respiratory system. The major organs of the respiratory system function primarily to provide oxygen to body tissues for cellular respiration, remove the waste product carbon dioxide, and help to maintain acid-base balance. Portions of the respiratory system are also used for non-vital functions, such as sensing odors, speech production, and for straining, such as during childbirth or coughing. Keep in mind that organ systems interact, or work, with other organ systems in order to keep the body functioning!

## Ke Haumana ka `apo (Student Learning Outcomes)

1. Describe the type of medical treatment the pulmonologist provides.
2. Describe the primary functions of the respiratory system.
3. Apply medical terminology to diseases, conditions, and procedures related to the respiratory system.
4. Demonstrate word-building skills by constructing medical terms related to the respiratory system.
5. Define common abbreviations and symbols related to the respiratory system.
6. Recognize, define, pronounce, and spell terms correctly.

## Organs and Structures of the Respiratory System

- ❏ Nasal cavity
- ❏ Oral cavity
- ❏ Pharynx
    - ❏ Nasopharynx
    - ❏ oropharynx
- ❏ Larynx
- ❏ Trachea
- ❏ Lungs
    - ❏ bronchi
        - ❏ bronchioles
        - ❏ alveoli
- ❏ Diaphragm

**Major Respiratory Structures**

The major respiratory structures span the nasal cavity to the diaphragm.

Functionally, the respiratory system can be divided into a conducting zone and a respiratory zone. The conducting zone of the respiratory system includes the organs and structures not directly involved in gas exchange. The gas exchange occurs in the respiratory zone.

## Conducting Zone

The major functions of the conducting zone are to provide a route for incoming and outgoing air, remove debris and pathogens from the incoming air, and warm and humidify the incoming air. Several structures within the conducting zone perform other functions as well. The epithelium of the nasal passages, for example, is essential to sensing odors, and the bronchial epithelium that lines the lungs can metabolize some airborne carcinogens.

## Upper Airway

Several bones that help form the walls of the nasal cavity have air-containing spaces called the paranasal sinuses, which serve to warm and humidify incoming air. Sinuses are lined with a mucosa. Each paranasal sinus is named for its associated bone: frontal sinus, maxillary sinus, sphenoidal sinus, and ethmoidal sinus. The sinuses produce mucus and lighten the weight of the skull.

The nares and anterior portion of the nasal cavities are lined with mucous membranes, containing sebaceous glands and hair follicles that serve to prevent the passage of large debris, such as dirt, through the nasal cavity. An olfactory epithelium used to detect odors is found deeper in the nasal cavity.

The conchae, meatuses, and paranasal sinuses are lined by respiratory epithelium composed of pseudostratified ciliated columnar epithelium (Figure). The epithelium contains goblet cells, one of the specialized, columnar epithelial cells that produce mucus to trap debris. The cilia of the respiratory epithelium help remove the mucus and debris from the nasal cavity with a constant beating motion, sweeping materials towards the throat to be swallowed. Immune cells that patrol the connective tissue deep to the respiratory epithelium provide additional protection.

**Pseudostratified Ciliated Columnar Epithelium**

Respiratory epithelium is pseudostratified ciliated columnar epithelium. Seromucous glands provide lubricating mucus. LM × 680. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

## Pharynx

The pharynx is a tube formed by skeletal muscle and lined by mucous membrane that is continuous with that of the nasal cavities (see Figure). The pharynx is divided into three major regions: the nasopharynx, the oropharynx, and the laryngopharynx (Figure).

## Divisions of the Pharynx

The pharynx is divided into three regions: the nasopharynx, the oropharynx, and the laryngopharynx.

The **nasopharynx** is flanked by the conchae of the nasal cavity, and it serves only as an airway. At the top of the nasopharynx are the pharyngeal tonsils. A **pharyngeal tonsil**, also called an **adenoid**, is an aggregate of lymphoid reticular tissue similar to a lymph node that lies at the superior portion of the nasopharynx. The **uvula** is a small bulbous, teardrop-shaped structure located at the apex of the soft palate. Both the uvula and soft palate move like a pendulum during swallowing, swinging upward to close off the nasopharynx to prevent ingested materials from entering the nasal cavity. In addition, auditory (Eustachian) tubes that connect to each middle ear cavity open into the nasopharynx. This connection is why colds often lead to ear infections.

The **oropharynx** is a passageway for both air and food. The oropharynx is bordered superiorly by the nasopharynx and anteriorly by the oral cavity. The oropharynx contains two distinct sets of tonsils, the **palatine** and **lingual** tonsils. A palatine tonsil is one of a pair of structures located laterally in the oropharynx in the area of the fauces. The lingual tonsil is located at the base of the tongue.

The **laryngopharynx** is inferior to the oropharynx and posterior to the larynx. It continues the route for ingested material and air until its inferior end, where the digestive and respiratory systems diverge. The stratified squamous epithelium of the oropharynx is continuous with the laryngopharynx. Anteriorly, the laryngopharynx opens into the larynx, whereas posteriorly, it enters the esophagus.

## Larynx

The larynx is a cartilaginous structure inferior to the laryngopharynx that connects the pharynx to the trachea and helps regulate the volume of air that enters and leaves the lungs. The structure of the larynx is formed by several pieces of cartilage. Three large cartilage pieces—the thyroid cartilage (anterior), epiglottis (superior), and cricoid cartilage (inferior)—form the major structure of the larynx. The thyroid cartilage is the largest piece of cartilage that makes up the larynx. The thyroid cartilage consists of the laryngeal prominence, or "Adam's apple," which tends to be more prominent in males. The thick cricoid cartilage forms a ring, with a wide posterior region and a thinner anterior region. Larynx

The larynx extends from the laryngopharynx and the hyoid bone to the trachea.

The epiglottis, attached to the thyroid cartilage, is a very flexible piece of elastic cartilage that covers the opening of the trachea (see Figure). When in the "closed" position, the unattached end of the epiglottis rests on the glottis. The glottis is composed of the vestibular folds, the true vocal cords, and the space between these folds ([Figure](#)). A vestibular fold, or false vocal cord, is one of a pair of folded sections of mucous membrane. A true vocal cord is one of the white, membranous folds attached by muscle to the thyroid and arytenoid cartilages of the larynx on their outer edges. The inner edges of the true vocal cords are free, allowing oscillation to produce sound. The size of the membranous folds of the true vocal cords differs between individuals, producing voices with different pitch ranges. Folds in males tend to be larger than those in females, which create a deeper voice. The act of swallowing causes the pharynx and larynx to lift upward, allowing the pharynx to expand and the epiglottis of the larynx to swing downward, closing the opening to the trachea. These movements produce a larger area for food to pass through, while preventing food and beverages from entering the trachea.

**Vocal Cords**

The true

whereas the rings of cartilage provide structural support and prevent the trachea from collapsing. In addition, the trachealis muscle can be contracted to force air through the trachea during exhalation. The trachea is lined with pseudostratified ciliated columnar epithelium, which is continuous with the larynx. The esophagus borders the trachea posteriorly.

**Trachea**

vocal cords and vestibular folds of the larynx are viewed inferiorly from the laryngopharynx.

Continuous with the laryngopharynx, the superior portion of the larynx is lined with stratified squamous epithelium, transitioning into pseudostratified ciliated columnar epithelium that contains goblet cells. Similar to the nasal cavity and nasopharynx, this specialized epithelium produces mucus to trap debris and pathogens as they enter the trachea. The cilia beat the mucus upward towards the laryngopharynx, where it can be swallowed down the esophagus.

## Trachea

The **trachea** (windpipe) extends from the larynx toward the lungs ([Figure](#) a). The trachea is formed by 16 to 20 stacked, C-shaped pieces of hyaline cartilage that are connected by dense connective tissue.

The trachealis muscle and elastic connective tissue together form the fibroelastic membrane, a flexible membrane that closes the posterior surface of the trachea, connecting the C-shaped cartilages. The fibroelastic membrane allows the trachea to stretch and expand slightly during inhalation and exhalation,

(a) The tracheal tube is formed by stacked, C-shaped pieces of hyaline cartilage. (b) The layer visible in this cross-section of tracheal wall tissue between the hyaline cartilage and the lumen of the trachea is the mucosa, which is composed of pseudostratified ciliated columnar epithelium that contains goblet cells. LM × 1220. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

## Bronchial Tree

The trachea branches into the right and left primary bronchi at the carina. These bronchi are also lined by pseudostratified ciliated columnar epithelium containing mucus-producing goblet cells (Figure b). The carina is a raised structure that contains specialized nervous tissue that induces violent coughing if a foreign body, such as food, is present. Rings of cartilage, similar to those of the trachea, support the structure of the bronchi and prevent their collapse. The primary bronchi enter the lungs at the hilum, a concave region where blood vessels, lymphatic vessels, and nerves also enter the lungs. The bronchi continue to branch into bronchial a tree. A bronchial tree (or respiratory tree) is the collective term used for these multiple-branched bronchi. The main function of the bronchi, like other conducting zone structures, is to provide a passageway for air to move into and out of each lung. In addition, the mucous membrane traps debris and pathogens.

A bronchiole branches from the tertiary bronchi. Bronchioles, which are about 1 mm in diameter, further branch until they become the tiny terminal bronchioles, which lead to the structures of gas exchange. There are more than 1000 terminal bronchioles in each lung. The muscular walls of the bronchioles do not contain cartilage like those of the bronchi. This muscular wall can change the size of the tubing to increase or decrease airflow through the tube.

# Respiratory Zone

In contrast to the conducting zone, the respiratory zone includes structures that are directly involved in gas exchange. The respiratory zone begins where the terminal bronchioles join a respiratory bronchiole, the smallest type of bronchiole (Figure), which then leads to an alveolar duct, opening into a cluster of alveoli.

**Respiratory Zone**

Bronchioles lead to alveolar sacs in the respiratory zone, where gas exchange occurs.

## Alveoli

An alveolar duct is a tube composed of smooth muscle and connective tissue, which opens into a cluster of alveoli. An alveolus is one of the many small, grape-like sacs that are attached to the alveolar ducts. An alveolar sac is a cluster of many individual alveoli that are responsible for gas exchange. An alveolus is approximately 200 µm in diameter with elastic walls that allow the alveolus to stretch during air intake, which greatly increases the surface area available for gas exchange. Alveoli are connected to their neighbors by alveolar pores, which help maintain equal air pressure throughout the alveoli and lung (Figure).

**Structures of the Respiratory Zone**

(a) The alveolus is responsible for gas exchange. (b) A micrograph shows the alveolar structures within lung tissue. LM × 178. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

- The alveolar wall consists of three major cell types: type I alveolar cells, type II alveolar cells, and alveolar macrophages.
- A type I alveolar cell is a squamous epithelial cell of the alveoli, which constitute up to 97 percent of the alveolar surface area. These cells are about 25 nm thick and are highly permeable to gases.
- A type II alveolar cell is interspersed among the type I cells and secretes pulmonary surfactant, a substance composed of phospholipids and proteins that reduces the surface tension of the alveoli.
- Roaming around the alveolar wall is the alveolar macrophage, a phagocytic cell of the immune system that removes debris and pathogens that have reached the alveoli.

- The simple squamous epithelium formed by type I alveolar cells is attached to a thin, elastic basement membrane. This epithelium is extremely thin and borders the endothelial membrane of capillaries.
- Taken together, the alveoli and capillary membranes form a respiratory membrane that is approximately 0.5 mm thick. The respiratory membrane allows gases to cross by simple diffusion, allowing oxygen to be picked up by the blood for transport and $CO_2$ to be released into the air of the alveoli.

## FOCUS ON DISEASES OF THE…Respiratory System:

Asthma is a chronic disease characterized by inflammation and edema of the airway, and bronchospasms (that is, constriction of the bronchioles), which can inhibit air from entering the lungs. In addition, excessive mucus secretion can occur, which further contributes to airway occlusion (Figure). Cells of the immune system, such as eosinophils and mononuclear cells, may also be involved in infiltrating the walls of the bronchi and bronchioles. Bronchospasms occur periodically and lead to an "asthma attack." An attack may be triggered by environmental factors such as dust, pollen, pet hair, or dander, changes in the weather, mold, tobacco smoke, and respiratory infections, or by exercise and stress.

(a) Normal lung tissue does not have the characteristics of lung tissue during (b) an asthma attack, which include thickened mucosa, increased mucus-producing goblet cells, and eosinophil infiltrates.

Symptoms of an asthma attack involve coughing, shortness of breath, wheezing, and tightness of the chest. Symptoms of a severe asthma attack that requires immediate medical attention would include difficulty breathing that results in blue (cyanotic) lips or face, confusion, drowsiness, a rapid pulse, sweating, and severe anxiety. The severity of the condition, frequency of attacks, and identified triggers influence the type of medication that an individual may require. Longer-term treatments are used for those with more severe asthma. Short-term, fast-acting drugs that are used to treat an asthma attack are typically administered via an inhaler. For young children or individuals who have difficulty using an inhaler, asthma medications can be administered via a nebulizer.

In many cases, the underlying cause of the condition is unknown. However, recent research has demonstrated that certain viruses, such as human rhinovirus C (HRVC), and the bacteria Mycoplasma pneumoniae and Chlamydia pneumoniae that are contracted in infancy or early childhood, may contribute to the development of many cases of asthma.

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# Glossary

**ala**: (plural = alae) small, flaring structure of a nostril that forms the lateral side of the nares

**alar cartilage**: cartilage that supports the apex of the nose and helps shape the nares; it is connected to the septal cartilage and connective tissue of the alae

**alveolar duct**: small tube that leads from the terminal bronchiole to the respiratory bronchiole and is the point of attachment for alveoli

**alveolar macrophage**: immune system cell of the alveolus that removes debris and pathogens

**alveolar pore**: opening that allows airflow between neighboring alveoli

**alveolar sac**: cluster of alveoli

**alveolus**: small, grape-like sac that performs gas exchange in the lungs

**apex**: tip of the external nose

**bronchial tree**: collective name for the multiple branches of the bronchi and bronchioles of the respiratory system

**bronchiole**: branch of bronchi that are 1 mm or less in diameter and terminate at alveolar sacs

**bronchus**: tube connected to the trachea that branches into many subsidiaries and provides a passageway for air to enter and leave the lungs

**conducting zone**: region of the respiratory system that includes the organs and structures that provide passageways for air and are not directly involved in gas exchange

**cricoid cartilage**: portion of the larynx composed of a ring of cartilage with a wide posterior region and a thinner anterior region; attached to the esophagus

**dorsum nasi**: intermediate portion of the external nose that connects the bridge to the apex and is supported by the nasal bone

**epiglottis**: leaf-shaped piece of elastic cartilage that is a portion of the larynx that swings to close the trachea during swallowing

**external nose**: region of the nose that is easily visible to others

**fauces**: portion of the posterior oral cavity that connects the oral cavity to the oropharynx

**fibroelastic membrane**: specialized membrane that connects the ends of the C-shape cartilage in the trachea; contains smooth muscle fibers

**glottis**: opening between the vocal folds through which air passes when producing speech

**laryngeal prominence**: region where the two lamina of the thyroid cartilage join, forming a protrusion known as "Adam's apple"

**laryngopharynx**: portion of the pharynx bordered by the oropharynx superiorly and esophagus and trachea inferiorly; serves as a route for both air and food

**larynx**: cartilaginous structure that produces the voice, prevents food and beverages from entering the trachea, and regulates the volume of air that enters and leaves the lungs

**lingual tonsil**: lymphoid tissue located at the base of the tongue

**meatus**: one of three recesses (superior, middle, and inferior) in the nasal cavity attached to the conchae that increase the surface area of the nasal cavity

**naris**: (plural = **nares**) opening of the nostrils

**nasal bone**: bone of the skull that lies under the root and bridge of the nose and is connected to the frontal and maxillary bones

**nasal septum**: wall composed of bone and cartilage that separates the left and right nasal cavities

**nasopharynx**: portion of the pharynx flanked by the conchae and oropharynx that serves as an airway

**oropharynx**: portion of the pharynx flanked by the nasopharynx, oral cavity, and laryngopharynx that is a passageway for both air and food

**palatine tonsil**: one of the paired structures composed of lymphoid tissue located anterior to the uvula at the roof of isthmus of the fauces

**paranasal sinus**: one of the cavities within the skull that is connected to the conchae that serve to warm and humidify incoming air, produce mucus, and lighten the weight of the skull; consists of frontal, maxillary, sphenoidal, and ethmoidal sinuses

**pharyngeal tonsil**: structure composed of lymphoid tissue located in the nasopharynx

**pharynx**: region of the conducting zone that forms a tube of skeletal muscle lined with respiratory **epithelium**; located between the nasal conchae and the esophagus and trachea

**philtrum**: concave surface of the face that connects the apex of the nose to the top lip

**pulmonary surfactant**: substance composed of phospholipids and proteins that reduces the surface tension of the alveoli; made by type II alveolar cells

**respiratory bronchiole**: specific type of bronchiole that leads to alveolar sacs

**respiratory epithelium**: ciliated lining of much of the conducting zone that is specialized to remove debris and pathogens, and produce mucus

**respiratory membrane**: alveolar and capillary wall together, which form an air-blood barrier that facilitates the simple diffusion of gases

**respiratory zone**: includes structures of the respiratory system that are directly involved in gas exchange

**root**: region of the external nose between the eyebrows

**thyroid cartilage**: largest piece of cartilage that makes up the larynx and consists of two lamina

**trachea**: tube composed of cartilaginous rings and supporting tissue that connects the lung bronchi and **the larynx**; provides a route for air to enter and exit the lung

**trachealis muscle**: smooth muscle located in the fibroelastic membrane of the trachea

**true vocal cord**: one of the pair of folded, white membranes that have a free inner edge that oscillates as air passes through to produce sound

**type I alveolar cell**: squamous epithelial cells that are the major cell type in the alveolar wall; highly permeable to gases

**type II alveolar cell**: cuboidal epithelial cells that are the minor cell type in the alveolar wall; secrete pulmonary surfactant

**vestibular fold**: part of the folded region of the glottis composed of mucous membrane; supports the epiglottis during swallowing

*Ha`awina 11: HLTH 140*

# The Endocrine system

## Hō`ulu`ulu Pōkole (Overview)

The endocrine system is really more of a meta-system...a system of systems. This is because the endocrine system regulates the other body systems. The endocrine system is a group of glands that store and releases hormone that act as signals telling the organs what to do, from how fast to metabolize energy to when to store minerals, to when to grow or stop growing . This is done through feedback mechanisms built into receptors in all organs. Interestingly, hormones released by the endocrine system are dispersed throughout the bloodstream, but only react with very specific receptors. *We will review the following endocrine major glands:

- ❏ Pituitary /hypothalamus complex
- ❏ Thyroid
- ❏ Parathyroid
- ❏ Adrenal
- ❏ Endocrine Pancreas

*Several organs also have endocrine aspects that we will not talk about here. Also, the thymus and pineal glands are left out, however this information is available in the OpenStax A & P text

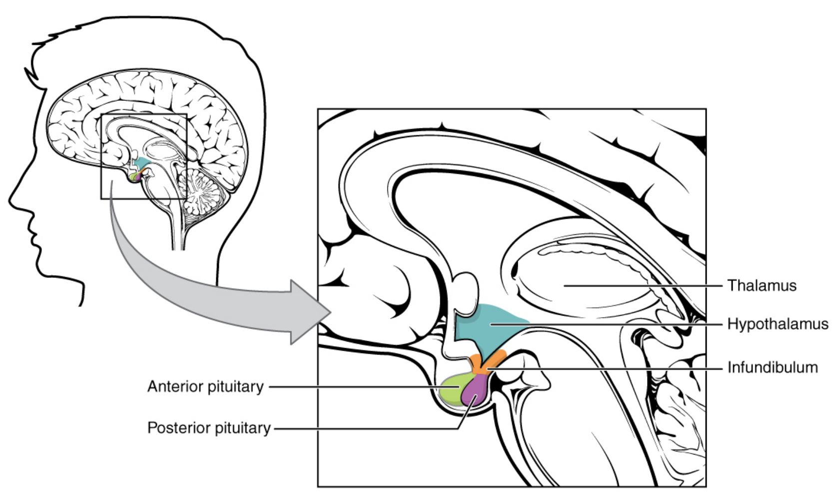
## Ke Haumana ka `apo (Student Learning Outcomes)

1. Identify the structures of the endocrine system
2. Describe the primary functions of the endocrine system
3. Apply word building skills by constructing medical terms related to the endocrine system
4. Recall common abbreviations used in reference to the endocrine system
5. recognize, define, and pronounce terms related to the endocrine system correctly

## The Pituitary Gland and Hypothalamus

The hypothalamus–pituitary complex can be thought of as the "command center" of the endocrine system. This complex secretes several hormones that directly produce responses in target tissues, as well as hormones that regulate the synthesis and secretion of hormones of other glands. In addition, the hypothalamus–pituitary complex coordinates the messages of the endocrine and nervous systems. In many cases, a stimulus received by the nervous system must pass through the hypothalamus–pituitary complex to be translated into hormones that can initiate a response.

The hypothalamus is a structure of the diencephalon of the brain located anterior and inferior to the thalamus (Figure). It has both neural and endocrine functions, producing and secreting many hormones. In addition, the hypothalamus is anatomically and functionally related to the pituitary gland (or hypophysis), a bean-sized organ suspended from it by a stem called the infundibulum (or pituitary stalk). The pituitary gland is cradled within the sellaturcica of the sphenoid bone of the skull. It consists of two lobes that arise from distinct parts of embryonic tissue: the posterior pituitary (neurohypophysis) is neural tissue, whereas the anterior pituitary (also known as the adenohypophysis) is glandular tissue that develops from the primitive digestive tract. The hormones secreted by the posterior and anterior pituitary, and the intermediate zone between the lobes are summarized in Table.




**Hypothalamus–Pituitary Complex**

The hypothalamus region lies inferior and anterior to the thalamus. It connects to the pituitary gland by the stalk-like infundibulum. The pituitary gland consists of an anterior and posterior lobe, with each lobe secreting different hormones in response to signals from the hypothalamus.

## Table: Pituitary Hormones

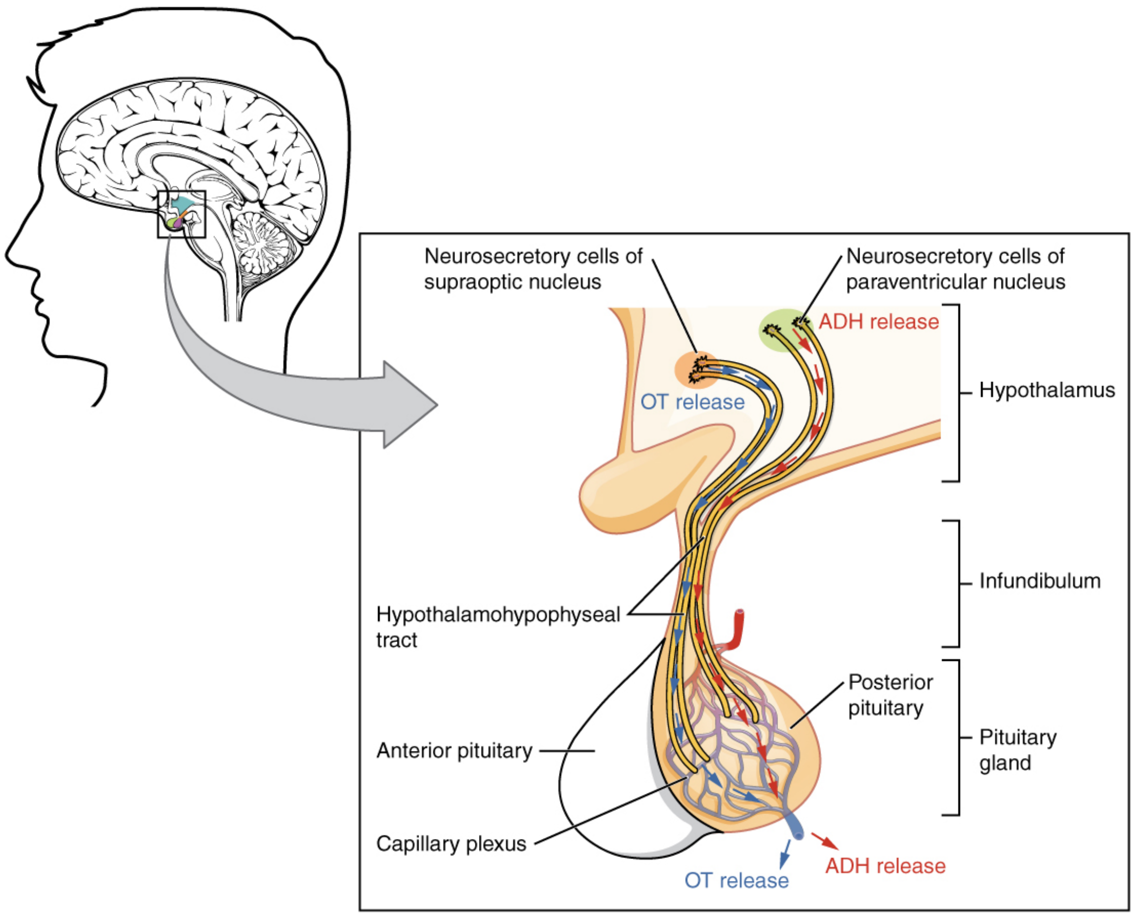
| Lobe | Hormone released | Hormone effect |
|---|---|---|
| Anterior | Growth hormone (GH) | Promotes growth of body tissues |
| Anterior | Prolactin (PRL) | Promotes milk production from mammary glands |
| Anterior | Thyroid-stimulating hormone (TSH) | Stimulates thyroid hormone release from thyroid |
| Anterior | Adrenocorticotropic hormone | Stimulates hormone release by |

| | | |
|---|---|---|
| | (ACTH) | adrenal cortex |
| Anterior | Follicle-stimulating hormone (FSH) | Stimulates gamete production in gonads |
| Anterior | Luteinizing hormone (LH) | Stimulates androgen production by gonads |
| Posterior | Antidiuretic hormone (ADH) | Stimulates water reabsorption by kidneys |
| Posterior | Oxytocin | Stimulates uterine contractions during childbirth |
| Intermediate zone | Melanocyte-stimulating hormone | Stimulates melanin formation in melanocytes |

## Posterior Pituitary

The posterior pituitary is actually an extension of the **neurons** of the **hypothalamus**. The cell bodies of these regions rest in the hypothalamus, but their axons descend within the infundibulum, and end in axon terminals that comprise the **posterior pituitary** (Figure). This is an example how the nervous system and the endocrine system interact with each other.

**Posterior Pituitary**




So the posterior pituitary gland does not produce hormones, but rather stores and secretes hormones **oxytocin** and **antidiuretic hormone (ADH)** produced by the hypothalamus.

## Oxytocin

When fetal development is complete, the peptide-derived hormone oxytocin (tocia- = "childbirth") stimulates uterine contractions and dilation of the cervix.

- Oxytocin is necessary for the milk ejection reflex (commonly referred to as "let-down") in breastfeeding women. As the newborn begins suckling, sensory receptors in the nipples transmit signals to the hypothalamus. In response, oxytocin is secreted and released into the bloodstream. Within seconds, cells in the mother's milk ducts contract, ejecting milk into the infant's mouth. Secondly, in both males and females, oxytocin is thought to contribute to parent–newborn bonding, known as attachment.
- Oxytocin is also thought to be involved in feelings of love and closeness, as well as in the sexual response.

### Antidiuretic Hormone (ADH)

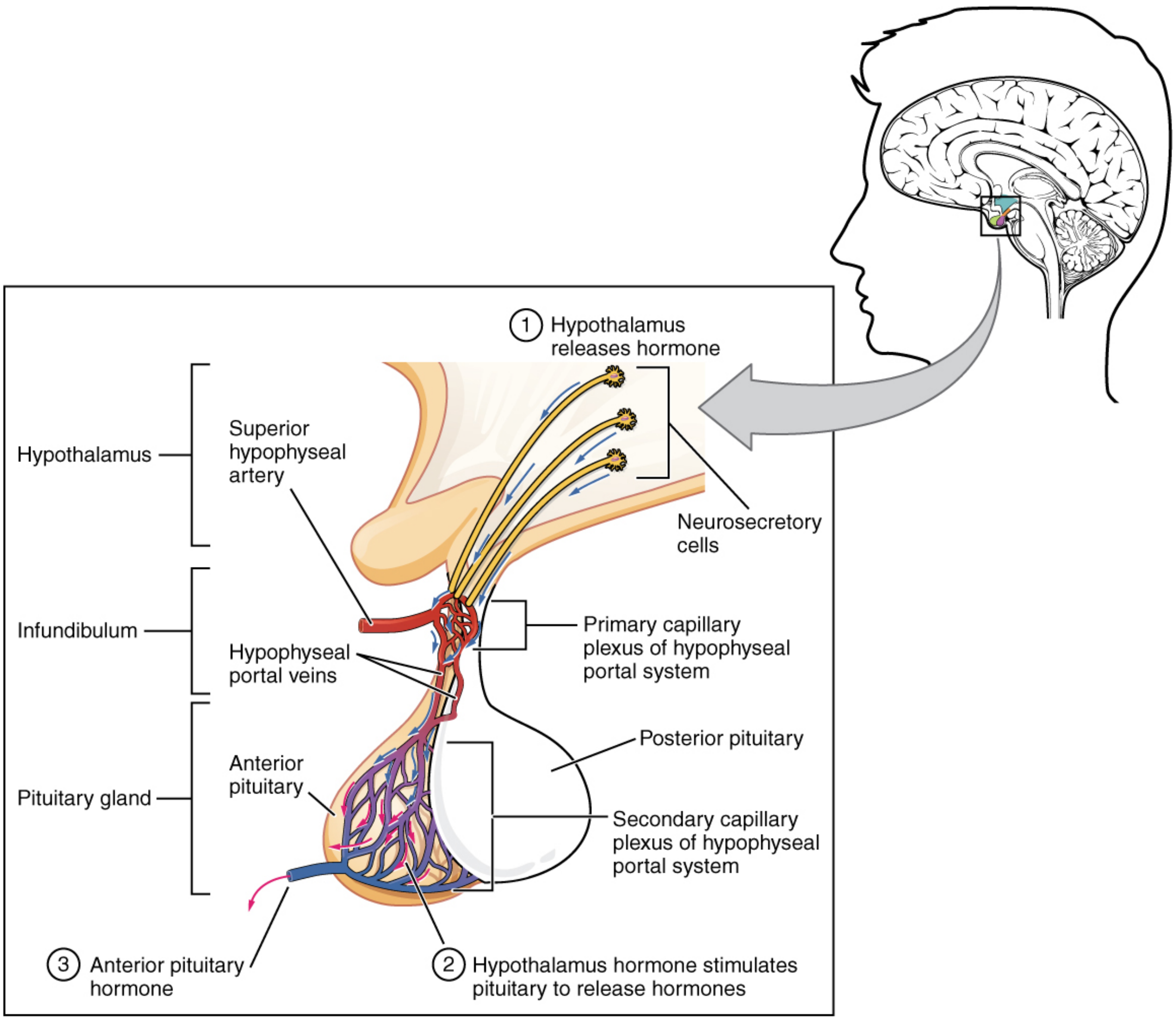
In response to high blood **osmolarity**, which can occur during dehydration or following a very salty meal, the osmoreceptors signal the posterior pituitary to release antidiuretic hormone (ADH). The target cells of ADH are located in the **tubular cells of the kidneys**. Its effect is to

- increase epithelial permeability to water, allowing increased water reabsorption. The more water reabsorbed from the filtrate, the greater the amount of water that is returned to the blood and the less that is excreted in the urine. A greater concentration of water results in a reduced concentration of solutes.
- ADH is also known as **vasopressin** because, in very high concentrations, it causes constriction of blood vessels, which increases blood pressure by increasing peripheral resistance.
- The release of ADH is controlled by a negative feedback loop. As blood osmolarity decreases, the hypothalamic osmoreceptors sense the change and prompt a corresponding decrease in the secretion of ADH. As a result, less water is reabsorbed from the urine filtrate.

## Anterior Pituitary

Recall that the posterior pituitary does not synthesize hormones, but merely stores them. In contrast, the anterior pituitary does manufacture hormones. However, the secretion of hormones from the anterior pituitary is regulated by two classes of hormones. These hormones—secreted by the hypothalamus—are the releasing hormones that stimulate the secretion of hormones from the anterior pituitary and the inhibiting hormones that inhibit secretion.

**Hypothalamic hormones** are secreted by neurons, but enter the anterior pituitary through blood vessels (Figure). Within the **infundibulum** is a bridge of capillaries that connects the hypothalamus to the anterior pituitary. This network, called the hypophyseal portal system, allows hypothalamic hormones to be transported to the anterior pituitary without first entering the systemic circulation. Anterior Pituitary

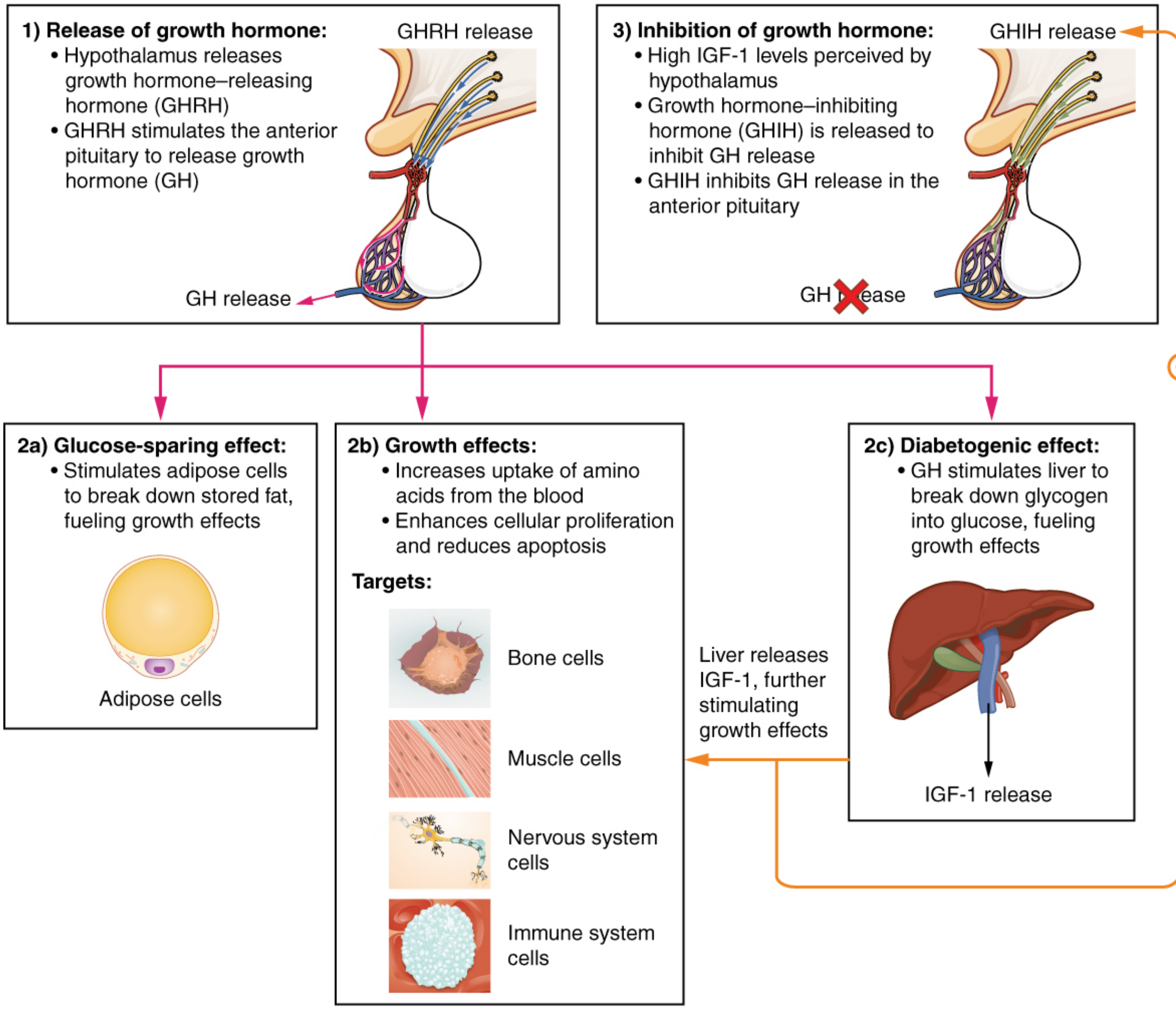



The anterior pituitary produces seven hormones. These are the **growth hormone (GH)**, **thyroid-stimulating hormone (TSH)**, **adrenocorticotropic hormone (ACTH)**, **follicle-stimulating hormone (FSH)**, **luteinizing hormone (LH)**, **beta endorphin**, and **prolactin**. Of the hormones of the anterior pituitary, TSH, ACTH, FSH, and LH are collectively referred to as **tropic** hormones (trope- = "turning") because they turn on or off the function of other endocrine glands.

## Growth Hormone

The endocrine system regulates the growth of the human body, protein synthesis, and cellular replication. A major hormone involved in this process is growth hormone (GH), also called **somatotropin**—a protein hormone produced and secreted by the anterior pituitary gland. Its primary function is **anabolic**; it promotes protein synthesis and tissue building through direct and indirect mechanisms (Figure). GH levels are controlled by the release of GHRH and GHIH (also known as somatostatin) from the hypothalamus.

**Hormonal Regulation of Growth**




Growth hormone (GH) directly accelerates the rate of protein synthesis in skeletal muscle and bones. Insulin-like growth factor 1 (IGF-1) is activated by growth hormone and indirectly supports the formation of new proteins in muscle cells and bone.

## Thyroid-Stimulating Hormone

The activity of the thyroid gland is regulated by **thyroid-stimulating hormone (TSH)**, also called **thyrotropin**. TSH is released from the anterior pituitary in response to **thyrotropin-releasing hormone** (TRH) from the hypothalamus. TRH  triggers the secretion of thyroid hormones by the thyroid gland. In a classic negative feedback loop, elevated levels of thyroid hormones in the bloodstream then trigger a drop in production of TRH and subsequently TSH. Clinicians test blood for TSH to evaluate thyroid function.

## Adrenocorticotropic Hormone

The **adrenocorticotropic hormone (ACTH)**, also called **corticotropin**, stimulates the **adrenal cortex** (the more superficial outer part of the adrenal glands) to secrete **corticosteroid hormones** such as

**cortisol**.

## Follicle-Stimulating Hormone and Luteinizing Hormone

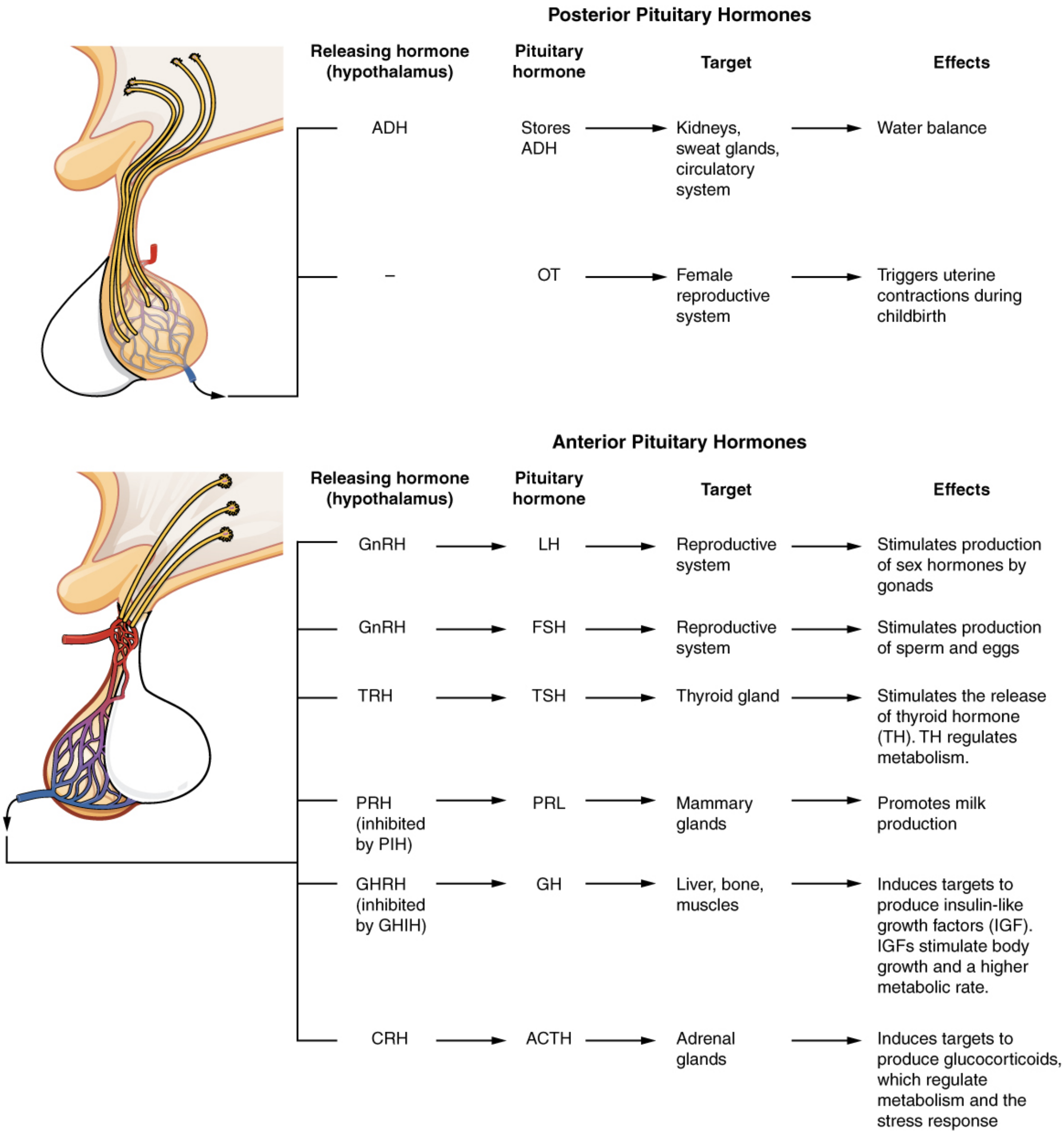
Much of the development of the reproductive system occurs during puberty and is marked by the development of sex-specific characteristics in both male and female adolescents. Puberty is initiated by **gonadotropin-releasing hormone (GnRH)**, a hormone produced and secreted by the hypothalamus. GnRH stimulates the anterior pituitary to secrete **gonadotropins**—hormones that regulate the function of the **gonads**. The levels of GnRH are regulated through a negative feedback loop; high levels of reproductive hormones inhibit the release of GnRH. Throughout life, gonadotropins regulate reproductive function and, in the case of women, the onset and cessation of reproductive capacity.

The gonadotropins include two glycoprotein hormones: **follicle-stimulating hormone (FSH)** stimulates the production and maturation of sex cells, or gametes, including ova in women and sperm in men. FSH also promotes follicular growth; these follicles then release estrogens in the female ovaries. **Luteinizing hormone (LH)** triggers ovulation in women, as well as the production of estrogens and progesterone by the ovaries. LH stimulates production of testosterone by the male testes.

## Prolactin

As its name implies, **prolactin (PRL)** promotes lactation (milk production) in women. During pregnancy, it contributes to development of the mammary glands, and after birth, it stimulates the mammary glands to produce breast milk.

**Major pituitary hormones and their target organs.**

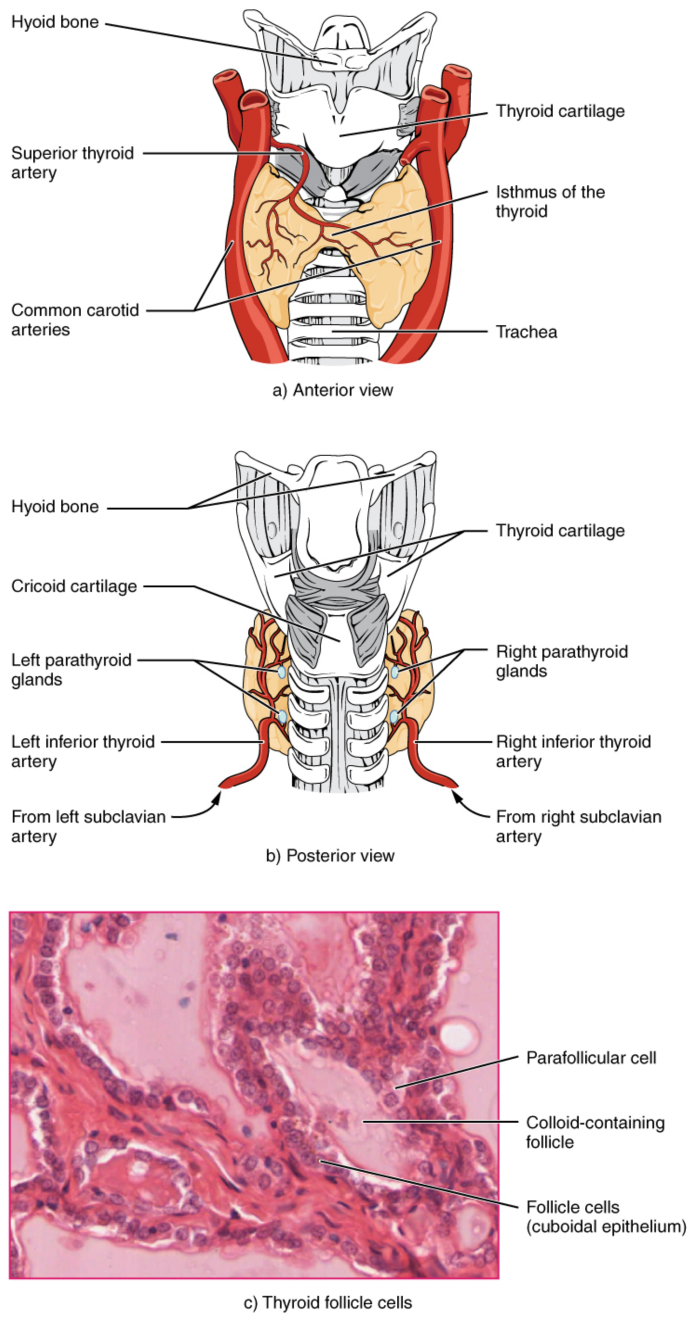



## Review

The hypothalamus–pituitary complex is located in the diencephalon of the brain. The hypothalamus and the pituitary gland are connected by a structure called the infundibulum, which contains vasculature and nerve axons. The pituitary gland is divided into two distinct structures with different embryonic origins. The posterior lobe houses the axon terminals of hypothalamic neurons. It stores and releases into the bloodstream two hypothalamic hormones: oxytocin and antidiuretic hormone (ADH). The anterior lobe is connected to the hypothalamus by vasculature in the infundibulum and produces and secretes six hormones. Their secretion is regulated, however, by releasing and inhibiting hormones from the hypothalamus. The six anterior pituitary hormones are: growth hormone (GH), thyroid-stimulating hormone (TSH), adrenocorticotropic hormone (ACTH), follicle-stimulating hormone (FSH), luteinizing hormone (LH), and prolactin (PRL).

## The Thyroid Gland

A butterfly-shaped organ, the thyroid gland is located anterior to the trachea, just inferior to the larynx (Figure). The medial region, called the isthmus, is flanked by wing-shaped left and right lobes. Each of the thyroid lobes are embedded with parathyroid glands, primarily on their posterior surfaces. The tissue of the thyroid gland is composed mostly of thyroid follicles. The follicles are made up of a central cavity filled with a sticky fluid called colloid. Surrounded by a wall of epithelial follicle cells, the colloid is the center of thyroid hormone production, and that production is dependent on the hormones' essential and unique component: iodine.




(Micrograph provided by the Regents of University of Michigan Medical School © 2012)

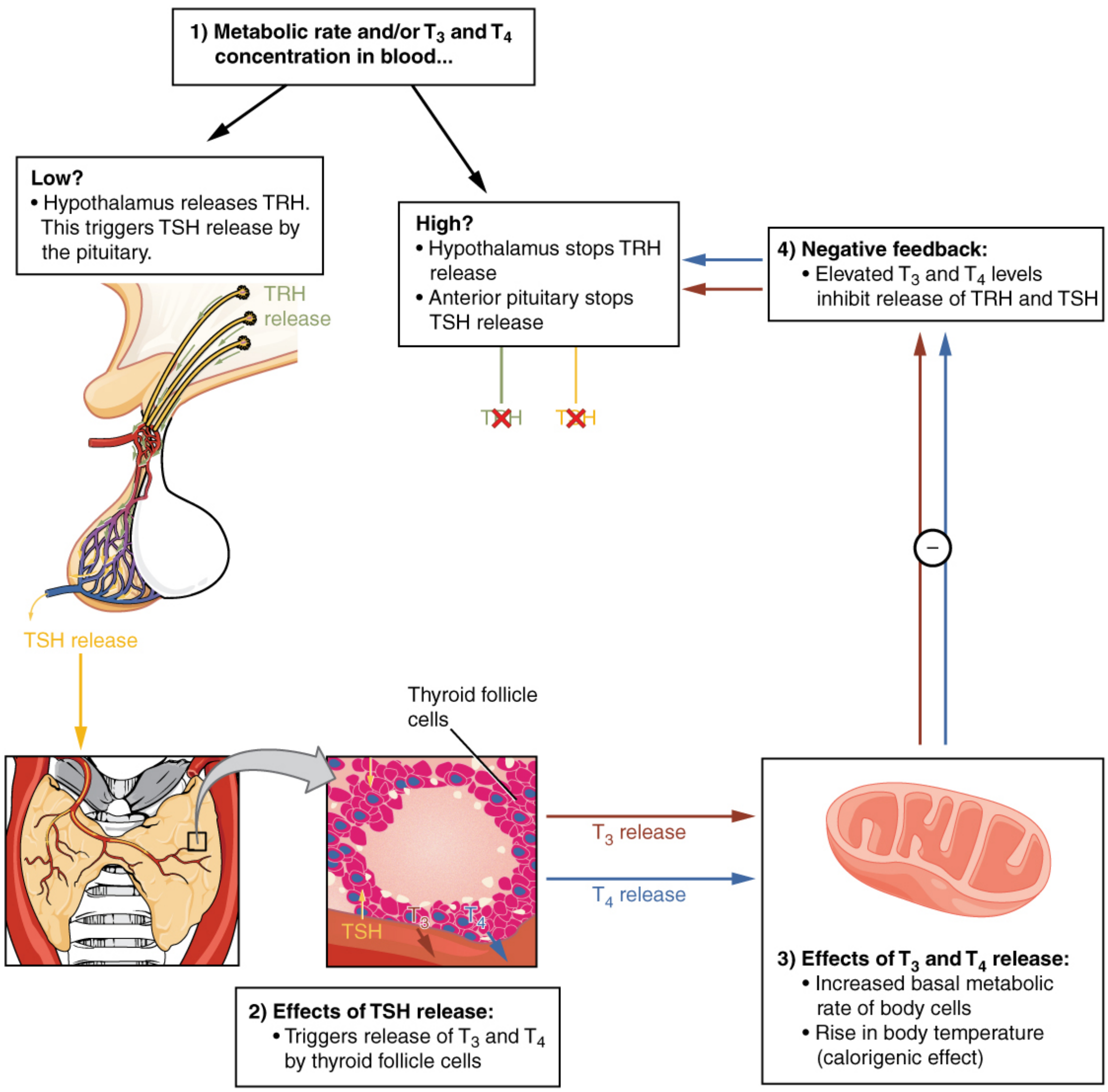
**Synthesis and Release of Thyroid Hormones**

- Binding of TSH to its receptors in the thyroid gland causes the cells to actively transport iodide ions (I–) across their cell membrane, from the bloodstream
- Iodide ions then move to the lumen of the follicle cells that border the colloid. There, the ions undergo oxidation (their negatively charged electrons are removed). The oxidation of two iodide ions (2 I–) results in iodine ($I_2$), which passes through the follicle cell membrane into the colloid.

- ❑ triiodothyronine (T3), a thyroid hormone with three iodines. Much more commonly, two copies of the second intermediary bond, forming tetraiodothyronine, also known as thyroxine (T4), a thyroid hormone with four iodines.
- ❑ T3 and T4 stimulate or slow down the body's metabolic rate, how the body metabolizes energy.

### Regulation of TH Synthesis

**Classic Negative Feedback Loop**



A classic negative feedback loop controls the regulation of thyroid hormone levels.

## DISORDERS OF THE…Endocrine System: Iodine Deficiency, Hypothyroidism, and Hyperthyroidism

As discussed above, dietary iodine is required for the synthesis of T3 and T4. But for much of the world's population, foods do not provide adequate levels of this mineral, because the amount varies according to the level in the soil in which the food was grown, as well as the irrigation and fertilizers used. Marine fish and shrimp tend to have high levels because they concentrate iodine from seawater, but many people in landlocked regions lack access to seafood. Thus, the primary source of dietary iodine in many countries is iodized salt. Fortification of salt with iodine began in the United States in 1924, and international efforts to iodize salt in the world's poorest nations continue today.

Dietary iodine deficiency can result in the impaired ability to synthesize $T_3$ and $T_4$, leading to a variety of severe disorders. When $T_3$ and $T_4$ cannot be produced, TSH is secreted in increasing amounts. As a result of this hyperstimulation, thyroglobulin accumulates in the thyroid gland follicles, increasing their deposits of colloid. The accumulation of colloid increases the overall size of the thyroid gland, a condition called a goiter (Figure). A goiter is only a visible indication of the deficiency. Other iodine deficiency disorders include impaired growth and development, decreased fertility, and prenatal and infant death. Moreover, iodine deficiency is the primary cause of preventable mental retardation worldwide. Neonatal hypothyroidism (cretinism) is characterized by cognitive deficits, short stature, and sometimes deafness and muteness in children and adults born to mothers who were iodine-deficient during pregnancy.

In areas of the world with access to iodized salt, dietary deficiency is rare. Instead, inflammation of the thyroid gland is the more common cause of low blood levels of thyroid hormones. Called hypothyroidism, the condition is characterized by a low metabolic rate, weight gain, cold extremities, constipation, reduced libido, menstrual irregularities, and reduced mental activity. In contrast, hyperthyroidism—an abnormally elevated blood level of thyroid hormones—is often caused by a pituitary or thyroid tumor. In Graves' disease, the hyperthyroid state results from an autoimmune reaction in which antibodies overstimulate the follicle cells of the thyroid gland. Hyperthyroidism can lead to an increased metabolic rate, excessive body heat and sweating, diarrhea, weight loss, tremors, and increased heart rate. The person's eyes may bulge (called exophthalmos) as antibodies produce inflammation in the soft tissues of the orbits. The person may also develop a goiter.

Goiter (credit: "Almazi"/Wikimedia Commons)

### Calcitonin

The thyroid gland also secretes a hormone called calcitonin. Calcitonin is released in response to a rise in blood calcium levels. It appears to have a function in decreasing blood calcium concentrations by:

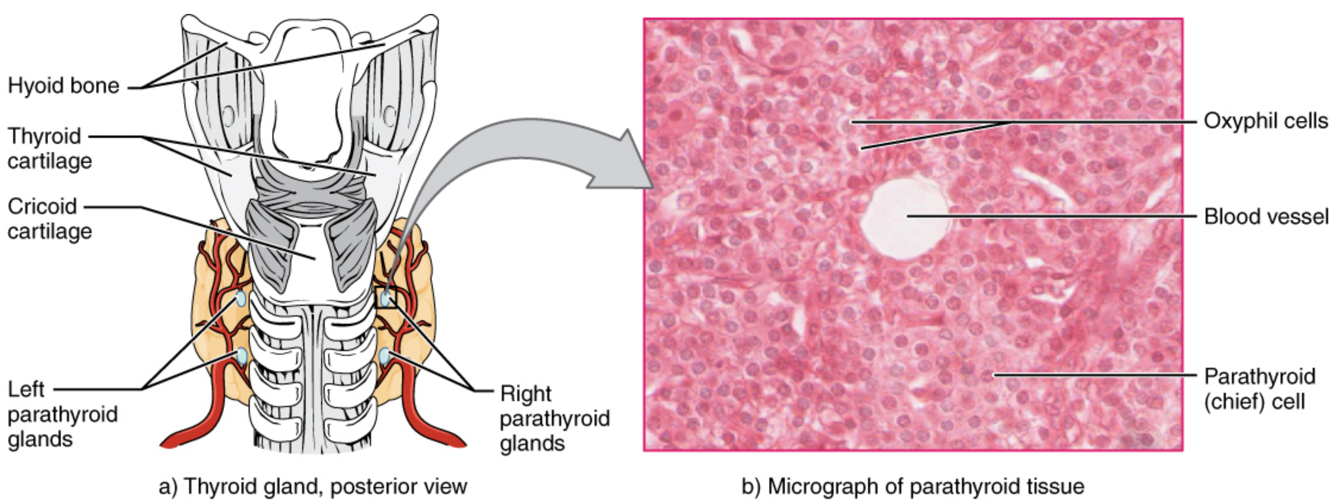
- ❑ Inhibiting the activity of osteoclasts, bone cells that release calcium into the circulation by degrading bone matrix
- ❑ Increasing osteoblastic activity
- ❑ Decreasing calcium absorption in the intestines
- ❑ Increasing calcium loss in the urine

**Thyroid Hormones**

| Associated hormones | Effect |
|---|---|
| Thyroxine (T4), triiodothyronine (T3) | Stimulate basal metabolic rate |
| Calcitonin | Reduces blood Ca2+ levels |

## Parathyroid Glands

Calcium is critical for many other biological processes. It is a second messenger in many signaling pathways, and is essential for muscle contraction, nerve impulse transmission, and blood clotting. Given these roles, it is not surprising that blood calcium levels are tightly regulated by the endocrine system. The organs involved in the regulation are the **parathyroid glands**. The parathyroid glands are tiny, round structures usually found embedded in the posterior surface of the thyroid gland (Figure). A thick connective tissue capsule separates the glands from the thyroid tissue. Most people have four parathyroid glands. The primary function of the parathyroid glands are to produce and secrete the **parathyroid hormone (PTH),** the major hormone involved in the regulation of blood calcium levels.




## Review

**Thyroid Gland**

The thyroid gland is a butterfly-shaped organ located in the neck anterior to the trachea. Its hormones regulate basal metabolism, oxygen use, nutrient metabolism, the production of ATP, and calcium homeostasis. They also contribute to protein synthesis and the normal growth and development of body tissues, including maturation of the nervous system, and they increase the body's sensitivity to catecholamines. The thyroid hormones triiodothyronine (T3) and thyroxine (T4) are produced and secreted by the thyroid gland in response to thyroid-stimulating hormone (TSH) from the anterior pituitary. Synthesis of the amino acid–derived T3and T4 hormones requires iodine. Insufficient amounts of iodine in the diet can lead to goiter, cretinism, and many other disorders.

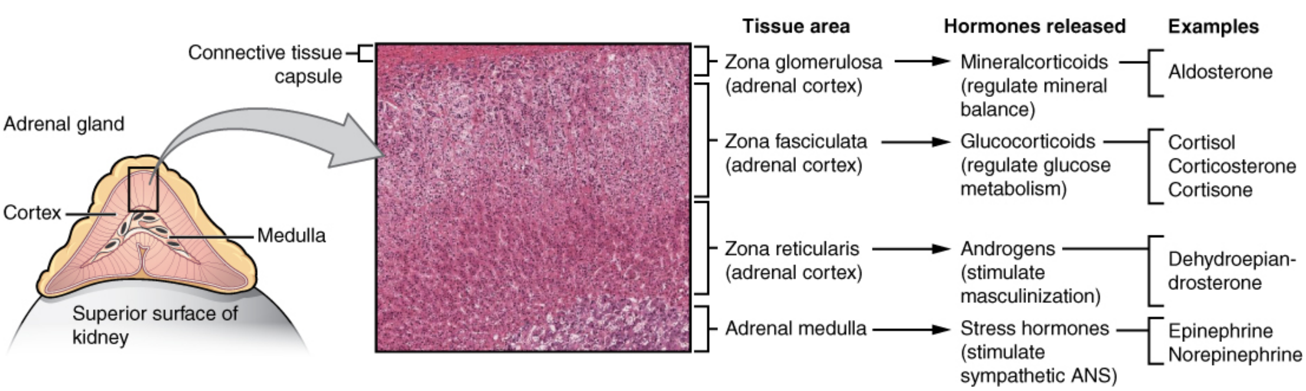
### Parathyroid Gland

Calcium is required for a variety of important physiologic processes, including neuromuscular functioning; thus, blood calcium levels are closely regulated. The parathyroid glands are small structures located on the posterior thyroid gland that produce parathyroid hormone (PTH), which regulates blood calcium levels. Low blood calcium levels cause the production and secretion of PTH. In contrast, elevated blood calcium levels inhibit secretion of PTH and trigger secretion of the thyroid hormone calcitonin. Underproduction of PTH can result in hypoparathyroidism. In contrast, overproduction of PTH can result in hyperparathyroidism.

## The Adrenal Glands

The adrenal glands are wedges of glandular and **neuroendocrine** tissue adhering to the top of the kidneys by a fibrous capsule (Figure). The adrenal glands have a rich blood supply and experience one of the highest rates of blood flow in the body. They are served by several arteries branching off the aorta, including the suprarenal and renal arteries. Blood flows to each adrenal gland at the adrenal cortex and then drains into the adrenal medulla. Adrenal hormones are released into the circulation via the left and right suprarenal veins.

**Adrenal Glands**




Both adrenal glands sit atop the kidneys and are composed of an outer cortex and an inner medulla, all surrounded by a connective tissue capsule. The cortex can be subdivided into additional zones, all of which produce different types of hormones.

(Micrograph provided by the Regents of University of Michigan Medical School © 2012)

The adrenal gland consists of an outer cortex of glandular tissue and an inner medulla of nervous tissue. The cortex itself is divided into three zones: the zona glomerulosa, the zona fasciculata, and the zona reticularis. Each region secretes its own set of hormones.

The adrenal cortex, as a component of the **hypothalamic-pituitary-adrenal (HPA) axis**, secretes **steroid** hormones important for the regulation of the long-term stress response, blood pressure and blood volume, nutrient uptake and storage, fluid and electrolyte balance, and inflammation. The HPA axis involves the stimulation of hormone release of adrenocorticotropic hormone (ACTH) from the pituitary by the hypothalamus. ACTH then stimulates the adrenal cortex to produce the hormone cortisol.

The adrenal medulla is neuroendocrine tissue composed of **postganglionic sympathetic nervous system (SNS)** neurons. It is really an extension of the **autonomic nervous system**, which regulates homeostasis in the body. The **sympathomedullary (SAM)** pathway involves the stimulation of the medulla by impulses from the hypothalamus via neurons from the thoracic spinal cord. The medulla is stimulated to secrete the amine hormones **epinephrine** and **norepinephrine**.

One of the major functions of the adrenal gland is to respond to stress. Stress can be either physical or psychological or both. Physical stresses include exposing the body to injury, walking outside in cold and wet conditions without a coat on, or malnutrition. Psychological stresses include the perception of a physical threat, a fight with a loved one, or just a bad day at school.

- ❏ The body responds in different ways to short-term stress and long-term stress following a pattern known as the general adaptation syndrome (GAS). Stage one of GAS is called the alarm reaction. This is short-term stress, the fight-or-flight response, mediated by the hormones epinephrine and norepinephrine from the adrenal medulla via the SAM pathway. Their function is to prepare the body for extreme physical exertion. Once this stress is relieved, the body quickly returns to normal. The section on the adrenal medulla covers this response in more detail.
- ❏ If the stress is not soon relieved, the body adapts to the stress in the second stage called the stage of resistance. If a person is starving for example, the body may send signals to the gastrointestinal tract to maximize the absorption of nutrients from food.
- ❏ If the stress continues for a longer term however, the body responds with symptoms quite different than the fight-or-flight response. During the stage of exhaustion, individuals may begin to suffer depression, the suppression of their immune response, severe fatigue, or even a fatal heart attack. These symptoms are mediated by the hormones of the adrenal cortex, especially cortisol, released as a result of signals from the HPA axis.

Adrenal hormones also have several non–stress-related functions, including the increase of blood sodium and glucose levels, which will be described in detail below.

## Adrenal Cortex

The adrenal cortex consists of multiple layers of lipid-storing cells that occur in three structurally distinct regions. Each of these regions produces different hormones.

### Hormones of the Zona Glomerulosa

The most superficial region of the adrenal cortex is the zona glomerulosa, which produces a group of hormones collectively referred to as **mineralocorticoids** because of their effect on body minerals, especially sodium and potassium. These hormones are essential for fluid and electrolyte balance.

- Aldosterone is the major mineralocorticoid. It is important in the regulation of the concentration of sodium and potassium ions in urine, sweat, and saliva. Aldosterone is also a key component of the **renin-angiotensin-aldosterone system (RAAS)** in which specialized cells of the kidneys secrete the enzyme renin in response to low blood volume or low blood pressure by: .
    - Initiating vasoconstriction of the arterioles, decreasing blood flow
    - Stimulating kidney tubules to reabsorb NaCl and water, increasing blood volume
    - Signaling the adrenal cortex to secrete **aldosterone** (a mineralcorticoid), the effects of which further contribute to fluid retention, restoring blood pressure and blood volume

### Hormones of the Zona Fasciculata

The intermediate region of the adrenal cortex is the zona fasciculata, named as such because the cells form small fascicles (bundles) separated by tiny blood vessels. The cells of the zona fasciculata produce hormones called **glucocorticoids** because of their role in glucose metabolism. The most important of these is **cortisol**, some of which the liver converts to **cortisone**, and **corticosterone**. In response to long-term stressors, the hypothalamus secretes CRH, which in turn triggers the release of ACTH by the anterior pituitary. ACTH triggers the release of the glucocorticoids. Their overall effect is to inhibit tissue building while stimulating the breakdown of stored nutrients to maintain adequate fuel supplies.

> You are probably familiar with prescription and over-the-counter medications containing glucocorticoids, such as cortisone injections into inflamed joints, prednisone tablets and steroid-based inhalers used to manage severe asthma, and hydrocortisone creams applied to relieve itchy skin rashes. These drugs reflect another role of cortisol—the downregulation of the immune system, which inhibits the inflammatory response.

### Hormones of the Zona Reticularis

The deepest region of the adrenal cortex is the zona reticularis, which produces small amounts of a class of steroid sex hormones called **androgens**. During puberty and most of adulthood, androgens are produced in the gonads. The androgens produced in the zona reticularis supplement the gonadal androgens.

## Adrenal Medulla

As noted earlier, the adrenal cortex releases glucocorticoids in response to long-term stress such as severe illness. In contrast, the adrenal medulla releases its hormones in response to acute, short-term stress mediated by the sympathetic nervous system (SNS).

- The medullary tissue produces the neurotransmitters **epinephrine** (also called **adrenaline**) **and norepinephrine** (or noradrenaline).
- Epinephrine is produced in greater quantities—approximately a 4 to 1 ratio with norepinephrine—and is the more powerful hormone.

Both epinephrine and norepinephrine signal the liver and skeletal muscle cells to convert glycogen into glucose, resulting in increased blood glucose levels. These hormones increase the heart rate, pulse, and blood pressure to prepare the body to fight the perceived threat or flee from it. In addition, the pathway dilates the airways, raising blood oxygen levels. It also prompts vasodilation, further increasing the oxygenation of important organs such as the lungs, brain, heart, and skeletal muscle. At the same time, it triggers vasoconstriction to blood vessels serving less essential organs such as the gastrointestinal tract, kidneys, and skin, and downregulates some components of the immune system. Epinephrine and norepinephrine re widely used in medicine.

**Major Hormones of the Adrenal Glands**

| Adrenal gland | Associated hormones | Chemical class | Effect |
|---|---|---|---|
| Adrenal cortex | Aldosterone | Steroid | Increases blood Na+ levels |
| Adrenal cortex | Cortisol, corticosterone, cortisone | Steroid | Increase blood glucose levels |
| Adrenal medulla | Epinephrine, norepinephrine | Amine | Stimulate fight-or-flight response |

# Disorders Involving the Adrenal Glands

Several disorders are caused by the dysregulation of the hormones produced by the adrenal glands.

- **Cushing's disease** is a disorder characterized by high blood glucose levels and the accumulation of lipid deposits on the face and neck. It is caused by **hypersecretion** of **cortisol**.
- In contrast, the **hyposecretion** of corticosteroids can result in **Addison's disease**, a rare disorder that causes low blood glucose levels and low blood sodium levels. The signs and symptoms of Addison's disease are vague and are typical of other disorders as well, making diagnosis difficult. They may include general weakness, abdominal pain, weight loss, nausea, vomiting, sweating, and cravings for salty food.

## Review

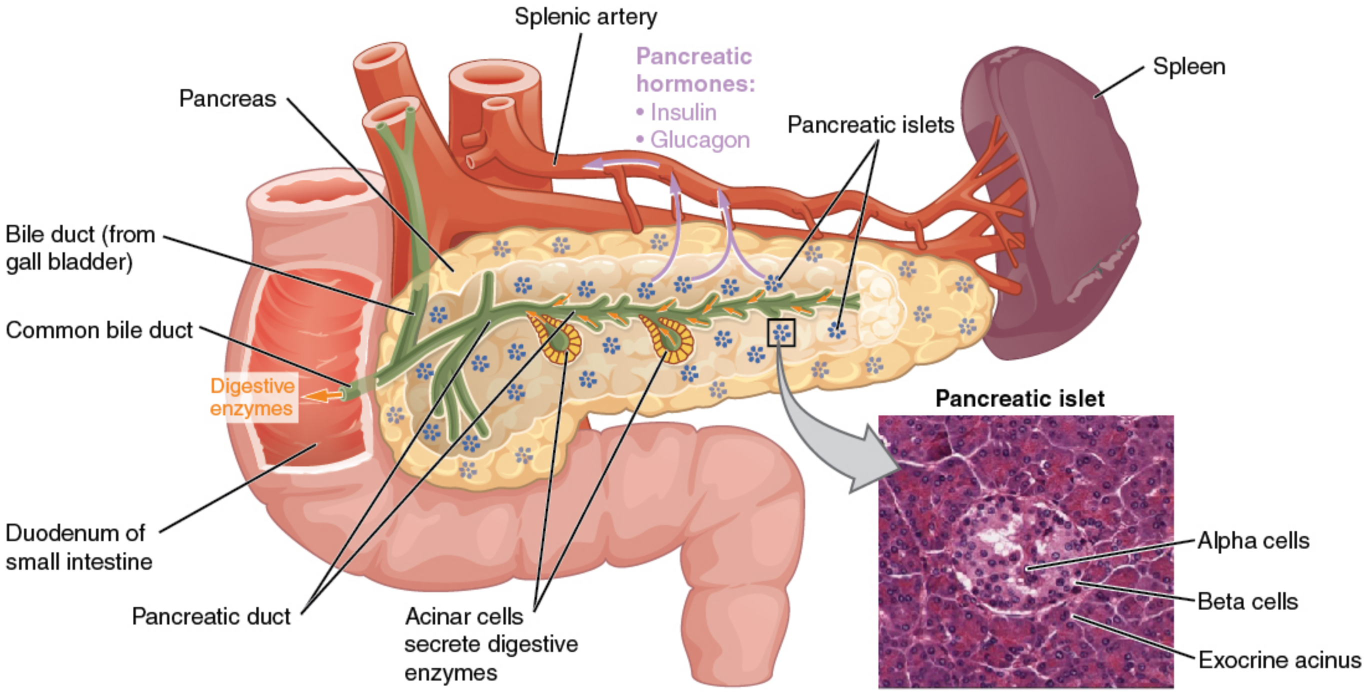
The adrenal glands, located superior to each kidney, consist of two regions: the adrenal cortex and adrenal medulla. The adrenal cortex—the outer layer of the gland—produces mineralocorticoids, glucocorticoids, and androgens. The adrenal medulla at the core of the gland produces epinephrine and norepinephrine.

The adrenal glands mediate a short-term stress response and a long-term stress response. A perceived threat results in the secretion of epinephrine and norepinephrine from the adrenal medulla, which mediate the fight-or-flight response. The long-term stress response is mediated by the secretion of CRH from the hypothalamus, which triggers ACTH, which in turn stimulates the secretion of corticosteroids from the adrenal cortex. The mineralocorticoids, chiefly aldosterone, cause sodium and fluid retention, which increases blood volume and blood pressure.

## The Endocrine Pancreas

The pancreas is a long, slender organ, most of which is located posterior to the bottom half of the stomach (Figure). Although it is primarily an exocrine gland, secreting a variety of digestive enzymes, the pancreas has an endocrine function. Its pancreatic islets—clusters of cells formerly known as the **islets of Langerhans**—secrete the hormones **glucagon**, **insulin**, **somatostatin**, and **pancreatic polypeptide (PP)**.

**Pancreas**




The pancreatic exocrine function involves the acinar cells secreting digestive enzymes that are transported into the small intestine by the pancreatic duct. Its endocrine function involves the secretion of insulin (produced by beta cells) and glucagon (produced by alpha cells) within the pancreatic islets. These two hormones regulate the rate of glucose metabolism in the body. The micrograph reveals pancreatic islets. (Micrograph provided by the Regents of University of Michigan Medical School © 2012)

## Cells and Secretions of the Pancreatic Islets

The pancreatic islets each contain four varieties of cells:

- The **alpha cell** produces the hormone glucagon and makes up approximately 20 percent of each islet. Glucagon plays an important role in blood glucose regulation; low blood glucose levels stimulate its release.
- The **beta cell** produces the hormone insulin and makes up approximately 75 percent of each islet. Elevated blood glucose levels stimulate the release of insulin.
- The **delta** cell secretes the peptide hormone somatostatin. An inhibiting hormone, pancreatic somatostatin inhibits the release of both glucagon and insulin.
- The **Pancreatic Polypeptide (PP)** cell accounts for about one percent of islet cells and secretes the pancreatic polypeptide hormone. It is thought to play a role in appetite, as well as in the regulation of pancreatic exocrine and endocrine secretions. It is also released in response to fasting.

## Regulation of Blood Glucose Levels by Insulin and Glucagon

Glucose is required for cellular respiration and is the preferred fuel for all body cells. The body derives glucose from the breakdown of the carbohydrate-containing foods and drinks we consume. Glucose not immediately taken up by cells for fuel can be stored by the liver and muscles as glycogen, or converted to triglycerides and stored in the adipose tissue. Hormones regulate both the storage and the utilization of glucose as required. Receptors located in the pancreas sense blood glucose levels, and subsequently the pancreatic cells secrete glucagon or insulin to maintain normal levels.

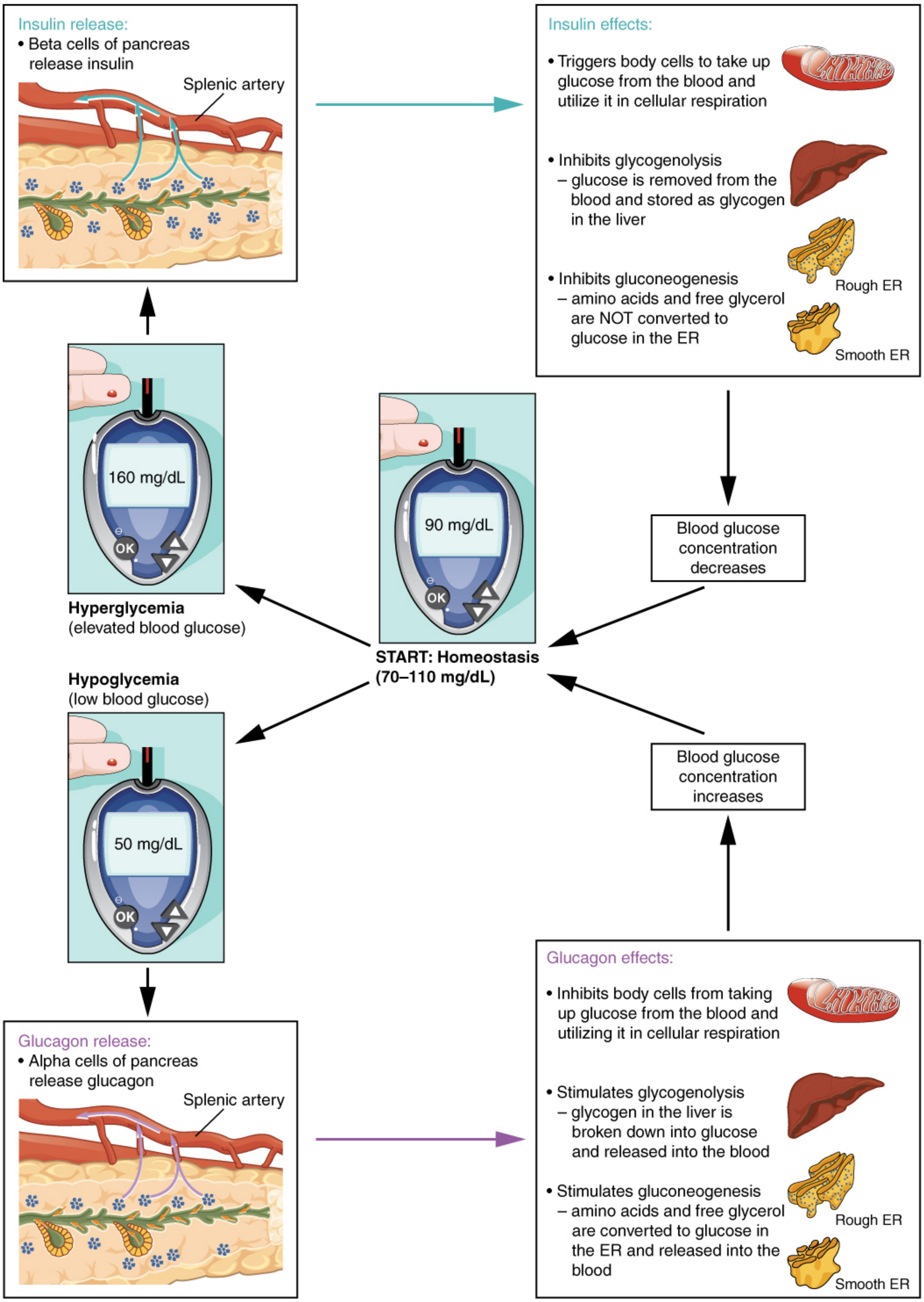
**Glucagon**

Receptors in the pancreas can sense the decline in blood glucose levels, such as during periods of fasting or during prolonged labor or exercise (Figure). In response, the alpha cells of the pancreas secrete the hormone glucagon, which has several effects:

- It stimulates the liver to convert its stores of glycogen back into glucose. This response is known as glycogenolysis. The glucose is then released into the circulation for use by body cells.
- It stimulates the liver to take up amino acids from the blood and convert them into glucose. This response is known as gluconeogenesis.
- It stimulates lipolysis, the breakdown of stored triglycerides into free fatty acids and glycerol. Some of the free glycerol released into the bloodstream travels to the liver, which converts it into glucose. This is also a form of gluconeogenesis.
- Taken together, these actions increase blood glucose levels. The activity of glucagon is regulated through a negative feedback mechanism; rising blood glucose levels inhibit further glucagon production and secretion.

**Homeostatic Regulation of Blood Glucose Levels**

Blood glucose concentration is tightly maintained between 70 mg/dL and 110 mg/dL. If blood glucose concentration rises above this range, insulin is released, which stimulates body cells to remove glucose from the blood. If blood glucose concentration drops below this range, glucagon is released, which stimulates body cells to release glucose into the blood.



Insulin release:
• Beta cells of pancreas release insulin
Splenic artery
Insulin effects:
• Triggers body cells to take up glucose from the blood and utilize it in cellular respiration
• Inhibits glycogenolysis
– glucose is removed from the blood and stored as glycogen in the liver
• Inhibits gluconeogenesis
– amino acids and free glycerol are NOT converted to glucose in the ER
Rough ER
Smooth ER
160 mg/dL
OK
Hyperglycemia
(elevated blood glucose)
90 mg/dL
OK
START: Homeostasis
(70–110 mg/dL)
Blood glucose concentration decreases
Hypoglycemia
(low blood glucose)
50 mg/dL
OK
Blood glucose concentration increases
Glucagon release:
• Alpha cells of pancreas release glucagon
Splenic artery
Glucagon effects:
• Inhibits body cells from taking up glucose from the blood and utilizing it in cellular respiration
• Stimulates glycogenolysis
– glycogen in the liver is broken down into glucose and released into the blood
• Stimulates gluconeogenesis
– amino acids and free glycerol are converted to glucose in the ER and released into the blood
Rough ER
Smooth ER

**Insulin**

The primary function of insulin is to facilitate the uptake of glucose into body cells. Red blood cells, as well as cells of the brain, liver, kidneys, and the lining of the small intestine, do not have insulin receptors on their cell membranes and do not require insulin for glucose uptake. Although all other body cells do require insulin if they are to take glucose from the bloodstream, skeletal muscle cells and adipose cells are the primary targets of insulin.

Precisely how insulin facilitates glucose uptake is not entirely clear. However, insulin appears to activate a tyrosine kinase receptor, triggering the phosphorylation of many substrates within the cell. These multiple biochemical reactions converge to support the movement of intracellular vesicles containing facilitative glucose transporters to the cell membrane. In the absence of insulin, these transport proteins are normally recycled slowly between the cell membrane and cell interior. Insulin triggers the rapid movement of a pool of glucose transporter vesicles to the cell membrane, where they fuse and expose the glucose transporters to the extracellular fluid. The transporters then move glucose by facilitated diffusion into the cell interior.

http://openstaxcollege.org/l/pancreas1

| Hormones of the Pancreas | | |
|---|---|---|
| Associated hormones | Chemical class | Effect |
| Insulin (beta cells) | Protein | Reduces blood glucose levels |
| Glucagon (alpha cells) | Protein | Increases blood glucose levels |
| Somatostatin (delta cells) | Protein | Inhibits insulin and glucagon release |
| Pancreatic polypeptide (PP cells) | Protein | Role in appetite |

## DISORDERS OF THE…Endocrine System: Diabetes Mellitus

Dysfunction of insulin production and secretion, as well as the target cells' responsiveness to insulin, can lead to a condition called **diabetes mellitus**. There are two main forms of diabetes mellitus. **Type 1 diabetes** is an **autoimmune disease** affecting the beta cells of the pancreas. Certain genes are recognized to increase susceptibility. The beta cells of people with type 1 diabetes do not produce insulin; thus, synthetic insulin must be administered by injection or infusion. This form of diabetes accounts for less than five percent of all diabetes cases.

Type 2 diabetes accounts for approximately 95 percent of all cases. It is acquired, and lifestyle factors such as poor diet, inactivity, and the presence of pre-diabetes greatly increase a person's risk. In type 2 diabetes, cells become resistant to the effects of insulin. In response, the pancreas increases its insulin secretion, but over time, the beta cells become exhausted.

Two of the early manifestations of diabetes are excessive urination (**polyuria**) and excessive thirst (**polydipsia**).

- ❏ The kidneys are responsible for filtering glucose from the blood.
- ❏ Excessive blood glucose draws water into the urine,
- ❏ as a result the person eliminates an abnormally large quantity of sweet urine.
- ❏ The use of body water to dilute the urine leaves the body dehydrated, and so the person is unusually and continually thirsty.
- ❏ The person may also experience persistent hunger because the body cells are unable to access the glucose in the bloodstream.

Over time, persistently high levels of glucose in the blood injure tissues throughout the body, especially those of the blood vessels and nerves. Inflammation and injury of the lining of arteries lead to atherosclerosis and an increased risk of heart attack and stroke. Damage to the microscopic blood vessels of the kidney impairs kidney function and can lead to kidney failure. Damage to blood vessels that serve the eyes can lead to blindness. Blood vessel damage also reduces circulation to the limbs, whereas nerve damage leads to a loss of sensation, called neuropathy, particularly in the hands and feet. Uncontrolled diabetes can also lead to a dangerous form of **metabolic acidosi**s called **ketoacidosis**. Deprived of glucose, cells increasingly rely on fat stores for fuel. However, in a glucose-deficient state, the liver is forced to use an alternative lipid metabolism pathway that results in the increased production of **ketone bodies** (or **ketones**), which are acidic. The build-up of ketones in the blood may lead to a life-threatening "diabetic coma." Together, these complications make diabetes the seventh leading cause of death in the United States.

Diabetes is diagnosed when lab tests reveal that blood glucose levels are higher than normal, a condition called **hyperglycemia**. Some patients with type 2 diabetes may be unable to control their disease with lifestyle changes, and will require medication.

Visit this link to view an animation describing the role of insulin and the pancreas in diabetes.

http://openstaxcollege.org/l/insulin

# Glossary

## Thyroid and Parathyroid Glands

**calcitonin**:peptide hormone produced and secreted by the parafollicular cells (C cells) of the thyroid gland that functions to decrease blood calcium levels

**colloid**: viscous fluid in the central cavity of thyroid follicles, containing the glycoprotein thyroglobulin

**goiter**: enlargement of the thyroid gland either as a result of iodine deficiency or hyperthyroidism

**hyperparathyroidism**: disorder caused by overproduction of PTH that results in abnormally elevated blood calcium

**hyperthyroidism**: clinically abnormal, elevated level of thyroid hormone in the blood; characterized by an increased metabolic rate, excess body heat, sweating, diarrhea, weight loss, and increased heart rate

**hypoparathyroidism**:disorder caused by underproduction of PTH that results in abnormally low blood calcium

**hypothyroidism**: clinically abnormal, low level of thyroid hormone in the blood; characterized by low metabolic rate, weight gain, cold extremities, constipation, and reduced mental activity

**neonatal hypothyroidism**: condition characterized by cognitive deficits, short stature, and other signs and symptoms in people born to women who were iodine-deficient during pregnancy

**parathyroid glands**: small, round glands embedded in the posterior thyroid gland that produce parathyroid hormone (PTH)

**parathyroid hormone (PTH)**: peptide hormone produced and secreted by the parathyroid glands in response to low blood calcium levels

**thyroid gland**: large endocrine gland responsible for the synthesis of thyroid hormones

**thyroxine** (also, **tetraiodothyronine**, $\mathbf{T_4}$) amino acid–derived thyroid hormone that is more abundant but less potent than $T_3$ and often converted to T3 by target cells

**triiodothyronine** (also, $\mathbf{T_3}$) amino acid–derived thyroid hormone that is less abundant but more potent than $T_4$

## Pituitary Gland

**Acromegaly**: disorder in adults caused when abnormally high levels of GH trigger growth of bones in the face, hands, and feet

**adrenocorticotropic hormone (ACTH)**: anterior pituitary hormone that stimulates the adrenal cortex to secrete corticosteroid hormones (also called corticotropin)

**antidiuretic hormone (ADH)**: hypothalamic hormone that is stored by the posterior pituitary and that signals the kidneys to reabsorb water

**follicle-stimulating hormone (FSH)**: anterior pituitary hormone that stimulates the production and maturation of sex cells

**gigantism**: disorder in children caused when abnormally high levels of GH prompt excessive growth

**gonadotropins**: hormones that regulate the function of the gonads

**growth hormone (GH)**: anterior pituitary hormone that promotes tissue building and influences nutrient metabolism (also called **somatotropin**)

**hypophyseal portal system**: network of blood vessels that enables hypothalamic hormones to travel into the anterior lobe of the pituitary without entering the systemic circulation

**hypothalamus**: region of the diencephalon inferior to the thalamus that functions in neural and endocrine signaling

**infundibulum**: stalk containing vasculature and neural tissue that connects the pituitary gland to the hypothalamus (also called the pituitary stalk)

**insulin-like growth factors (IGF)**: protein that enhances cellular proliferation, inhibits apoptosis, and stimulates the cellular uptake of amino acids for protein synthesis

**luteinizing hormone (LH)**: anterior pituitary hormone that triggers ovulation and the production of ovarian hormones in females, and the production of testosterone in males

**osmoreceptor**: hypothalamic sensory receptor that is stimulated by changes in solute concentration (osmotic pressure) in the blood

**oxytocin**: hypothalamic hormone stored in the posterior pituitary gland and important in stimulating uterine contractions in labor, milk ejection during breastfeeding, and feelings of attachment (also produced in males)

**pituitary dwarfism**: disorder in children caused when abnormally low levels of GH result in growth retardation

**pituitary gland**: bean-sized organ suspended from the hypothalamus that produces, stores, and secretes hormones in response to hypothalamic stimulation (also called hypophysis)

**prolactin (PRL)**: anterior pituitary hormone that promotes development of the mammary glands and the production of breast milk

**thyroid-stimulating hormone (TSH)**: anterior pituitary hormone that triggers secretion of thyroid hormones by the thyroid gland (also called thyrotropin)

## Adrenal Gland

**adrenal cortex**: outer region of the adrenal glands consisting of multiple layers of epithelial cells and capillary networks that produces mineralocorticoids and glucocorticoids

**adrenal glands**: endocrine glands located at the top of each kidney that are important for the regulation of the stress response, blood pressure and blood volume, water homeostasis, and electrolyte levels

**adrenal medulla**: inner layer of the adrenal glands that plays an important role in the stress response by producing epinephrine and norepinephrine

**angiotensin-converting enzyme**: the enzyme that converts angiotensin I to angiotensin II

**alarm reaction**: the short-term stress, or the fight-or-flight response, of stage one of the general adaptation syndrome mediated by the hormones epinephrine and norepinephrine

**aldosterone**: hormone produced and secreted by the adrenal cortex that stimulates sodium and fluid retention and increases blood volume and blood pressure

**chromaffin**: neuroendocrine cells of the adrenal medulla

**cortisol**: glucocorticoid important in gluconeogenesis, the catabolism of glycogen, and downregulation of the immune system

**epinephrine**: primary and most potent catecholamine hormone secreted by the adrenal medulla in response to short-term stress; also called adrenaline

**general adaptation syndrome (GAS)**: the human body's three-stage response pattern to short- and long-term stress

**glucocorticoids**: hormones produced by the zona fasciculata of the adrenal cortex that influence glucose metabolism

**mineralocorticoids**: hormones produced by the zona glomerulosa cells of the adrenal cortex that influence fluid and electrolyte balance

**norepinephrine**: secondary catecholamine hormone secreted by the adrenal medulla in response to short-term stress; also called noradrenaline

**stage of exhaustion**: stage three of the general adaptation syndrome; the body's long-term response to stress mediated by the hormones of the adrenal cortex

**stage of resistance**: stage two of the general adaptation syndrome; the body's continued response to stress after stage one diminishes

**zona fasciculata**: intermediate region of the adrenal cortex that produce hormones called glucocorticoids

**zona glomerulosa**: most superficial region of the adrenal cortex, which produces the hormones collectively referred to as mineralocorticoids

**zona reticularis**:deepest region of the adrenal cortex, which produces the steroid sex hormones called androgens

## The Endocrine Pancreas

**alpha cell**: pancreatic islet cell type that produces the hormone glucagon

**beta cell**: pancreatic islet cell type that produces the hormone insulin

**delta cell**: minor cell type in the pancreas that secretes the hormone somatostatin

**diabetes mellitus**: condition caused by destruction or dysfunction of the beta cells of the pancreas or cellular resistance to insulin that results in abnormally high blood glucose levels

**glucagon**: pancreatic hormone that stimulates the catabolism of glycogen to glucose, thereby increasing blood glucose levels

**hyperglycemia**: abnormally high blood glucose levels

**insulin**: pancreatic hormone that enhances the cellular uptake and utilization of glucose, thereby decreasing blood glucose levels

**pancreas**: organ with both exocrine and endocrine functions located posterior to the stomach that is important for digestion and the regulation of blood glucose

**pancreatic islets**: specialized clusters of pancreatic cells that have endocrine functions; also called islets of Langerhans

**PP** cell: minor cell type in the pancreas that secretes the hormone pancreatic polypeptide